POWER ELECTRONICS

7th Sem E&C

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Power Semiconductor Devices

❖ **Give the definition of power electronics. Explain the relationship of power electronics to power, electronics and control. Mention any two applications of PE.** **June-11,6M**

Power electronics combines power, electronics and control. Power electronics may be defined as the applications of solid-state electronics for the control and conversion of electric power.

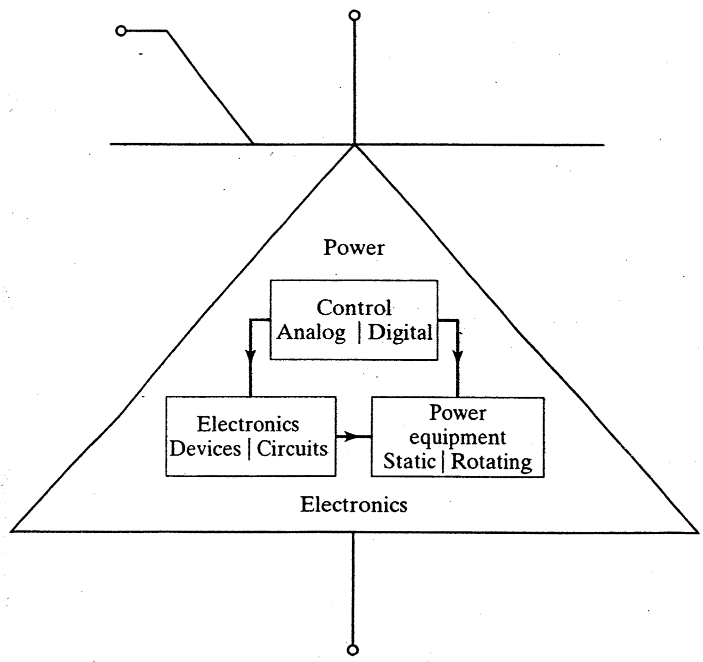


FIGURE 1
Relationship of power electronics to power, electronics, and control.

Power :- Power deals with the static and rotating power equipment for the generation, transmission and distribution of electric energy.

Electronics :- Electronics deal with the solid-state devices and circuits for signal processing to meet the desired control objectives.

Control :- The control deals with the stability and response (steady state & dynamic) characteristics of closed loop systems.

Applications of PE :-

1) **Home appliances** :- Refrigerators, washing machines, vaccum cleaners, mixers, cooking applications, fans etc.

2) **Games and entertainment** :- Toys, TV and projectors etc.

3) **Commercial** :- Advertising, battery chargers, computers, photo copiers, power supplies, elevators etc.

4) **Automotive** :- Alarms and security system, electric vehicles etc.

5) **Medical** :- Laser power supplies, medical instrumentation etc.

❖ Block diagram of power electronic system :-

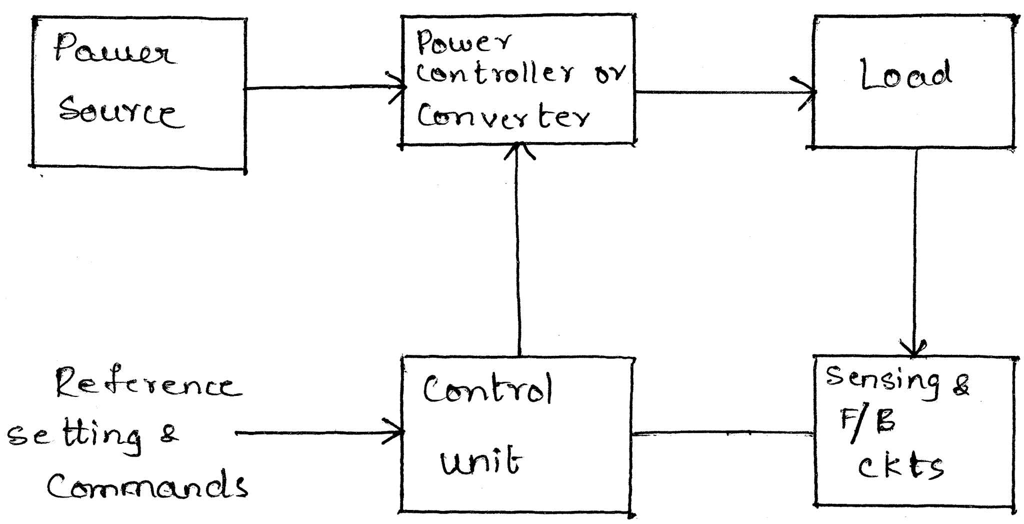


Figure shows the block diagram of the power system using a power converter or controller.

❖ The power controller or converter can use power devices such as thyristor (SCR), GTO, MOSFET, BJT or IGBT as a switch.

❖ The power source can be ac mains, generator or batteries. The power controller converts the input power which is suitable for the load. Let us take example of a speed control system for a dc motor. The power converter and controller is then a controlled rectifier which produces a variable dc voltage as its output.

- The sensing element is a speed sensor which senses the actual speed of the dc motor and produces a feedback signal proportional to actual speed of the motor.

- This feedback signal is compared with a reference signal which represents the desired speed. Based on the difference between these two signals, the control circuit will produce a control signal for the power converter and controller. This will change the dc output voltage of the converter so as to adjust the motor speed to the desired value.

Power semiconductor devices :-

The power semiconductor devices are used as **ON/OFF switches** in power control circuit. These devices are classified as follows:

Power Devices

Diodes
1. General purpose
2. High speed
3. Schottky

Thyristors
1. SCRs
2. GTO
3. RCT
4. SITH
5. GATT
6. LASCR
7. MCT
8. TRIAC

Transistors
1. BJT
2. MOSFET
3. IGBT
4. SIT

Power Diodes :-

Power diodes are required in most of the power converters. Power diode is **uncontrolled device**.

There are 3 types of power diodes :

1) **General purpose diodes**
2) **High speed (Fast recovery) diodes**
3) **Schottky diodes**

1) General purpose diodes :-

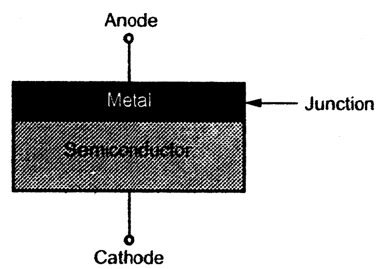
These diodes have high reverse recovery time of about 25μsec. Hence these are used in low speed applications suchas rectifiers and converters. They can operate 1Khz. The rating are from 1A/50V to 1000A/500V.

2) Fast recovery diodes :-

These diodes have the reverse recovery time less than 5μsec. Hence these diodes are used in high speed applications such as choppers and inverters.

These diodes have ratings from 1A/50V to 100A/3KV.

3) Schottky diodes :-



- In schottky diodes, the pn junction is eliminated. A thin film of metal is placed directly on the semiconductor as shown in figure. Aluminium is deposited on n-type semiconductor. The metal is anode and semiconductor is cathode.
- Since there is no pn junction, the storage time is absent. Hence turn-off time is very small. So schottky diodes have high switching frequencies. Schottky diodes are used in low voltage converters as feedback and freewheeling diodes.

Applications of power diodes :-

1. Power diodes are used in uncontrolled rectfiers.
2. Feedback and freewheeling operations in choppers, inverters and controlled converters use power diodes.
3. Almost all the commutating circuits for SCR's use power diodes.
4. Half controlled converters and half bridge inverters use power diodes.

Thyristors family :-

Input/Output Characteristics of power semiconductor devices :-

- List the major types of power electronic devices with their symbols. In each case, draw their output characteristics. June-11,6M(E&E)

- Write the characteristics features of following power devices.

  i) SCR ii) TRIAC iii) LASCR iv) MCT v) SITH

  June-10,10M

- Give symbol, characteristic features of the following devices :

  GTO, TRIAC, MOSFET, MCT June-10,8M

- ~~List out and explain the different types of power electronic converters. Show their output input characteristics. June-09,8M~~

- Plot the input and output characteristics of any four power semiconductor devices. June-08,8M

- Draw the input and output characteristics of four of the following devices:

  i)BJT ii) MOSFET iii) IGBT iv) UJT v) SCR

  June-06,8M

- Give the characteristics features of the following devices:

  i) MOSFET ii) TRIAC iii) GTO iv) RCT

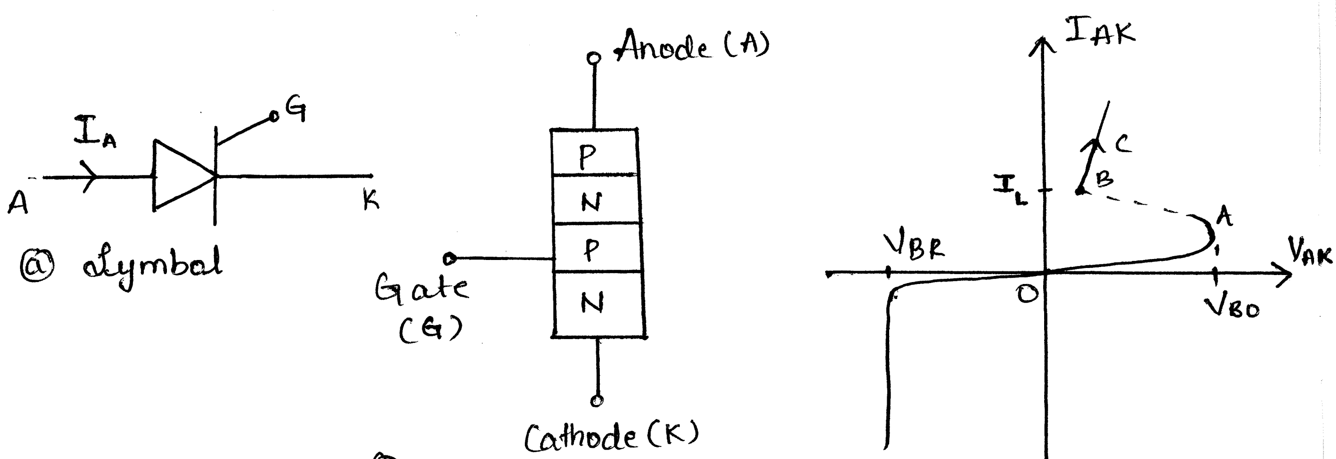
  Jan-08,8M

There are 8 types of power devices in thyristor family, they are:

1. **Silicon Controlled Rectifiers (SCR)**
2. **Gate turn-OFF thyristor (GTO)**
3. **Reverse conducting thyristor (RCT)**
4. **Static Induction thyristor (SITH)**
5. **Gate assisted turn-OFF thyristor (GATT)**
6. **Light activated silicon controlled rectifier (LASCR)**
7. **MOS- Controlled thyristor (MCT)**
8. **TRIAC**

Out of all these devices, SCR is the most commonly used thyristor.

1. Silicon Controlled Rectifiers (SCR) :-



(a) symbol (b) Internal Structure (c) Characteristic curve.

* The SCR has three terminals namely
Anode (A)
Cathode (K)
Gate (G)
Internally it is having four layers PNPN as shown in fig (b)

* When anode is made +ve wrt cathode then SCR is forward biased.

A small +ve voltage is applied between gate and cathode to turn ON the SCR. Now current flows from anode to cathode in the SCR.

* When a thyristor is in a conduction mode, the forward voltage drop is very small typically 0.5 to 2V. Once the SCR is turned ON, the gate has no control over the conduction of SCR. Even if the gate is removed, SCR doesnot turn-OFF

* A conduction thyristor can be turned OFF by making the potential of the anode equal to or less than the cathode potential

Advantages :-

1) Very small amount of gate-drive is required
2) SCR's with high voltage and current ratings are available
3) ON-state losses in SCR's are reduced.

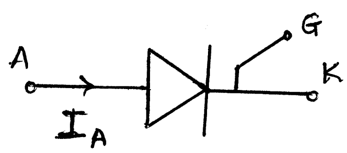
Disadvantages :-

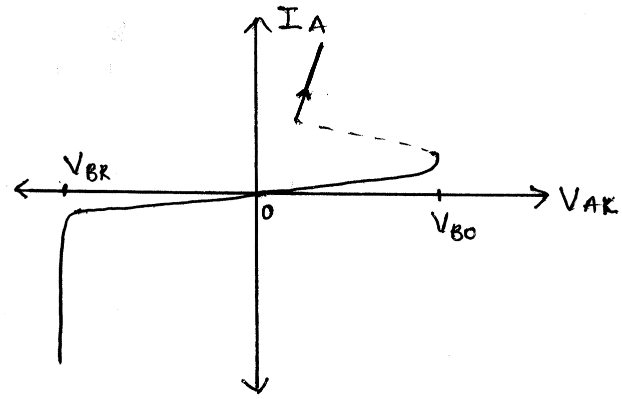
1) Gate has no control once the SCR is turned ON
2) External ckts are required to turn-OFF the SCR.
3) Operating frequencies are very low
4) Snubber (RC ckts) are required for dv/dt protection

Applications

1) SCR are best suited for controlled rectifiers.
2) AC regulators, lighting and heating applications
3) DC motor drives, large power supplies and electronic circuit brakes.

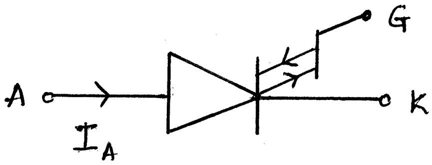
2) Static Induction Thyristor (SITH):-

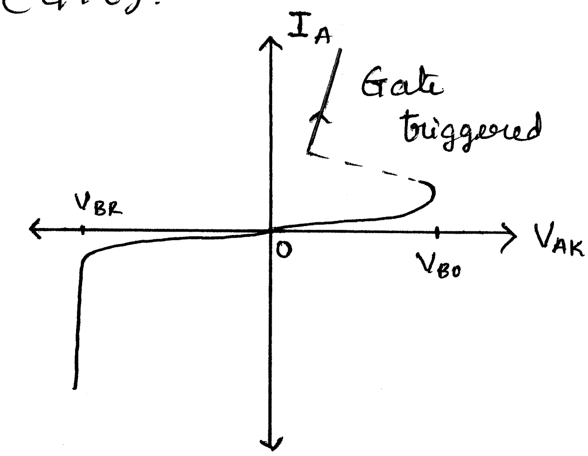




* SITH can be turned -OFF by applying -ve gate pulse. Thus gate has full control over conduction of SITH.
* SITH donot require any commutation ckt.
* SITH is turned ON by giving +ve gate pulse
* When input is not given and gate pulse is made +ve, then SITH is in turn OFF state
* When input is given and gate pulse is made +ve, then SITH is turned OFF
* SITH are used in medium power converter ckts.

3) Gate Turn-off Thyristor (GTO):-





* GTO can be turned off by applying -ve gate pulse. Thus gate has full control over the conduction of GTO. GTO donot require any commutation ckt.

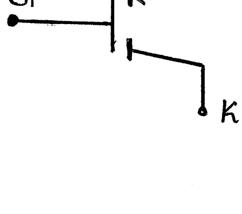
* GTO is turned ON by giving +ve gate pulse

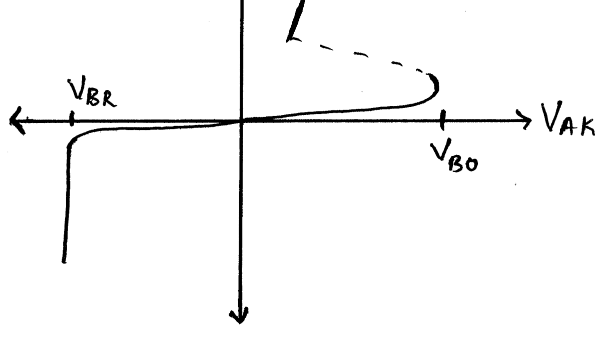
* When input is not given and gate pulse is made +ve, then GTO is in turn off state

  When input is given and gate pulse is made +ve, then GTO is turned ON.

* GTO are used for low power applications. The gate drive (pulse) required for turn OFF is very large. Hence drive ckt of GTO require more power.

4) MCT - MOS - controlled Thyristor

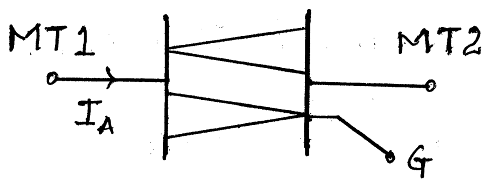


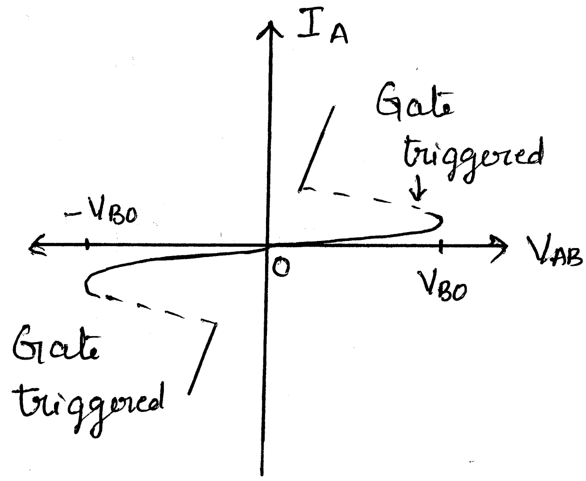


* The MCT can be turned ON by negetive voltage to the gate, & it can be turned OFF by +ve gate voltage

* MCT have power ratings

5) TRIAC :-

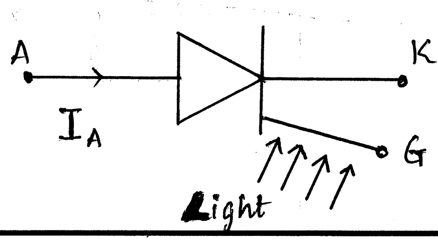


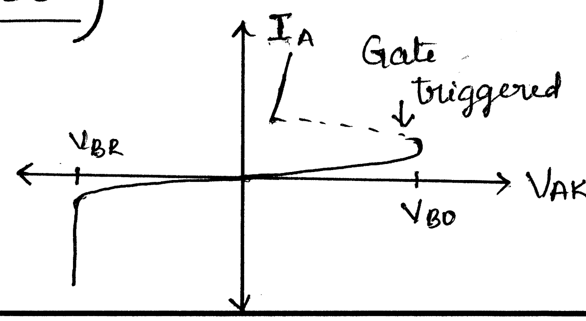


* TRIAC can be considered as antiparallel SCR. TRIAC conducts in both directions & it has single gate. The current flow through a TRIAC can be controlled in either direction

* TRIAC are widely used in all types of simple heat controls, light controls, motar controls & ac switches

6) LASCR (Light activated SCR)



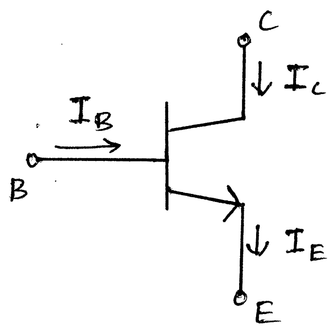


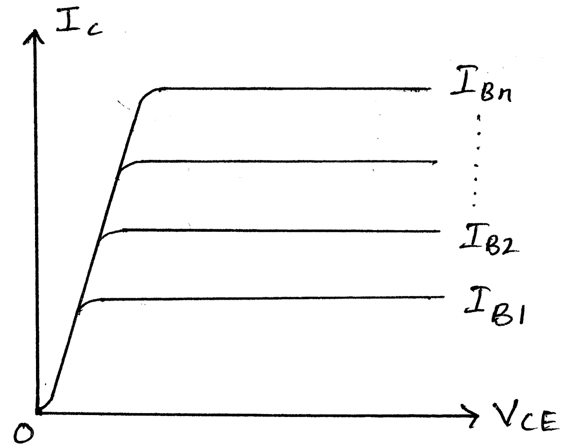
* The LASCR can be turned ON by light signal. The gate is photosensitive and SCR turns ON when light falls on it.

* LASCRs provides isolation between the gate and the drive ckt.

LASCRs are used in HVDC in transmission

7) NPN BJT :-





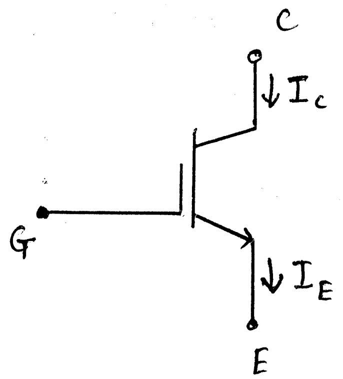
* A bipolar transistor has three terminals. Base, emitter and collector. It is normally operated as a switch in the common-emitter configurations

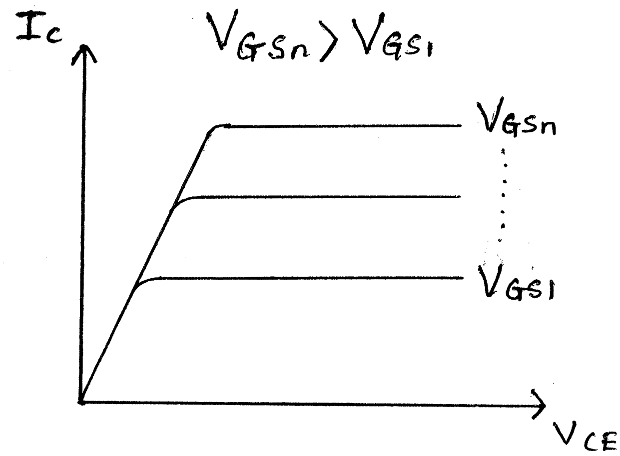
* When base voltage is at higher potential then the emitter and base current is sufficiently large to drive the transistor in the saturation region, the transistor remains ON

* The forward drop of a conducting transistor is in the range 0.5 to 1.5V.

* When base voltage is removed transistor remains in OFF mode.

8) IGBT :-





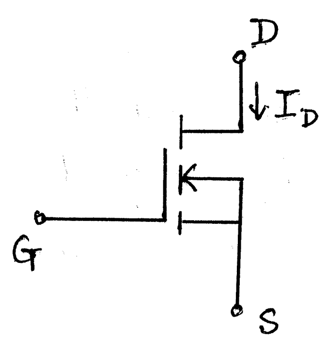
* IGBT are voltage controlled power transistor. They are inherently faster than BJT's but less faster than MOSFET's

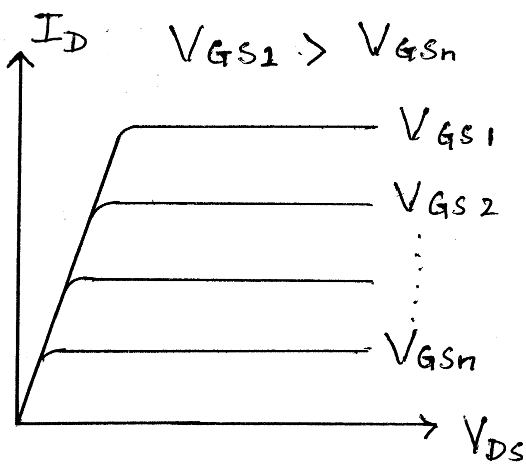
* The drive and output characteristics of IGBTs are far superior than BJTs.

* IGBTs are suitable for high current and frequencies upto 20KHz

* IGBTs are available upto 1200V, 400A.

9) N-channel MOSFET :-





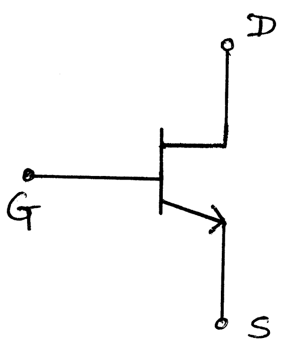
* There are two types of MOSFET's namely
  i) n-channel MOSFET
  ii) P-Channel MOSFET

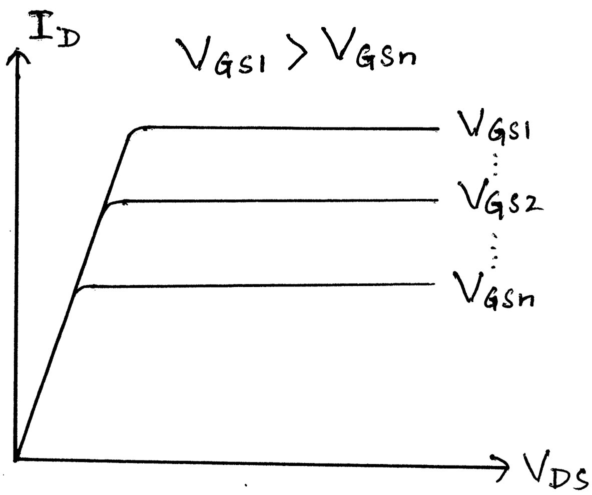
* MOSFET's are used for low power and high speed applications at a frequency range of several tens of Kilohertz.

Applications :-

1) Low power SMPS
2) Inverters

10) SIT - Static - Induction Transistor :-





* A SIT is a high-power, high frequency device. It is similar to a JFET. It has a low-noise, low-distortion, high audio frequency power capability.

* The turn-ON & turn-OFF times are very short, typically 0.25 μsec.

* The current rating of SITs can be upto 1200V, 300A & switching speed can be as high as 100Khz.

Applications :-

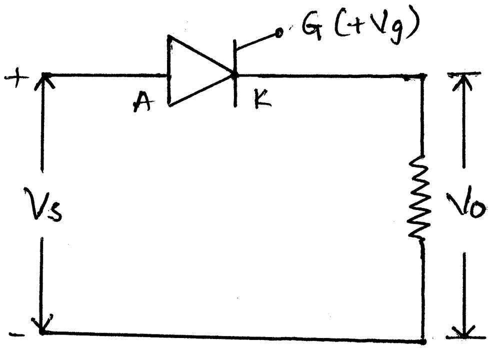
SIT's are most suitable for high power high frequency applications.

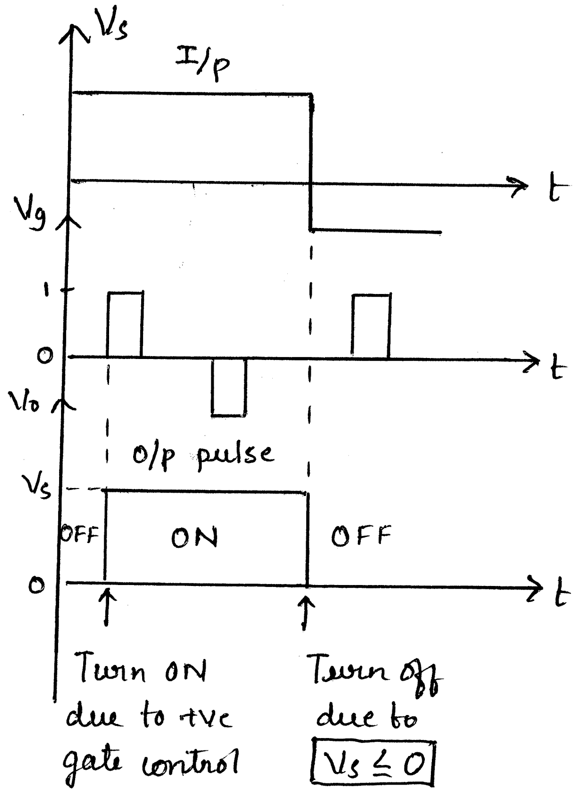
Ex :- Audio, VHF/UHF and μwave amplifiers.

Control characteristics of power semiconductor devices :-

- With the circuit diagram, input and output waveform, explain the control characteristics of SCR and IGBT. **June-11,6M**
- Mention and explain the classification of power semiconductor switching devices on the basis of control characteristics. Give an example. **June-10,6M**
- Explain the control characteristics of SCR and GTO with circuit diagrams and waveforms of control signal and output voltage. **Jan-10,8M**
- With neat circuit and waveforms of control signal and output voltage, explain the control characteristics of IGBT and SCR. **Jan-09,8M**
- Explain control characteristics of GTO, MCT, SITH with the help of waveforms and circuit diagrams. **June-08,M**
- With circuit diagram and waveforms of control signal and output voltage, explain the control characteristics of SCR and MOSFET. **June-04,8M**

1) Control characteristics of SCR (Thyristor):





* A thyristor (SCR) can be made to conduct by applying a +ve pulse to its gate, when its anode vtg is more +ve than its cathode vtg

* Once a thyristor stards conducting, it behaves like a closed switch & it becomes insensitive to gate signal ie when SCR is turned ON, the gate looses its control over the device (If gate looses its control over the device then gate is made either 0 or -ve, which will not have any effect on its conduction).

Due to this property the thyristor is considered as a "latched device"

* The thyristor can be turned OFF by applying a reverse bias vtg ie $\boxed{V_{AK} \le 0}$

2) Control characteristics of BJT :-

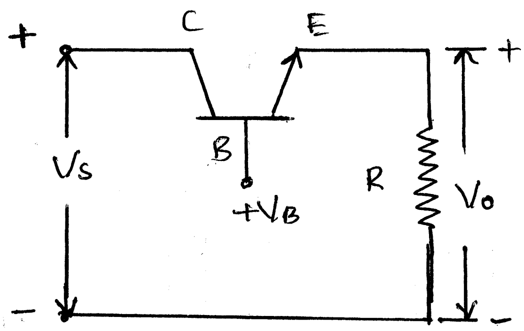
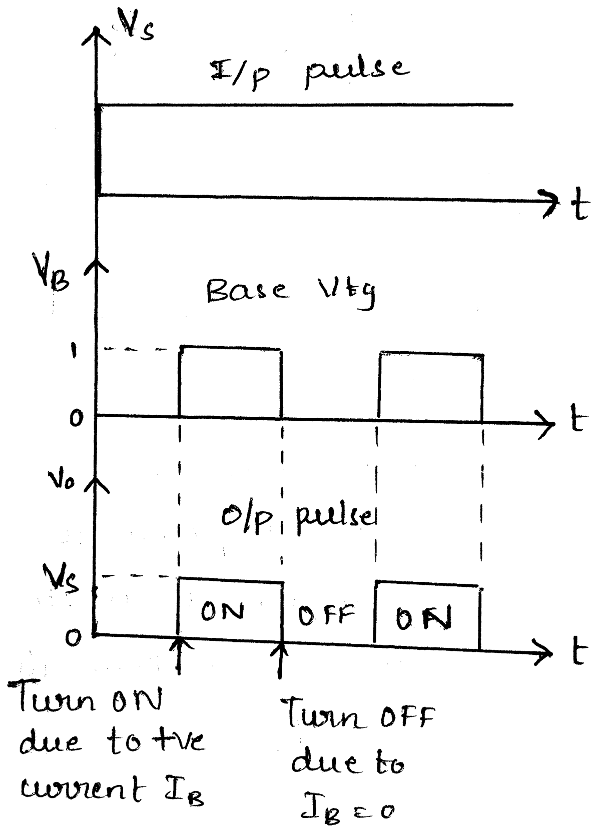
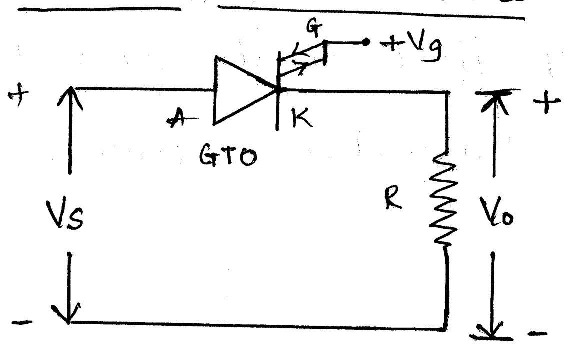


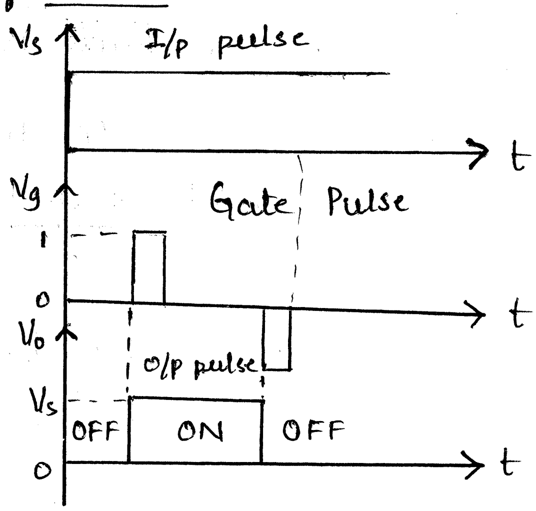
fig :- Transistor Switch



* Power transistor can be turned ON by applying a signal to its base, & as soon as the base current is removed, the BJT is turned OFF. Hence the power transistor requires continous base current for its conduction

3) Control characteristics of GTO





* GTO is turned ON by applying a +ve gate pulse and is turned OFF by applying −ve pulse to the gate

* Whenever GTO is turned ON Vtg V_s appears across the load, when the device is OFF, the o/p Vtg is zero.

4) Control characteristics of SITH

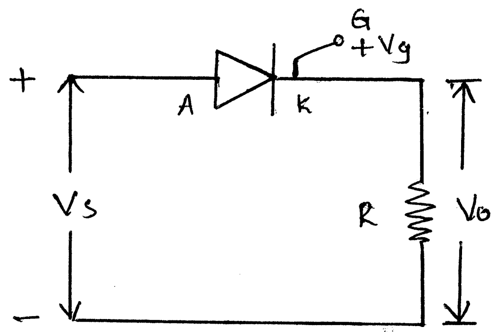
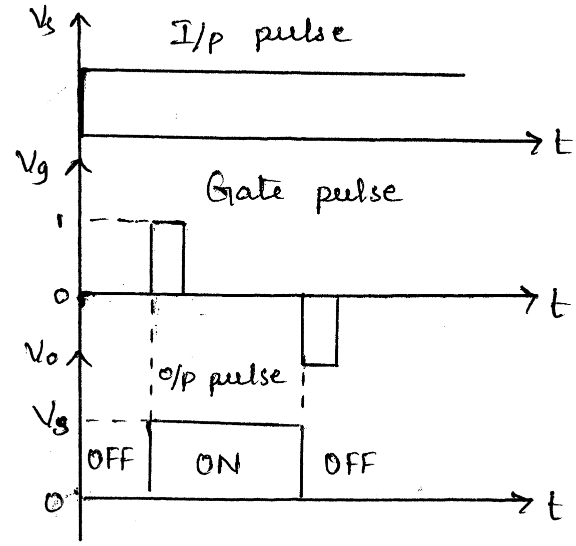


fig: SITH switch



* SITH is turned ON by applying a +ve gate pulse & is turned OFF by applying a –ve pulse to the gate.

* Whenever SITH is turned ON, the Vtg V_s appears across the load, when the device is OFF, the o/p Vtg is zero.

5) Control characteristics of MOSFET

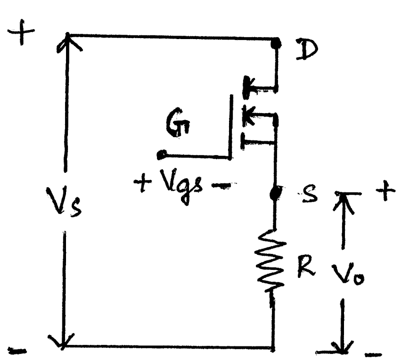
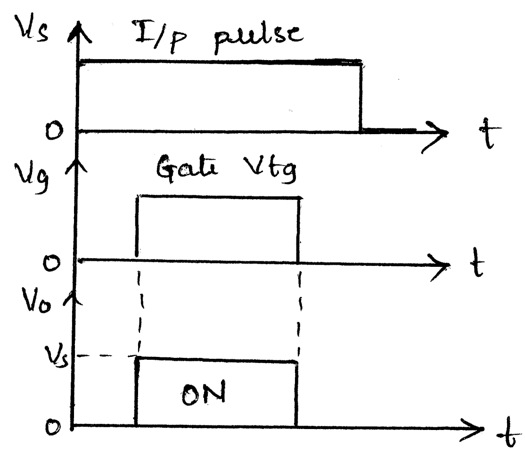


fig: MOSFET switch



When :

Turned ON : Vs appears at O/p

Turned OFF : O/p is 0

* MOSFET is voltage controlled device, hence it requires gate voltage to turn ON. As long as gate voltage is +ve, the MOSFET conducts.

* When gate voltage is made zero or −ve, MOSFET is turned OFF

6) <u>Control</u> <u>characteristics</u> of <u>IGBT</u>

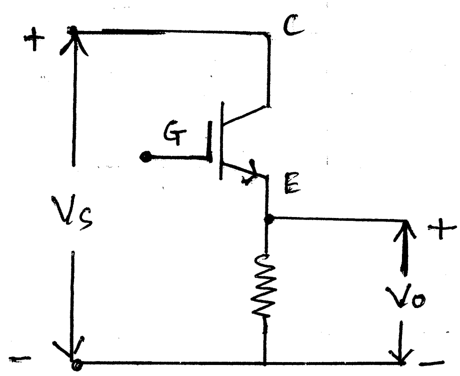
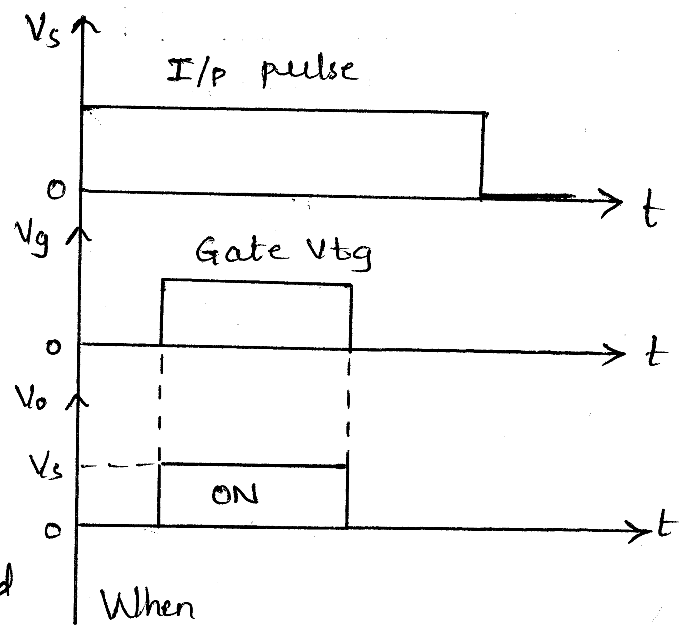


fig : IGBT Switch



* IGBT is voltage controlled device, hence it requires gate voltage to turn <u>ON</u>. As long as the gate vtg is +ve IGBT conducts.

When

Turned ON : Vs appears at O/p

Turned OFF : O/p is 0

* When gate voltage is made zero or −ve IGBT is turned OFF

* Control characteristics of MCT

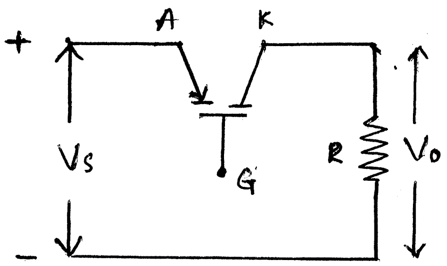
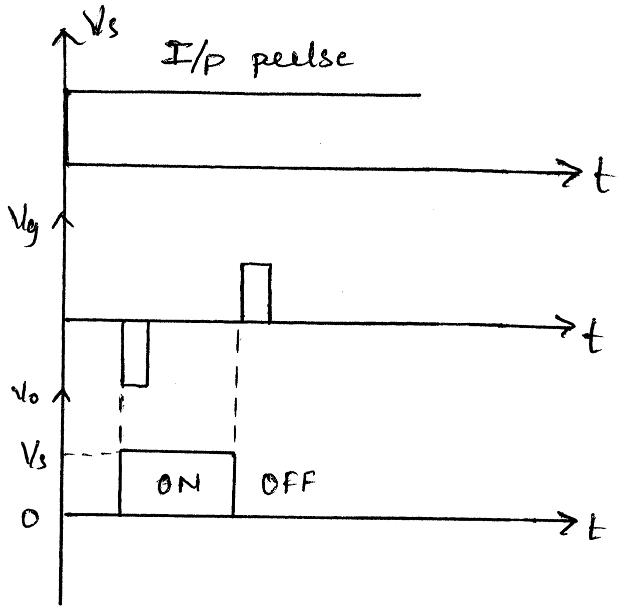


fig MCT switch



* In MCT, a +ve gate pulse causes it to Turn <u>OFF</u> and a −ve gate pulse causes it to Turn <u>ON</u>

* Whenever MCT is turned ON, the Vtg Vs appears accross the load, when the device is OFF, the O/p Vtg is zero.

ARUNKUMAR.G M.Tech, Lecturer in E&CE dept. S.T.J.I.T, Ranebennur.

Power electronic circuits or Converters :-

- Explain any four types of power converter circuits with the circuit, input & output waveforms. Also, mention one application of each type. **June-11,6M**
- Mention and explain the different types of power electronic converter systems. Draw their input output characteristics. **June-11,6M(E&E)**
- Explain in brief the different types of power electronic converter circuit and mention the type of input supply and its related output in each case. Also indicate two application in each case

June-10,6M Jan-10,10M June-10,8M June-08,8M June-07,8M

Jan-07,5M June-06,6M June-05,4M June-04,6M

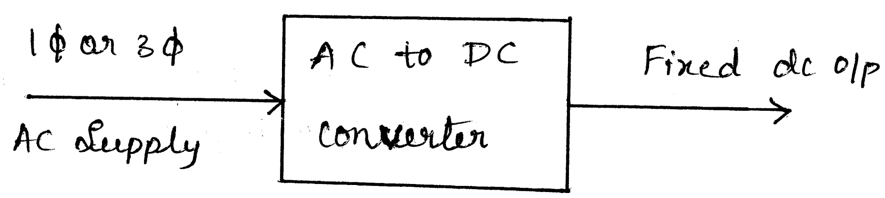
- Explain briefly the different types of thyristor power converters and mention two applications of each. **Jan-09,9M**
- What is power converter? List the different types of power converters and mention their conversion functions. **Jan-06,7M**

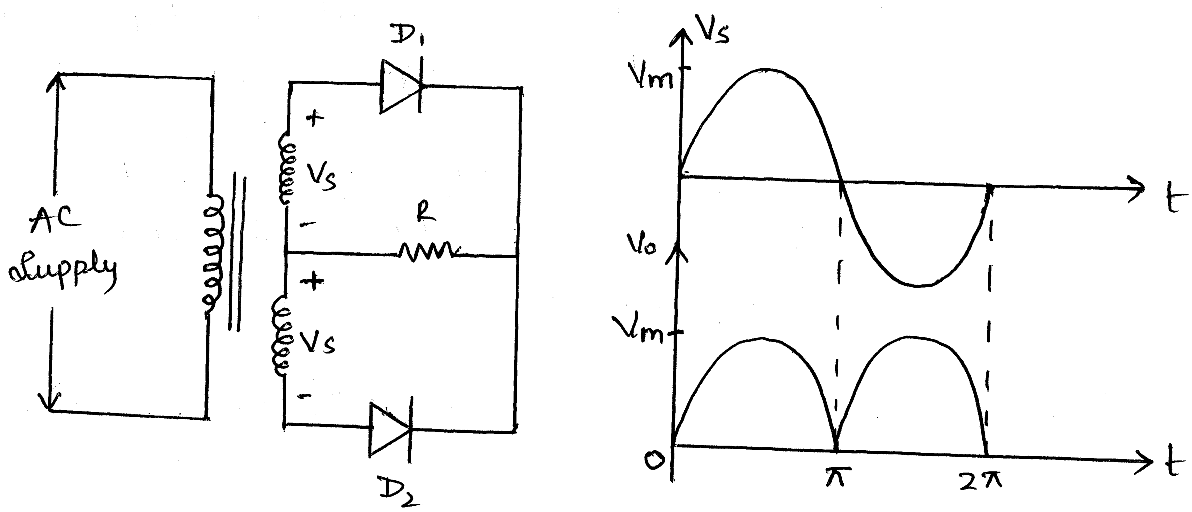
Types of power electronic circuits :-

The power electronic circuit can be classified into 6 types :

1) Diode Rectifiers (uncontrolled rectifiers)
2) AC - DC converter (controlled rectifiers)
3) AC - AC converter (AC Vtg converter)
4) DC - DC converter (DC choppers)
5) Static switches.

1) Diode Rectifiers





* A diode Rectifier circuit converts AC voltage into fixed DC voltage as shown in figure.

The I/P voltage to the Rectifier V_i could be either single phase or 3 phase.

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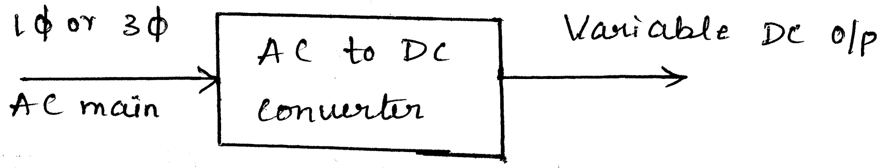
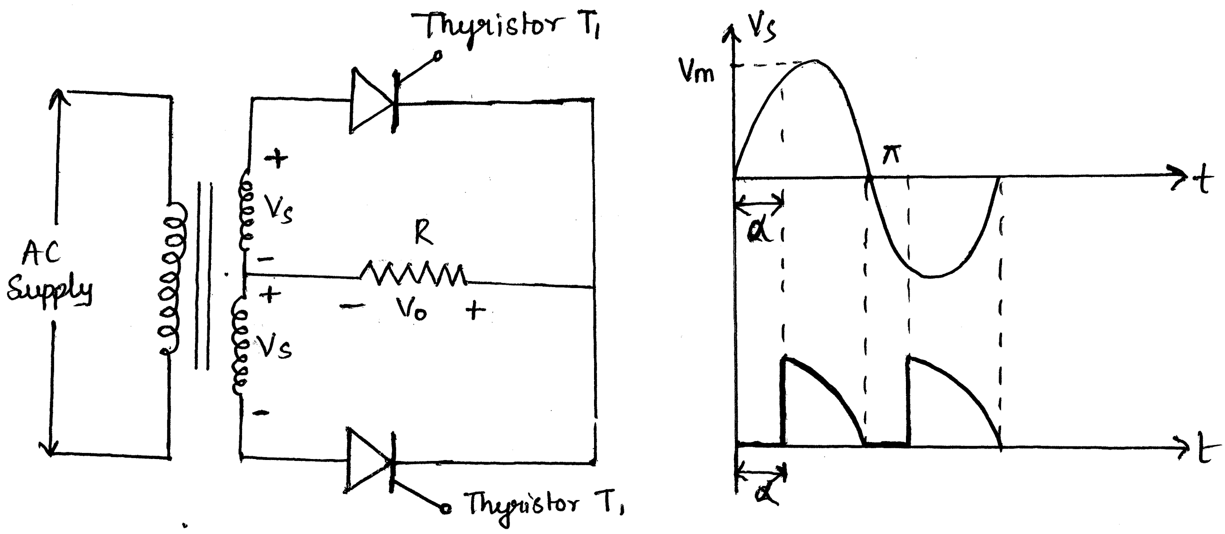
2) AC - DC Converter [Controlled Rectifier]





* The input voltage is available from the main source (Input Voltage is fixed AC voltage)

* The o/p of the converter is variable dc O/p ie o/p is controlled dc voltage & currents.

* The control rectifiers mainly use SCR's. The average value of the o/p voltage can be controlled by varying the firing angle 'α'.

* The SCR are turned off by natural commutation

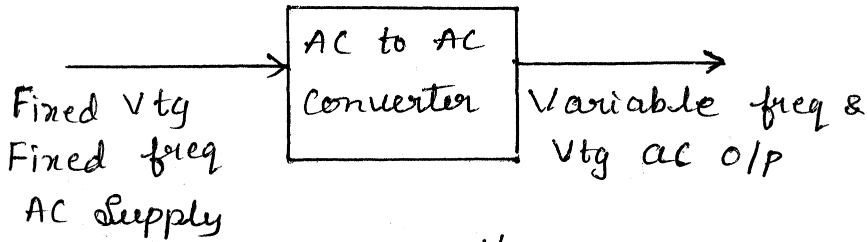
Applications:

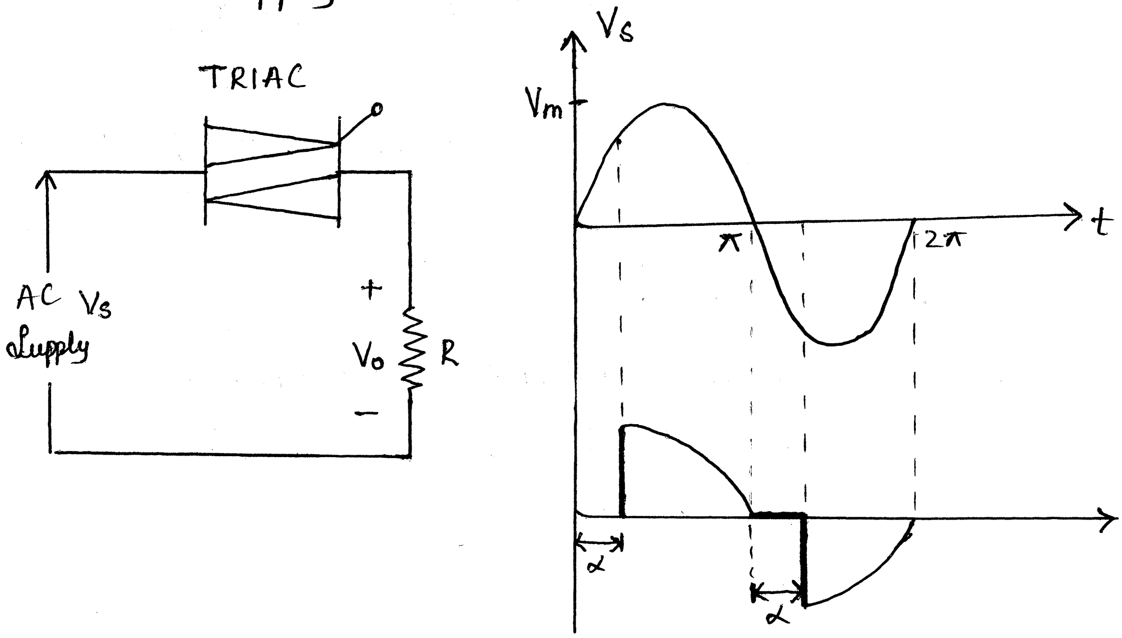
i) DC Motor drives

ii) Regulated DC power supplies

iii) Battery charger ckts etc

3) AC to AC converters :-

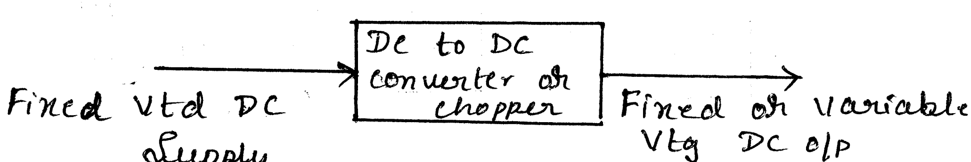


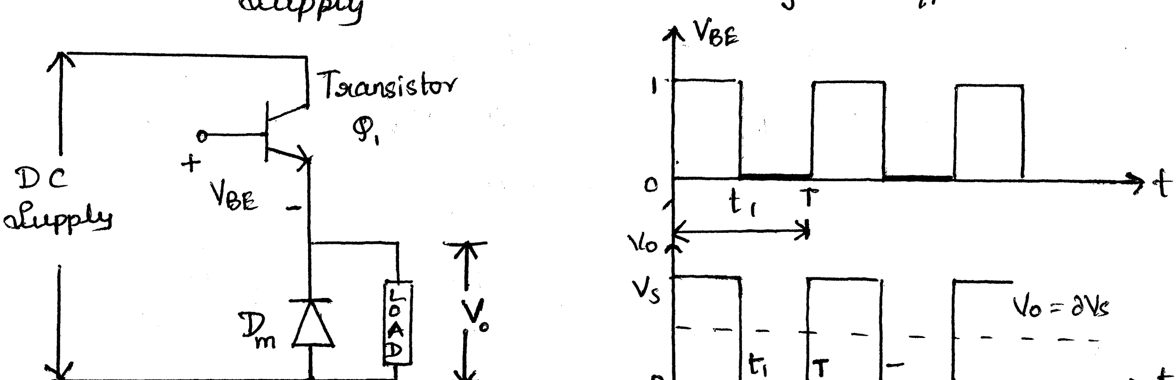


* The I/p Voltage to the converter is 1φ or 3φ fixed AC voltage.

The o/p is an variable ac vtg.

4) DC - DC converters [choppers] :-





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* A DC-DC converter is also known as a chopper or switching Regulator.

Fig shows transistor chopper.

* The average o/p is controlled by varying the conduction time 't_1' of transistor Q_1.

* The duty cycle ∂ of the chopper is given by

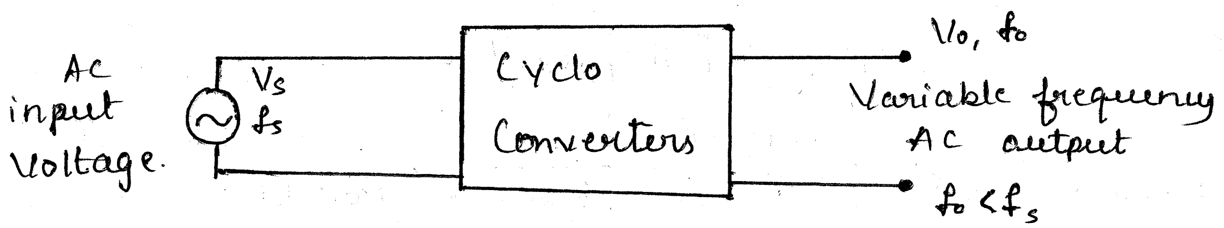
$$\boxed{\partial = \frac{t_1}{T}}$$

* The converter use TRIAC as shown in the fig. The o/p Vtg is controlled by varying the firing angle of TRIAC ie 'α'.

Applications

Widely used for lighting control, speed control of fans, pumps etc.

ii) CYCLO CONVERTERS :-



* These ckts converts Input power at one frequency to o/p power at a different frequency through one stage conversion

* These are designed using Thyristors. The o/p frequency is lower than the source frequency.

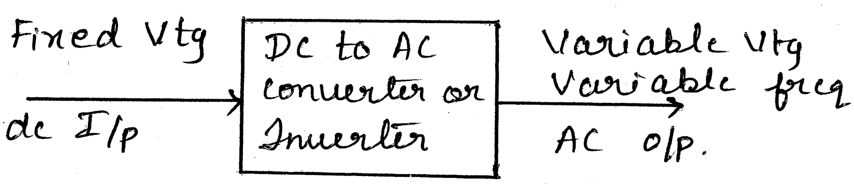
Application

These are mainly used for slow speed, Very high power industrial drives

Application of DC - DC Converters

1) Battery driven Vehicles
2) SMPS
3) DC drives
4) Trolly trucks etc

5) DC - AC converters :-



* A DC - AC converter is also known as an Inverter

The I/p to the inverter is fixed DC Vtg usually Obtained from battery

The o/p of the inverter is the fixed or variable frequency ac voltage. Inverter are used Whenever mains are not available

Applications :-

1) Inverter
2) UPS
3) HVDC etc

6) Static Switches

Since the power devices can be used as static switches or contactors the supply to these switches could be either AC or DC and the switches are called as AC static switches or DC switches.

Applications:-

Static switches posses many advantages over mechanical & electromechanical circuit breakers.

Design of Power electronic equipments :-

The design of power electronic equipment may be divided into four parts

1) Design of power circuits
2) Protection of power devices.
3) Determination of control strategy
4) Design of logic and gating circuits

The following points are considered while designing power electronic module

1) **Analysis :-**

The complete analysis of the circuit must be done. This is very important to understand the operation of the circuit and to establish the characteristic and control strategy

2) **Investigation :-**

Before a prototype is built, the designer must investigate the effects of the circuit parameters and the device imperfections & should modify the design if necessary.

3) **Prototype module :-**

At this stage a prototype or test module is built and tested. Once the module works in the desired manner, the designer will be confident about the validity of the design and can estimate more accurately. Some of the circuit parameters.

PERIPHERALS EFFECTS

❖ **What are the peripheral effects of power converter system?**

Jan-11,6M June-10,4M(IT) June-09,4M Jan-08,6M June-07,4M Jan-07,5M

❖ **What are the peripherals effects of power electronic circuit? What are the remedies for them?** **Jan-06,5M**

❖ **What are the advantages of static power converters? Mention the peripheral (terminal) effects of such staticpower converters.**

June-10,10M

❖ **What are the peripheral effects of power electronic circuits on load and source?** **Jan-09,3M**

❖ **What are the advantages of static power converters? Mention the peripheral effects of such static power converters.** **June-08,6M**

❖ **What are the peripheral effects of power electronic components and equipments? How to eliminate them?** **June-08,6M**

Due to the switching of power semiconductor devices, the power converter will introduce voltage & current harmonics into the supply system (ie I/p or source) & on the O/p of the converter (ie O/p)

* These harmonics will distort the O/p & causes interference with the communication & signalling ckts. Hence to reduce these harmonics levels the filters are used at both I/p & O/p of the converter.

These filters attenuate the harmonics and noise spikes

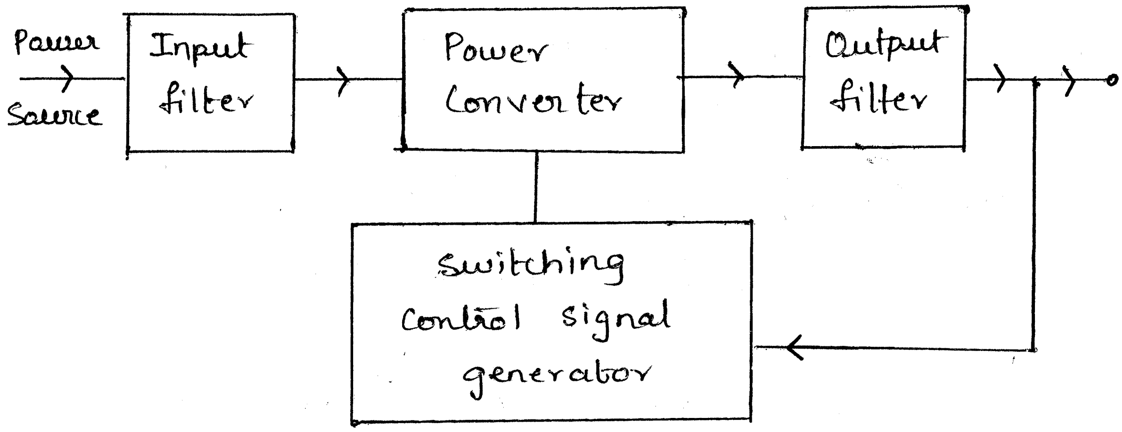


Fig ① shows the Block diagram of a generalized power converter

In order to resolve this problem (peripheral effects), it is required to know the quality of power & contents of harmonics

This can be analysed by calculating the Total harmonic distortion (THD),

Harmonic factor (HF)

I/p power factor (IPF)

These factors can be determined by analysing the voltage and current waveforms with the help of fourier series.

* The power converters can cause radio frequency interface due to electromagnetic radiation & the gating ckts may generate erraneous signals. This interference can be avoided by grounded shielding

Advantages or Merits of PE Systems

1) High efficiency due to low loss in power semiconductor devices.
2) High reliability of power-electronic converter systems
3) Fast dynamic response because static devices are used.
4) Low power loss as the device connected in the converter operate as switches & not in their active region.
5) Less maintenence and long life due to absence of any moving parts.
6) Compact or small size & light weight of the controller due to electronic devices.
7) Lower cost of the converter equipment.
8) Higher flexibility because converters use (μP) microprocessor based control unit.

Disadvantages or Demerits :-

1) Power electronic converter circuits generate Harmonics. These harmonics affect the performance of the system.
2) Some of the power converts have a very low power factor. So power factor correction techniques are required to be used
3) Due to abrupt switching of large currents, electromagnetic radiation takes place from the power

converters. This affect the neighbouring electronic circuits such as telephone networks.

4) Need of large heat sinks, large filters Inductors and capacitors, the low frequency power converters become bulky & costly.

5) For very simple conversion requirements power electronic converters may be costly.

6) Power-electronic controllers have low overload capacity.

7) Regeneration of power is difficult in power electronic converter system.

Applications of power electronics

1) Home Appliences :- Refrigerators, washing machines, Vaccum cleaners, mixers, cooking appliences, sewing machines, air conditioning, fans, dryers etc

2) Games & Entertainment :- Games & toys, TV projectors etc

3) Commercial :- Advertising Battery chargers, computers, photocopiers, light dimmer, flashers, power suppliers, elevators, UPS etc.

4) Aerospace :- Aircraft power systems, space vehicle, power systems, satellite power systems

5) Automotive :- Alarms & security systems, electric vehicles, audio & RF amplifiers regulators.

6) Industrial :- Blowers, boilers, ckt breakers, cranes electric furnaces, ovens gas turbine starters, generators, compressors. printing machinery, pumps, welding equipment motor drives & starters, nuclear reactor control paper mill machinery, power supplier etc

7) Security Systems :- Alarms & Security systems, radar sonar.

8) Medical :- Fitness machines, laser, power supplies, medical instrumentation

9) Telecommunications :- UPS, VLF Txer, wireless, communication power supplies, Battery chargers. etc

10) Transportation :- Trains & locomotives, motor drives trolly busses, electric vehicles, Battery chargers, automotive electronics

11) Utility Systems :- High voltage DC Transmission (HVDC) power factor correction, Supplementary energy systems (Solar, wind) Static ckt breakers

❖ **List out some applications of power controller.** **June-10,6M**

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POWER TRANSISTOR

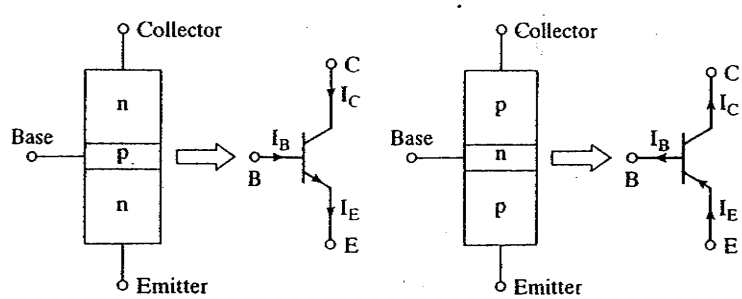
- Power transistor have controlled turn-ON and turn-OFF characteristics and are used as switching elements. Power transistors are operated in saturation region, resulting in a low ON-state voltage drop.
- The switching speed of modern transistors is much higher than that of thyristors and are extensively used in dc-dc and dc-ac converters.

Power transistors can be classified into five types :

1) **Bipolar Junction Transistor (BJT)**
2) **Metal Oxide Bipolar Transistor (MOSFETs)**
3) **Insulated Gate Bipolar Transistor (IGBT)**
4) **Static Induction Transistors (SITs)**
5) **COOLMOS**

Bipolar Junction Transistor (BJT) :-

Construction



(a) NPN-transistor (b) PNP-transistor

FIGURE
Bipolar transistors.

BJT has three terminals namely : Emitter, collector & base
It has 3 layers (either NPN or PNP) & has two junctions
collector - base junction (CBJ) & base emitter
junction (BEJ)

- A bipolar transistor is formed by adding a second p or n region to a pn junction diode i.e. p-region is sandwiched between two transistor n-region toform npn transistor.Transistor is having 3 terminals namely :

Emitter (E), Base (B) andCollector (C).

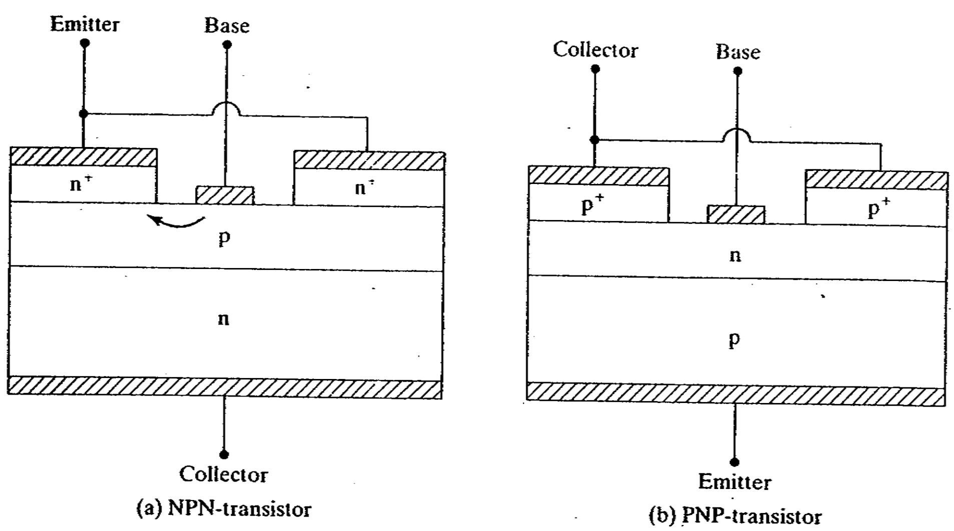


FIGURE 4.3
Cross sections of BJTs.

* There are two n^+- regions for the emitter of NPN-type transistor shown in fig ②ⓐ. & two p^+- regions for the emitter of the PNP-Type transistors shown in fig ②ⓑ

* For an NPN type, the emitter side n-layer is made wide, the p-base is narrow & the collector side n-layer is narrow and heavily doped.

* For a PNP - type the emitter side p-layer is made wide, the n-base is narrow, & the collector side p-layer is narrow & heavily doped.

* When transistor conducts, resulting in a low ON-state collector - emitter resistance, R_{CE} (ON).

❖ STEADY-STATE Characteristics of a BJT (Transistor) :-

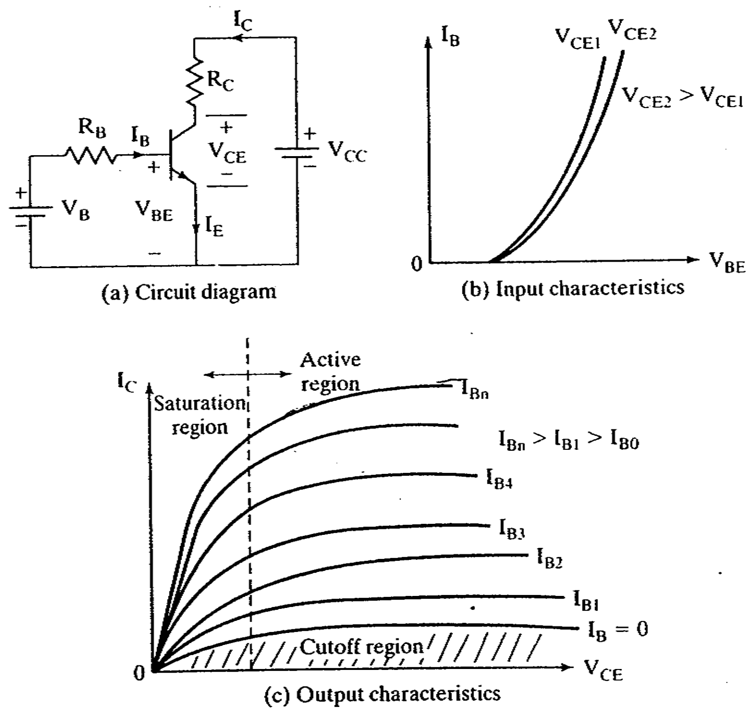
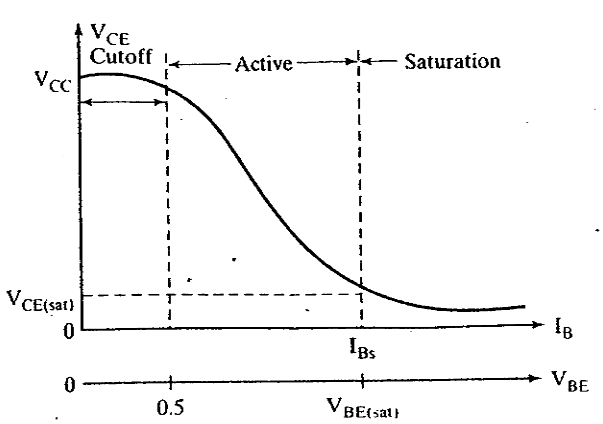


FIGURE 4.4

Characteristics of *NPN*-transistors.



FIGURE

Transfer characteristics.

* WKT for a transistor the emitter current is given by:

$$\boxed{I_E = I_B + I_C} \longrightarrow (1)$$

* The ratio of the collector current I_C, to base current I_B is known as forward current gain 'β_F'.

$$\boxed{\beta_F = h_{FE} = \frac{I_C}{I_B}} \quad \& \quad \boxed{\alpha_F = \frac{I_C}{I_E}}$$

Dividing eq (1) by I_C, we get

$$\frac{I_E}{I_C} = \frac{I_B}{I_C} + \frac{\cancel{I_C}}{\cancel{I_C}}^{1}$$

$$\frac{I_E}{I_C} = \frac{I_B}{I_C} + 1$$

$$\boxed{\frac{1}{\alpha_F} = \frac{1}{\beta_F} + 1} \longrightarrow (2)$$

Solving for α_F

$$\frac{1}{\alpha_F} = \frac{1+\beta_F}{\beta_F}$$

$$\boxed{\alpha_F = \frac{\beta_F}{1+\beta_F}}$$

from eqn (2), Solving for β_F

$$\frac{1}{\alpha_F} = \frac{1}{\beta_F} + 1$$

$$\frac{1}{\beta_F} = \frac{1}{\alpha_F} - 1$$

$$\frac{1}{\beta_F} = \frac{1-\alpha_F}{\alpha_F}$$

$$\boxed{\beta_F = \frac{\alpha_F}{1-\alpha_F}}$$

* Let us consider the ckt of fig 1ⓐ, where the transistor is operated as a switch.

Applying KVL to the input ckt, we get

$$V_B - I_B R_B - V_{BE} = 0$$

$$V_B - V_{BE} = I_B R_B$$

$$\boxed{I_B = \frac{V_B - V_{BE}}{R_B}} \longrightarrow (3)$$

* Applying KVL to the o/p ckt, we get

$$\boxed{V_{CE} = V_{CC} - I_C R_C} \longrightarrow (4)$$

But WKT $I_C = \beta_F I_B = \beta_F\left[\frac{V_B - V_{BE}}{R_B}\right]$

Substituting I_C value in Eq (4), we get

$$V_{CE} = V_{CC} - \beta_F\left[\frac{V_B - V_{BE}}{R_B}\right] R_C$$

$$V_{CE} = V_{CC} - \frac{\beta_F R_C}{R_B}\left[V_B - V_{BE}\right] \longrightarrow (5)$$

* The maximum collector current in the active region can be obtained by setting $V_{CB} = 0$ & $V_{BE} = V_{CE}$

ie $I_{C(max)} = \frac{V_{CC} - V_{CE}}{R_C} = \frac{V_{CC} - V_{BE}}{R_C}$

& the corresponding value of base current

$$I_{B(max)} = \frac{I_{CM}}{\beta_F}$$

* When transistor is in saturation, the collector current remains almost constant & $V_{CE} = V_{CE(sat)}$

$$\therefore \boxed{I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C}}$$

& the corresponding value of base current is

$$\boxed{I_{B(sat)} = \frac{I_{C(sat)}}{\beta_F}}$$

* Normally, the ckt is designed so that I_B is higher than $I_{B(sat)}$. <u>over drive factor (ODF)</u>:

The ratio of I_B to $I_{B(sat)}$ is called the overdrive factor (ODF).

$$ODF = \frac{I_B}{I_{B(sat)}}$$

<u>Forced β</u>:-

It is the ratio of $I_{C(sat)}$ to I_B is called as forced β (β_{forced})

ie $$\boxed{\beta_{forced} = \frac{I_{C(sat)}}{I_B}}$$

* The total power loss in the two junctions

is $$\boxed{P_T = V_{BE} I_B + V_{CE} I_C}$$

NOTE :- Power $= V \cdot I$

Total power P_T = I/p power + O/p power

I/p power = I/p Vtg × I/p current ie $V_{BE} I_B$

O/p power = O/p Vtg × O/p current ie $V_{CE} I_C$

BIPOLAR JUNCTION TRANSISTOR (BJT) :-

❖ **Explain the important characteristicss features of power transistors. With the aid of output and transfer characteristics discuss the different operating regions of a power BJT**

Jan-05,10M

Construction

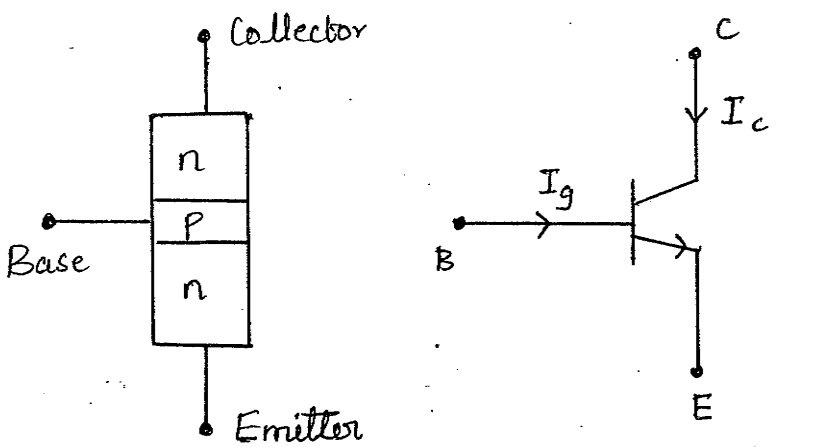


Fig 1ⓐ NPN - transistor

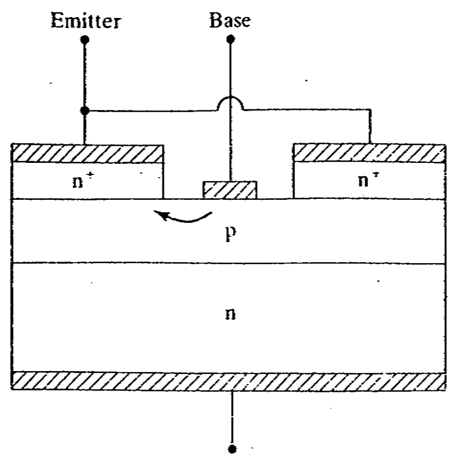
A bipolar transistor is formed by adding a second p or n-region to a pn-junction diode.
ie p-region is sandwitched between two n-region to form npn transistor.

Transistor is having 3 terminals namely:

Emitter (E)

Base (B)

Collector (C)



(a) NPN-transistor

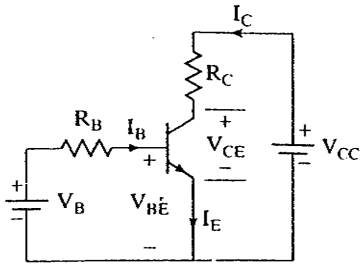
fig 1 ⓑ cross section of NPN transistor.

There are two n^+ regions for the emitter of NPN transistor as shown in fig 1ⓑ.

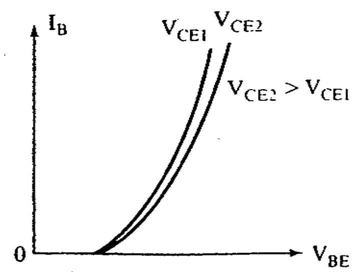
The n layer of emitter is made wider, the p-layer of base is narrow & the n-layer of collector is narrow and heavily doped.

* The base & collector current flows through two parallel paths, resulting in a low on-state collector-emitter resistance $R_{CE(ON)}$

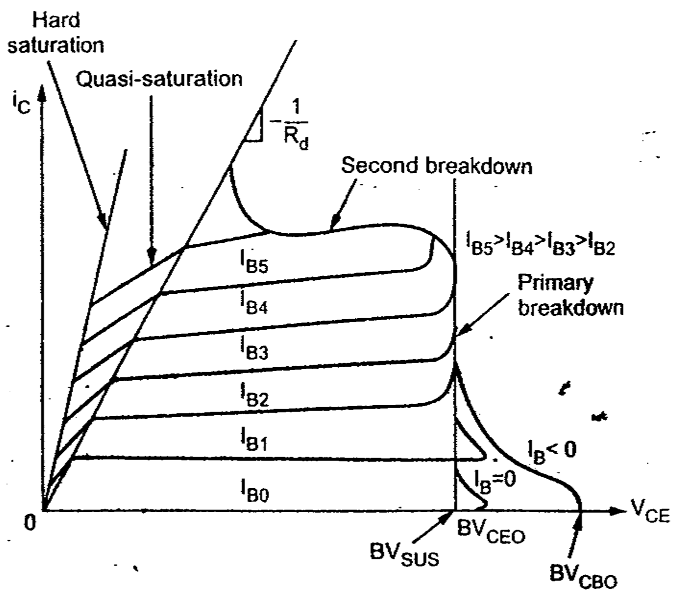
Steady state characteristics :-

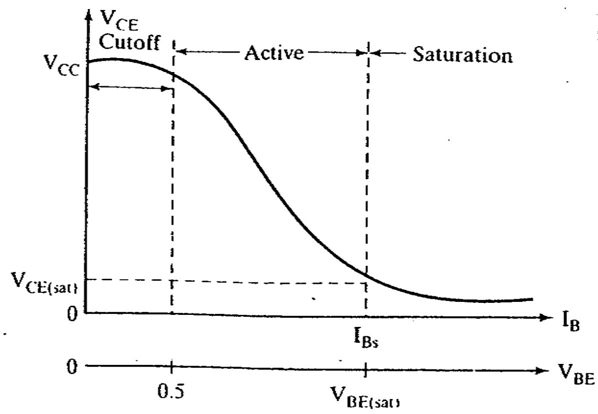


(a) Circuit diagram



(b) Input characteristics





V-I characteristics of npn power BJT and different regions of operation

I/P characteristics :-

A graph between base current I_B & base-emitter voltage V_{BE} gives I/P characteristics. As the base emitter junction of a transistor is like a diode, I_B versus V_{BE} graph resembles a diode curve.

* When $V_{CE2} > V_{CE1}$, base current decreases as shown in fig 2(b).

O/P characteristics :-

There are three operating of a transistor :

i> Cut-off
ii> Active
iii> Saturation

i> Cut-off region :-

The transistor is off ie. The base current 'I_B' is not enough to turn it ON & both junctions are reverse biased.

ii> Active region :-

In active region, the transistor acts as an amplifier. The collector - base junction is reverse biased and base - emitter junction is forward biased.

* The base current is amplified by a gain and the the V_{CE} decreases with the base current.

iii> Saturation region :-

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

Both, junctions are forward biased.

Second breakdown :-

from fig 2(c), it is clear that at the large collector currents, the collector emitter voltage (V_{CE}) drops. Due to this drop in voltage, the collector current increases. Thus power dissipation increases.

This power dissipation is not spread across the entire device. Thus the local temperature grows rapidly & the BJT is damaged.

1) $I_{C(sat)} = \dfrac{V_{CC} - V_{CE(sat)}}{R_C}$

2) $I_B = \dfrac{V_B - V_{BE}}{R_B}$

3) $\beta_{forced} = \dfrac{I_{C(sat)}}{I_B}$

4) $I_{B(sat)} = \dfrac{I_{C(sat)}}{\beta_{(minimum)}}$

5) $ODF = \dfrac{I_B}{I_{B(sat)}}$

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

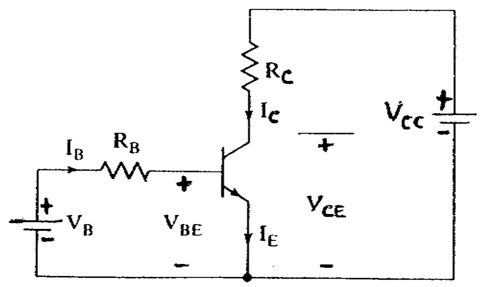
TRANSISTOR SWITCHING PROBLEMS.

1) The bipolar transistor in figure1 shown below is specified to have β_f in the range of 8 to 40. The load resistance is R_c=11Ω. The dc supply voltage is V_{CC}=200v and the input and $V_{BE(sat)}$=1.5v, V_B=10V find

a) The value of RB that results in saturation with an ODF of 5

b) The β forced and

c) The power loss PT in the transistor.



Given :- $V_{cc} = 200V$ $\beta_{min} = 8$, $\beta_{max} = 40$, $R_c = 11\Omega$, ODF = 5, $V_B = 10V$, $V_{CE(sat)} = 1.0V$ & $V_{BE(sat)} = 1.5V$

Soln :-

$$I_B = \frac{V_B - V_{BE(sat)}}{R_B}$$

$$I_B = ?$$

$$I_{B(sat)} = \frac{I_{c(sat)}}{\beta_{min}}$$

$$* \ I_{c(sat)} = \frac{V_{cc} - V_{CE(sat)}}{R_c} = \frac{200V - 1V}{11\Omega}$$

$$\boxed{I_{c(sat)} = 18.09A}$$

$$* \ I_{B(sat)} = \frac{I_{c(sat)}}{\beta_{min}} = \frac{18.09}{8}$$

$$\boxed{I_{B(sat)} = 2.26A}$$

* WKT $ODF = \frac{I_B}{I_{B(sat)}}$

$$I_B = ODF \cdot I_{B(sat)}$$

$$= 5 \times 2.26A$$

$$\boxed{I_B = 11.33A}$$

* WKT $R_B = \frac{V_B - V_{BE(sat)}}{I_B} = \frac{10V - 1.5V}{11.33A}$

$$\boxed{R_B = 0.7522\,\Omega}$$

(b) Forced β factor :-

$$\beta_{forced} = \frac{I_{C(sat)}}{I_B} = \frac{18.09A}{11.33A}$$

$$\boxed{\beta_{forced} = 1.6}$$

(c) Power loss in the transistor

$$P_T = V_{BE} I_B + V_{CE(sat)} \cdot I_{C(sat)}$$

$$= 1.5 \times 11.33 + (1) \times 18.33$$

$$\boxed{P_T = 35W}$$

2) A simple transistor switch is used to connect a 24v dc supply across a relay coil, which has a dc resistance of 200Ω. An input pulse of 0 to 5V amplitude isapplied through a series base resistor R_B at the base so as to turn ON the transistor switch. Sketch the device current waveform with reference to the input pulse.

Jan-05,10M

Given :

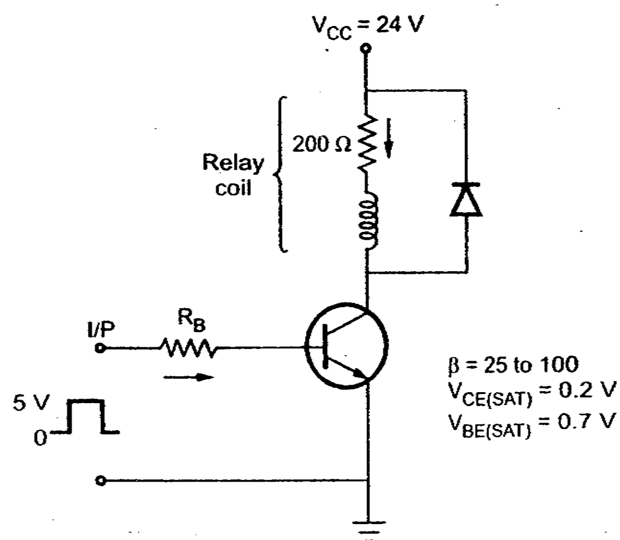
VCC=24V

VCE(sat) = 0.2V

VBE(sat)= 0.7V

VB=5V

β = 25 to 100



Soln:

i) $I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C} = \frac{24 - 0.2V}{200} = 0.12\,A$

$$\boxed{I_{C(sat)} = 0.12mA}$$

ii) $R_B = ?$ for ODF = 2

WKT $I_{B(sat)} = \frac{I_{C(sat)}}{\beta_{(min)}} = \frac{12mA}{25}$

$$\boxed{I_{B(sat)} = 4.8\,mA}$$

Also $ODF = \frac{I_B}{I_{B(sat)}}$

$I_B = ODF \times I_{B(sat)} = 2 \times 4.8mA$

$\boxed{I_B = 9.6mA}$

* WKT $R_B = \frac{V_B - V_{BE}}{I_B} = \frac{5 - 0.7V}{9.6mA}$

$\boxed{R_B = 448 \Omega}$

iii) To obtain power dissipation

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

$= 0.7 \times 9.6mA + 0.2 \times 0.12$

$\boxed{P_T = 0.03070 W}$

---

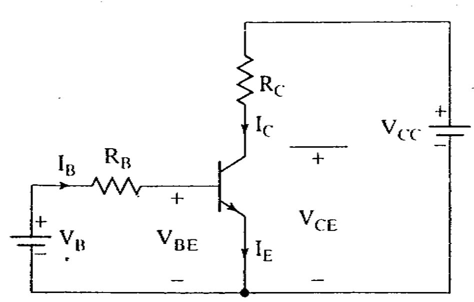
3) For the switching circuit shown in fig1 calculate :

i) the forced β of transistor

ii)The minimum ODF if the manufacturer specified β is 10

iii)The power loss P_T of the transistor.

Jan-10,6M



Given

Soln: Given : $V_{CC} = 100V$, $V_B = 5V$, $R_B = 0.8\Omega$, $R_C = 12\Omega$

$V_{CE(sat)} = 1V$, $V_{BE(sat)} = 1.5V$, $\beta = 10$.

Soln :- i) $\beta_{forced} = \dfrac{I_{C(sat)}}{I_B}$

$$I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C} = \frac{100V - 1V}{12\Omega} = \underline{8.25A}$$

$$I_B = \frac{V_B - V_{BE(sat)}}{R_B} = \frac{5V - 1.5\Omega}{0.8\Omega} = \underline{4.375A}$$

$$\beta_{forced} = \frac{I_{C(sat)}}{I_B} = \frac{8.25A}{4.375A} = 1.89$$

$$\boxed{\beta_{forced} = 1.89} \longleftarrow 2m$$

ii) $ODF = \dfrac{I_B}{I_{B(sat)}}$

$$I_{B(sat)} = \frac{I_{C(sat)}}{\beta} = \frac{8.25A}{10}$$

$$\boxed{I_{B(sat)} = 0.825A}$$

$$ODF = \frac{4.375A}{0.825A} \qquad \boxed{ODF = 5.3} \longleftarrow 2m$$

iii) Power loss

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

$$= 1.5 \times 4.375 + 1 \times 8.25$$

$$\boxed{P_T = 14.8W} \longleftarrow 2m$$

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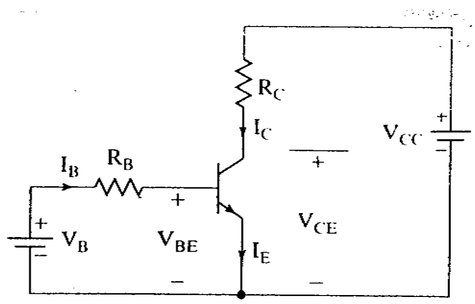
4) A power BJT is connected as a switch as in fig1 with the following data calculate :

i) The value of R_B that will result in saturation with an over drive factor of 20.

ii) Power loss in the transistor

June-06,8M



$V_{CC} = 100V$, $V_B = 8V$
$V_{CE(sat)} = 2.5V$
$V_{BE(sat)} = \cancel{2.5V}\ 1.75V$
β of the transistor is valid from 10 to 60
$R_C = 10\Omega$.

Given :- $V_B = 8V$, $V_{CC} = 100V$, $V_{CE(sat)} = 2.5V$, $V_{BE(sat)} = 1.75V$
$\beta_{min} = 10$, $\beta_{max} = 60$ $R_C = 10\Omega$.

i> $R_B = ?$ with ODF = 20

WKT , $I_{C(sat)} = \dfrac{V_{CC} - V_{CE(sat)}}{R_C} = \dfrac{100-25}{10}$

$$\boxed{I_{C(sat)} = 9.75A}$$

And $I_{B(sat)} = \dfrac{I_{C(sat)}}{\beta_{min}} = \dfrac{9.75}{10}$

$$\boxed{I_{B(sat)} = 0.975A}$$

$\therefore$ ODF $= \dfrac{I_B}{I_{B(sat)}}$

$\therefore I_B = ODF \times I_{B(sat)} = 20 \times 0.975\ A$

$$\boxed{I_B = 19.5A}$$

$* \; R_B = \frac{V_B - V_{BE}}{I_B} = \frac{8V - 0.7V}{19.5A}$

$\boxed{R_B = 0.32\,\Omega}$

ii) $\beta_{forced} = \frac{I_{C(sat)}}{I_B} = \frac{9.75}{19.5}$

$\boxed{\beta_{forced} = 0.5}$

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

$= 1.75 \times 95 + 25 \times 9.75$

$\boxed{P_T = 58.5W}$

---

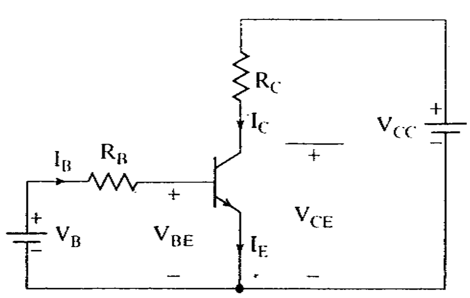
5) A transistor switch of fig1 has β in the range of 8 to 40. Calculate

i)The value of R_B that results in saturation with a overide factor of 5.

ii) The forced β_f and

iii)The power loss in the BJT.

June-04,6M June-08,7M Jan-07,8M



$R_c = 10\Omega$, $V_{cc} = 200V$,

$V_{BE(sat)} = 2V$ $V_{BB} = 10V$

$V_{CE(sat)} = 1V$

Sol:- i) R_B with ODF = 5

$$I_{(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C} = \frac{200-1}{10} = 19.9A$$

$$I_{B(sat)} = \frac{I_{(sat)}}{\beta_{(min)}} = \frac{19.9}{8} = 2.4875A$$

$$ODF = \frac{I_B}{I_{B(sat)}}$$

$$I_B = ODF \times I_{B(sat)} = 5 \times 2.4875 = 12.4375A$$

$$R_B = \frac{V_B - V_{BE}}{I_B} = \frac{10 - 1.5V}{12.4375}$$

$$\boxed{R_B = 0.6834\ \Omega}$$

ii) $$\beta_{forced} = \frac{I_{(sat)}}{I_B} = \frac{19.9}{12.4375} = 1.6$$

iii) $$P_T = V_{BE} I_B + V_{CE} I_C = 1.5 \times 12.4375 + 1 \times 19.9$$

$$\boxed{P_T = 38.55W}$$

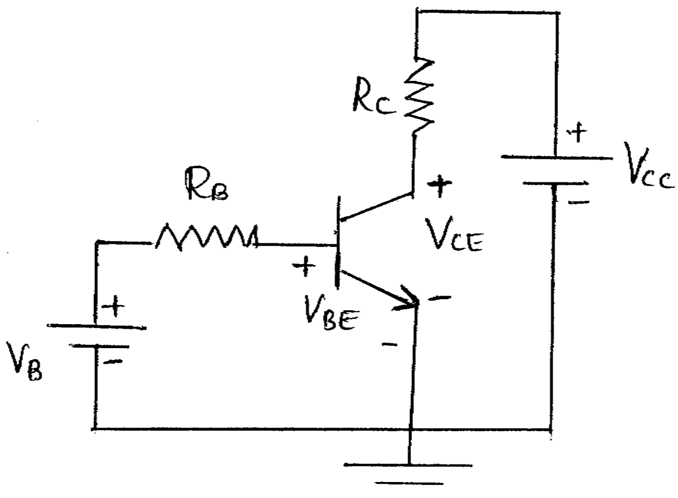
6) The beta(β) bipolar transistor shown in fig1 below varies from 12 to 75. The load resistance R_C=1.5Ω . The dc supply voltage is V_{CC}=40V and input voltage to the base circuit V_B=6V, if $V_{CE(sat)}$=1.6v, R_B=0.7Ω. Determine :

i) **Over drive factor (ODF)**

ii) **The forced β and**

iii) **The power loss in the transistor P_T.**

June-10,10M



Given : $\beta \rightarrow 12$ to 75, $R_c = 1.5\,\Omega$, $V_{cc} = 40V$, $V_B = 6V$

$V_{CE(sat)} = 1.2V$, $V_{BE(sat)} = 1.6V$, $R_B = 0.7\,\Omega$

$\beta_{min} = 12$, $\beta_{max} = 75$.

Soln:

i) $ODF = \dfrac{I_B}{I_{B(sat)}}$

WKT $I_{c(sat)} = \dfrac{V_{cc} - V_{CE(sat)}}{R_c} = \dfrac{40V - 1.2V}{1.5\,\Omega}$

$\boxed{I_{c(sat)} = 25.86\,A}$

$* \quad I_{B(sat)} = \dfrac{I_{c(sat)}}{\beta_{min}} = \dfrac{25.86\,A}{12}$

$\boxed{I_{B(sat)} = 2.155\,A}$

* $I_B = \frac{V_B - V_{BE}}{R_B} = \frac{6V - 1.6V}{0.7}$

$$\boxed{I_B = 6.285A}$$

$\therefore$ $ODF = \frac{I_B}{I_{B(sat)}} = \frac{6.285A}{2.1555A} = 2.915 \cancel{A}$

$$\boxed{ODF = 2.915}$$

ii) Forced β

$\beta_f = \frac{I_{C(sat)}}{I_B} = \frac{25.86A}{6.285A}$

$$\boxed{\beta_f = 4.114}$$

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

$= (1.6 \times 6.285) + (1.2 \times 25.86)$

$= 10.056 + 31.032$

$$\boxed{P_T = 41.088 W}$$

7) In the circuit of fig1, the BJT has β in the ange 10 to 25. If V_{CC}=230V, R_C=12Ω, V_{BB}=15v, $V_{CE(sat)}$=1.2v and $V_{BE(sat)}$=1.8v, calculate :

i) the value of R_B required to move the transistor into saturation with an ODF of 6

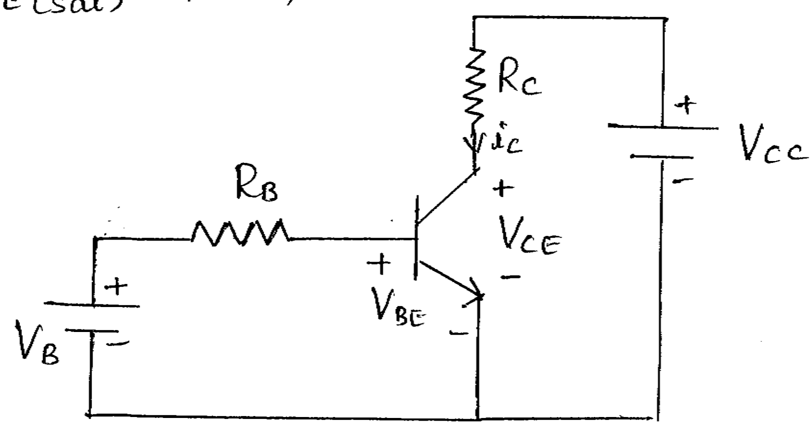
ii) forced beta β_f

iii) total power dissipation

Given : $\beta \to 10$ to 25, $\beta_{min} = 10$, $\beta_{max} = 25$ **June-09,6M**

$V_{cc} = 230V$, $R_c = 12\Omega$, $V_{BB} = 15V$, $V_{CE(sat)} = 1.2V$

$V_{BE(sat)} = 1.8V$, ODF = 6



Soln: i) $R_B = ?$, for ODF = 6

WKT, $I_{c(sat)} = \frac{V_{cc} - V_{CE(sat)}}{R_c} = \frac{230V - 1.2V}{12\Omega}$

$\boxed{I_{c(sat)} = 19.0667A}$

WKT, $I_{B(sat)} = \frac{I_{c(sat)}}{\beta_{min}} = \frac{19.0667A}{10}$

$\boxed{I_{B(sat)} = 1.9067A}$

WKT, $ODF = \frac{I_B}{I_{B(sat)}}$

$I_B = ODF \times I_{B(sat)} = 6 \times 1.9067A$

$\boxed{I_B = 11.4402A}$

WKT, $R_B = \frac{V_{BB} - V_{BE}}{I_B} = \frac{15V - 1.8V}{11.4402A}$

$\boxed{R_B = 1.1538\Omega}$

ii) $\beta_F = \frac{I_{c(sat)}}{I_B} = \frac{19.0667A}{11.4402A}$

$\boxed{\beta_F = 1.6666}$

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

$= (1.8 \times 11.4402) + (1.2 \times 19.0667)$

$\boxed{P_T = 43.4724 \, W}$

❖ SWITCHING Characteristics of a BJT (Transistor) :-

❖ **With the necessary waveform explain the switching characteristics of a power transistor.** **Jan-11,8M**

❖ **Explain the switching characteristics of BJT, with the neat wavefirm.** **June-10,8M(IT)**

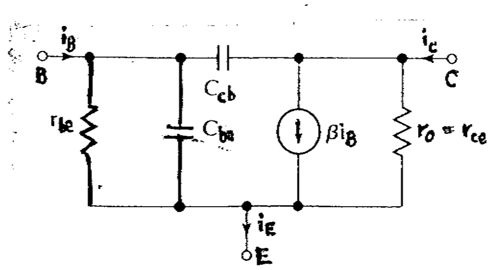
❖ **With necessay waveforms, explain the switching performance of power BJT.** **June-09,7M**

❖ **Name and explain various switching limits in case of power BJT's. With a circuit diagram, explain anisaturation control ofBJT. Mention the improvement and drawback of this arrangement** **June-08,8M**

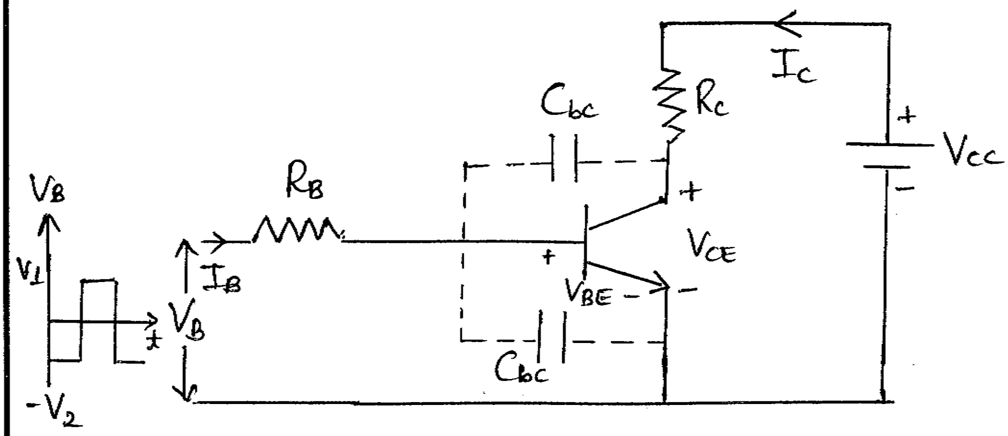
❖ **Sketch and explain the switching characteristics of power BJT. The sketch should have the waveforms of i) V_{BE} ii) I_B iii) I_C** **Jan-08,6M**

❖ **With the necessary waveforms explain the switching characterstics of a power transistor.** **June-07,7M**

❖ **With model and waveforms, explain how the internal capacitances of the transistor influence the switching characteristics of the transistor.** **Jan-07,10M**



(a) Model with current gain



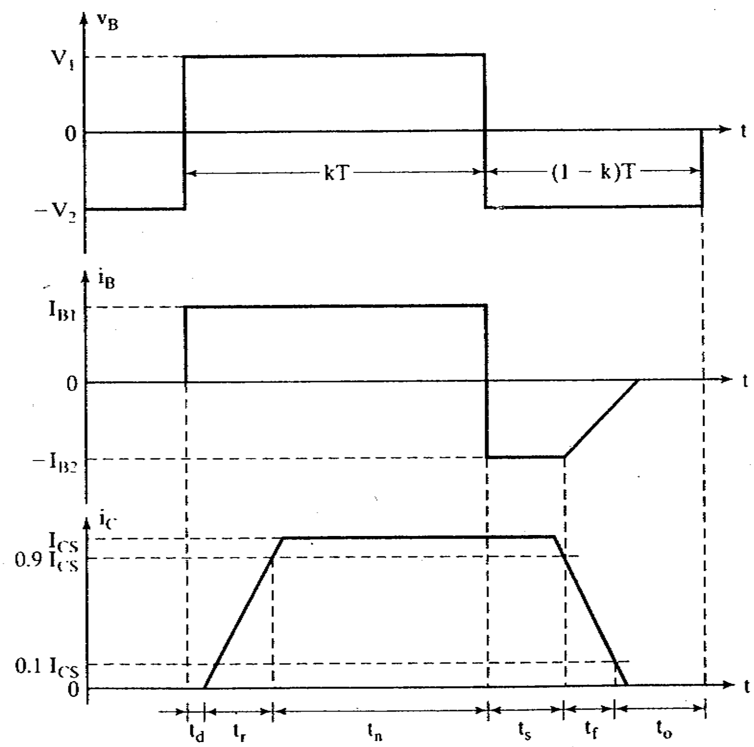


FIGURE 4.9

Switching times of bipolar transistors.

* A forward biased Pn - junction exhibits two parallel capacitence : a depletion layer - layer capacitence & a diffussion capacitance

* Under reverse - biased condition, pn - junction has only depletion capacitance

under steady-state conditions, these capacitence do not play any role

Under transient conditions, the capacitance influence the turn-ON & turn-OFF behaviour of the transistor.

* Due to internal capacitences, the transistor doesnot turn -ON instantly. Fig (3) shows the W/F's & switching

* As the i/p Vtg V_B rises from zero to V_1 & the base current rises to I_{B1}, the collector current does not start flowing. This is because, the collector-base junction capacitence (C_{be}) starts charging when base drive is applied.

This is a delay, known as delay time 't_d'

* This delay is required to charge up the capacitence 'C_{be}' to the forward bias Vtg ie $V_{BE} = 0.7V$.

After this delay, the collector current rises to the steady state value of I_{cs}.

* The rise time 't_r' depends on the time constant of 'C_{be}' capacitence.

* When the I/p Vtg is reversed from V_1 to $-V_2$ & the base current is also changed to $-I_{B2}$, the collector current doesnot change for a time ts, called the storage time 'ts'.

* During 'ts' the saturation charge is removed from the base. After the stored charge are removed, the base current starts reducing & collector current also starts falling.

* The stored charge is removed because of the -ve base current.

once the extra charge is removed, the C_{be} capacitence charges to the I/p vtg $-V_2$ & the base current falls to zero. The fall time 't_f' depends on the time constants, which is determined by the capacitence 'C_{be}'.

* Turn-ON time t_{ON} is given by.

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

Where :- delay time = 't_d'

It is the time taken by the I_c to rise from 0 to $0.1 I_{cs}$

Rise time :- It is the time taken by the I_c to rise from $0.1 I_{cs}$ to $0.9 I_{cs}$

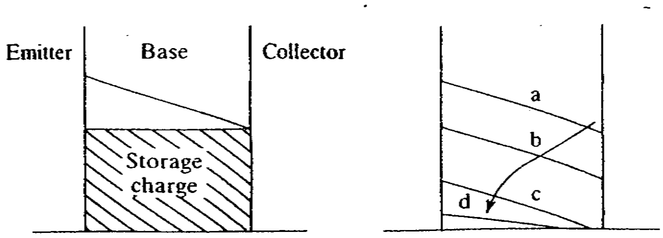
* Turn OFF time t_{OFF} is given by

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

Where

Storage time 't_s' :- It is the time taken by the I_c to fall from I_{cs} to $0.9 I_{cs}$.

Fall time 't_f' :- It is the time taken by I_c to fall from $0.9 I_{cs}$ to $0.1 I_{cs}$.



(a) Charge storage in base

(b) Charge profile during turn-off

Fig ③ Charge storage in saturated bipolar transistors.

fig ③ shows the extra storage in the base of a saturated transistor.

During turn-OFF, this extra charge is removed 1st in time ts & the charge profile is changed from a to c as shown fig 3ⓑ

During fall time, the charge profile decreases from profile 'c' untill all charges removed.

❖ BASE DRIVE CONTROL :-

❖ The Switching speed of the power transistor can be increased by reducing $\mathbf{t_{on}}$ and $\mathbf{t_{off}}$ periods.

❖ $\mathbf{t_{on}}$ can be reduced by allowing base current peaking during turn-on and $\mathbf{t_{off}}$ Can be reduced by reversing base current and allowing base current peaking during turn-off.

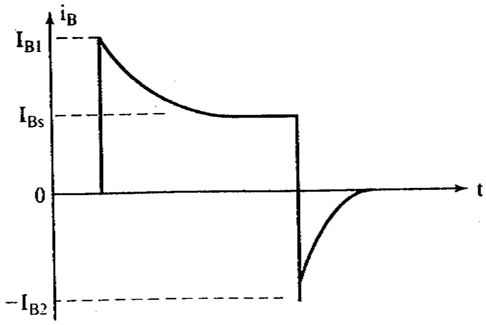


FIGURE 17.3
Base drive current waveform.

❖ To overcome the drawbacks of slow switching speed, the following techniques are used (i.e. base drive control methods).

1) Turn-ON control

2)Turn-OFF control

3)Proportional base control

4)Antisaturation control (Baker's clamp circuit)

❖ Describe briefly the various base drive control methods used in junction transistors

June-05,10M

1) Turn-ON control :-

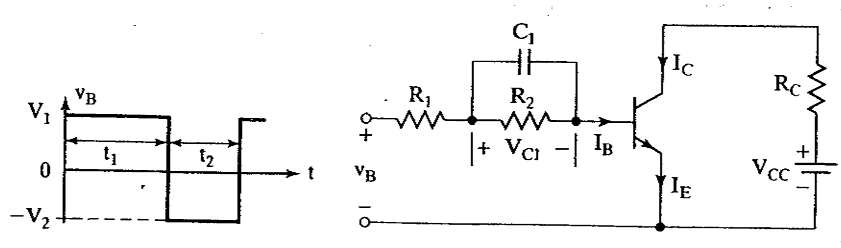


FIGURE 17.4
Base current peaking during turn-on.

* When the I/p vtg 'V_B' is applied the capacitor 'C_1' acts as a short ckt. Hence R_2 is virtually by passes

∴ The initial value of base current is limited by only R_1 & is given by

$$\boxed{I_B = \frac{V_B - V_{BE}}{R_1}}$$

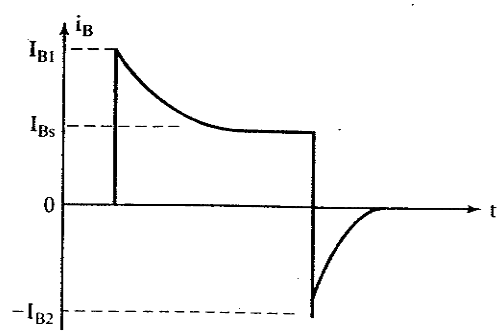


FIGURE 17.3
Base drive current waveform.

This heavy base current drives the transistor into saturati-on for quick turn-ON.

* The Final value of the base current is

$$\boxed{I_{BS} = \frac{V_1 - V_{BE}}{R_1 + R_2}}$$

* The Capacitor 'C_1' charges upto a final value of

$$\boxed{V_C = \frac{V_1 R_2}{R_1 + R_2}} \quad \left\{ \begin{array}{l} V_c = I R_2 \\ V_C = \dfrac{V_1}{R_1 + R_2} \cdot R_2 \end{array} \right.$$

* The charging time constant of the capacitor is

$$\boxed{\tau_1 = \frac{R_1 R_2 C_1}{R_1 + R_2}} \quad \&$$

* The discharging time constant is given by

$$\boxed{\tau_2 = R_2 C_1}$$

* The ON-period of the transistor must be

$$\boxed{T_1 \geq 5\tau_1}$$

* The OFF period of the transistor must be

$$\boxed{T_2 \geq 5\tau_2}$$

∴ The maximum switching frequency

$$f = \frac{1}{T} = \frac{1}{T_1 + T_2} = \frac{1}{5\tau_1 + 5\tau_2}$$

$$\boxed{f = \frac{0.2}{\tau_1 + \tau_2}}$$

2) Turn-OFF control :-

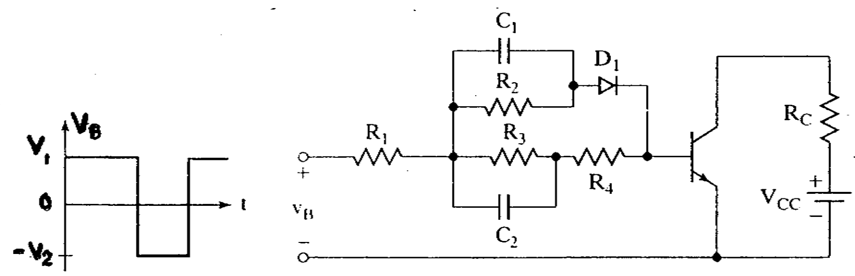


FIGURE 17.5

Base current peaking during turn-on and turn-off.

* If the input voltage in figure ① is changed to $-V_2$ during turn-OFF, the capacitor Vtg 'V_c' is added to V_2 as a reverse vtg across the Transistor.

* There will be base current peaking I_{B2} ~~during~~ whitner during ~~I_{B2}~~ whitner turn-OFF. As the capacitor C_1 discharges, the reverse vtg can be reduced to a steady state value of V_2.

* In fig ② C_2, R_4 work during turn-ON & C_1 R_2 R_3 work during turn-OFF to provide different time (T_1 & T_2)

* The diode D_1 isolates the forward Base drive ckt from reverse base drive ckt during Turn-OFF

3) Proportional Base control :-

❖ **What is the necessity of base drive control in a power transistor? Explain proportional base control.**

June-11,8M

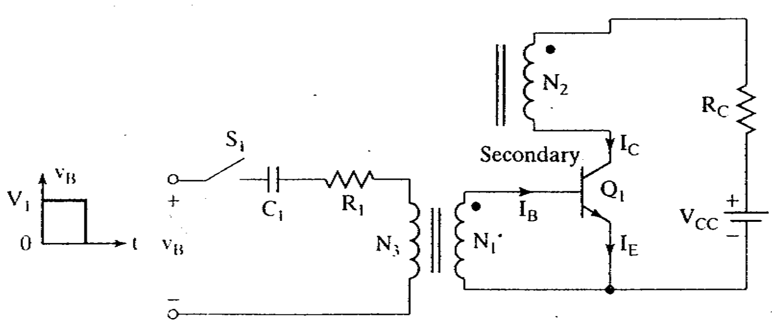


FIGURE 17.6
Proportional base drive circuit.

* In this method if the collector current changes due ~~collector current due~~ to change in load demand, the base drive current is changed in proportion to the collector current.
  Hence the name proportional base current

* The ckt arrangement is as shown in fig ③.
  When switch 's' is turned-ON, a pulse current of short duration would flow through the base of transistor & transistor is turned ON.

* Once the collector current starts to flow, a corresponding base current is induced due to the transformer action.

* The Turns ratio is $\frac{N_2}{N_1} = \frac{I_C}{I_B} = \frac{\beta \cancel{I_B}}{\cancel{I_B}}$

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$$\boxed{\frac{N_2}{N_1} = \beta}$$

4) Antisaturation control OR Baker's clamp circuit :-

❖ **What is the necessity of base drive control in high power transistor? Explain proportional base and anti-saturation control.**

June-09,8M

❖ **Explain how antisaturation base control improves the switching performance of a BJT.** **June-08,6M**

❖ **What is the need of a base drive control in a power transistor? Explain proportional and antisaturation control.** **June-07,8M**

❖ **Explain the antisaturation control techniques used to improve the switching speed of a power BJT.** **Jan-07,6M**

❖ **Explain how antisaturation base control techniques used to improve the performance of BJT.** **Jan-06,6M**

❖ **With a circuit diagram, explain antisaturation control of BJT. Mention the improvement and drawback of this arrangement.**

June-04,6M

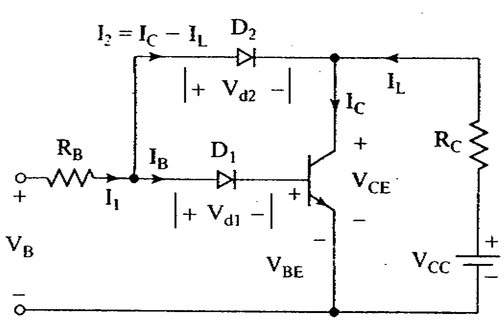

FIGURE 17.7
Collector clamping circuit.

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* If the transistor is operated in hard saturation, the storage time increases & the switching speed is reduced

The storage time can be reduced by operating the transistor in soft saturation rather than hard saturation

This can be accomplished by clamping the collector emitter voltage.

* The collector current is given by

$$\boxed{I_c = \frac{V_{cc} - V_{cm}}{R_c}} \longrightarrow (1)$$

WKT

$$\because I_c = \frac{V_{cc} - V_{CE}}{R_c}$$

Where V_{cm} is the clamping Vtg &

$$V_{cm} > V_{CE(sat)}$$

* The base current without clamping, which drive the transistor into hard saturation is given by

$$\boxed{I_B = I_1 = \frac{V_B - V_{d1} - V_{BE}}{R_B}} \longrightarrow (2)$$

Applying KVL to the I/p ckt we get

$$V_B - I_B R_B - V_{d1} - V_{BE} = 0$$

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

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

& the corresponding collector current is given by

$$\boxed{I_c = \beta I_B} \longrightarrow (3)$$

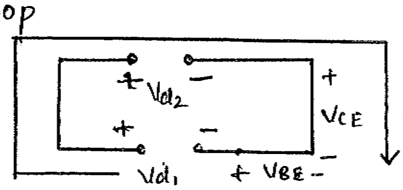
* Once the transistor is Turned ON, the diode D_2 gets forward biased and conducts. Thus clamping takes place.

Then

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

$$\boxed{V_{CE} = V_{BE} + V_{d1} - V_{d2}} \longrightarrow (4)$$

Applying KVL to this loop



* The load current is

$$\boxed{I_L = \frac{V_{CC} - V_{CE}}{R_C}} \longrightarrow (5)$$

$V_{BE} + V_{d1} - V_{d2} - V_{CE} = 0$

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

Substituting eqn (4) in (5) we get

$$\boxed{I_L = \frac{V_{CC} - V_{BE} - V_{d1} + V_{d2}}{R_C}}$$

* Applying KCL at node A, we get

$I_1 - I_2 - I_B = 0$

$I_B = I_1 - I_2$

from fig WKT

$I_2 = I_C - I_L$

$I_B = I_1 - [I_C - I_L]$

$$\boxed{I_B = I_1 - I_C + I_L} \longrightarrow (6)$$

The collector current with clamping is

$$\boxed{I_C = \beta I_B} \longrightarrow (7)$$

Substituting eq (6) in (7) we get

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

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

$I_C + \beta I_C = \beta[I_1 + I_L]$

$I_C[1 + \beta] = \beta[I_1 + I_L]$

$$\boxed{I_C = \frac{\beta}{1+\beta}[I_1 + I_L]}$$

* For clamping $V_{d1} > V_{d2}$

The clamping action results in a reduced collector current & almost eliminate storage time & thus a fast turn-ON is accomplished.

Antisaturation Control

FORMULAE

* Collector current without clamping:-

1) $I_B = I_1 = \frac{V_B - V_{d1} - V_{BE}}{R_B}$

2) $I_c = \beta I_B$

*) Collector to emitter clamping Vtg V_{CE}

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

* Collector current with clamping

1) $I_L = \frac{V_{cc} - V_{BE} - V_{d1} + V_{d2}}{R_c}$

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

Antisaturation Control PROBLEMS

❖ **The collector clamping circuit of fig1 has V_{CC}=100v, R_C=1.5Ω, V_{d1}=2.1v, V_{d2}=0.9v, V_{BE}=0.7v, V_B=15vv and R_B=2.5Ω and β=16. Calculate**

i) the collector current without clamping

i) the collector-emitter clamping voltage, V_{CE} and

ii) the collector current with clamping. **Jan-08,6M**

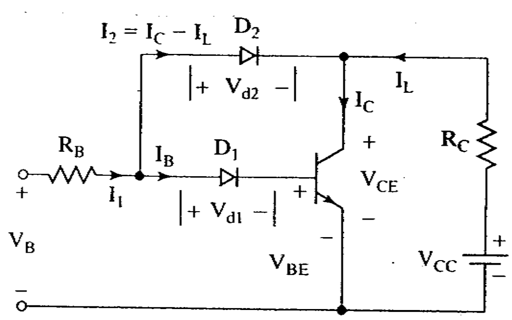


FIGURE 17.7
Collector clamping circuit.

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Given :- $V_{CC} = 100V$, $R_C = 1.5\Omega$, $V_{d1} = 2.1V$, $V_{d2} = 0.9V$, $V_{BE} = 0.7V$
$V_B = 15V$, $R_B = 2.5\Omega$ & $\beta = 16$.

Soln :-

(a) Collector current without clamping:

$$I_B = I_1 = \frac{V_B - V_{d1} - V_{BE}}{R_B} = \frac{15V - 2.1V - 0.7V}{2.5\Omega}$$

$$\boxed{I_B = I_1 = 4.88A}$$

$$I_C = \beta I_B = 16 \times 4.88$$

$$\boxed{I_C = 78.08A}$$

(b) The collector-emitter clamping Vtg.

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

$$= 0.7V + 2.1V - 0.9V$$

$$\boxed{V_{CE} = 1.9V}$$

(c) Collector current with clamping

* $$I_L = \frac{V_{CC} - V_{BE} - V_{d1} + V_{d2}}{R_C} = \frac{100V - 0.7V - 2.1V + 0.9V}{1.5\Omega}$$

$$\boxed{I_L = 65.4A}$$

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

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

$$\boxed{I_C = 66.15A}$$

❖ ISOLATION of GATE and BASE DRIVES :-

❖ **Discuss the needs and methods for providing isolation of gate/base circuits from power circuit with necessary circuit diagrams**

June-11,7M (E&E)

❖ **What is the need for isolation of gate drive circuits? Discuss the different methods of providing isolation of gate drive circuits from power circuit.** **Jan-10,8M**

❖ **With relevant diagrams, discuss the method for providing isolation of gate/base drive control in power circuits and what are its limitation?** **June-09,7M**

❖ **Explain different methods of providing gate and base drive isolation.** **June-08,8M**

❖ **Discuss methods of providing isolation of gate/base circuits from power circuits.** **Jan-07,6M**

❖ **Discuss methods for providing isolation of gate/base circuits from power circuits, with circuit diagrams.** **June-04,8M**

Need for Isolation of gate and base drive circuits :-

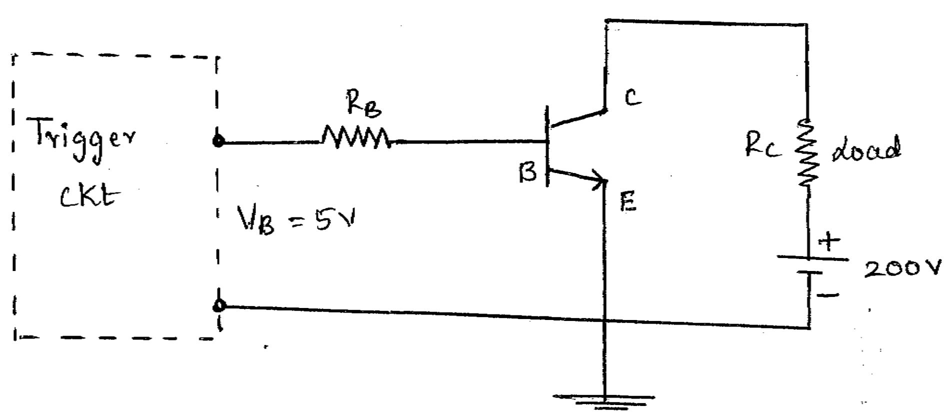

fig ① Base drive ckt

* WKT the driver ckt operate at very low power levels. The gate & base drives are connected to power devices which operate at high power levels as shown in fig ①

* In fig ① observe that collector of BJT have voltage of 200V. But base is connected to trigger ckt that have vtg of 5V.

* If BJT is damaged and collector-base gets shorted, then high voltage will get connected to trigger ckt. This will damage the trigger ckt also.

∴ To avoid any damage to the trigger ckt there must be some electrical isolation b/w. Gate, base drive (Triggering) ckt & the power ckt.

* There are two ways of floating or isolating the control (or) gate signal wrt ground.

1) Pulse transformers
2) Opto couplers.

1) <u>Isolation using pulse transformers</u> :-

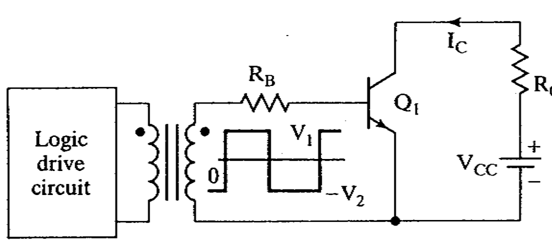

FIGURE
Transformer-isolated gate drive.

* Pulse transformer have one primary winding and can have one or more secondary winding.

Fig ① shows a transformer-isolated gate drive arrangement.

* The transformer should have a very small leakage inductance & the rise time of the o/p pulse should be very small.

In fig ① Observe the triggering ckt electrically isolated from BJT. Hence if there is any electric damage to the BJT, there will be no effect on triggering ckt.

Advantages :-

1) Pulse transformer doesnot need external power for its operation
2) It is very simple to use.

Disadvantages :-

1) Pulse transformer saturates at lower frequency hence it can be used only for high frequencies
2) Due to magnetic coupling, the signal is distorted.

Isolation using optocouplers :-

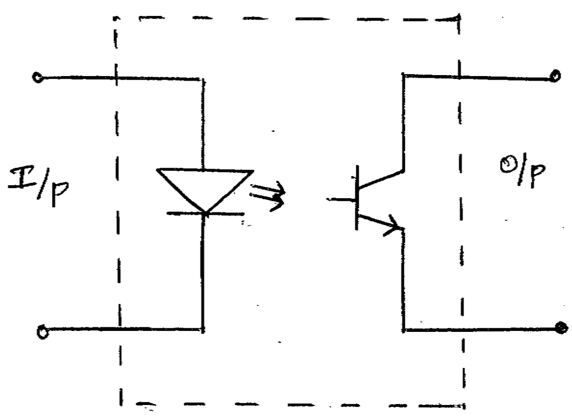

fig ② : opto coupler

Optocoupler consist of a pair of infrared LED (ILED) & photo transistor

When the input signal is applied to the ILED, it turns-ON. Now the light falls on the photo transistor.

∴ Photo transistor also starts conducting

* There is no electrical connection between LED & photo transistor
* The rise and fall times of phototransistors are very small.

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MOSFET Triggering ckt using optocoupler :-

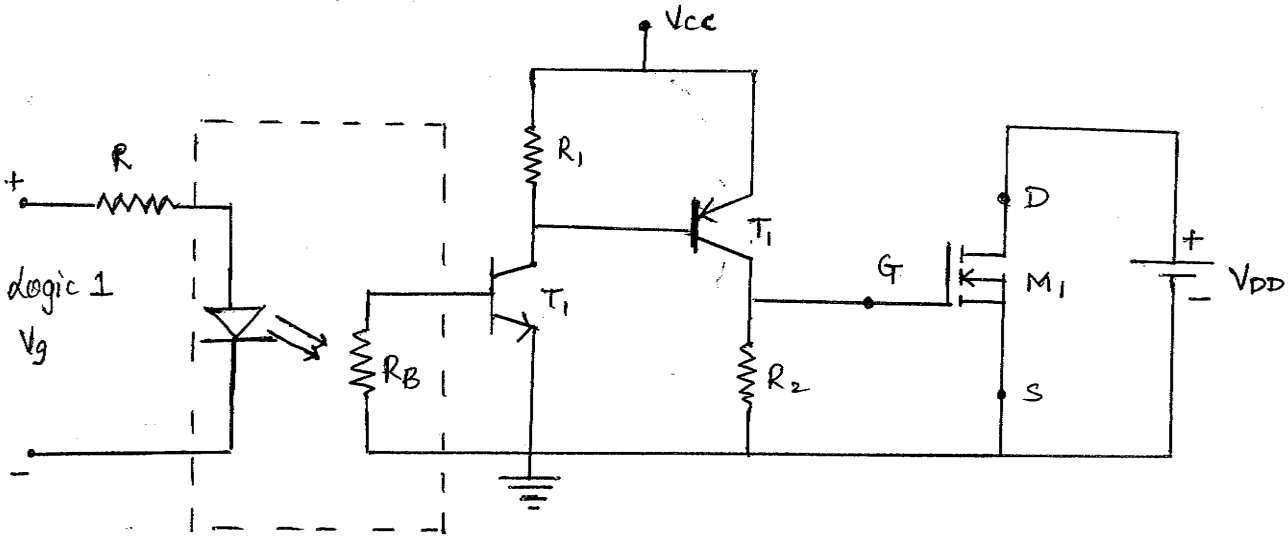


fig ② Opto coupler gate isolation

* In fig ② triggering pulses are given to the I/p (LED) of optocoupler.

When Vg is +ve LED turns ON

Now light falls on photo transistor due to this T1, turns ON

Now gate of MOSFET is activated. Thus MOSFET is turned ON.

* When Vg = 0, the LED turns OFF, therefore phototransistor also turns OFF. Therefore no signal appears at the gate of MOSFET.

Thus MOSFET is turned OFF

Hence isolation is provided between the drive or the triggering ckt & power devices (MOSFET).

❖ MOSFET :-

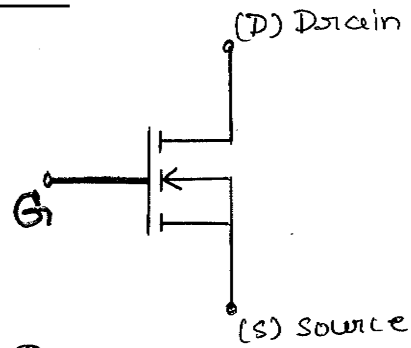


fig (a) : n-channel

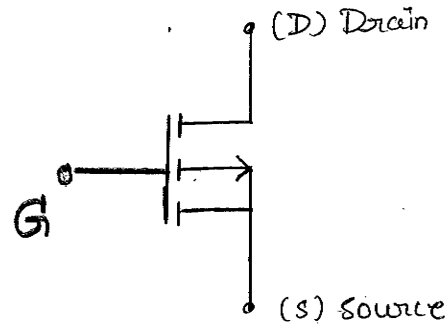


fig (b) : P-channel

❖ The Metal-Oxide Semiconductor field effect transistor (MOSFET) are majority carrier devices. The MOSFET has three terminals: **Gate (G), Drain (D)** and **Source (S).**

❖ A Power MOSFET is a voltage controlled device and requires only a small input current. The switching speed is very high and the switching times are of the order of nanoseconds.

❖ MOSFETS are of two types :

1) **Depletion MOSFETs** and

2) **Enhancement MOSFETs**

❖ Depletion MOSFET :-

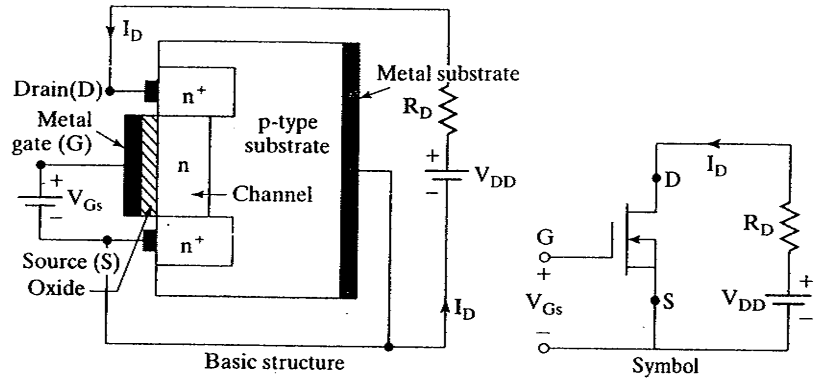
❖ N-Channel Enhancement-type MOSFET :-

❖ **Sketch the structure of n-channel enhancement type MOSFET and explain its working principle. Also draw its transfer characteristics.**

Jan-09,8M

❖ **Sketch the output characteristics of enhancement type MOSFET. What are the differences in control of BJT and MOSFET?**

June-04,6M



(a) n-Channel depletion-type MOSFET

* A n-channel depletion-type MOSFET is formed on a p-type silicon substrate with two heavily doped n^+ silicon for low resistence connections as shown in fig 1(a).

* The gate is isolated by from the channel by a thin silicon diode (SiO_2) layer.

MOSFET is having 3 terminals:
Gate (G), Source (S), and drain (D).
The substrate is normally connected to the source.

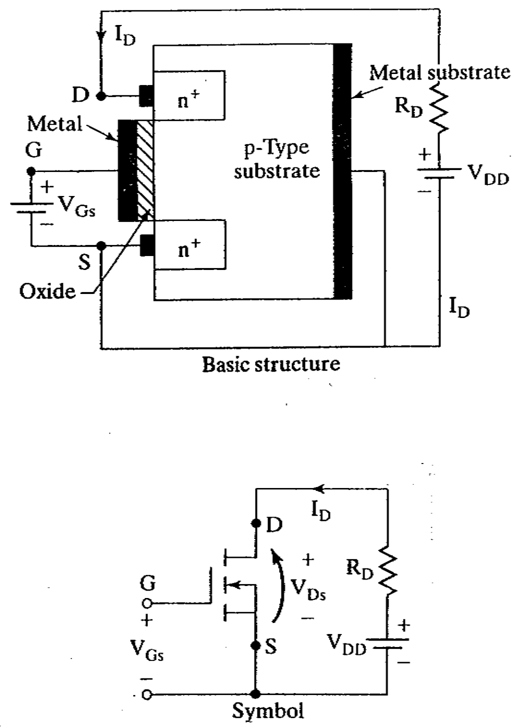
Operation:-

i) When V_{GS} is -ve :

If V_{GS} is -ve some of the electrons in the n-channel area are repelled and a depletion region is created below the oxide layer, resulting in a narrower channel and a high resistence from the drain to source R_{DS}.

If V_{GS} is made -ve enough, the channel become completely depleted, offering a high value of R_{DS}, and no current flows from the drain to source ie $I_{DS} = 0$

n-Channel Enhancement-type MOSFET :-



(a) n-Channel enhancement-type MOSFET

An n-channel enhancement-type MOSFET has no physical channel as shown in fig 1(a).

* If V_{GS} is ~~posist~~ positive, an induced vtg ~~across~~ attracts the electrons from the p-substrate and accumulate them at the surface beneath the oxide layer.

* If V_{GS} is greater than or equal to a value known as threshold voltage 'V_T', a sufficient number of electrons are accumulated to form a virtual-n-channel and the current flows from the drain to source.

* When $V_{GS} < V_T$, $I_D = 0$.
  When $V_{GS} \geq V_T$, I_D current flows in the ckt.

The -ve V_{GS} voltage for which $I_{DS} = 0$ is called pinch - off voltage 'V_p'.

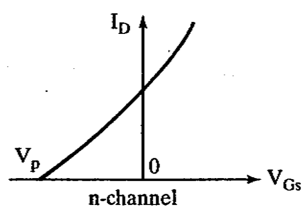
ii) When V_{GS} is +ve :-

When V_{GS} is made +ve, the channel becomes wider and I_{DS} increases due to reduction in R_{DS}

NOTE :-

For p - channel depletion -type MOSFET, the polarities of V_{DS} & I_{DS} and V_{GS} are reversed.

Steady state characteristics :-



(a) Depletion-type MOSFET

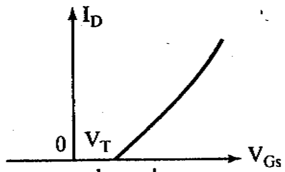
* Transconductance is the ratio of drain current to gate voltage & is denoted by g_m.

ie $$\boxed{g_m = \left.\frac{\Delta I_D}{\Delta V_{GS}}\right|_{V_{DD} = \text{constant}}}$$

* Fig 2 @ shows the transfer characteristics of n-channel MOSFET's.

Steady state characteristics :-

* Transconductance 'g_m' is defined as the ratio of the change in drain current to the change in V_{GS} for constant V_{DS}.



(b) Enhancement-type MOSFET

ie $\boxed{g_m = \dfrac{\Delta I_D}{\Delta V_{GS}} \Big|_{V_{DS} = \text{constant}}}$

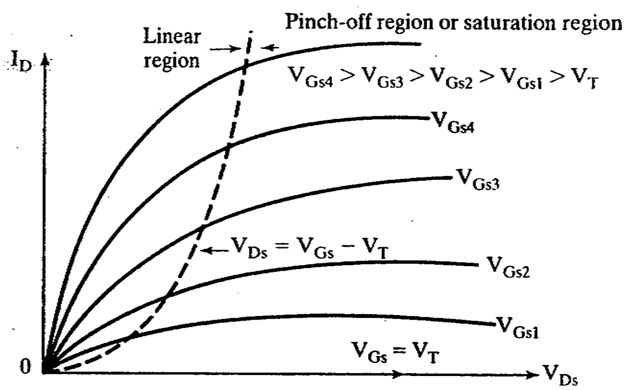


FIGURE
Output characteristics of enhancement-type MOSFET.

fig 2-ⓑ o/p characteristics of enhancement-type MOSFET.

There are three regions of operation.

1) cutt-off region
2) Pinch-off region or saturation region and
3) linear region.

1) In cut-off region, $V_{GS} < V_T$, thus $I_D = 0$.

2) In pinch-off or saturation region, $V_{DS} \geq V_{GS} - V_T$, Now I_D is more. Pinch-off occurs $V_{DS} = V_{GS} - V_T$

3) In linear region, the drain - ~~source~~ current I_D ~~Voltage V_{DS}~~ varies in proportional to the drain source voltage V_{DS}.

* Due to high drain current & low drain voltage, the power MOSFET's are operated in the linear region

for switching action

The o/p resistance $r_o = R_{DS}$ is defined as

$$\boxed{R_{DS} = \frac{\Delta V_{DS}}{\Delta I_D}}$$

Switching Characteristics of MOSFET or

Steady-State Switching models of MOSFET :-

- ❖ **Draw and explain the switching characteristics of power MOSFET** **June-11,6M**
- ❖ **Discuss steady state characteristics power MOSFETs compare this with characteristics of power BJT.** **June-10,10M**
- ❖ **With the help of switching waveforms explain the switching times of a power MOSFET.** **June-08,7M**
- ❖ **Draw the switching model and switching waveforms of a power MOSFET. Define the different switching times.** **June-06,6M**
- ❖ **With the help of switching waveforms explain the switching times of power MOSFET** **Jan-06,7M**

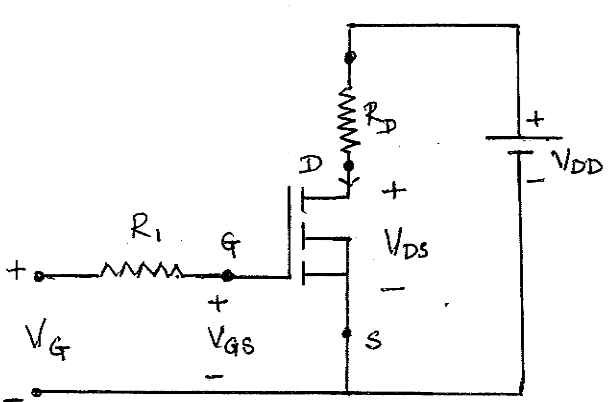


fig 1 ⓐ ckt diagram

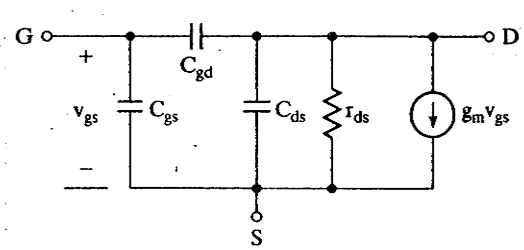


fig 1 ⓑ Switching model of MOSFET's

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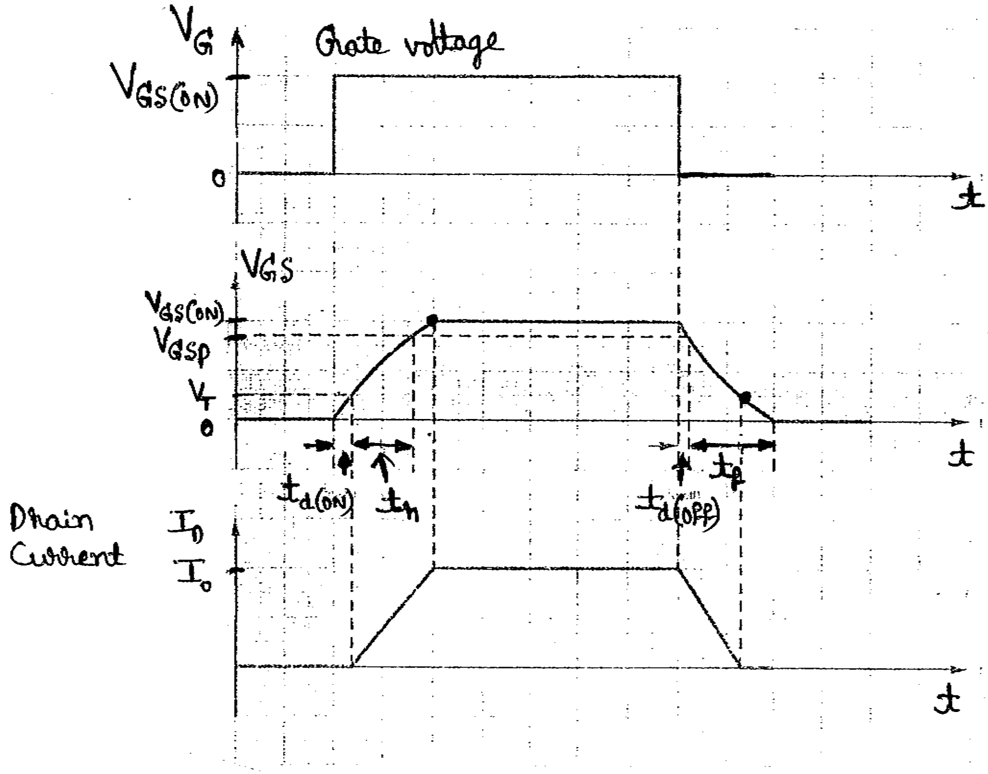


Switching characteristics of MOSFET

MOSFET can be turned ON by applying +ve gate voltage

* The internal capacitence of MOSFET affect the turn-ON & turn-OFF times of MOSFET.

Fig 1 (b) show switching models of MOSFET.

* When the gate voltage is applied, the gate to source capacitence Cgs starts charging

The turn-ON delay '$t_{d(ON)}$' is the time required to charge Cgs to the threshold voltage 'V_T'.

After this voltage, the drain current I_D starts rising

* The Cgs charges from V_T to full gate voltage 'V_{gsp}'

The time required for this charging is called rise time 't_r'

* When drain current raises to its full value ie I_o The MOSFET is then said to have fully turned ON

$$\therefore \boxed{t_{ON} = t_{d(ON)} + t_{ri}}$$

* To turn-OFF the MOSFET, the gate voltage is made -ve or zero. The V_{GS} the reduces from $V_{gs(ON)}$ to V_{GSP} ie C_{gs} discharges.

The time required for this discharge is called turn-OFF delay time $t_{d(OFF)}$.

The drain current also start reducing. The C_{gs} keep on discharging & its voltage becomes equal to 'V_T'.

* The ~~drain~~ time required to discharge C_{gs} from V_{GSP} to V_T is called fall time 't_f'.

When $V_{GS} < V_T$, then drain current becomes zero ie

$\therefore$ Turn off time of the MOSFET is

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

❖ Advantages or MERITS of MOSFETs :-

1) Gate has full control over the operation of MOSFET
2) MOSFETs donot require commutation circuit.
3) MOSFETs have very simple drive circuit.
4) Power MOSFETs can operate at high switching frequency.
5) The input resistance of MOSFETs is high and they are voltage controlled device.

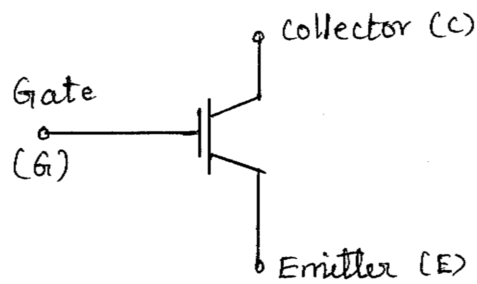
❖ Disadvantages or DEMERITS of MOSFETs :-

1) ON-state losses in MOSFETs are high.
2) MOSFETs are used only for low power applications
3) MOSFETS suffer from static charge.

❖ APPLICATIONS of MOSFETs :-

1) In low power ac and dc drives.
2) In SMPS
3) In stepper motor controllers
4) High frequency and low power inverters.

❖ INSULATED GATE BIPOLAR TRANSISTOR (IGBT) :-



fig①: Symbol of IGBT

❖ IGBT is obtained by combining the properties of BJT and MOSFET. The IGBT has three terminals :

Gate (G), Collector (C) and Emitter (E)

❖ Whenever a voltage between gate and emitter is applied, current flows from collector to emitter and IGBT is said to be turned ON. When gate-emitter voltage is removed, IGBT turns-OFF. Thus gate has full control over the conduction of IGBT.

❖ Steady static (V-I) Characteristics of IGBT :-

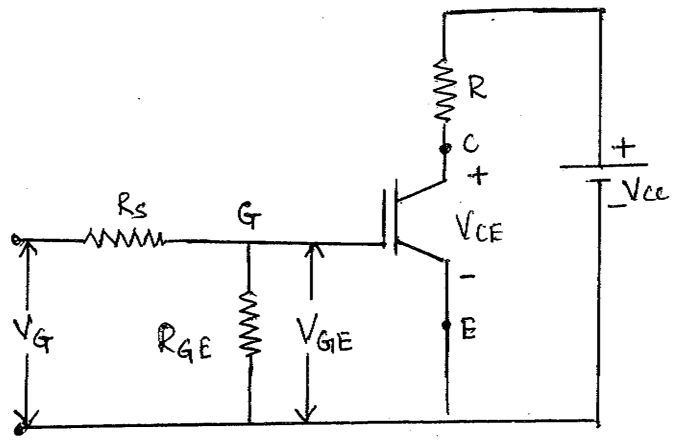


fig 1 (a) Ckt diagram

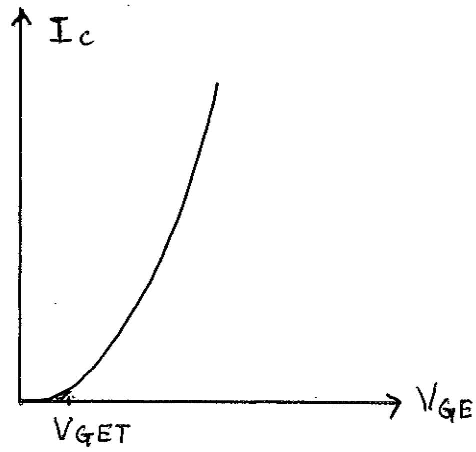


fig 1 (b) Transfer characteristics

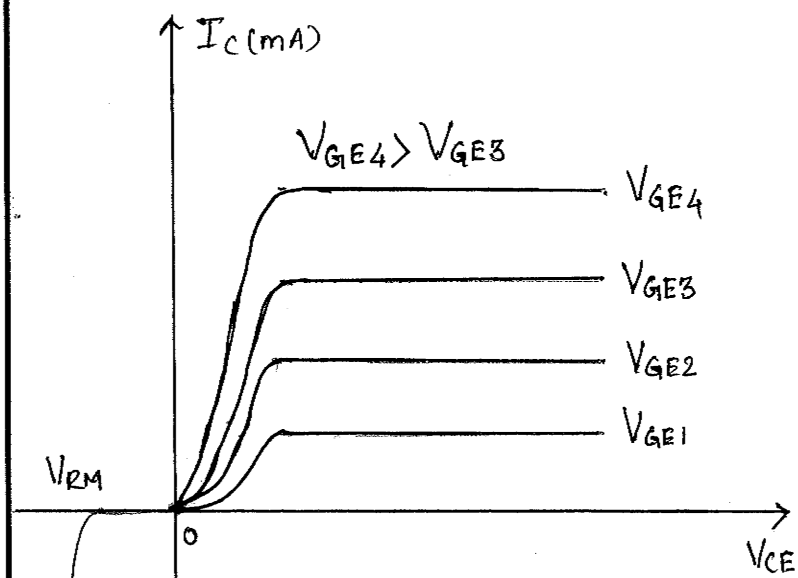


fig 1 (c) Static V-I characteristics

fig 1 (c) shows the V-I characteristics of n-channel IGBT.

The characteristics are plotted for collector current 'I_c' with respect to collector to emitter Vtg 'V_{CE}'.

The characteristics are plotted for different values of gate to emitter voltage 'V_{GE}'.

* When V_{GE} is less than the threshold Voltage V_{GET} (ie $V_{GE} < V_{GET}$), I_{GBT} is in the OFF-state. Now junction J_2 Blocks forward voltage.

* When $V_{GE} > V_{GET}$, then IGBT turns -ON

❖ Construction of IGBT

❖ Give the construction, static characteristics and applications of IGBT **Jan-08,6M**

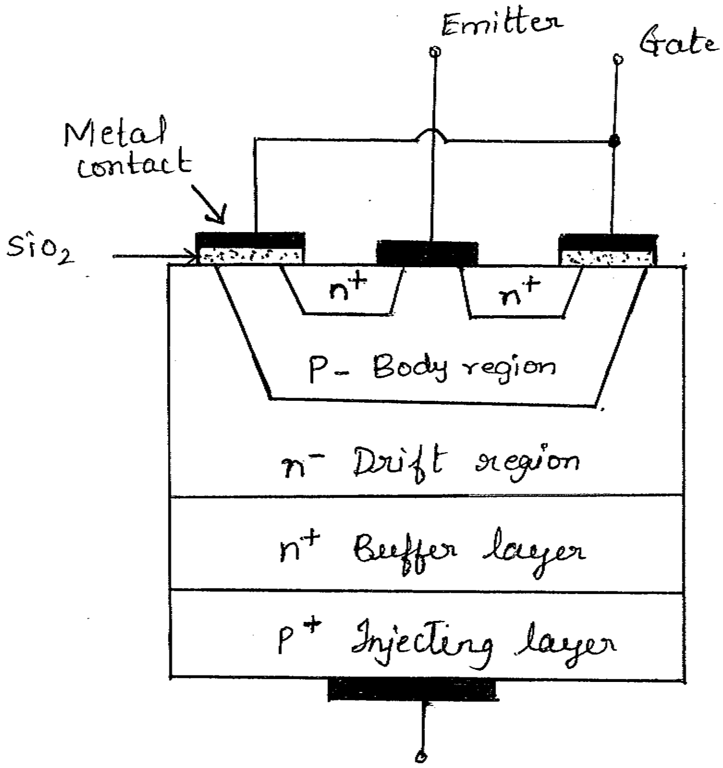


fig 1 ⓐ: Vertical cross section of IGBT

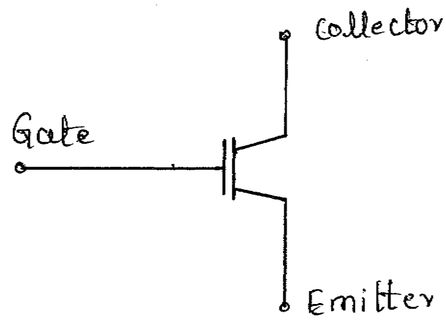


fig 1 ⓑ: Symbol of IGBT

* The IGBT is obtained By combining the properties of BJT and MOSFET.

The gate ckt of MOSFET and collector - emitter ckts of BJT are combined together to form a new device called IGBT.

* IGBT has 3 terminals
  Gate (G), Collector (C), Emitter (E).

* The structure of IGBT is similar to that of MOSFET. In this structure there is additional p^+ layer & is called collector of IGBT

* This p^+ injecting layer is heavily doped ie 10^{19} per cm^3. n^+ layer also having 10^{19} per cm^3 doping level.

The p-type body has doping level of 10^{16} per cm^3

The ~~drift~~ drift region is lightly doped 10^{14} per cm^3.
n^-

❖ Switching Characteristics of IGBT :-

❖ **With necessary sketches, explain briefly the switching characteristics of an IGBT.** **June-11,6M**

❖ **With the necessay sketches, explain the switching characteristics of an IGBT** **June-07,7M**

* The turn - ON time is given by

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

Where

Delay time '$t_{d(ON)}$':

i) The time for collector - emitter vtg to fall from V_{CE} to $0.9V_{CE}$

ii) It is also defined as the time the collector current to rise from its initial leakage current I_{CE} to $0.1 I_C$

Rise time 't_r':

i> The time during which collector - emitter voltage falls from $0.9V_{CE}$ to $0.1V_{CE}$

ii> It is also defined as the time for the collector current to raise from $0.1I_c$ to its final value I_c.

Turn - OFF time is given by

$$\boxed{t_{OFF} = t_{d(OFF)} + t_{f_1} + t_{f_2}.}$$

Where

Delay time '$t_{d(OFF)}$'

i> The time during which gate voltage falls from V_{GE} to threshold vtg V_{GET}

ii> During delay time, the collector current falls from I_c to $0.9I_c$.

First fall time 't_{f1}' :-

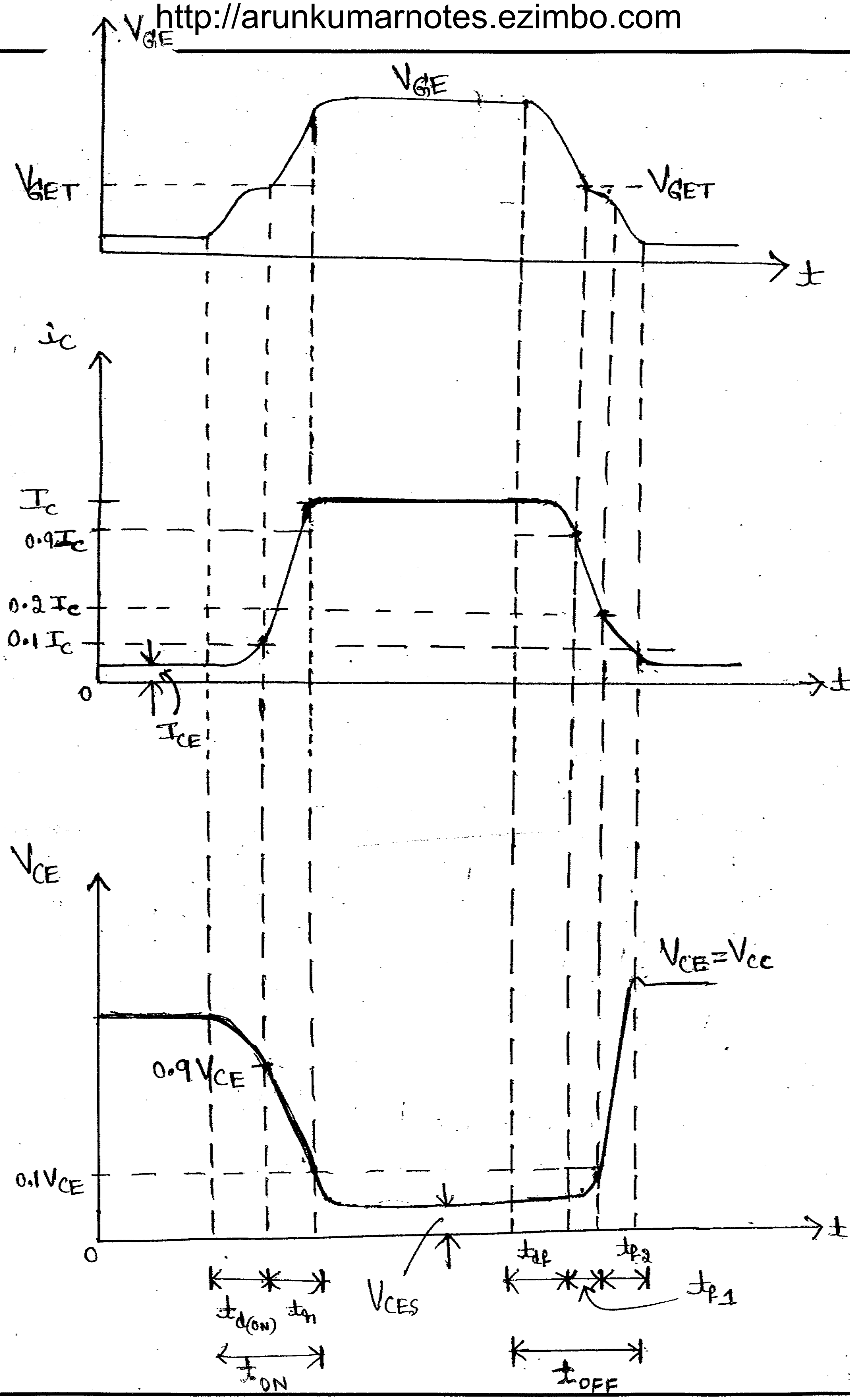
i> The time during which collector current falls from 90% to 20% of its initial value of I_c

ii> The time during which collector - emitter voltage rises from V_{CES} to $0.1V_{CE}$

Final fall time 't_{f2}' :-

i> The time during which collector current falls from 20% to 10% of I_c

ii> The time during which collector emitter voltage rises from $0.1V_{CE}$ to final value of V_{CE}.



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❖ ADVANTAGES or MERITS of IGBT :-

1) IGBT is a voltage controlled device hence drive circuit is very simple.
2) ON-state losses are reduced.
3) No commutation circuits are required.
4) Switching frequencies arehigher than thyristors.
5) Gate have full control over the operation of IGBT
6) IGBT have flat temperature co-efficient.

❖ DISADVANTAGES or DEMERITS of IGBT :-

1) IGBT's have stable charge problems.
2) TGBTs are costlier than BJTs and MOSFETs
3) Excessive power dissipation can take place at the time of turn-OFF due to the "current tail" present in the turn-OFF characteristics.

❖ APPLICATIONS of IGBT :-

1) Ac motor drives i.e INVERTERS.
2) DC to DC power supplies i.e CHOPPERS.
3) In UPS systems.
4) Harmonic Compensators.

COMPARISIONS

❖ **Give the comparision between MOSFET ang IGBT**

June-10,6M

❖ **Compare the characteristic of power MOSFET ang IGBT**

June-10,4M (E&E)

❖ **Compare an SCR with BJT** **Jan-10,6M**

❖ **Compare BJT, MOSFET and SCR with reference to power switching applications.** **June-06,6M**

❖ **Give the comparison between SCR, MOSFET and IGBT**

June-07,6M

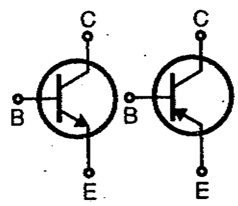
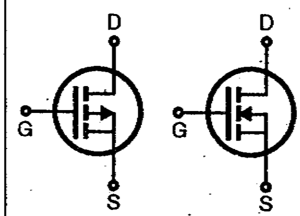
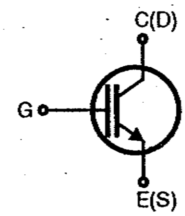
Sr. No.	BJT	MOSFET
1.	This is bipolar device.	This is majority carrier device.
2.	Controlled by base.	Controlled by gate.
3.	Current controlled device.	Voltage controlled device.
4.	Negative temperature coefficient.	Positive temperature coefficient.
5.	Paralleling of BJTs is difficult.	Paralleling of MOSFETs is simple.
6.	Losses are low.	Losses are higher than BJTs.
7.	Drive circuit is complex.	Drive circuit is simple.
8.	Switching frequency is lower than MOSFET.	Switching frequency is high.
9.	BJTs are suitable for high power applications.	MOSFETs are suitable for low power application.
10.	BJTs are available with higher voltage and current ratings.	MOSFETs have less voltage and current ratings.

Table Comparison of BJT and MOSFET

Sr. No.	SCR	BJT
1.	Four layer (PNPN) device.	Three layer (PNP or NPN) device.
2.	Turns on by regeneration.	No regeneration exists.
3.	Gate has no control once SCR is turned on.	Base has full control over the operation of BJT.
4.	External circuits are required to turn off the SCR.	No external circuits are required. BJT turns off if base drive is removed.
5.	Switching frequencies are low.	Switching frequencies are high.
6.	False triggering takes place if dv/dt is exceeded.	BJT is damaged if dv/dt is exceeded.
7.	Used for controlled rectifiers, AC regulators and DC motor drives.	Used for inverters, UPS, AC motor drives and SMPS.

Table Comparison of BJT and SCR

Comparison of Power Devices :

Sr. No.	Parameter	Power BJT	Power MOSFET	IGBT
1.	Symbol			
2.	Type of device	Minority carrier device	Majority carrier device	Majority carrier device
3.	Temperature coefficient	Negative	Positive	Flat
4.	Voltage blocking capacity	Asymmetric	Asymmetric	Asymmetric or symmetric depending on punch through or non-punch through structure.
5.	Operating frequency	10 kHz	100 kHz	10 kHz
6.	Trigger circuit	Current controlled needs continuous base drive	Voltage controlled needs continuous gate drive	Voltage controlled needs continuous gate drive
7.	On state voltage drop.	< 2 Volts	4 – 5 Volts	3 Volts
8.	Snubbers	Necessary (polarised)	Snubber can be eliminated. If used a polarised snubber is used.	Snubber can be eliminated. If used a polarised snubbers is used.
9.	Maximum VI ratings	2 kV/1000 A	600 V/200 Amp	1500 V/400 Amp
10.	Applications	UPS, SMPS, static VAR systems, AC motor control, SMPS	AC motor control, SMPS	SMPS, BLDC drives, AC motor control UPS.

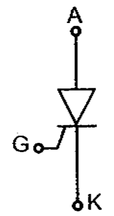
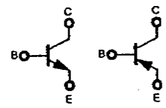
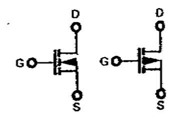
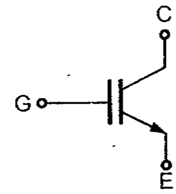
Sr.No.	Parameter	SCR	BJT	MOSFET	IGBT
1	Symbol				
2	Triggered i.e. latching or linear	Triggered or latching device	Linear trigger	Linear trigger	Linear trigger
3	Type of carriers in device	Majority carrier device	Bipolar device	Majority carrier device	Majority carrier device
4	Control of gate or base	Gate has no control once turned on	Base has full control	Gate has full control	Gate has full control
5	On-state drop	< 2 volts	< 2 volts	4-6 volts	3.3 volts
6	Switching frequency	500 Hz	10 kHz	Upto 100 kHz	20 kHz
7	Gate drive	Current	Current	Voltage	Voltage
8	Snubber	Unpolarized	Polarized	Not essential	Not essential
9	Temperature coefficient	Negative	Negative	Positive	Approximately flat, but positive at high current
10	Voltage and current ratings	10 kV/ 4 kA	2 kV/1 kA	1 kV/50 A	1.5 kV/400 A
11	Voltage blocking capability	Symmetric and asymmetric (both)	Asymmetric	Asymmetric	Asymmetric
12	Applications	AC to DC converters, AC voltage controllers, electronic circuit breakers	DC to AC converters, induction motor drives, UPS, SMPS, Choppers	DC choppers, low powers UPS, SMPS, brushless DC motor drives	DC to AC converters, AC motor drives, UPS, choppers, SMPS etc.

Table Comparison of power devices

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THYRISTORS

SCR :-

❖ **With neat sketch, explain the static V-I characteristics of an SCR? What are the significance of Latching current, Holding current and Break over voltage.** **Jan-09,8M Jan-05,8M**

❖ **Sketch the static V-I characteristics of an SCR and explain :**

i) Latching current **iii) Break over voltage**

ii) Holding current

June-10,8M(IT) June-08,7M June-07M

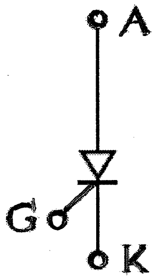
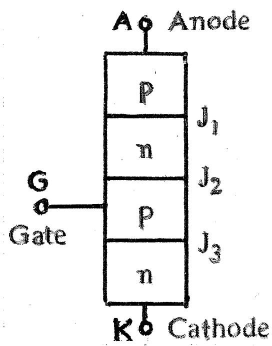


Fig a.: Symbol



A thyristor is a four (4) layer, three junction, three terminal semiconductor device. The terminals are **Anode (A)**, **Cathode (K)** and **Gate (G)**. Thyristors are operated as bistable switches, operating from OFF state to ON state. Thyristor is also called as **Silicon Controlled Rectifier (SCR)**.

Characteristics of Thyristor :-

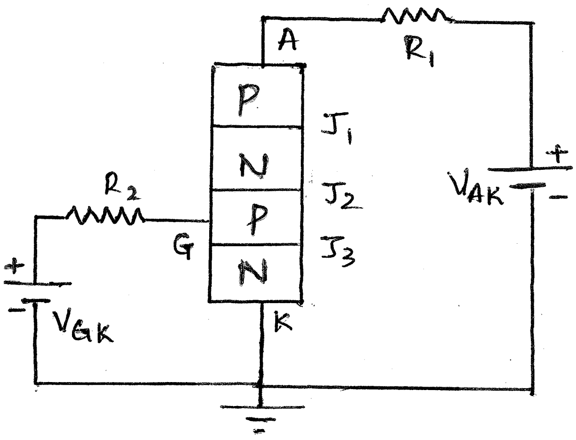


Fig 2a. Circuit Diagram.

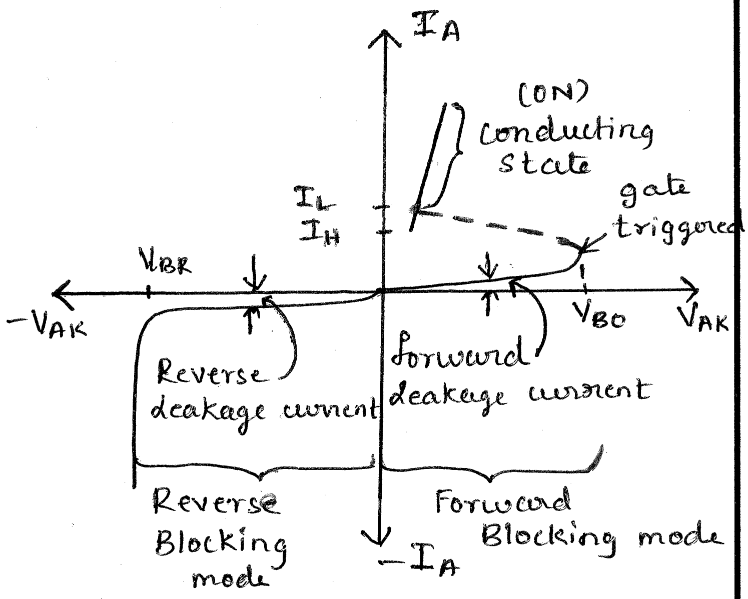


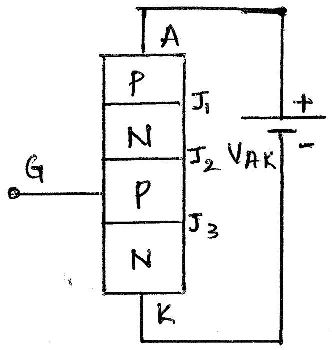
Fig 2b. V-I Characteristics

* When the anode voltage is made +ve wrt to the cathode, the junction J_1 & J_3 are forward biased. The junction J_2 is reverse biased. Hence forward Vtg is to be held by junction J_2.

  A very small current flows from anode to cathode. This current is called as forward leakage current. The thyristor is then said to be in forward blocking mode.
  The thyristor is treated as an open switch.

* A thyristor can be turned ON by applying a gate pulse between gate & cathode and is called as forward conduction mode.

  In this mode thyristor is in ON condition and behaves as a closed switch.



* When anode vtg is made -ve w.r.t to cathode, the thyristor is reverse biased Junction J_1 & J_3 are reverse biased where as Junction J_2 is forward biased.

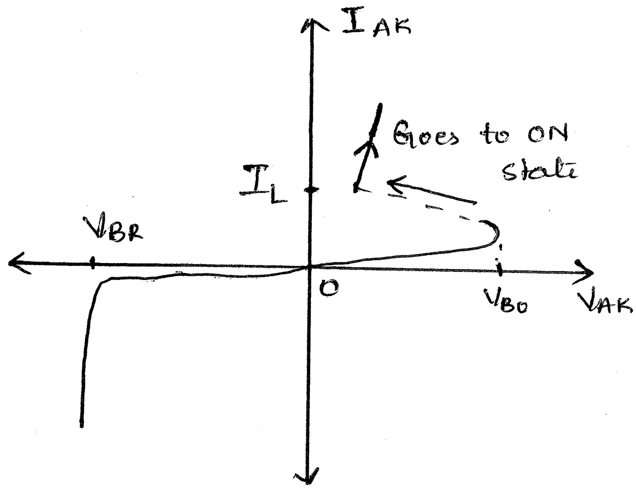
A very small current flows from cathode to Anode. This current is called reverse leakage current & this mode is called reverse blocking mode.

* At reverse breakdown vtg (V_{BR}), the reverse current increases rapidly. At the same time reverse break-down, the high vtg is present across the thyristor & heavy current flows through it. Hence large power dissipation takes place in the thyristor. Due to this dissipation the thyristor will damage.

During reverse blocking mode, the +ve gate signal should not be applied. If the +ve signal is applied between gate and cathode, junction J_3 is forward biased hence current starts flowing through it.

Latching Current :-

Latching current is the minimum forward current that flows through the thyristor to keep it in forward conduction mode (ie ON state) at the time of Triggering.



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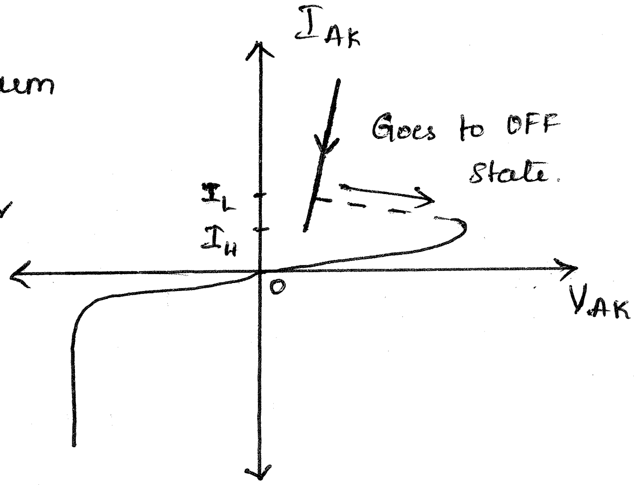
* If forward current is less than latching current, thyristor doesnot turn-ON.

ie $I_{AK} < I_L$

After triggering $I_{AK} \geq I_L$ for thyristor to remain in ON state. The latching current is of the order of 10 to 15mA.

Holding Current :-



* Holding current is minimum forward current that flows through the thyristor to keep it in forward conduction mode. When forward current reduces below holding current. thyristor turns-OFF

* The holding current of the thyristor is of order 8 to 10mA.

Break over Voltage (V_{BO}) :-

When gate is open & if anode to cathode voltage exceeds forward Breakover voltage 'V_{BO}', the SCR is driven into forward conduction.

In other words V_{BO} is the maximum vtg that SCR can withstand in forward direction.

❖ Comparision between holding and latching currents :-

1) Latching current is effective at the time of turning ON whereas holding current is effective at the time of turning - OFF the thyristor.

2) Latching current is the maximum current that should flow at the time of triggering to turn ON the thyristor.

Whereas once the thyristor is already in ON - state its current should not reduce below holding current otherwise it turns - OFF

3) Latching current is greater than holding current even though their magnitude are much related.

❖ TWO TRANSISTOR ANALOGY of SCR

❖ **Using two transistor models, explain how a small gate current can turn on a SCR when blocking forward voltage.** **June-11,6M (E&E)**

❖ **Explain the turn-on mechanism of a thyristor using two transistor analogy and derive an expression for the anode current in terms of transistor parameters.** **Jan-10,8M**

❖ **Usingthe Two transistor model, explain how a small gate current can turn on an SCR**

June-10,6M June-08,6M June-04,6M

❖ **With help of two transistor model of an SCR, derive the expression for anode current. There from explain the switching action and significance of Gate control.** **June-09,8M**

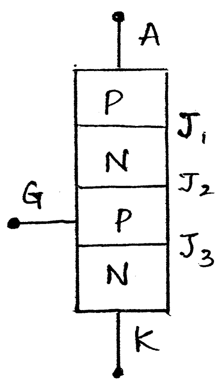
❖ **Using two transistor analogy, derive an expression for anode current of SCR.** **Jan-09,8M**

❖ **Explain the principle of an SCR using two transistor model.**

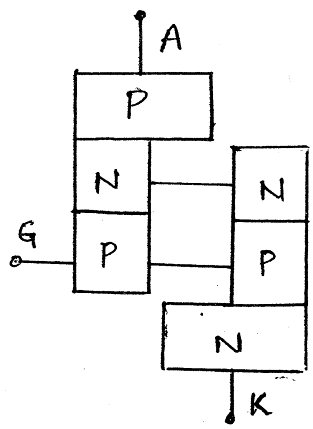
Jan-07,6M June-08,6M

❖ **Using two transistor model, explain the switching action of a thyistor and significance of gate control. Also derive an expression for the anode current.** **Jan-08,8M**

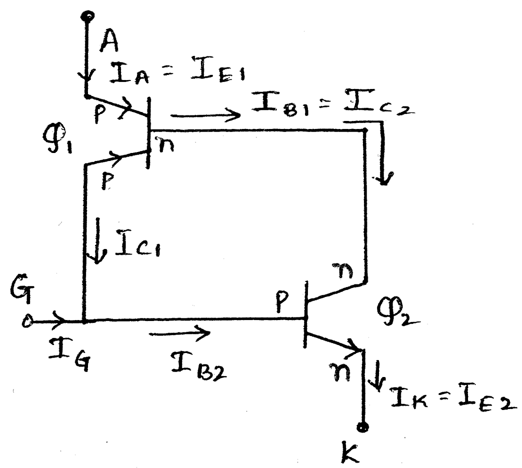
❖ **Using two transistor model, explain the the turn-ON mechanism of a SCR. Derive an expression for anode current in terms of transistor parameters.** **June-06,8M**



a) Four layer Structure Of Thyristor



b) Two transistor model



c)

* The operation of the thyristor can be explained with the help of two transistor model as shown in fig b. The middle two layers are split into two seperate parts. Because of this the two transistors are formed. The transistor Q_1 is PNP & Q_2 is NPN.

* The Base of Q_1 is connected to collector of Q_2. Similarly base of Q_2 is connected to collector of Q_1.

* These transistors are in common base (CB) configuration. In general the relationship between collector current 'I_C', emitter current 'I_E' & leakage current I_{CBO} of a transistor is

$$\boxed{I_C = \alpha I_E + I_{CBO}} \longrightarrow (1)$$

Where $\alpha = \frac{I_C}{I_E}$, common base current gain

* For transistor Q_1

$$\boxed{I_{C1} = \alpha I_{E1} + I_{CBO1}} \longrightarrow (2)$$

from fig (c), $I_{E1} = I_A$

Substituting I_{E1} value in eqn (2), we get

$$\boxed{I_{C1} = \alpha I_A + I_{CBO1}} \longrightarrow (3)$$

Where α_1 is CB current gain of Q_1

I_{CBO} is CB leakage current of Q_1

* Similarly for transistor Q_2

$$\boxed{I_{C2} = \alpha_2 I_{E2} + I_{CBO2}} \longrightarrow (4)$$

from fig (C), $I_{E2} = I_K$

Substituting I_{E2} value in eq (4), we get

$$\boxed{I_{C2} = \alpha_2 I_K + I_{CBO2}} \longrightarrow (5)$$

Where α_2 is CB current gain of Q_2

I_{CBO2} is CB leakage current of Q_2

From fig (C), it is clear that

$$\boxed{I_A = I_{C1} + I_{C2}} \longrightarrow (6)$$

Substituting eqn (3) & (5) in eqn (6), we get

$$I_A = \alpha I_A + I_{CBO1} + \alpha_2 I_K + I_{CBO2}$$

from fig (C) $\boxed{I_K = I_A + I_G}$

$$I_A = \alpha_1 I_A + I_{CBO1} + \alpha_2 [I_A + I_G] + I_{CBO2}$$

$$I_A = \underline{\alpha_1 I_A} + I_{CBO1} + \underline{\alpha_2 I_A} + \alpha_2 I_G + I_{CBO2}$$

$$I_A - \alpha_1 I_A - \alpha_2 I_A = I_{CBO1} + I_{CBO2} + \alpha_2 I_G$$

$$I_A [1 - \alpha_1 - \alpha_2] = I_{CBO1} + I_{CBO2} + \alpha_2 I_G$$

$$I_A = \frac{I_{CBO1} + I_{CBO2} + \alpha_2 I_G}{1 - \alpha_1 - \alpha_2}$$

$$\boxed{I_A = \frac{I_{CBO1} + I_{CBO2} + \alpha_2 I_G}{1 - (\alpha_1 + \alpha_2)}} \longrightarrow (7)$$

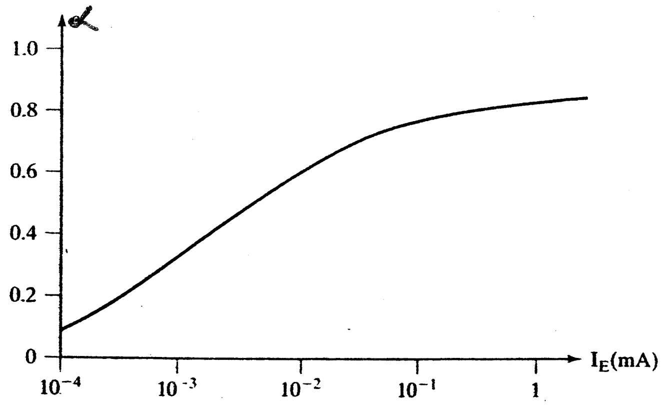


FIGURE
Typical variation of current gain with emitter current.

* The current gain α_1 varies with the emitter current $I_A = I_{E1}$ & α_2 varies with $I_K = I_A + I_G$

  A typical variation of current gain α with the emitter current I_E is shown in fig ②

* If the gate current I_G is suddenly increased say (0 to 1mA) this immediately increases anode current I_A, which would further increase α_1 & α_2.

  If $(\alpha_1+\alpha_2)$ tends to be unity, then denominator of eq ⑦ approaches zero, resulting in a large value of anode current I_A & the thyristor turns ON with a small gate current.

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❖ Methods of SCR Turn-ON :

❖ **Explain the different types of turn-ON methods(triggering mechanisms) used to switch-ON a thyristor device. Use the two transistor model of a thyristor as the basis to explain the switching behaviour of the thyristor.**

Jan-05,10M

❖ **Explain the various methods of turn-ON of our SCR**

June-10,6M(IT)

❖ **Mention the different turn-ON methods employed to switch-ON SCR. Explain with waveforms, the resistancetriggering circuit to Turn-ON the SCR in the phase control circuit.**

June-09,10M

❖ **Explain the various methods of Turn-ON of an SCR and mention the advantages of gate triggering.** **June-07,8M**

With anode +ve wrt cathode, a thyristor can be turned ON by one of the following techniques :

1) Thermals or High temperature triggering
2) Light triggering
3) High voltage (Forward Vbg) triggering
4) dv/dt triggering
5) Gate triggering

P.T.O

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1) Thermals or High temperature triggering

If the temperature of a thyristor is high, there is an increase in the number of electron hole pairs, which increases the leakage current. This increase in current causes α_1 & α_2 to increase so $(\alpha_1+\alpha_2)$ may tend to be unity & the thyristor may be turned ON

This type of turn ON May cause thermal runaway & it normally avoided

2) Light triggering :-

If light is allowed to strike the gate to cathode junction of the thyristor, the electron-hole pairs increase and the thyristor may be turned ON.

3) High Voltage (High forward Voltage) :-

If the forward anode-to-cathode voltage is greater than the forward breakdown vtg ie $V_{AK} > V_{BO}$, sufficient leakage current flows to initiate regenerate turn-ON

This type of turn ON may be destructive & should be avoided

4) $\frac{dv}{dt}$:-

If the rate of rise of anode-cathode voltage is high, the charging current of the capacitive junction may be sufficient enough to turn-ON the thyristor

A high value of charging current may damage the thyristor & device must be protected against high $\frac{dv}{dt}$

5) Gate triggering :-

If a thyristor is forward biased, the injection of the gate current by applying +ve gate vtg b/w the gate and cathode terminal & turns ON the thyristor.

As the gate current is increased, the forward blocking vtg is decreased as shown in fig ①

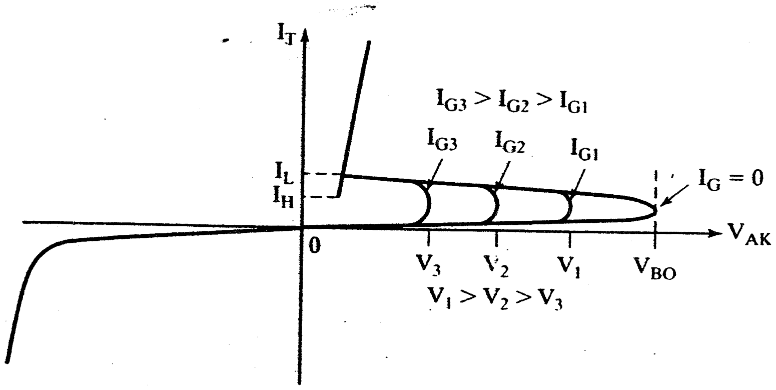


FIGURE ①

Effects of gate current on forward blocking voltage.

❖ Switching Characteristics of Thyristor (SCR) :-

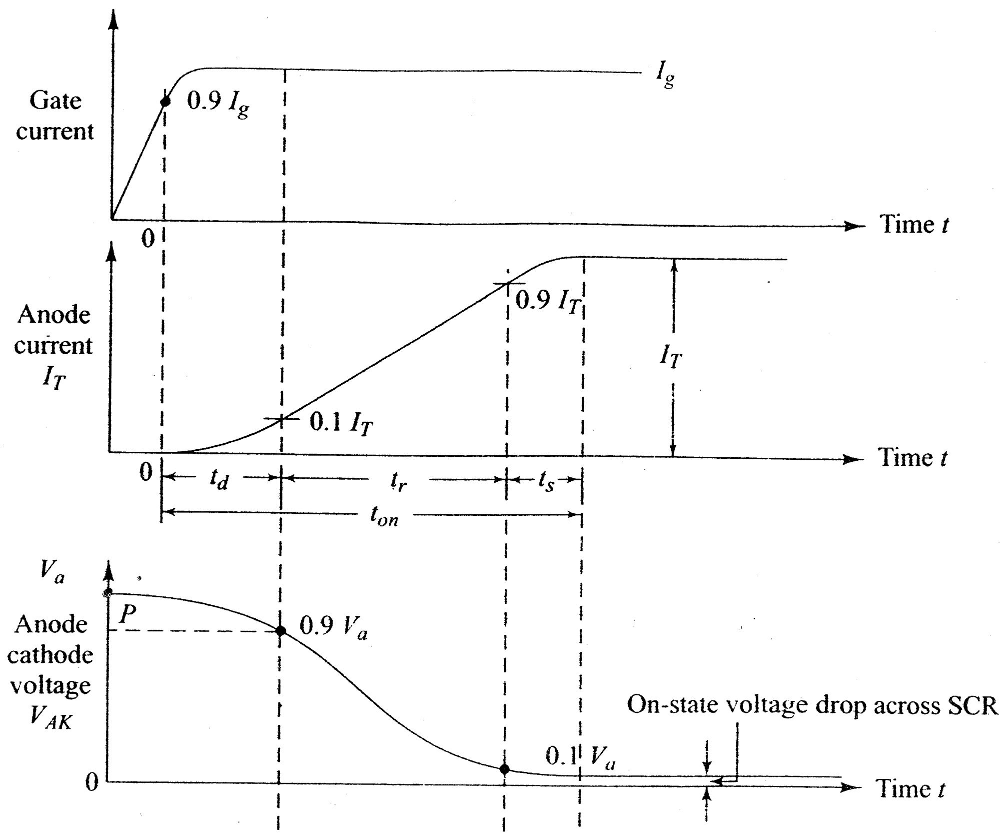
OR

❖ SCR Turn-ON and Turn-OFF Characteristics

❖ **Explain the turn-ON and turn-OFF characteristics of the SCR**

June-05,8M

Dynamic turn-ON switching characteristics :



The turn ON time 'ton' of the SCR is subdivided into three distinct periods

i> Delay time 'td'

ii> Rise time 'tr'

iii> Spread time 'ts'

i> Delay time :-

This is the time between the instant a which the gate current reaches to 90% of its final value (from 0 to 90% I_g) & the instant at which the anode current reaches 10% of its final value (ie 10% I_A)

It can also be defined as the time during which anode vtg fall from 100% of V_{AK} to 90% of V_{AK} as shown in fig.

ii) Rise time 't_r':-

This is the time required for the anode current to rise from 10 to 90% of its final value.

It is also defined as the time during which anode vtg (V_{AK}) falls from 90% of V_{AK} to 10% of V_{AK}.

During rise time, turn-ON losses are the highest due to high anode vtg V_{AK} & large anode current I_A, occuring together in the thyristor. Hence large dissipation takes place in the thyristor.

ie $\boxed{P = V_A \cdot I_A}$

This power dessipation is called switching losses of Thyristor.

iii) Spread-time 't_s':-

The spread time is the time required for the anode voltage V_{AK} to fall from 10% V_{AK} to the ON-state vtg drop (1V to 1.5V)

After spread time, anode current attains steady state values & the vtg drop across the SCR is equal to the ON-State vtg drop of the order of 1V to 1.5V.

* The turn ON Time of thyristor is given by

$$\boxed{t_{ON} = t_d + t_r + t_s}$$

Turn-OFF characteristics :

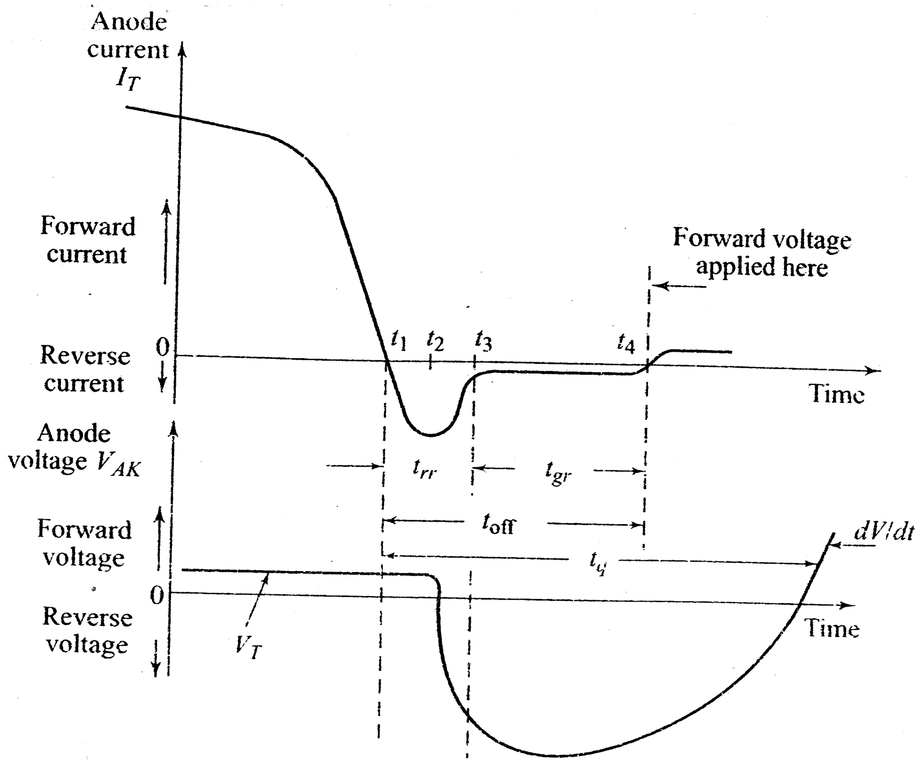


Fig. *Waveforms during SCR turn-off*

Once thyristor is ON. gate looses its control. The thyristor can be turned OFF by reducing the anode current below holding current ie $I_A < I_H$.

Turn-OFF time is divided into
i> Reverse recovery time 't_{rr}'
ii> Gate recovery time 't_{gr}'.

i> Reverse Recovery time 't_{rr}' :-

Once anode current is zero, the device start to turn OFF but not immediately & it will take some time to turn OFF

* The time taken by the minority carriers present in the PN-junction to recombine with the opposite charges & to be neutralized. This time is called Reverse recovery time 't_{rr}'.

ii) Gate recovery time 'tgr' :-

The Time taken by charges for the recombination when reverse vtg is maintained across the thyristor.

The time taken by the thyristor to change state from ON state to OFF - state is called turn-OFF state

Turn-OFF time is the sum of trr & tgr.

$$\boxed{t_{OFF} = t_{rr} + t_{gr}}$$

* The turn-OFF time of the thyristor varies from 50μsec to 100μsec

❖ **Define turn-OFF time of thyristor and mention any two factors that affect it.** **Jan-06,3M**

❖ Inverter Grade Thyristors :-

- The thyristor with **FAST turn-OFF time** i.e. **3 to 50 μsec** are called Inverter grade SCR's.
- Inverter grade thyristors are costlier and are used in INVERTERS and CHOPPERS.

❖ Converter Grade Thyristors :-

- Thyristor with **SLOW turn-OFF time** i.e. **50 to 100 μsec** are called Converter grade thyristors.
- These are cheaper and are used in Phase-Controlled rectifiers, ac voltage controllers, cyclo-converters etc.

❖ Thyristor Gate Characteristics :-

❖ Sketch the gate characteristics of an SCR and explain the different regions of gate characteristics. Also indicate different voltages and different currents on the gate characteristics.

June-11,10M

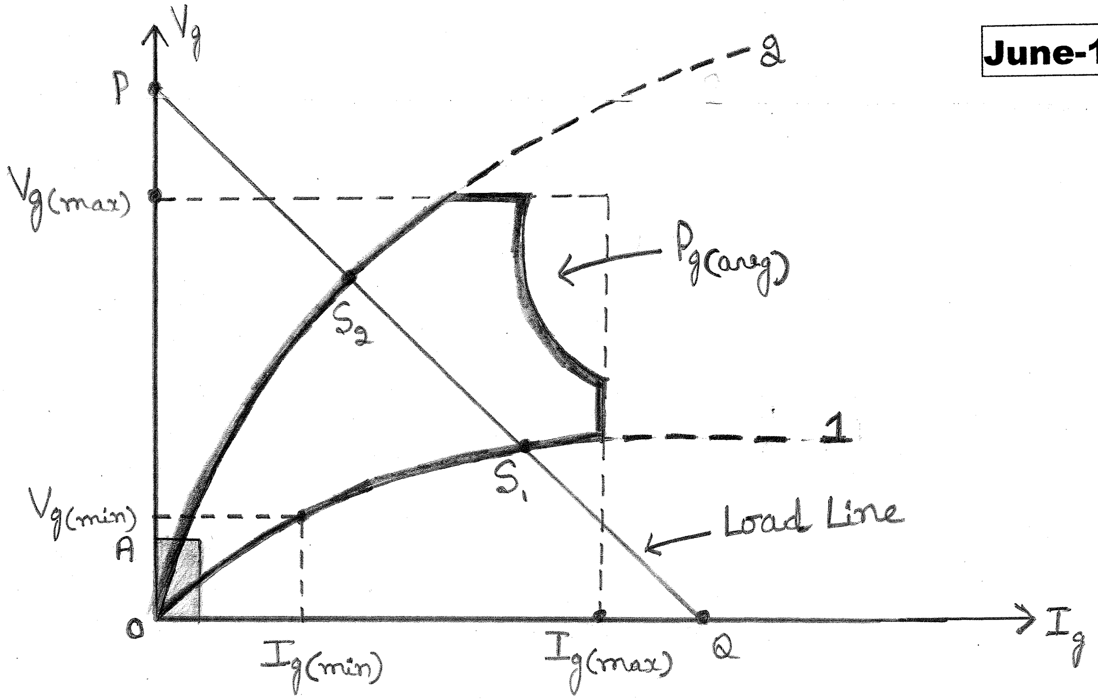


Fig ① shows the gate characteristics of a thyristor. Here, +ve gate cathode voltage Vg and +ve gate to cathode current Ig represents dc values.

* For a particular type of SCRs Vg - Ig characteristics has a spread b/w curves 1 & 2 as shown in fig ①. This spread or scatter of gate characteristics is due to difference in low doping levels of p and n layers.

* Curve 1 represents the lowest voltages values that must be applied to turn-ON the SCR & curve 2 gives the highest possible voltage values that can be safely applied to gate circuit.

* Each thyristor has maximum limits as Vg(max) for voltage and Ig(max) for gate current. There is also a limit on the maximum gate Power dessipation

($P_{g(max)} = V_g I_g$)

These limits should not be exceeded in order to avoid permanent damage of junction J_3.

* There are also minimum limits for V_g & I_g for reliable turn-ON, these are represented by $V_{g(min)}$ & $V_{g(max)}$ as shown in fig (1).

* If $V_{g(max)}$, $I_{g(max)}$ & $P_{g(avg)}$ are exceeded, the thyristor can be destroyed.

There are three important regions:

1) The first region 'OA' lies the origin and is defined by the maximum gate voltage that will not trigger any device. The gate must be operated in this region whenever forward bias is applied across the thyristor & triggering is not necessary. (This region sets a limit on the maximum false signals that can be tolerated in the gate firing circuit)

2) The second region is the minimum value of gate -voltage & current required to trigger the SCR.

3) The third region is the largest limits on the gate - signals for reliable firing. For applications, where fast turn-ON is required, a hard firing signal is needed.

* A thyristor may be considered to be a charged controlled device. Thus, higher the magnitude of gate current pulse lesser is the time needed to inject the required. charge for turning ON the thyrist -or. Therefore the SCR turn-ON time can reduced by using gate current of higher magnitude.

❖ Thyristor FIRING circuits or SCR FIRING or TRIGGERING circuits :-

- ❖ Thyristor can be turned ON by many methods like, overvoltage turn-ON, dv/dt turn-ON, temperature turn-ON, light turn-ON and gate turn-ON.
- ❖ The most commonly employed method to turn-ON thyristor is gate turn-ON. In this method a gate pulse is used to turn-ON thyristor and a circuit used to generate gate pulse is called firing or triggering circuit.

The different firing or triggering circuits are :

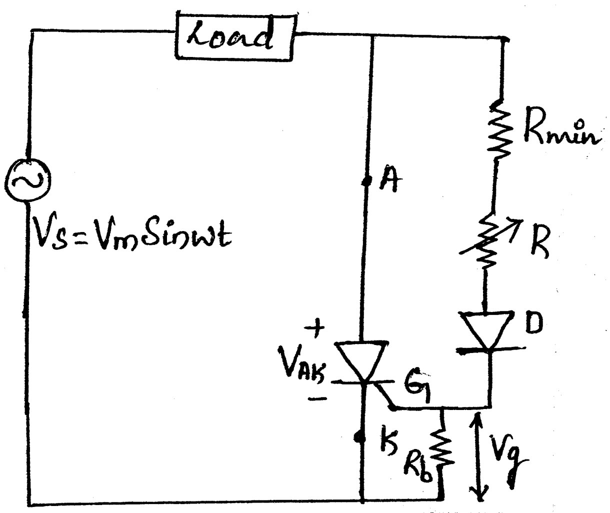
1) **Resistance firing circuit (R-Firing)**
2) **RC triggering circuit and**
3) **UJT relaxation oscillator.**

❖ Resistance firing circuit (R-Firing) :-

❖ **With a neat circuit diagram and waveforms, explain the resistor triggering circuit.**

June-11, 6M

❖ **Mention the different turn-ON methods employed to switch ON SCR. Explain with waveforms, the resistance triggering circuits to turn-ON SCR in the phase control circuit.** **Jan-09,10M**



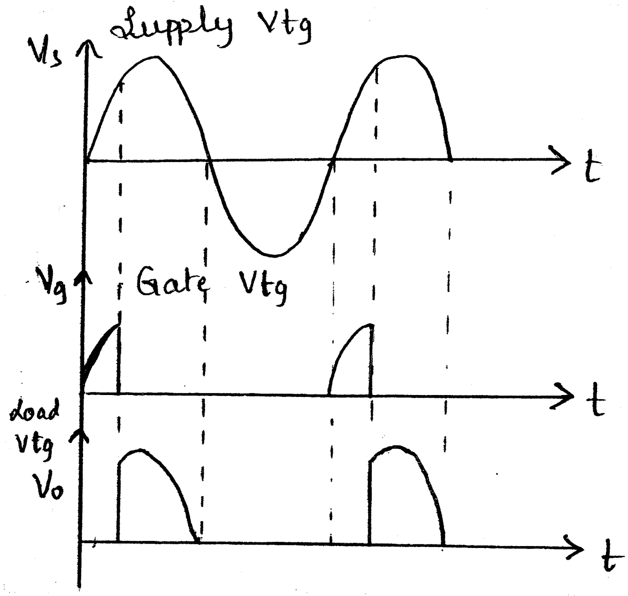


Fig ①

* Resistance firing is the simplest & most economical, but it has limited range of firing angle control ie 0° to 90°.

Fig ① a shows the basic resistance ckt. R is variable resistance, R_b is the stablizing resistance. The function of Rmin is to limit the gate current to a safe value when R is zero.

(This current should not exceed maximum permissible gate current I_{gm}).

* The value of Rmin can be calculated from to eq

$$\boxed{\frac{V_m}{R_{min}} \le I_{gm}} \quad \text{or} \quad \boxed{R_{min} \ge \frac{V_m}{I_{gm}}}$$

Where V_m is the maximum value of source vtg.

* The Stablization resistor R_b should have such a value that the maximum vtg drop across it does not exceed maximum possible gate vtg $V_{g(max)}$.

This can happen only when R is zero under this condition

$$\boxed{I R_b \leq V_{g(max)}}$$

$$\frac{V_m}{R_{min}+R_b} \cdot R_b \leq V_{g(max)}$$

$$V_m R_b \leq (R_{min}+R_b) V_{g(max)}$$

$$V_m R_b \leq R_{min} V_{g(max)} + R_b V_{g(max)}$$

$$R_b (V_m - V_{g(max)}) \leq R_{min} V_{g(max)}$$

$$\boxed{R_b \leq \frac{R_{min} V_{g(max)}}{V_m - V_{g(max)}}}$$

Drawbacks

1) Firing angle is limited to 0 to 90°.

❖ Resistance-Capacitance (RC) firing circuit :-

OR

❖ RC Half wave firing :-

❖ **With the help of neat circuit diagram and waveforms, explain RC firing circuit used with half controlled rectifier**

June-10,6M

❖ **With a circuit diagram and waveforms explain RC-triggering circuit.**

June-06,4M

❖ **With circuit diagrams and waveforms, discuss the operation of RC firing circuit for a half wave SCR controlled rectifier.**

June-04,8M

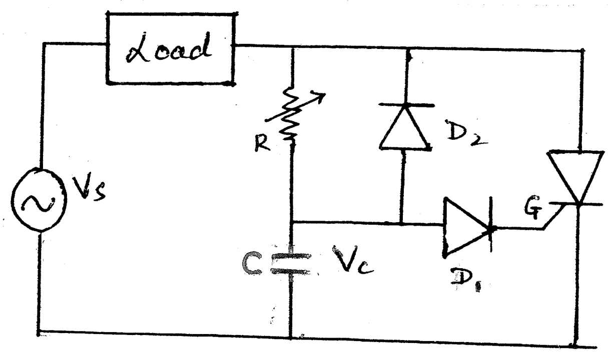


Fig ①

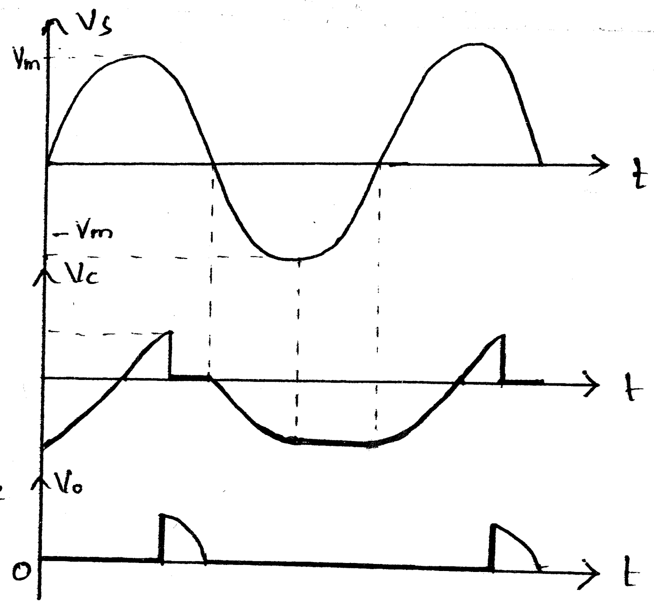


Fig ① shows the RC half wave trigger ckt. To overcome the drawback of R-firing circuit, RC firing circuits are used.

Operation :-

* During each -ve half cycle of I/p voltage, the capacitor charges to the peak supply voltage through diode 'D_1' with lower plate positive wrt to the top plate $\left(\frac{-}{+}\right)$

The diode D_1 is provided in order to by pass 'R' during each negetive half cycle of the supply vtg. so that the capacitor charges fast to the negetive peak value of the supply vtg $-V_m$.

This capacitor voltage remains at $-V_m$ until supply voltage attains zero value ($V_s = 0$).

* When the SCR anode Voltage becomes +ve, the Capacitor starts charging through the resistor R.

  When the capacitor charging voltage becomes equal to $V_{gt} + V_d$, the SCR turns ON

* In fig (i), diode D_1 is used to prevent the breakdown of gate to cathode junction.

The value of RC for zero o/p voltage is given by

$$\boxed{RC \geq \frac{1.3T}{2}}$$

Where $T = \frac{1}{f}$

* The SCR will trigger when

$$\boxed{V_c = V_{gt} + V_d} \longrightarrow (i)$$

The maximum value of R is given by

$$\boxed{V_s \geq I_{gt} R + V_c} \longrightarrow (2)$$

Substituting eq (1) in (2), we get

$$\boxed{V_s \geq I_{gt} R + V_{gt} + V_d}$$

$$V_s - V_{gt} - V_d \geq I_{gt} R$$

$$\frac{V_s - V_{gt} - V_d}{I_{gt}} \geq R$$

$$\boxed{R \leq \frac{V_s - V_{gt} - V_d}{I_{gt}}}$$

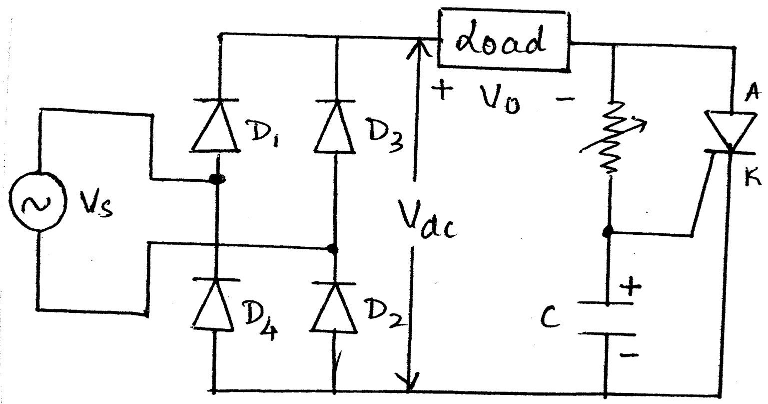
Where $V_d \rightarrow$ Voltage drop across D_2

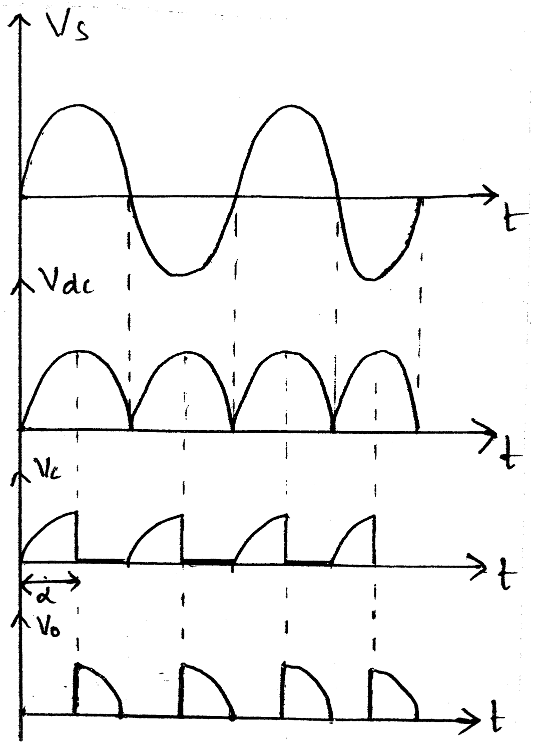
$V_{gt} \rightarrow$ Minimum gate turn-ON voltage

$I_{gt} \rightarrow$ Gate turn ON current

* By varying 'R', the firing angle can be varied from 0° to 180°.

❖ RC - FULL wave triggering circuit :-





In RC - Half wave triggering ckt, the power delivered to the load is only during +ve half cycle. This limitation can be overcome by using Full wave RC triggering ckt.

Here AC I/p Signal 'Vs' is converted into pulsating dc by full wave bridge rectifier ckt. This allows the SCR to be triggered on for both half cycle of the AC i/p voltage, which doubles the power delievered to the load.

* When the capacitor charges to a voltage equal to V_{gt}, SCR triggers & rectified vtg V_{dc} appears across load as V_0. The value of RC is obtained from the following relation

$$\boxed{RC \geq \frac{50T}{2}}$$

For the ckt 'R' can be calculated as

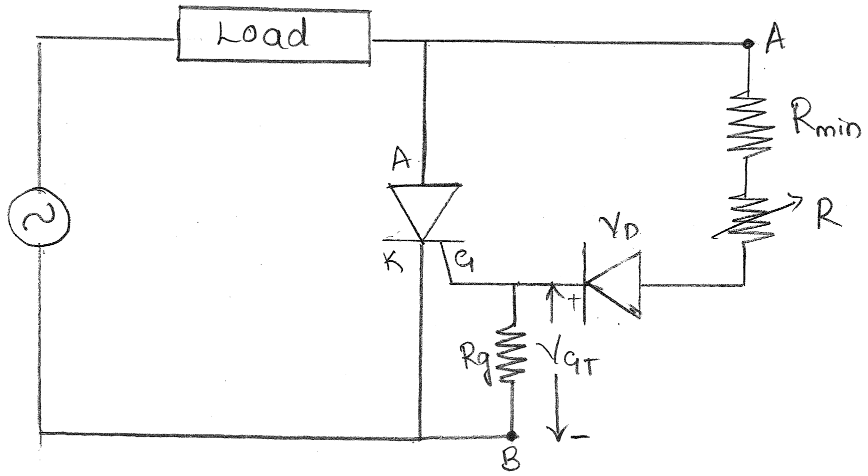
$$V_s = I_{gt} R + V_c$$

$$V_s = I_{gt} R + V_{gt}$$

$$= V_s - V_{gt}$$

$$\boxed{R = \frac{V_s - V_{gt}}{I_{gt}}}$$

❖ **For the thyristor in the circuit of fig1, the gate voltage required to trigger is V_{GT}=0.6V and the corresponding gate current is I_{GT}=250μA. The diode used is of silicon material and the input voltage is V=100sinwt. Find the firing angle α at which the thyristor will turn ON if R_{min}=10KΩ, R=220KΩ.**



Given : $V_{GT} = 0.6V$, $I_{GT} = 250\mu A$, $V = 100 \sin\omega t$, $R_{min} = 10K\Omega$, $R = 220K\Omega$, $V_m = 100V$, Assuming $V_D = 0.7V$.

Soln :- Applying KVL from V, A & B, we get

$$V - I_{GT} R_{min} - I_{GT} R - V_D - {}_{GT} R_g = 0$$

$$V - \underbrace{I_{GT}(R_{min} + R) - V_D - V_{GT}}_{} = 0$$

$$V = I_{GT}(R_{min} + R) + V_D + V_{GT}$$

$$V = 250 \times 10^{-6}(10K\Omega + 220K\Omega) + 0.7 + 0.6$$

$$\boxed{V = 58.8V}$$

WKT $V = V_m \sin\alpha$

$$\frac{V}{V_m} = \sin\alpha$$

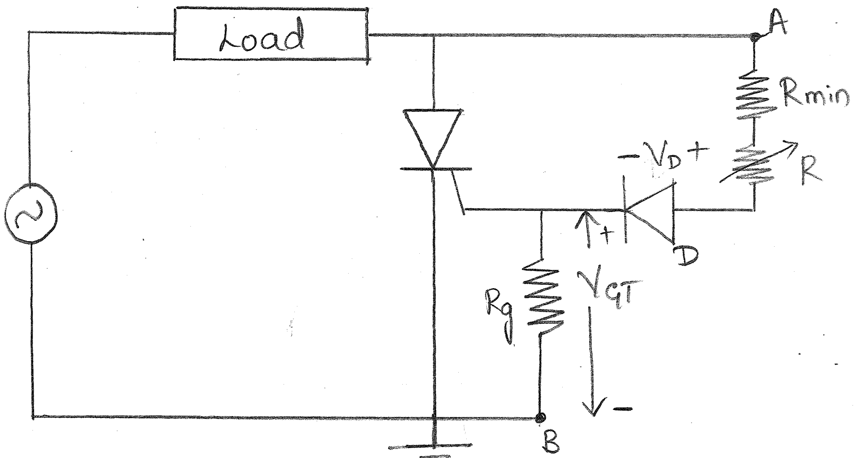
PTO →

$$\alpha = \sin^{-1}\left(\frac{V}{V_m}\right)$$

$$= \sin^{-1}\left(\frac{58.8}{100}\right)$$

$$\boxed{\alpha = 36.01^\circ}$$

❖ **The circuit of fig1 uses an SCR with $I_{g(min)}$=0.1mA and $V_{g(min)}$=0.5v. The diode is silicon and the peak amplitude of the input is 24volts. Determine the trigger angle α for R=100KΩ and Rmin=10KΩ.**



Given: $V_{g(min)} = 0.5V$, $I_{g(min)} = 0.1mA$, $V_m = 24V$, $R = 100k\Omega$, $R_{min} = 10k\Omega$, Assuming $V_D = 0.7V$.

Soln: Applying KVL from V, A & B we get

$$V - I_{gt} R_{min} - I_{gt} R - V_D - V_{gt} = 0$$

$$V - I_{gt}(R_{min} + R) - V_D - V_{gt} = 0$$

$$V = I_{gt}(R_{min} + R) + V_D + V_{gt}$$

$$V = 0.1mA\,(10k\Omega + 100k\Omega) + 0.7V + 0.5V$$

$$\boxed{V = 12.2V}$$

WKT,

$$V = V_m \sin\alpha$$

$$\alpha = \sin^{-1}\left(\frac{V}{V_m}\right)$$

$$= \sin^{-1}\left(\frac{12.2}{24}\right)$$

$$\boxed{\alpha = 30.6^\circ}$$

❖ **The ON-State voltage drop across the thyristor in the circuit of fig1 is 0.8v. The thyristor has a holding current of 15mA with I_G=0. If the thyristor is turned ON by a momentary pulse of gate current. Determine the value of voltage V below which the thyristor will turn-OFF.**

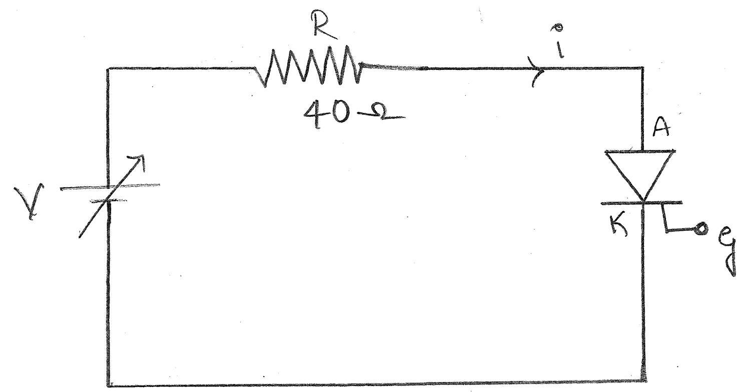


fig ①

Given : $V_{AK} = 0.8V$, $I_H = 15mA$, $R = 40\Omega$

Soln: Applying KVL to the ckt, we get

$$V - IR - V_{AK} = 0$$

$$V = IR + V_{AK}$$

$$= 15mA \times 40\Omega + 0.8V$$

$$\boxed{V = 1.4V}$$

When $V = 1.4V$, the current equal to I_H. Hence to turn OFF the thyristor, 'V' must be reduced below 1.4V

❖ **Design a suitable RC half wave triggering circuit for a thyristorised network operation on a 220V,50Hz supply. The specifications of SCR are $V_{gt(min)}$=5V and $I_{gt(max)}$=30mA.**

Given: $V_{gt(min)} = 5V$, $I_{gt(max)} = 30mA$, $V_s = 220V$,

$f = 50Hz$, $T = \frac{1}{f} = \frac{1}{50Hz}$

$$\boxed{T = 20msec}$$

Assuming: $V_D = 0.7V$

Soln: WKT

$$R = \frac{V_s - V_{gt} - V_D}{I_{gt}}$$

$$= \frac{220V - 5V - 0.7}{30mA}$$

$$\boxed{R = 7.1433\,k\Omega}$$

WKT $RC \geq \frac{1.3T}{2}$

$$C \geq \frac{1.3 \times 20\,m\,Sec}{2 \times 7.1433\,K\Omega}$$

$$\boxed{C \geq 1.8199\,\mu F}$$

❖ **A thyristor has the forward breakover voltage of 175V when gate pulse of 2mA is made to flow. Find the delay angle and conduction angle if a sine wave of 350V peak is applied.**

Given : $V_{BO} = V_s = 175V$, $I_g = 2mA$, $V_m = 350V$, $\alpha = ?$ & $\beta = ?$

Soln : WKT

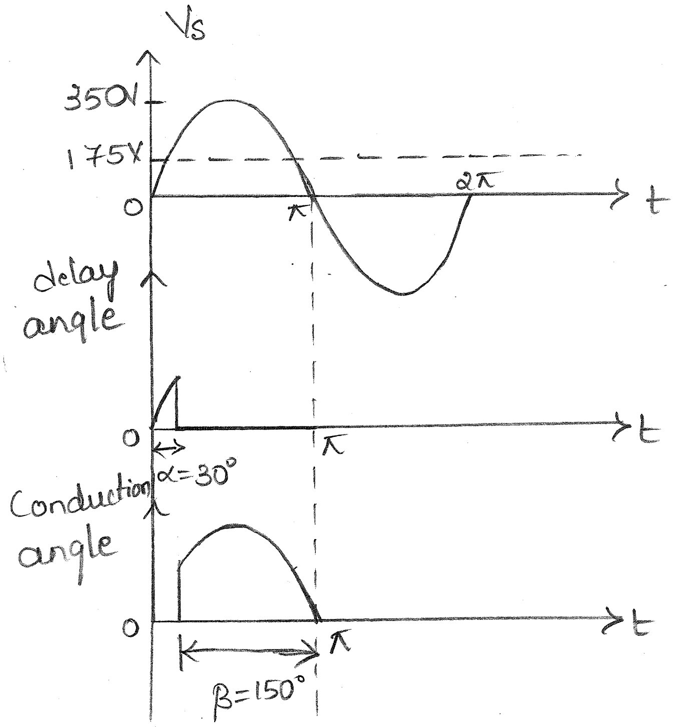
$$V_s = V_m \sin\alpha$$

$$\alpha = \sin^{-1}\left(\frac{V_s}{V_m}\right)$$

$$\alpha = \sin^{-1}\left(\frac{175}{350}\right)$$

∴ Delay angle 'α' is

$$\boxed{\alpha = 30^\circ}$$



WKT $\pi = \alpha + \beta$

$$\beta = \pi - \alpha$$

$$\beta = 180^\circ - 30^\circ$$

∴ Conduction angle is

$$\boxed{\beta = 150^\circ}$$

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Firing Angle Problems - FORMULAE

1) $V_{BO} = V_m \sin\alpha$

Where $V_m = \sqrt{2}\, V_{rms}$

2) $\alpha = \sin^{-1}\left(\frac{V_{BO}}{V_m}\right)$

3) Delay angle or Firing angle

$$\boxed{\alpha = 180^\circ - \beta}$$

4) Conduction angle

$$\boxed{\beta = 180^\circ - \alpha}$$

❖ **A thyristor is supplied from 230V,50Hz mains. If the conduction angle is 120°, determine the voltage at which the thyristor is triggered.**

Jan11-4M

Given :- $V_{rms} = 230V, \quad \beta = 120^\circ$

Sol :-

$V_m = \sqrt{2}\, V_{rms}$

$= \sqrt{2} \times 230V$

$$\boxed{V_m = 325.26V}$$

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* Firing angle

$$\alpha = 180^\circ - \beta$$

$$\alpha = 180^\circ - 120^\circ$$

$$\boxed{\alpha = 60^\circ}$$

* $V_{BO} = V_m \sin\alpha$

$$= 325.26V \times \sin(60^\circ)$$

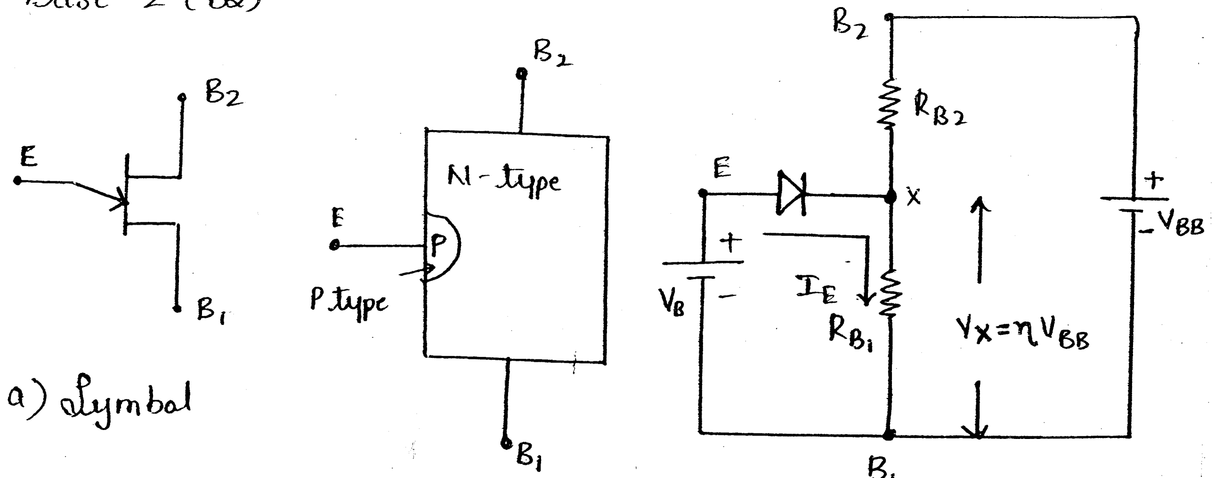
$$\boxed{V_{BO} = 281.68V}$$

❖ UNIJUNCTION Transistor :-

* The drawback with R - firing & RC - firing is that power dissipation in the gate ckt is more, to overcome this drawback, UJT firing ckt is used.

* UJT is an abbrevation for unijunction transistor made up of n type silicon material to which P-type emitter is fixed

UJT has 3 terminals namely Emitter (E) Base-1 (B1) & Base-2 (B2)



a) Symbol b) Structure c) Equivalent ckt.

* R_{B1} & R_{B2} are the internal resistance respectively from Bases B_1 & B_2 to x-point.

When a voltage V_{BB} is applied across the two base terminals B_1 & B_2, the potential of point X wrt B_1 is given by

$$V_X = I R_{B1}$$

$$= \frac{V_{BB}}{R_{B1}+R_{B2}} \cdot R_{B1}$$

$$= \frac{R_{B1}}{R_{B1}+R_{B2}} V_{BB}$$

$$V_x = \eta V_{BB}$$

$$\text{where } \eta = \frac{R_{B1}}{R_{B1}+R_{B2}}$$

$$* \; R_{BB} = R_{B1} + R_{B2} \quad \therefore \eta = \frac{R_{B1}}{R_{BB}}.$$

Where η is the internal UJT vtg divider ratio & is called the intrinsic stand off ratio.

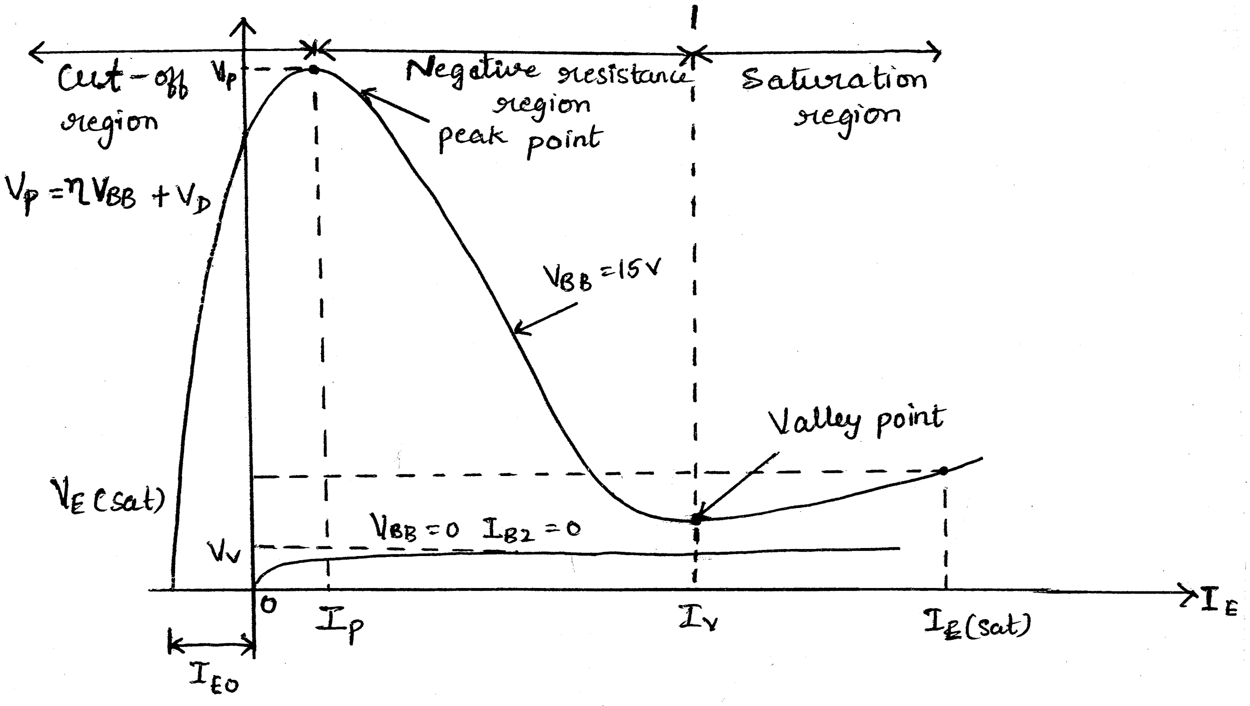


fig :- Characteristics for $V_{BB} = 0$ & $V_{BB} = 15V$.

The characteristics can be divided into three main regions

1) <u>Cut-off region</u> :-

When the emitter valtage V_E is less than V_P, the p-n junction is reverse biased. A small amount of reverse saturation current I_{EO} flows through the device.

2) <u>Negetive resistance region</u>:-

When the emitter voltage V_E becomes equal to V_P, the p-n junction becomes forward biased and I_E starts flowing. The voltage across the device decreases in this region, though the current through the devices increases. Hence the region is called <u>negetive resistance</u> region. This decreases the resistance R_{B1}. This region continues till valley point.

3) <u>Saturation region</u>:-

The further increase in the 'I_E' beyond the valley point current 'I_V' drives the device in the saturation region. The voltage corresponding to the valley point is called Valley point voltage denoted as V_V.

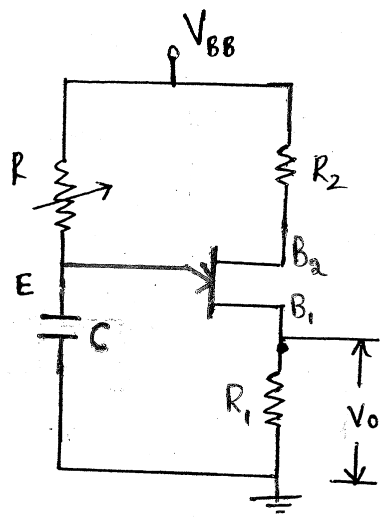
❖ UJT-Relaxation oscillator :-

❖ **With relevant circuit diagram and waveforms, explain the UJT relaxation oscillator.**

Jan-10,6M

❖ **Brief the working principle of a UJT relaxation oscillator with the help of a circuit diagram and show period of oscillation T= RC $\log_e(1/1-n)$.**

June-08,6M



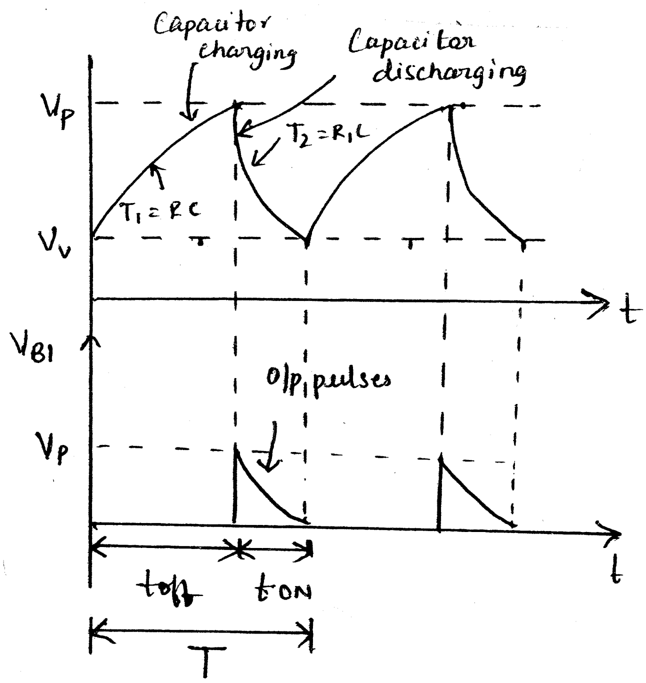


Fig ① shows a UJT relaxation oscillator.
When dc supply 'V_{BB}' is applied, Capacitor 'C' begins to charge through R exponentially toward V_{BB}. During this charging, emitter ckt of UJT is an open ckt

* The control Vtg $V_c = V_E$ is given by

$$V_c = V_E = V_{BB}(1 - e^{-t/RC})$$

* The charging time constant is given by

$$\boxed{\tau_1 = RC}$$

* When this emitter voltage $V_E = V_C$ reaches the peak point vtg $V_P = \eta V_{BB} + V_D$, the UJT turns ON & Capacitor 'C' discharges through low resistance R_1.

* The discharging time constant is given by

$$\boxed{\tau_2 = R_1 C}$$

Hence τ_2 is much smaller than τ_1

* When discharging vtg dropped to 'V_V', UJT turns OFF. The charging & discharging process of capacitor repeats for each period T & is given by

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

* R_2 is used for thermal stability of V_P, the value of R_2 can be calculated by using formula.

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

* The maximum value of R is determined by

$$R_{max} = \frac{V_{BB} - V_P}{I_P} = \frac{V_{BB} - (\eta V_{BB} + V_D)}{I_P}$$

The minimum value of R is given by

$$R_{min} = \frac{V_{BB} - V_V}{I_V}$$

* R_1 can be calculated as

$$\boxed{R_1 = \frac{V_{BB}}{\text{leakage current}} - R_2 - R_{B1} - R_{B2}}$$

Derive the expression for Periodic time 'T' of the UJT relaxation oscillator

Soln:- The voltage across the Capacitor is given by

$$V_P = V_{BB}(1 - e^{-t/RC})$$

When $V_P = \eta V_{BB} + V_D$, the capacitor will discharge through R_1

Substituting 'V_P' value in eq ①, we get

$$\eta V_{BB} + V_D = V_{BB}(1 - e^{-t/RC})$$

Since $V_{BB} >> V_D$, neglecting V_D

$$\eta V_{BB} = V_{BB}(1 - e^{-t/RC})$$

$$\eta = 1 - e^{-t/RC}$$

$$e^{-t/RC} = 1 - \eta$$

$$\frac{1}{e^{-t/RC}} = \frac{1}{1-\eta}$$

$$e^{t/RC} = \frac{1}{1-\eta}$$

Taking $\log_e$ on both side we get

$$\frac{t}{RC} = \log_e\left(\frac{1}{1+\eta}\right)$$

put $\boxed{t = T}$ is above equation

$$\boxed{T = RC\log_e\left(\frac{1}{1-\eta}\right)}$$

The frequency of oscillation 'f'

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

$$\boxed{f = \frac{1}{RC \log_e\left(\frac{1}{1-\eta}\right)}}$$

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UJT-Relaxation Oscillator Formulae :

1) Capacitor voltage $V_C = V_E$ is

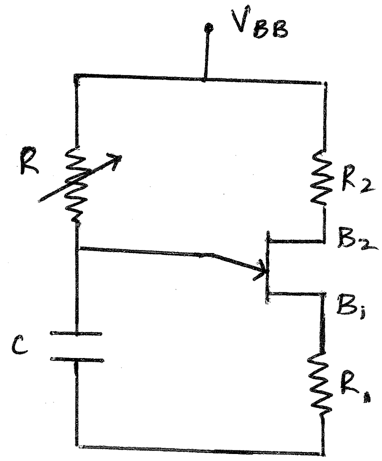
$$\boxed{V_C = V_E = V_{BB}\left(1 - e^{-t/RC}\right)}$$

2) Charging time constant

$$\boxed{\tau_1 = RC}$$

3) Discharging time constant

$$\tau_2 = R_1 C$$



4) $T = \tau_1 + \tau_2$ &

$$\boxed{T = RC \ln\left(\frac{1}{1-\eta}\right)}$$

5) $R_2 = \dfrac{10^4}{\eta V_{BB}}$ or $\boxed{R_2 = \dfrac{0.7\,(R_{B1} + R_{B2})}{\eta V_{BB}}}$

6) $R_1 = \dfrac{V_{BB}}{\text{leakage current}} - R_2 - R_{B1} - R_{B2}$

or

$$R_1 = \frac{V_{gt}}{I_{leakage}}$$

7) $R_{max} = \dfrac{V_{BB} - V_P}{I_P}$

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8) $R_{min} = \dfrac{V_{BB} - V_V}{I_V}$

9) $T = 1/f$

10) $V_P = \eta V_{BB} + V_D$

let $V_D = 0.8V$

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

PROBLEMS

1) A UJT is used to trigger the thyristor whose minimum gate triggering voltage is 6.2V, the UJT ratings are : η=0.66, I_P=3mA, I_V =0.5mA, $R_{B1}+R_{B2}$ = 5KΩ, leakage current = 3.2mA, V_P=14V and V_V=1V. Oscillator frequency is 2KHz and capacitor C=0.04μf. Design the complete circuit.

Soln :- Assume $V_D = 0.8V$

$$T = \frac{1}{f} = \frac{1}{2\times10^3}$$

WKT $$T = RC \ln\left(\frac{1}{1-\eta}\right)$$

$$\frac{1}{2\times10^3} = R\times 0.04\mu F\left(\frac{1}{1-0.66}\right)$$

$$\boxed{R = 11.6 K\Omega}$$

* The peak voltage is given by

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

$$V_{BB} = \frac{V_P - V_D}{\eta} = \frac{14V - 0.8V}{0.66}$$

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

* $$R_2 = \frac{0.7(R_{B1}+R_{B2})}{\eta V_{BB}} = \frac{0.7(5\times10^3)}{0.66\times 20}$$

$$\boxed{R_2 = 265.15\Omega}$$

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

$$20V = 3.2\times10^{-3}(R_1 + 265 + 5\times10^3)$$

$$\frac{20V}{3.2\times10^{-3}} = R_1 + 5.265\,k\Omega$$

$$R_1 = 625 - 5.265\,k\Omega$$

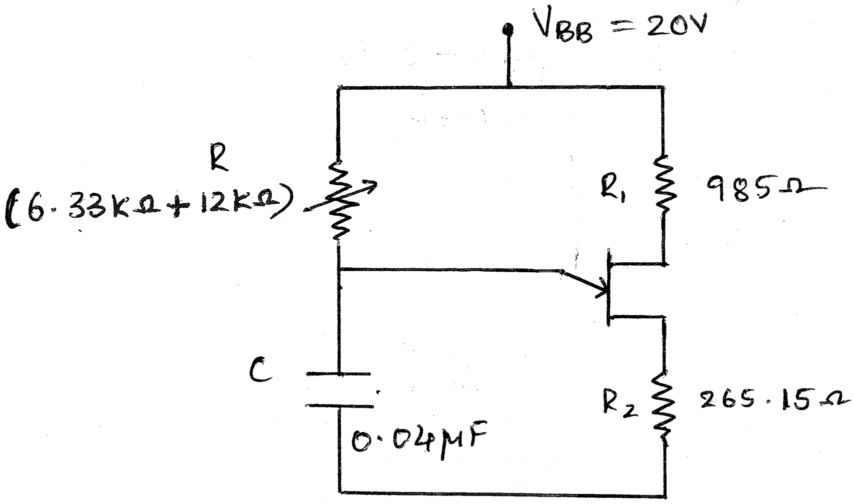
$$\boxed{R_1 = 985\,\Omega}$$

* $R_{(max)} = \dfrac{V_{BB} - V_P}{I_P} = \dfrac{20V - 14V}{0.5\times10^{-3}}$

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

* $R_{(min)} = \dfrac{V_{BB} - V_V}{I_V} = \dfrac{20V - 1V}{3\times10^{-3}}$

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



2) Design the UJT triggering circuit for SCR. Given V_{BB}=20V, η=0.6, I_P=10A, V_V=2V, I_V=10mA. The frequency of oscillation is 100HZ. The triggering pulse width should be 50μsec.

Given :- $V_{BB} = 20V$, $\eta = 0.6$, $I_p = 10\mu A$, $V_V = 2V$,

$I_V = 10mA$, $f = 100Hz$, $\tau_2 = 50\mu sec$.

Soln :- $T = \frac{1}{f} = \frac{1}{100Hz}$

WKT $T = RC \ln\left(\frac{1}{1-\eta}\right)$

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

$$RC = 0.0109135$$

Assuming $C = 1\mu F$

$$R = \frac{0.0109135}{1\mu F}$$

$$\boxed{R_C = 10.91K\Omega}$$

* Peak Voltage

$V_p = \eta V_{BB} + V_D$ (Take $V_D = 0.8V$)

$= 0.6 \times 20V + 0.8V$

$$\boxed{V_p = 12.8V}$$

* $R_{(min)} = \frac{V_{BB} - V_V}{I_V} = \frac{20V - 2V}{10 \times 10^{-3}}$

$$\boxed{R_{(min)} = 1.8K\Omega}$$

* $R_2 = \dfrac{10^4}{\eta V_{BB}} = \dfrac{10^4}{0.6 \times 20}$

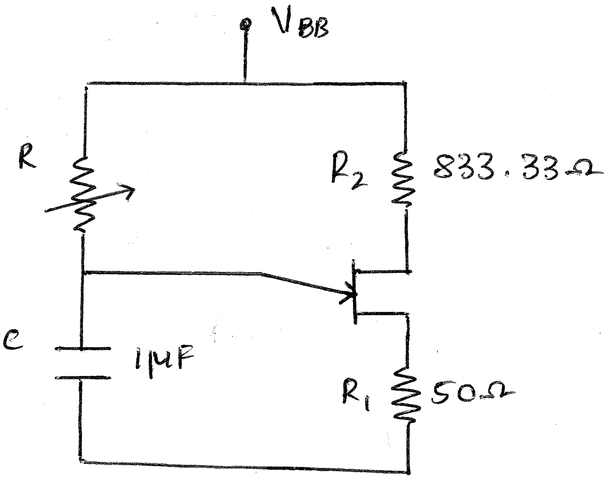
$$\boxed{R_2 = 833.33\,\Omega}$$

* The given pulse width $\tau_2 = 50\mu sec$

WKT $\tau_2 = R_1 C$

$R_1 = \dfrac{\tau_2}{C_1} = \dfrac{50\mu sec}{1\mu F}$

$$\boxed{R_1 = 50\,\Omega}$$



3) An UJT used in a relaxation oscillator circuit is having η=0.7, V_V=1V and the supply voltage to the circuit is 15V. Design the suitable values of R and C given that the frequency of oscillation is 1KHz. Peak current is 1mA and valley current is 8mA.

Sol: Given :- $V_{BB} = 15V$, $\eta = 0.7V$, $V_v = 1V$, $f = 1KHz$,

$I_p = 1mA$, $I_V = 8mA$

Assume $V_D = 0.8V$

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Soln :- Peak Voltage

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

$$= 0.7 \times 15V + 0.8V$$

$$\boxed{V_P = 11.3V}$$

* The period of oscillation

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

$$\frac{1}{1KH_z} = RC \ln\left(\frac{1}{1-0.7}\right)$$

$$RC = 8.3058 \times 10^{-4}$$

Assume $C = 1\mu F$

$$R = \frac{8.3058 \times 10^{-4}}{1\mu F}$$

$$\boxed{R = 830.58\,\Omega}$$

* $$R_{(max)} = \frac{V_{BB} - V_P}{I_P} = \frac{15V - 11.3V}{1 \times 10^{-3}}$$

$$\boxed{R_{(max)} = 3700\,\Omega}$$

* $$R_{(min)} = \frac{V_{BB} - V_V}{I_V} = \frac{15V - 1V}{8 \times 10^{-3}}$$

$$\boxed{R_{(min)} = 1750\,\Omega}$$

❖ **An UJT triggering circuit is connected across a 20V zener. The valley and peak point voltages are 1V and 15V respectively. The intrinsic stand-off ratio is 0.75. It operates at a frequency of 1200Hz. Find the charging capacitor if R=5.6KΩ.**

Given :- $V_{BB} = 20V$, $V_V = 1V$, $V_P = 15V$, $\eta = 0.75$,
$f = 1200 Hz$, $R = 5.6 K\Omega$ $T = \frac{1}{f}$

Sol :-

The period of UJT relaxation oscillator is

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

$$\frac{1}{1200} = 5.6 \times 10^3 \cdot C \cdot \ln\left(\frac{1}{1-0.75}\right)$$

$$\boxed{C = 0.107 \mu F}$$

Design a UJT relaxation oscillator for triggering a thyristor. The following data is given for UJT η=0.6, I_P=50μA, V_V=2V, VBB=10V and R_{BB}=6KΩ. The leakage current is 4mA. The triggering frequency is 2KHz and Vgt=0.3V. Also calculate minimum and maximum triggering frequency.

Soln :- Assuming $C = 0.01 \mu F$ & $V_D = 0.8V$

$$T = \frac{1}{f} = \frac{1}{2 KHz} = 0.5 msec$$

WKT

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

$$R = T / C \ln\left(\frac{1}{1-\eta}\right) = 0.5 msec / 0.01 \mu F \ln\left(\frac{1}{1-0.6}\right)$$

$$\boxed{R = 54.56\,K\Omega}$$

* $R_2 = \frac{10^4}{\eta V_{BB}} = \frac{10^4}{0.6 \times 10V}$

$$\boxed{R_2 = 1.66\,K\Omega}$$

* $R_1 = \frac{V_{gt}}{I_{leakage}} = \frac{0.3V}{4 \times 10^{-3}}$

$$\boxed{R_1 = 75\,\Omega}$$

* Peak Voltage : $V_P = \eta V_{BB} + V_D$

$V_P = 0.6 \times 10\,V + 0.8V$

$$\boxed{V_P = 6.8V}$$

* $R(max) = \frac{V_{BB} - V_P}{I_P} = \frac{10V - 6.8V}{50\mu A}$

$$\boxed{R(max) = 64\,K\Omega}$$

* $R(min) = \frac{V_{BB} - V_V}{I_V} = \frac{10V - 2V}{5mA}$

$$\boxed{R(min) = 1.6\,K\Omega}$$

* $T_{max} = R_{max}\, C \ln\left(\frac{1}{1-\eta}\right) = 64\,K\Omega \times 0.01\mu F \ln\left(\frac{1}{1-0.6}\right)$

$T_{max} = 5.86 \times 10^{-4}$ sec

$$f_{max} = \frac{1}{T_{max}} = \frac{1}{5.86 \times 10^{-4} sec}$$

$$\boxed{f_{max} = 1.705\, KH_3}$$

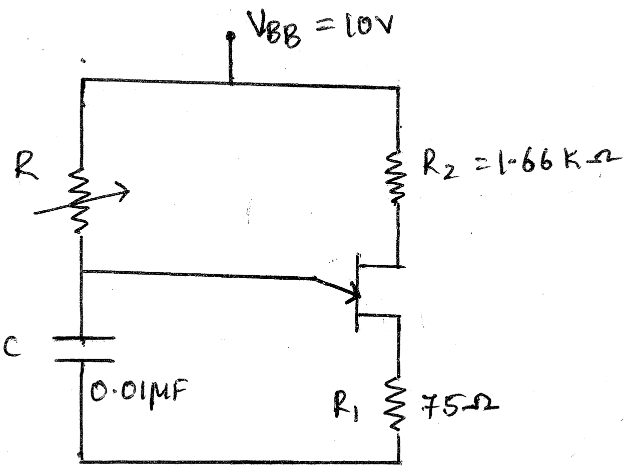
$$* \quad T_{min} = R_{min}\, C \ln\left(\frac{1}{1-\eta}\right)$$

$$= 1.6K\Omega \times 0.01\mu F \ln\left(\frac{1}{1-0.6}\right)$$

$$T_{min} = 1.466 \times 10^{-5} \ sec$$

$$f_{min} = \frac{1}{T_{min}} = \frac{1}{1.466 \times 10^{-5}}$$

$$\boxed{f_{min} = 68.21\, KH_3}$$



❖ **Design UJT relaxation oscillator for triggering of thyristor. The UJT has the following parameters =0.7, I_p=50μA, V_V=2V, I_V=6mA, V_{BB}=20V. R_{BB}=7KΩ, I_{EO}=2mA. Also determine the limits for the output frequency of the oscillator. Assume $V_{g(min)}$=0.2V**

June-11,6M

Given:- $\eta = 0.7$, $I_p = 50\mu A$, $V_V = 2V$, $I_V = 6mA$, $V_{BB} = 20V$,

$R_{BB} = 7K\Omega$, $I_{EO} = 2mA$ $V_{g(min)} = 0.2V$.

Soln:- Assume $\boxed{C = 0.1\mu F}$ & $V_D = 0.7V$

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

$$= 0.7 \times 20V + 0.7V$$

$$\boxed{V_p = 14.7V}$$

* $R_{(max)} = \dfrac{V_{BB} - V_p}{I_p} = \dfrac{20V - 14.7V}{50\mu A}$

$$\boxed{R_{max} = 106\,k\Omega} \longleftarrow \text{1M}$$

* $R_{(min)} = \dfrac{V_{BB} - V_V}{I_V} = \dfrac{20V - 2V}{6 \times 10^{-3}}$

$$\boxed{R_{min} = 3K\Omega} \longleftarrow \text{1M}$$

* $R_2 = \dfrac{10^4}{\eta V_{BB}} = \dfrac{10^4}{0.7 \times 20V}$

$$\boxed{R_2 = 714.28\,\Omega} \longleftarrow \text{1M}$$

* $R_1 = \dfrac{V_{gt}}{I_{leakage}} = \dfrac{V_{g(min)}}{I_{EO}} = \dfrac{0.2V}{2mA}$

$$\boxed{R_1 = 100\,k\Omega} \longleftarrow \text{1M}$$

* $T_{max} = R_{max} \cdot C \cdot \log_e \left(\frac{1}{1-\eta}\right)$

$= 106\,K\Omega \times 0.1\,\mu F \log_e \left(\frac{1}{1-0.7}\right)$

$\boxed{T_{max} = 12.76\ msec}$

* $T_{min} = R_{min} \times C \log_e \left(\frac{1}{1-\eta}\right)$

$= 3\,K\Omega \times 0.1\,\mu F \log_e \left(\frac{1}{1-0.7}\right)$

$\boxed{T_{min} = 0.36\ msec}$ 1M

* $f_{max} = \frac{1}{T_{min}} = \frac{1}{0.36\,msec}$

$\boxed{f_{max} = 2.77\ KHz}$

* $f_{min} = \frac{1}{T_{max}} = \frac{1}{12.76\,msec}$

$\boxed{f_{min} = 78.35\ Hz}$ 1M

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❖ dv/dt and di/dt protection :-

❖ dv/dt protection :-

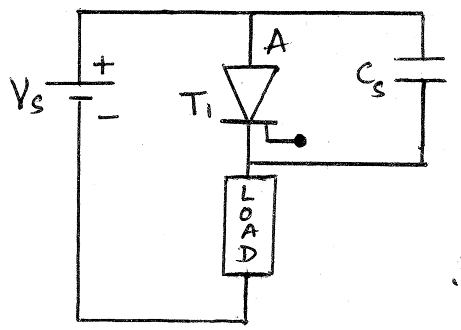
❖ **Discuss the need of protection against di/dt and dv/dt. Explain how it is achieved with suitable circuit diagrams.**

June-11,8M (E&E)

❖ **What is the need of di/dt protection and dv/dt protection? Explain how protection is provided.** **June-10,4M**

❖ **What is the need for protection of thyristors? Explain how thyristors are protected against high di/dt and high dv/dt**

June-08,7M Jan-07,7M



When forward vtg is applied accross anode and cathode of an SCR, Junction J_1 & J_3 are forward biased but Junction J_2 is reverse biased and acts as capacitor. Then the charging current is given by.

$$i = \frac{dq}{dt}$$

Where q is the charge & is given by

$$q = C_j V_s$$

$$i = \frac{d}{dt}(C_j V_s)$$

$$i = C_j \frac{dV_s}{dt} + V_s \frac{dC_j}{dt}$$

($\because$ C_j is almost constant)

$$\boxed{i = C_j \frac{dV_s}{dt}}$$

* If the rate of rise of forward Vtg increases, the charging current 'i' also increases, this current turns ON the SCR even when the gate current is Zero. This turn ON is called $\frac{dv}{dt}$ turn ON & it leads to false operation of the thyristor. Hence it is necessary to protect SCR from the $\frac{dv}{dt}$ turn ON

❖ di/dt protection :-

WKT, In thyristor at the time of turn-ON, anode current increases rapidly. This rapid variation of anode current doesnot spread accross the junction area of the thyristor. This creates the local hot spots in the junction & increases the junction temperature.

* If the junction temperature exceeds permissible value, then the thyristor is damaged.

The rapid variation of the thyristor current are also called $\frac{di}{dt}$

* The thyristor can be protected from excessive $\frac{di}{dt}$ by using an series inductor L_s as shown in fig ①.

* $\frac{di}{dt}$ can be calculated by using the formula

$$\frac{di}{dt} = \frac{V_s}{L_s}$$

$$L_s = \frac{V_s}{di/dt}$$

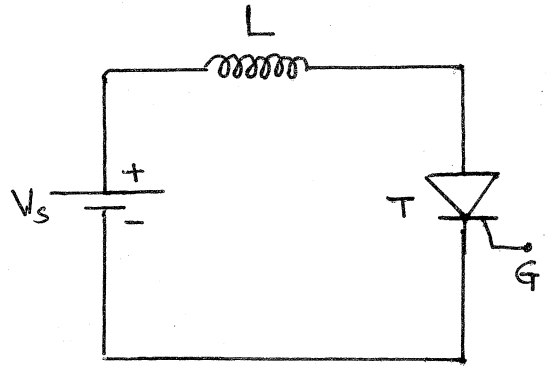


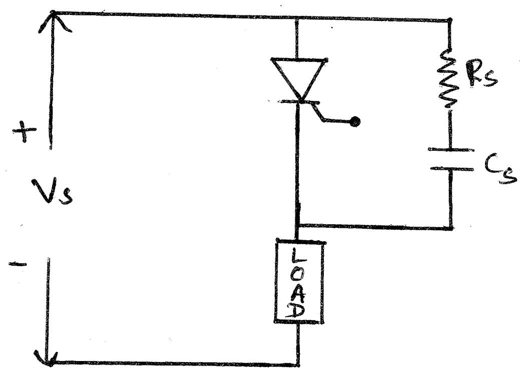
fig ①

❖ Snubber Circuit :-

Snubber ckt is used to protect SCR from $\frac{dv}{dt}$ turn-ON

A snubber ckt consist of a series combination of resistance R_s & Capacitence C_s in parallel with the thyristor as shown in fig

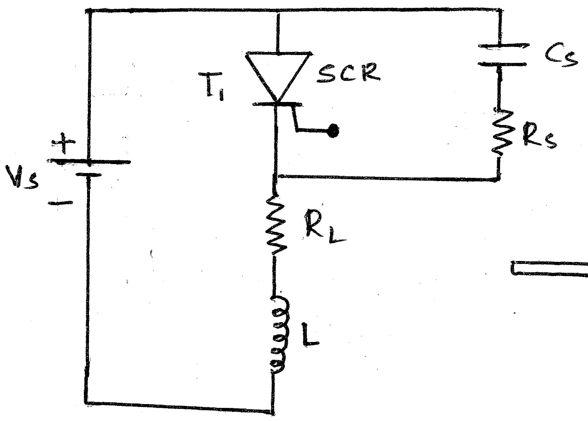
* When forward vtg is applied across the thyristor capacitor C_s charges slowly & prevents sudden rise of vtg accross the thyristor.



* The purpose of connecting Resistor R_s in series with C_s because, when thyristor turns ON, Capacitor discharges through thyristor & sends a heavy current and may damage the thyristor.

In order to limit the discharge current a resistance R_s is connected in series with C_s.

❖ Design of SNUBBER circuit :-



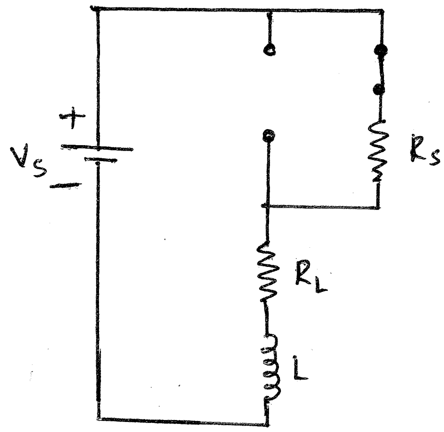


fig ⓐ : Snubber ckt

fig ⓑ : Equivalent ckt when SCR is OFF

* Snubber ckt is a series connection of Rs & Cs and is connected parallel to SCR. L is connected in series with load resistor R_L for $\frac{di}{dt}$ protection.

* The Capacitor 'C_s' behaves like a short circuit and SCR is in the forward blocking state offers a very high resistance as shown in fig ⓑ.

* The Voltage equation for fig ⓑ is

$$V_s = i(R_s + R_L) + L\frac{di}{dt} \longrightarrow (1)$$

Apply Laplace & inverse laplace transform & simplifying, the solution of eq ① is.

$$\boxed{i = I(1 - e^{-t/\tau})}$$

Where $I = V_s / R_s + R_L$ & $\tau = L / R_s + R_L$

Differentiating eq ② wrt 't', we get

$$\frac{di}{dt} = I\left[0 - e^{-t/\tau} \cdot -\frac{1}{\tau}\right]$$

$$\boxed{\because \frac{d}{dt} e^{at} = e^{at} \cdot \frac{1}{a}}$$

$$\boxed{\frac{di}{dt} = I e^{-t/\tau} \cdot \frac{1}{\tau}} \longrightarrow ③$$

Substituting I & τ values in eq ③, we get

$$\frac{di}{dt} = \frac{V_s}{R_s+R_L} e^{-t/\tau} \cdot \frac{1}{\frac{L}{R_s+R_L}}$$

$$\frac{di}{dt} = \frac{V_s}{R_s+R_L} e^{-t/\tau} \cdot \frac{R_s+R_L}{L}$$

$$\frac{di}{dt} = \frac{V_s}{L} e^{-t/\tau}$$

The value of $\frac{di}{dt}$ is maximum when $t=0$.

$$\left(\frac{di}{dt}\right)_{max} = \frac{V_s}{L} e^{-0/\tau}$$

$$\left(\frac{di}{dt}\right)_{max} = \frac{V_s}{L}$$

$$\therefore L = \frac{V_s}{\left(\frac{di}{dt}\right)_{max}}$$

* The Voltage across SCR is given by

$$V_{AK} = i R_s \longrightarrow ④$$

differentiate eqn ④ wrt t

$$\frac{dV_{AK}}{dt} = R_s \frac{di}{dt}$$

$$\left(\frac{dV_{AK}}{dt}\right)_{max} = R_s \cdot \left(\frac{di}{dt}\right)_{max}$$

Substituting $\left(\frac{di}{dt}\right)_{max}$ value in above equation

$$\left(\frac{dV_{AK}}{dt}\right)_{max} = R_s \cdot \frac{V_s}{L}$$

$$\therefore \boxed{R_s = \frac{L}{V_s}\left(\frac{dV_{AK}}{dt}\right)_{max}}$$

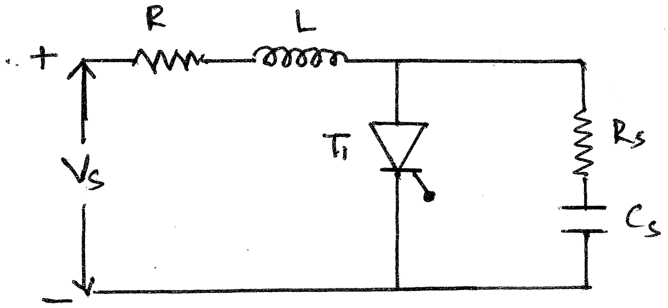
* Capacitor 'C_s' can be calculated by using the formulae

$$\boxed{C_s = \frac{1}{2L}\left[\frac{0.564\,V_m}{\frac{dv}{dt}}\right]^2}$$

Where V_m is the peak input Voltage

SNUBBER circuit Formulae :-

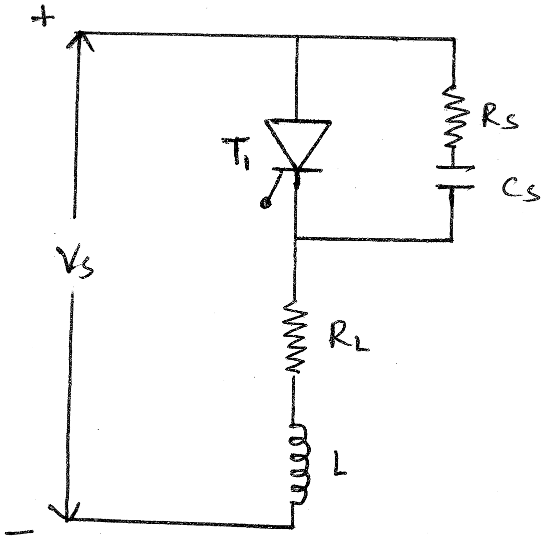
1) $\left(\frac{di}{dt}\right)_{max} = \frac{V_s}{L}$



or

2) $L = \frac{V_s}{\left(\frac{di}{dt}\right)_{max}}$

3) $R_s = \frac{L}{V_s}\left(\frac{dV_{AK}}{dt}\right)_{max}$



4) $(R_s + R_L) = 2\sqrt{\frac{L}{C}}$

5) $C_s = \frac{1}{2L}\left[\frac{0.564\, V_m}{dv/dt}\right]^2$

6) $V_s = i\,(R_s + R_L) + L\frac{di}{dt}$

NOTE :-

* $(R_s + R_L) = 2\xi\sqrt{\frac{L}{C}}$

Where ξ is the damping factor & is 0.65 ($\xi = 0.65$)

* $R_s = 2\xi\sqrt{\frac{L}{C}}$

* $R_s = \frac{V_s}{i}$

PROBLEMS

❖ **A SCR has a di/dt = 120 A/μs and a dv/dt of 300 V/μs. It operates on a 250V DC source with a load resistance of 10Ω . Find the suitable values for the components of the snubber circuit.**

Given :-

$\frac{di}{dt} = 120A/\mu s$, $\frac{dv}{dt} = 300V/\mu s$, $V_s = V_m = 250V$, $R_L = 10\Omega$

Soln :-

* $L = \frac{V_s}{\frac{di}{dt}} = \frac{250V}{120A/\mu s}$

$\boxed{L = 2.08\mu H}$

* $C = \frac{1}{2L}\left[\frac{0.564 V_m}{dv/dt}\right]^2 = \frac{1}{2\times 2.08\mu H}\left[\frac{0.564\times 250}{300V/\mu s}\right]^2$

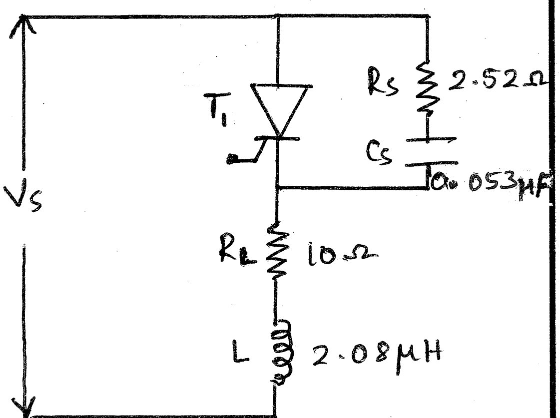
$\boxed{C = 0.053\mu F}$

* $(R_s + R_L) = 2\sqrt{\frac{L}{C}}$

$R_s + 10\Omega = 2\sqrt{\frac{2.08\mu H}{0.053\mu F}}$

$R_s + 10\Omega = 12.529\Omega$

$\boxed{R_s = 2.529\Omega}$



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❖ **Explain the need for dv/dt and di.dt protection for SCR. A SCR circuit has the following data: Supply voltage = 200V, dv/dt rating = 100 V/μs, di/dt rating = 50 A/μs. Calculate the snubber circuit elements using approximate expressions.**

Jan-06,8M

Given :- $V_s = V_m = 200V$, $\frac{dv}{dt} = 100V/\mu s$, $\frac{di}{dt} = 50A/\mu s$

assuming $\boxed{\xi = 0.65}$

Soln :-

* $L = \frac{V_s}{\frac{di}{dt}} = \frac{200V}{50\times10^6}$

$\boxed{L = 4\mu H}$

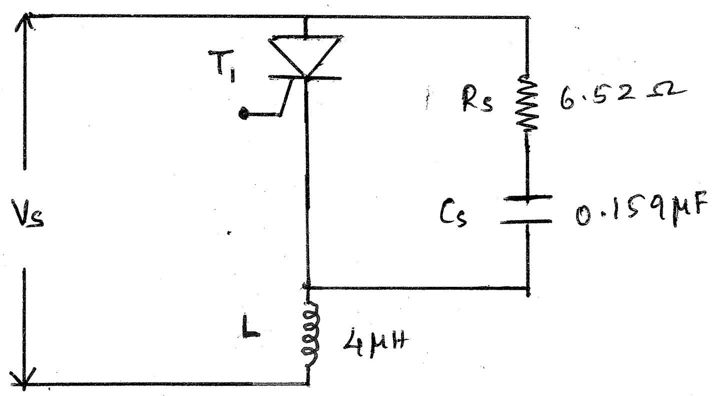
* $C = \frac{1}{2L}\left[\frac{0.564V_m}{dv/dt}\right]^2 = \frac{1}{4\mu H}\left[\frac{0.564\times200}{100\times10^6}\right]^2$

$C = 0.159\mu F$

* $R_s = 2\xi\sqrt{\frac{L}{C}}$

$= 2\times0.65\sqrt{\frac{4\mu H}{0.159\mu F}}$

$\boxed{R_s = 6.52\Omega}$



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❖ **Calculate the required parameters for snubber circuit to provide dv/dt protection to an SCR used in single phase bridge converter. The SCR has maximum dv/dt capacity of 60 V/µs. The input line to line voltage has a peak value of 425V and the source inductance is 0.2mH. Damping factor = 0.65.**

Jan-09,4M

Given : $\frac{dv}{dt} = 60V/\mu sec$, $L = 0.2mH$, $V_m = 425V$

Soln :

$$C = \frac{1}{2L}\left[\frac{0.564 V_m}{dv/dt}\right]^2$$

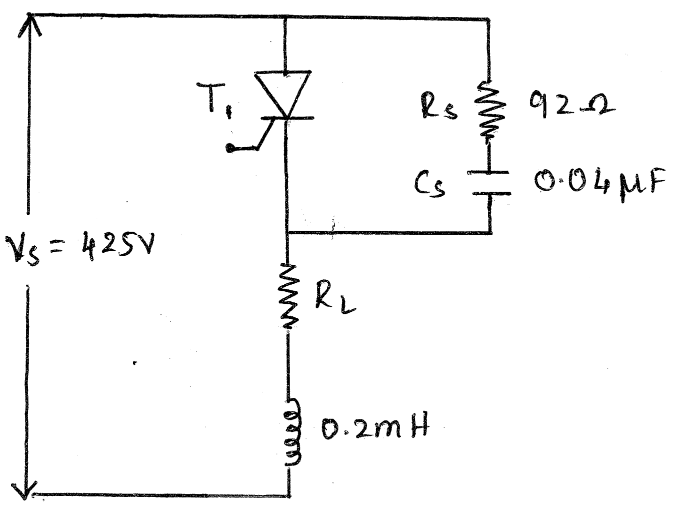
$$= \frac{1}{2 \times 0.2mH}\left[\frac{0.564 \times 425}{60 \times 10^6}\right]^2$$

$$\boxed{C = 0.04 \mu F}$$

* The damping factor $\xi = 0.65$

$$R_s = 2\xi\sqrt{\frac{L}{C}} = 2 \times 0.65\sqrt{\frac{0.2mH}{0.04\mu F}}$$

$$\boxed{R_s = 92\,\Omega}$$

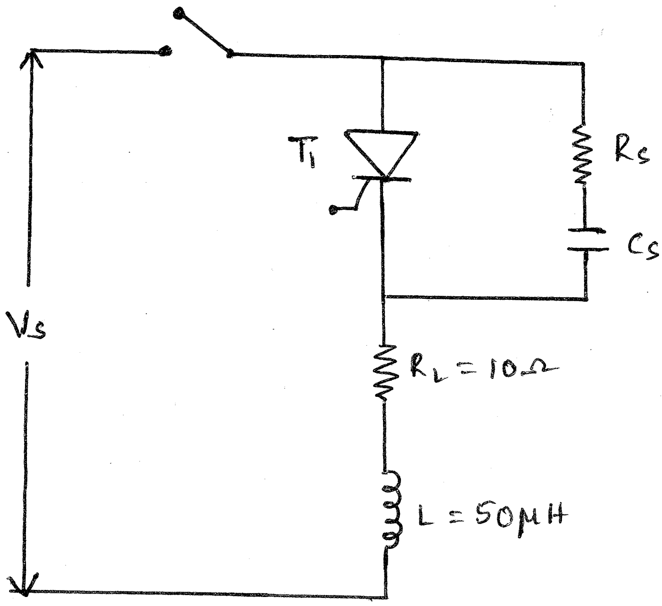


❖ **The input voltage to circuit shown below is Vs=200V with a load resistance of R=10Ω and a load inductance of L=50μH . If the damping ratio is 0.7 and discharging current of capacitor is 5A determine**

i) The values of Rs and Cs

ii) Maximum dv/dt

June-05,6M



Given :- $V_s = 200V$, $\xi = 0.7$, $R_L = 10\Omega$, $L = 50\mu H$, $i = 5A$,

$R_s = ?$, $C_s = ?$ $\left(\frac{dv}{dt}\right)_{max} = ?$ $V_s = V_m = 200V$

soln :-

WKT $\quad L = \dfrac{V_s}{(di/dt)_{max}}$

$$\left(\frac{di}{dt}\right)_{max} = \frac{V_s}{L} = \frac{200}{50\mu H}$$

$$\boxed{\left(\frac{di}{dt}\right)_{max} = 4A/\mu sec}$$

$$R_s = \frac{V_s}{i}$$

$$= \frac{200V}{5A}$$

$$R_s = 40\,\Omega$$

WKT

$$(R+R_s) = 2\xi\sqrt{\frac{L}{C_s}}$$

$$\sqrt{\frac{L}{C_s}} = \frac{R+R_s}{2\xi}$$

$$= \frac{10\,\Omega + 40\,\Omega}{2\times 0.7}$$

$$\sqrt{\frac{L}{C_s}} = 35.714$$

Squaring on both Sides

$$\frac{L}{C_s} = (35.714)^2$$

$$\frac{L}{C_s} = 1275.510$$

$$C_s = \frac{L}{1275.510} = \frac{50\,\mu H}{1275.510}$$

$$C_s = 0.0392\,\mu F$$

WKT

$$C_s = \frac{1}{2L}\left[\frac{0.564 V_m}{dv/dt}\right]^2$$

$$C_s\, 2L = \left[\frac{0.564 V_m}{dv/dt}\right]^2$$

$$0.0392\,\mu F \times 2 \times 50\,\mu H = \left[\frac{0.564\,V_m}{dv/dt}\right]^2$$

$$3.92 \times 10^{-12} = \left[\frac{0.564\,V_m}{dv/dt}\right]^2$$

$$\sqrt{3.92 \times 10^{-12}} = \frac{0.564\,V_m}{dv/dt}$$

$$\frac{dv}{dt} = \frac{0.564\,V_m}{\sqrt{3.92 \times 10^{-12}}}$$

$$\frac{dv}{dt} = \frac{0.564 \times 200}{1.9798 \times 10^{-6}}$$

$$\boxed{\frac{dv}{dt} = 56.972\,V/\mu sec}$$

❖ **To provide reliable dv/dt protection to an SCR used in a single phase fully controlled bridge, compute the required parameters for a snubber circuit. The SCR has maximum dv/dt capability of 50V/sec. The input line to line voltage has a peak value 380V and the source inductance is 0.1mH.**

Given :- $L = 0.1\,mH$, $V_m = 380\,V$, $(dV/dt)_{max} = 50\,V/\mu sec$

Soln :-

$$C_s = \frac{1}{2L}\left[\frac{0.564\,V_m}{dV/dt}\right]^2$$

$$= \frac{1}{2 \times 0.1 \times 10^{-3}}\left[\frac{0.564 \times 380}{50\,V/\mu sec}\right]^2$$

$$\boxed{C_s = 0.092\,\mu F}$$

* Assuming $\xi = 0.65$

WKT

$$R_s = 2\xi\sqrt{\frac{L}{c}} = 2 \times 0.65 \times \sqrt{\frac{0.1 \times 10^{-3}}{0.092\mu F}}$$

$$R_s = 42.86\,\Omega$$

WKT

$$R + R_s = 2\xi\sqrt{\frac{L}{C_s}}$$

$$\sqrt{\frac{L}{C_s}} = \frac{R + R_s}{2\xi}$$

$$\sqrt{\frac{L}{C_s}} = \frac{10\,\Omega + 40\,\Omega}{2 \times 0.7}$$

$$\sqrt{\frac{L}{C_s}} = 35.714$$

Squaring on both sides

$$\left(\sqrt{\frac{L}{C_s}}\right)^{\cancel{2}} = (35.714)^2$$

$$\frac{L}{C_s} = 1275.510$$

$$C_s = \frac{L}{1275.510} = \frac{50\mu H}{1275.510}$$

$$\boxed{C_s = 0.0392\mu F}$$

* WKT

$$C_s = \frac{1}{2L}\left[\frac{0.564\,V_m}{dV/dt}\right]^2$$

$$C_s(2L) = \left(\frac{0.564\,V_m}{dV/dt}\right)^2$$

$$0.0392\mu F \times 2 \times 50\mu H = \left(\frac{0.564\,V_m}{dv/dt}\right)^2$$

$$3.92 \times 10^{-12} = \left(\frac{0.564\,V_m}{dv/dt}\right)^2$$

$$\sqrt{3.92 \times 10^{-12}} = \frac{0.564\,V_m}{dv/dt}$$

$$\frac{dv}{dt} = \frac{0.564\,V_m}{\sqrt{3.92 \times 10^{-12}}}$$

$$\frac{dv}{dt} = \frac{0.564 \times 200}{1.9798 \times 10^{-6}}$$

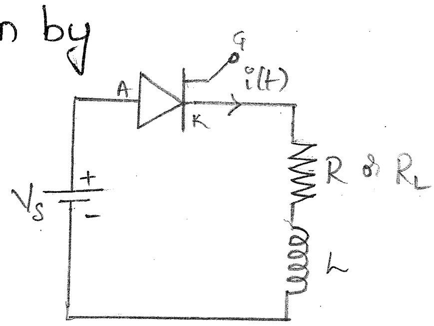
$$\boxed{\frac{dv}{dt} = 56.972\,V/\mu sec}$$

SCR CURRENT PROBLEMS

FORMULAE

1) Current through SCR is given by

$$\boxed{i(t) = \frac{V_S}{R}\left[1 - e^{-tR/L}\right]}$$



2) To determine 't' in current equation.

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

$$\frac{i(t) \cdot R}{V_S} = 1 - e^{-tR/L}$$

$$e^{-tR/L} = 1 - i(t) \cdot \frac{R}{V_S}$$

Taking natural log on both sides

$$\ln\left[e^{-tR/L}\right] = \ln\left[1 - i(t) \cdot \frac{R}{V_S}\right]$$

$$-\frac{tR}{L} \ln(e) = \ln\left[1 - \frac{i(t) \cdot R}{V_S}\right]$$

$$-\frac{tR}{L} = \ln\left[1 - \frac{i(t) \cdot R}{V_S}\right] \qquad \because \ln e = 1$$

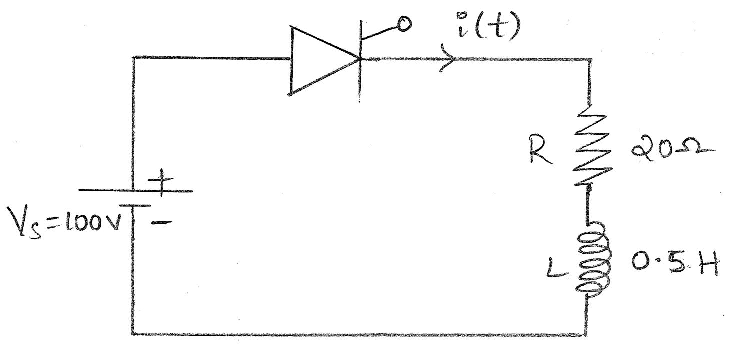
$$\boxed{t = -\frac{L}{R} \ln\left[1 - \frac{i(t) \cdot R}{V_S}\right]}$$

3) If $I_L > i(t)$, The SCR will not trigger. It will be in OFF state.

If $I_L < i(t)$, the SCR will trigger.

SCR CURRENT PROBLEMS

❖ **The SCR shown in fig1. Has the latching current of 20mA and is fired by the pulse of with 50sec. Determine whether the SCR triggers or not.**



fig(1)

Given: $I_L = 20mA$, $t = 50\mu s$, $R = 20\Omega$, $L = 0{\cdot}5H$, $V_S = 100V$.

Soln :

The Current $i(t)$ through the SCR at $50\mu Sec$

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

$$i(t) = \frac{100}{20}\left[1 - e^{-\frac{50\times10^{-6}\times 20}{0{\cdot}5}}\right]$$

$$\boxed{i(t) = 10mA}$$

The Current through the SCR is 10mA

The condition to trigger SCR is

$$\boxed{i(t) \geq I_L}$$

The $i(t) < I_L$. Thus SCR will not be triggered.

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❖ **A SCR is connected in series with a 0.5H inductor and 20Ω resistance. A 100V DC voltage is applied to this circuit. If the latching current of the SCR is 4mA. Find the minimum width of the gate trigger pulse required to properly turn-ON the SCR.**

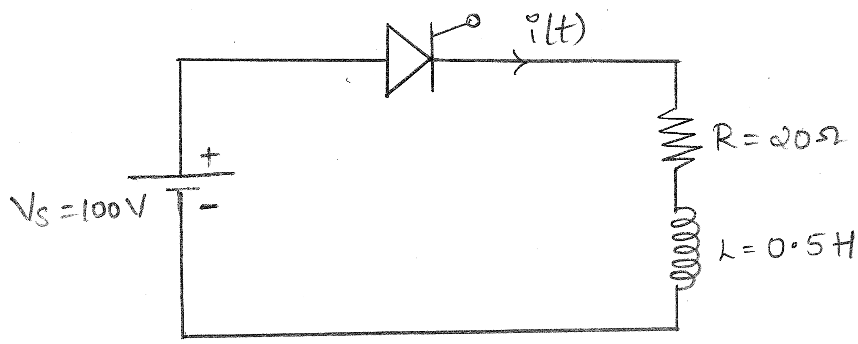

fig (1)

Given : $I_L = 4mA$, $L = 0.5H$, $R = 20\Omega$, $V_s = 100V$

The current through the RL ckt is given by:

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

In fig(1), when $i(t) = I_L$, SCR turns ON.

$$\Rightarrow \quad I_L = \frac{V_s}{R}\left[1 - e^{-tR/L}\right]$$

$$t = -\frac{L}{R}\ln\left[1 - \frac{I(L)\cdot R}{V_s}\right]$$

$$t = -\frac{0.5}{20}\ln\left[1 - \frac{4\times10^{-3}\times 20}{100}\right]$$

$$t = -0.025\ln\left[1 - 8\times10^{-4}\right]$$

$$t = -0.025\ln\left[0.9992\right]$$

$$t = -0.025 \times -8.0032\times10^{-4}$$

$$\boxed{t = 20\,\mu A}$$

❖ **The latching current of an SCR used in a phase controlled circuit, comprising an inductive load of R=10Ω and L=0.1h is 15mA. The input voltage is 325sin314t. Obtain the minimum gate pulse width required for reliable triggering of the SCR if gated at π/3 angle in every positive half cycle.**

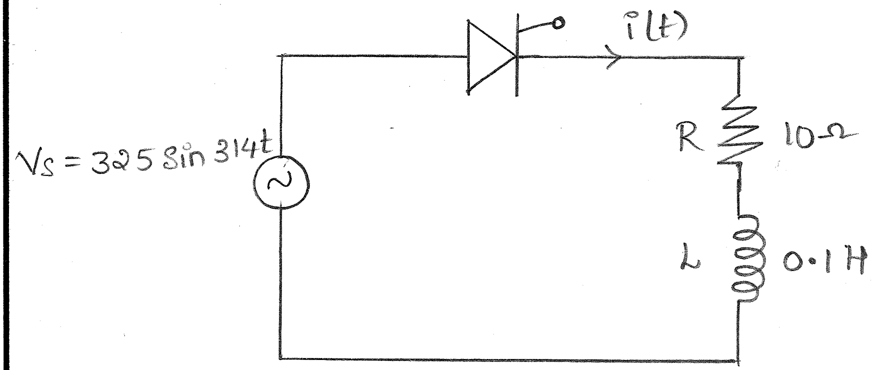

fig (1)

Given : $V_s = 325 \sin(314)t$, $R = 10\Omega$, $L = 0.1H$, $\alpha = \frac{\pi}{3}$

$I_L = 15mA$.

SCR is triggered at $\frac{\pi}{3}$. Hence applied voltage at this angle will be

$V_s = V_m \sin\alpha$

$V_s = 325 \sin(314)t$

$V_s = 325 \times 0.866602$

$\boxed{V_s = 281.45V}$

*> The current through Load is given by

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

$$t = \frac{-L}{R} \ln\left[1 - \frac{I_L \cdot R}{V_s}\right]$$

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$$t = \frac{-0.1}{10\Omega} \ln\left[1 - \frac{15\times10^{-3}\times 10}{281.45}\right]$$

$$t = -0.01 \ln\left[1 - 5.3295\times10^{-4}\right]$$

$$t = -0.01 \ln\left[0.99946\right]$$

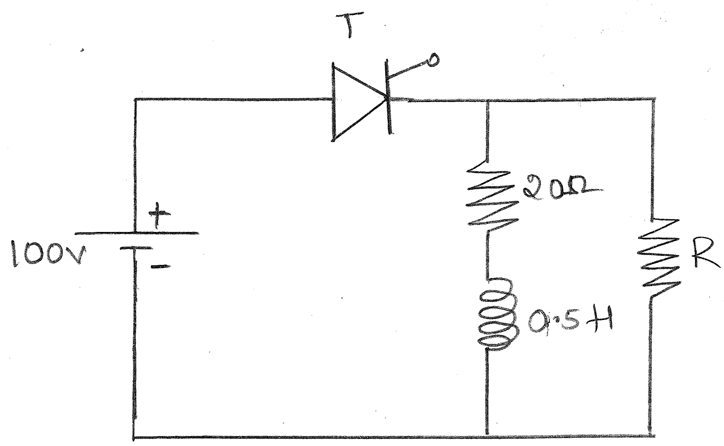
$$t = -0.01 \times -5.33096\times10^{-4}$$

$$\boxed{t = 5.33\mu Sec}$$

∴ The minimum gate pulse should be 5.33 μSec to reliably turn ON the SCR.

❖ **In the thyristor circuit shown in fig1 the thyristor has a latching current of 20mA and is fired by a gate pulse of width 50μs, show that without the resistance R, the thyristor will fail to remain ON. Also find the maximum value of 'R' to ensure firing.**

Jan-10,6M



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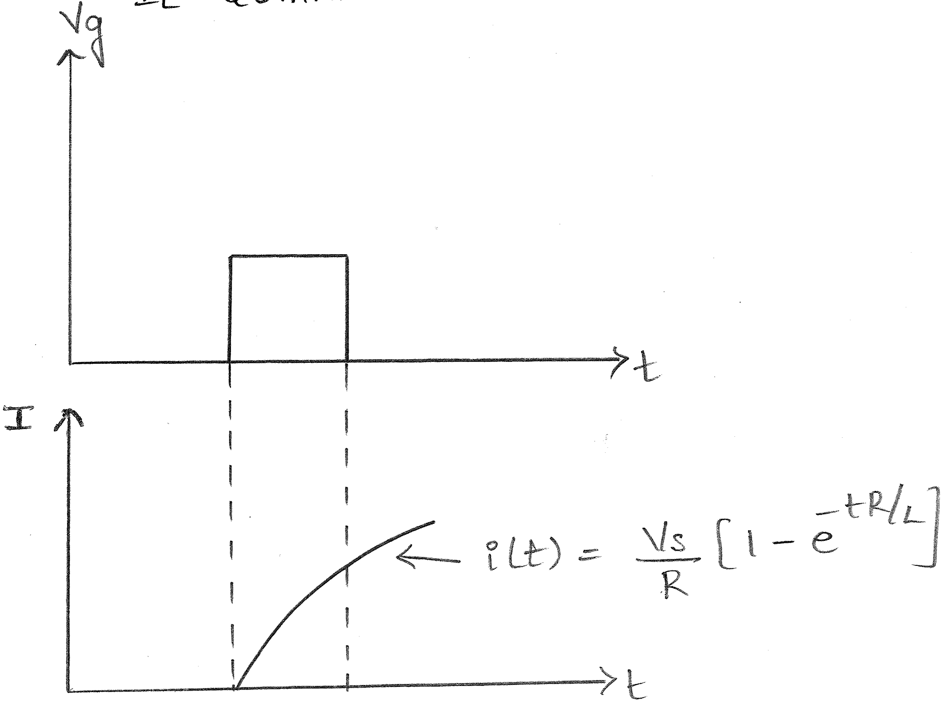
Given : $V_s = 100V$, $R = 20\Omega$, $L = 0.5H$, $t = 50\mu Sec$

$I_L = 20mA$.



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

at $t = 50\mu Sec$.

$$i(t) = \frac{100}{20}\left[1 - e^{-\frac{50\times10^{-6}\times20}{0.5}}\right]$$

$$i(t) = 5\left[1 - e^{-2\times10^{-3}}\right]$$

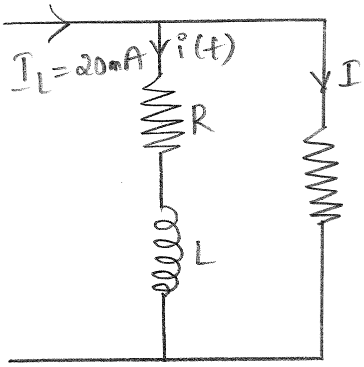
$$i(t) = 5\left[1 - 0.998\right]$$

$$i(t) = 5\left[1.99802\times10^{-3}\right]$$

$$i(t) = 9.99mA$$

$$\boxed{i(t) \simeq 10mA}$$

PTO →



$$I_L = i(t) + I$$

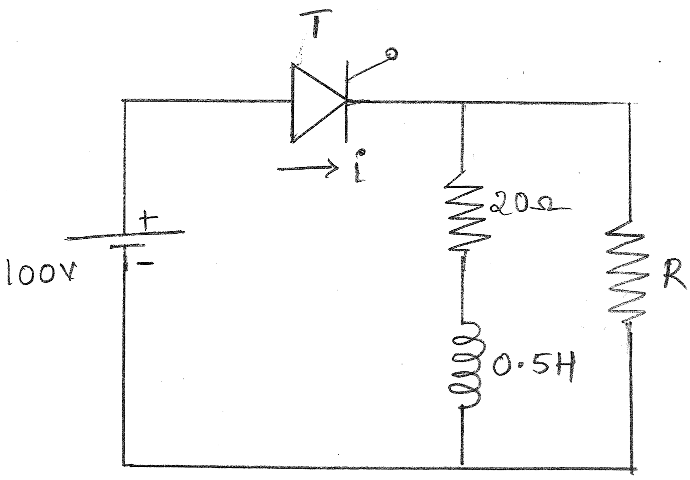
$$20mA = 10mA + I$$

$$\boxed{I = 10mA}$$

$$R = \frac{V_s}{I} = \frac{100V}{10mA}$$

$$\boxed{R = 10K\Omega}$$

❖ **In the thyristor circuit shown in fig1. Below, the SCR has a latching current of 50mA and is fired by a pulse of length 50μsec. Show that without resistance R', the thyristor will fail to remain ON, when the firing pulse ends and then find the maximum value of R to ensure firing.**



fig(1)

Given: $V_s = 100V$, $R = 20\Omega$, $L = 0.5H$, $R = ?$

$I_L = 50mA$, $t = 50\mu Sec$

Soln: WKT

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

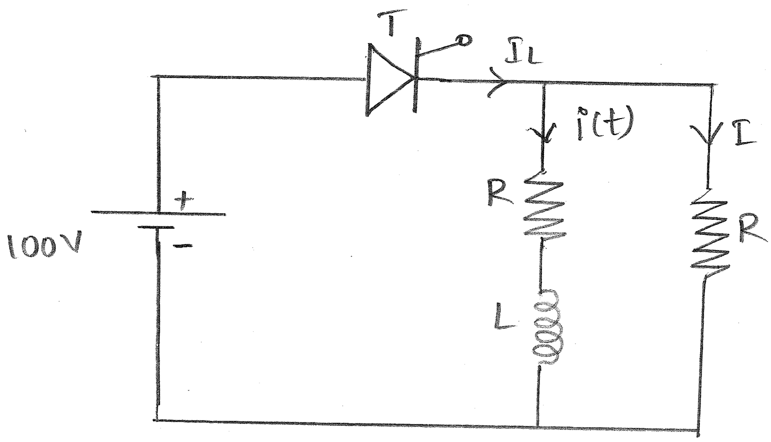
$$i(t) = \frac{100}{20}\left[1 - e^{-50\times10^{-6}\times\frac{20}{0.5}}\right]$$

$$= 5\left[1 - e^{-2\times10^{-3}}\right]$$

$$= 5\left[1 - 0.99800\right]$$

$$i(t) = 9.99mA$$

$$\boxed{i(t) = 10mA}$$



WKT

$$I_L = i(t) + I$$

$$50mA = 10mA + I$$

$$\boxed{I = 40mA}$$

$$R = \frac{V_s}{I}$$

$$R = \frac{100V}{40mA}$$

$$\boxed{R = 2500\Omega}$$

This is the maximum value of R' which ensures proper turn ON of the thyristor.

Proof:

Including of shunting resistance R'

$$I_L = I + i(t)$$

$$= \frac{V}{R} + i(t)$$

$$= \frac{100V}{2.5k\Omega} + 10mA$$

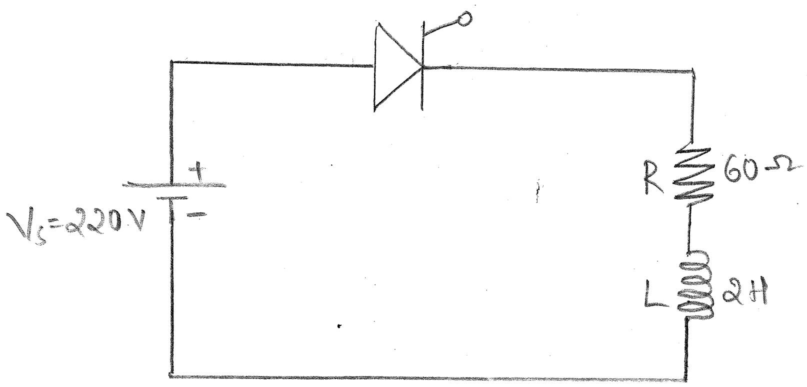
$$I_L = 40mA + 10mA$$

$$I_L = 50mA$$

$$50mA = 50mA$$

Thus by connecting R', thyristor will remain ON when the gate pulse ends.

❖ **The thyristor is gated with a pulse width of 40μsec. The latching current of thyristor is 36mA. For a load of 60Ω and 2H, will the thyristor get turned ON? If not, how it can be overcome for the given load? Find its value.** **June-07,4M**



Given : $V_S = 220V$, $R = 60\Omega$, $L = 2H$, $I_L = 36mA$

$t = 40\mu sec$, $\boxed{I_L = I_H = 36mA}$

Soln :

WKT

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

$$i(t) = \frac{220V}{60}\left[1 - e^{-40\times10^{-6} \times \frac{60}{2}}\right]$$

$$\boxed{i(t) = 4.397mA}$$

Since $i(t) < I_H$ i.e, $4.397mA < 36mA$.

Thus SCR will not turn ON.

SCR can be turned ON by changing t.

* The current through the load is given by

$$i(t) = I_L = \frac{V_S}{R}\left[1 - e^{-tR/L}\right]$$

$$\Rightarrow t = -\frac{L}{R}\ln\left[1 - \frac{I_L \cdot R}{V_S}\right]$$

$$t = -\frac{2}{60}\ln\left[1 - \frac{36\times10^{-3}\times60}{220}\right]$$

$$t = -0.0333 \ln\left[1 - 9.8181\times10^{-3}\right]$$

$$t = -0.0333 \ln\left[0.99018\right]$$

$$t = -0.0333 \times -0.98666\times10^{-3}$$

$$\boxed{t = 0.3285 \text{ mSec}}$$

Thus if the triggering pulse is 0.328 mSec long, then SCR current will rise to 36mA and it will remain in ON condition.

The current through the load is given by

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

$$100mA = \frac{200}{20}\left[1 - e^{-t\,20/0.2}\right]$$

$$100mA = 10\left[1 - e^{-100t}\right]$$

$$10mA = 1 - e^{-100t}$$

$$e^{-100t} = 0.99$$

taking natural log on both sides we get

$$-100t = \ln(0.99)$$

$$t = \frac{-0.01005}{-100}$$

$$\boxed{t = 0.1\,mSec}$$

❖ **The latching current for SCR inserted in between a dc voltage source of 200V and load is 100mA. Calculate the minimum width gate pulse current required to turn-on this SCR in case the load consist of i) L=0.2H; ii) R=20Ω in series with L=0.2H**

June-10,6M

Given: $V_s = 200V$, $I_L = 100mA$

i) $R = 20\Omega$, $L = 0.2H$, $t = ?$

WKT

$$I_L = \frac{V_s}{R}\left[1 - e^{-tR/L}\right]$$

$$100mA = \frac{200V}{20\Omega}\left[1 - e^{-t\,20/0.2}\right]$$

$$100\,mA = 10\left[1 - e^{-100t}\right]$$

$$10mA = 1 - e^{-100t}$$

$$e^{-100t} = 1 - 10mA$$

$$e^{-100t} = 0.99$$

taking natural log on both side, we get

$$-100t = \ln(0.99)$$

$$\boxed{t = 0.1mSec}$$

ii) $R = 20\Omega$, $L = 2.0H$, $t = ?$

WKT

$$I_L = \frac{V_S}{R}\left[1 - e^{-tR/L}\right]$$

$$100mA = \frac{200V}{20\Omega}\left[1 - e^{-t20/2}\right]$$

$$100mA = 10\left[1 - e^{-10t}\right]$$

$$10mA = 1 - e^{-10t}$$

$$e^{-10t} = 1 - 10mA$$

$$\boxed{e^{-10t} = 0.99}$$

taking natural log on both side, we get

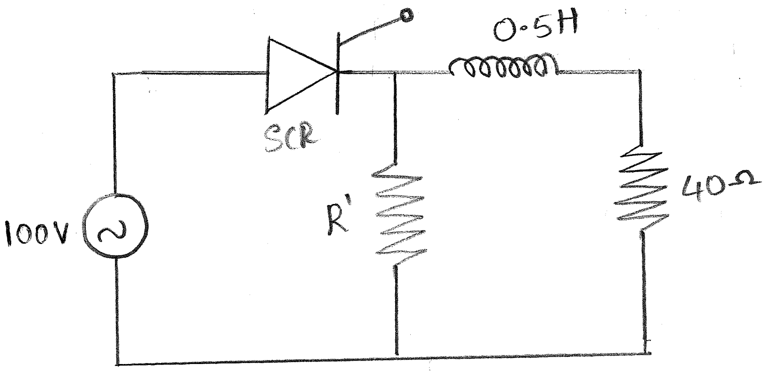
$$-10t = \ln(0.99)$$

$$t = \frac{-0.0100}{-10}$$

$$\boxed{t = 1m\,Sec.}$$

❖ **The SCR in the circuit of fig1 has a latching current of 50mA and if triggered by a gate pulse width of 50μsec. Show that without resistance R, the thyristor will fail to remain ON when the gating pulse ends. Also find the maximum value of R to ensure firing. The ON-state voltage drop of an SCR can be neglected.**

June-09,4M



Given : $V_s = 100V$, $L = 0{\cdot}5H$, $R = 40\Omega$, $I_L = 50mA$

$t = 50\mu sec$, $R' = ?$

Soln: WKT

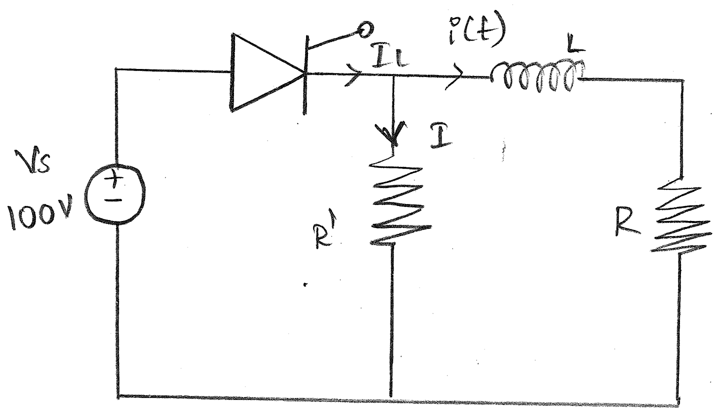
$$i(t) = \frac{V_s}{R}\left[1 - e^{-tR/L}\right]$$

$$i(t) = \frac{100V}{40\Omega}\left[1 - e^{-50\times10^{-6}\times 40/0{\cdot}5}\right]$$

$$i(t) = 2{\cdot}5\left[1 - e^{-4\times10^{-3}}\right]$$

$$i(t) = 2{\cdot}5\left[1 - 0{\cdot}9960\right]$$

$$\boxed{i(t) = 9{\cdot}980\,mA}$$



from fig ②

$$I_L = I + i(t)$$

$$50mA = I + 9.98mA$$

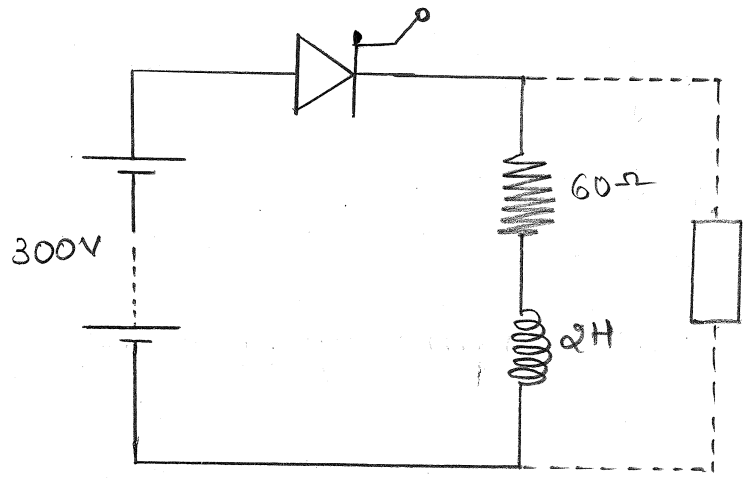
$$I = 50mA - 9.98mA$$

$$I = 40.02mA.$$

$$R = \frac{V_s}{I} = \frac{100V}{40.02mA}$$

$$\boxed{R = 2.498k\Omega}$$

* In the Circuit of fig ①, the thyristor is gated with a pulse width of 40μsec. The latching current of thyristor is 36mA. For a load of 60Ω & 2H, will the the thyristor get turned ON? check. If the answer is negative, how this difficulty can be overcome for the given load. Find the maximum value of the remedial parameter shown dotted



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Given: $V_s = 300V$, $R = 60\Omega$, $L = 2H$, $I_L = 36mA$ $t = 40\mu s$.

Soln: WKT

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

$$= \frac{300V}{60\Omega}\left[1 - e^{-40\times10^{-6}\times60/2H}\right]$$

$$\boxed{i(t) = 5.996\,mA}$$

$i(t) < I_L$, thus thyristor will not get turned ON.

* The remedial parameter shown in fig, should be resistance, say R_1, because current can rise in resistance without any time delay.

WKT

$$I_L = I + i(t)$$

$$I = I_L - i(t)$$

$$= 36mA - 5.996mA$$

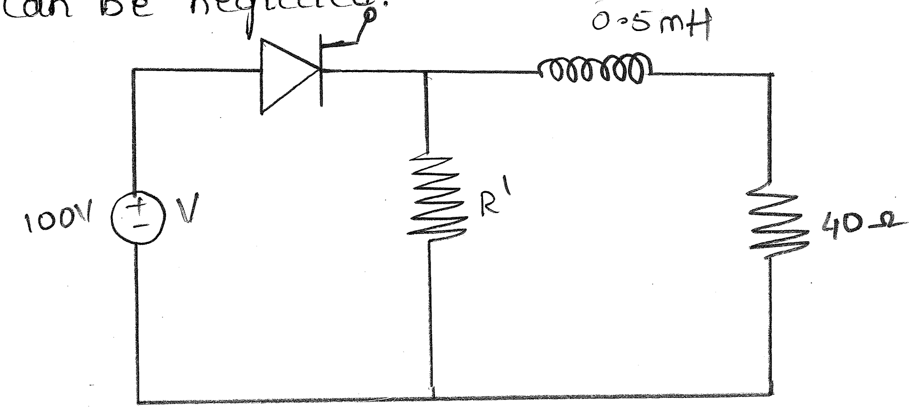
$$I = 30.004mA$$

$$R_1 = \frac{V_s}{I} = \frac{300V}{30.004mA}$$

$$\boxed{R_1 = 9.9986\,k\Omega}$$

* The thyristor in the circuit of fig ① has a latching current of 50mA and is triggered by a get pulse of width 50μsec. Show that without resistance R' the thyristor will fail to remain ON when the gating pulse ends. Also find the maximum value of R' to ensure →

→ firing. The ON-state voltage drop of the thyristor can be neglected.



Given: $V = 100V$, $L = 0.5mH$, $R = 40\Omega$, $I_L = 50mA$

$t = 50\mu sec$.

Soln: WKT

$$i(t) = \frac{V}{R}\left[1 - e^{-tL/R}\right]$$

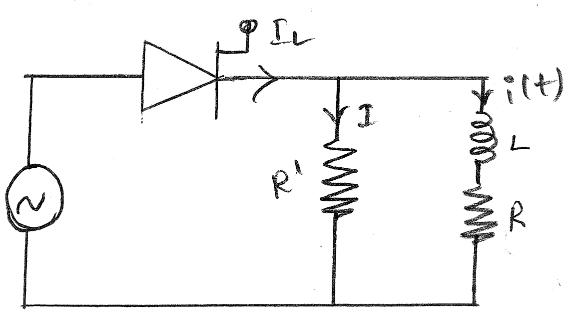
$$= \frac{100}{40}\left[1 - e^{-50 \times 10^{-6} \times 0.5mH / 40}\right]$$

$$\boxed{i(t) = 10mA}$$

Since $i(t) < I_L$ ie. $\boxed{10mA < 50mA}$

Since the thyristor current fails to reach the latching current value $I_L = 50mA$, when the gate pulse ends. Thus the thyristor fails to remains ON after the gate pulse ends

* By shunting R',



$I_L = I + i(t)$

$\boxed{I = I_L - i(t)}$ —— ①

$I = 50mA - 10mA$

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$$\boxed{I = 40mA}$$

$$R' = \frac{V}{I} = \frac{100V}{40mA}$$

$$\boxed{R' = 2.5 k\Omega}$$

This is the maximum value of R' which ensures proper turn ON of the thyristor.

Proof:

Including of shunting resistance R'

$$I_L = I + i(t)$$

$$= \frac{V}{R} + i(t)$$

$$= \frac{100V}{2.5 k\Omega} + 10mA$$

$$I_L = 40mA + 10mA$$

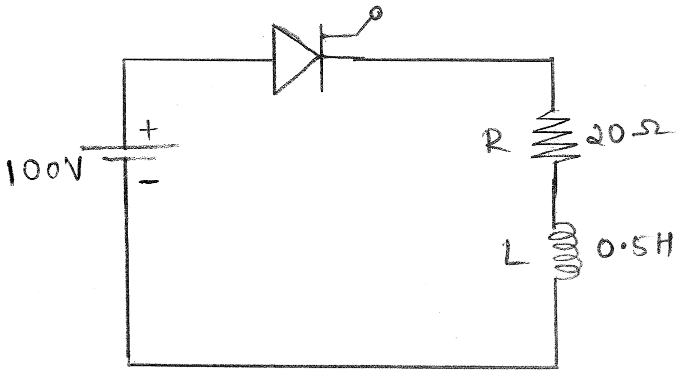
$$I_L = 50mA$$

$$\boxed{50mA = 50mA}$$

Thus by connecting R', thyristor will remain ON when the gate pulse ends.

❖ **The latching current of a thyristor shown in fig is 50mA. The duration of gate pulse is 50 μsec. Will the thyristor get fired?**

June-11, 4M



Given: $V_s = 100V$, $R = 20\Omega$, $L = 0.5H$, $I_L = 50mA$, $t = 50\mu sec$

Soln: WKT

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

$$i(t) = \frac{100V}{20\Omega}\left[1 - e^{-\frac{(50\times10^{-6})\times 20\Omega}{0.5}}\right]$$

$$i(t) = 9.99mA$$

At $t = 50\mu sec$, $i(t) < I_L$ i.e. $9.99mA < 50mA$

$\therefore$ SCR can't fire.

POWER ELECTRONICS

7th Sem E&C

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AC VOLTAGE CONTROLLER

Introduction :-

❖ What is an ac voltage controller?

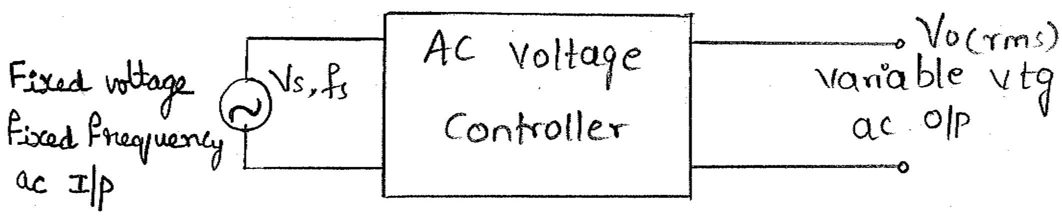


Fig. AC Voltage Controller

- ❖ AC voltage controller converts fixed ac signal into variable (Controlled) ac output voltage. The RMS value of the ac output voltage and the ac power flow to the load is controlled by varying (Adjusting) the triggering angle ' α'.
- ❖ These ac voltage controllers are used in speed control of ac motors, induction motors, fan regulators, light controllers etc.
- ❖ The main advantages of ac voltage controllers are high efficiency, compact in size, flexibility in control and simple circuitry.

Drawbacks :-

AC voltage controllers generates **HARMONICS.**

Types of AC voltage controllers :-

1) ON-OFF Control

2) Phase Control.

Principle of ON-OFF Control OR Integral Cycle control OR Zero Voltage Switching :-

- Draw the circuit diagram of a single phase AC voltage controller and explain the principle of ON-OFF control, with the help of relevant waveforms. Derive the expression for rms output voltage interms of rms supply voltage and duty cycle of the operation of the controller.

  June-10,6M   Jan-04,10M

- What is an ac voltage regulator(controller)? With the help of waveforms, explain ON-OFF control and phase control.

  June-09,6M

- With a circuit diagram and waveforms of gating pulses and output voltage, explain the operation of 1-phase ON-OFF type ac voltage controller. Derive an expression for Vo(rms).

  June-08,10M

- Derive an expression for the rms value of the output voltage f a bi-directional ac voltage controller, employing ON-OFF control.

  Jan-08,6M

- Draw the circuit of a single phase ac voltage controller and explain the principle of ON-OFF control, with the help of relevant waveforms. Derive the expression for the RMS output voltage in terms of the RMS supply voltage and the duty cycle of operation of the controller.

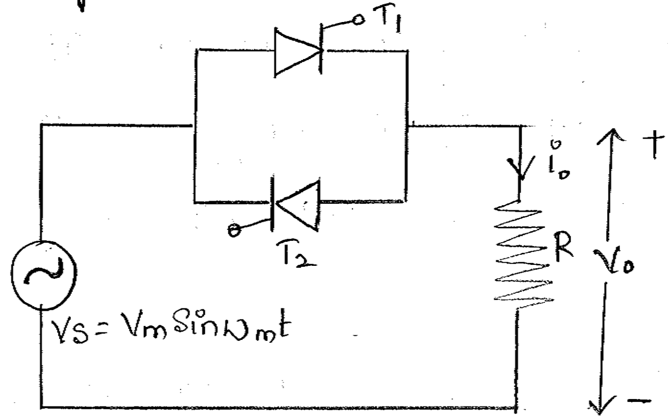
  Jan-05,8M

- What is an ac voltage controller? With the help of circuit diagram and waveform, explain the principle of phase control. **June-11,6M**

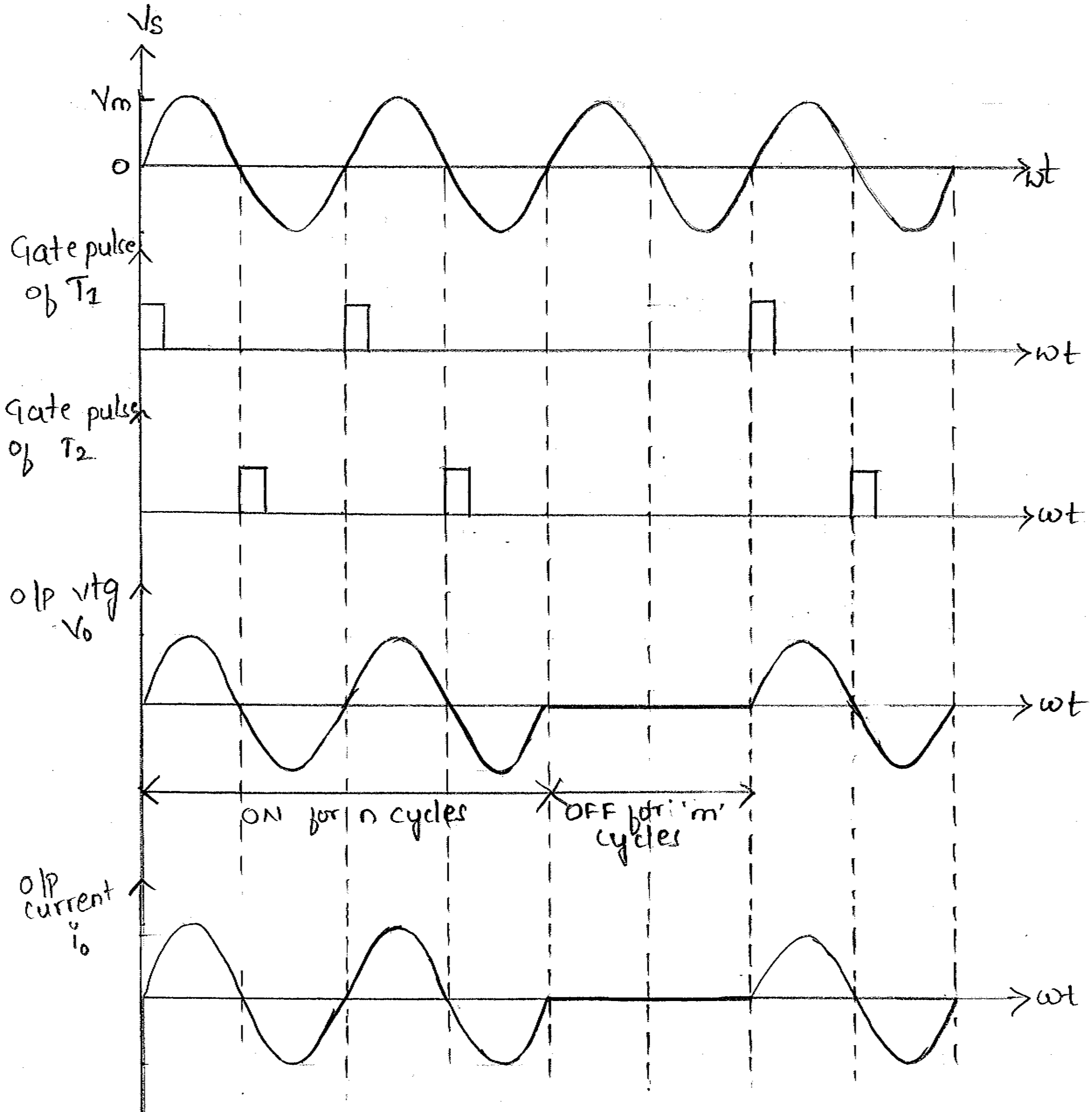
Principle of ON - OFF Control :-

(OR)

Integral cycle control or Zero vtg switching :-



(a) ckt.



(b) Waveforms

* ON-OFF Controller uses 2 SCR's connected in antiparallel as shown in fig (a).

* During +ve half cycle of the ac i/p at the instant $\omega t = 0, 2\pi, 4\pi \ldots$ SCR 'T_1' is triggered at $\alpha = 0$. Thus SCR 'T_1' conducts and +ve half cycles appears across the load.

* During -ve half cycle of the ac i/p at instants $\omega t = \pi, 3\pi, 5\pi, \ldots$ SCR 'T_2' is triggered at $\alpha = 0$. Thus SCR 'T_2' conducts and the -ve half cycles appears across the load.

* When gate pulses are removed, both the SCR's are OFF. Thus no o/p appears across the load.
  ∴ SCR's conducts for 'n' number of cycles and they are 'OFF' for 'm' number of cycles.
  Hence the name ON-OFF control.

* Fig (b) shows the i/p and o/p waveforms for resistive load.

(Note: In place of the antiparallel SCRs a triac can be used)

Advantages :-

1) The SCRs are switch ON at zero crossings. Hence the harmonics due to switching actions are reduced.

2) Electromagnetic interference to neighbouring electro-nic ckts is minimized.

Disadvantages :-

1) O/p will be discontinuous, hence the load has to sustain these variations.

2) Since the thyristors are triggered at zero crossing, their conducting is not being exploited.

Expression for RMS value of load voltage ($V_{o(rms)}$) :-

The o/p RMS voltage is given by:

$$V_{o(rms)} = \sqrt{\frac{1}{T}\int_0^{2\pi} V_s^2 \, d\omega t} \longrightarrow ①$$

Let the supply voltage is

$$\boxed{V_s = V_m \sin(\omega t)} \longrightarrow ②$$

Substitute eq ② in eq ①, we get.

$$V_{o(rms)} = \sqrt{\frac{n}{n+m} \cdot \frac{1}{2\pi}\int_0^{2\pi} V_m^2 \sin^2(\omega t) \, d\omega t}$$

PTO →

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

WKT $\sin^2(\omega t) = \dfrac{1-\cos 2(\omega t)}{2}$

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

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

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

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

$$\because \boxed{\int_0^{2\pi} \cos 2(\omega t)\, d\omega t = \frac{\sin 2(\omega t)}{2}}$$

$$= \left\{\frac{n}{(m+n)} \cdot \frac{V_m^2}{2\pi}\left[\left(\frac{2\pi}{2} - \frac{0}{2}\right) - \frac{1}{2}\left[\frac{\sin 2(2\pi)}{2} - \frac{\sin 2(0)}{2}\right]\right]\right\}^{1/2}$$

$$= \left\{\frac{n}{(m+n)} \cdot \frac{V_m^2}{2\pi}\left[(\pi) - \frac{1}{2}(0-0)\right]\right\}^{1/2}$$

$$\because \boxed{\begin{array}{l} \sin 2(2\pi) = 0 \\ \sin(0) = 0 \end{array}}$$

$$= \left\{ \frac{n}{(m+n)} \cdot \frac{V_m^2}{2\pi} (\pi) \right\}^{1/2}$$

$$= \left[\frac{n}{(m+n)} \cdot \frac{V_m^2}{2} \right]^{1/2}$$

$$= \sqrt{\frac{n}{(m+n)} \cdot \frac{V_m^2}{2}}$$

$$V_{o(rms)} = \frac{V_m}{\sqrt{2}} \sqrt{\frac{n}{(m+n)}}$$

$$V_{o(rms)} = \frac{V_m}{\sqrt{2}} \sqrt{K} \qquad \text{Where } K = \frac{n}{(m+n)}$$

WKT $\boxed{V_{s(rms)} = \frac{V_m}{\sqrt{2}}}$

$$\therefore \boxed{V_{o(rms)} = V_{s(rms)} \sqrt{K}}$$

<u>Average thyristor Current :-</u>

The average value of current in a thyristor T_1 is given by

$$I_{T1(avg)} = \frac{n}{(m+n)} \left\{ \frac{1}{2\pi} \int_0^{\pi} i(t)\, d\omega t \right\} \longrightarrow ①$$

The current can be expressed as

$$\boxed{i(t) = I_m \sin(\omega t)} \longrightarrow ②$$

WKT

$$V_{s(rms)} = \frac{V_m}{\sqrt{2}}$$

$$\boxed{V_m = \sqrt{2}\, V_{s(rms)}}$$

WKT

$$I_m = \frac{V_m}{R}$$

$$\therefore I_m = \frac{V_{s(rms)} \sqrt{2}}{R}.$$

Substituting eq② in eq①, we get.

$$I_{T1(avg)} = \frac{n}{(m+n)} \left\{ \frac{1}{2\pi} \int_0^{\pi} I_m \sin(\omega t)\, d\omega t \right\}$$

$$= \frac{n}{(m+n)} \left\{ \frac{I_m}{2\pi} \int_0^{\pi} \sin(\omega t).d\omega t \right\}$$

$$= \frac{n}{(m+n)} \left\{ \frac{I_m}{2\pi} \Big[-\cos(\omega t) \Big]_0^{\pi} \right\} \quad \because \int_0^{\pi} \sin(\omega t)\, d\omega t = -\cos\omega t.$$

$$= \frac{n}{(m+n)} \left\{ \frac{I_m}{2\pi} \Big[-\cos(\pi) - (-\cos(0)) \Big] \right\}$$

$$= \frac{n}{(m+n)} \left\{ \frac{I_m}{2\pi} \Big[-(-1) - (-1) \Big] \right\}$$

$$= \frac{n}{(m+n)} \left\{ \frac{I_m}{2\pi} (2) \right\}$$

$$= \frac{n}{(m+n)} \cdot \frac{I_m}{\pi}$$

$$\boxed{I_{T1(avg)} = K \cdot \frac{I_m}{\pi}}$$

WKT

$$I_m = \frac{\sqrt{2}\, V_{s(rms)}}{R}$$

$$\therefore \boxed{I_{T1(avg)} = K \cdot \frac{\sqrt{2}\, V_{s(rms)}}{\pi R}}$$

Note: Since both the thyristors share the load current equally their avg currents will be same ie.

$$\boxed{I_T = I_{T1} = I_{T2}}$$

RMS Current of thyristor $I_{(rms)}$:-

$$I_{(rms)} = \left[\frac{n}{(m+n)} \cdot \frac{1}{2\pi} \int_0^{\pi} i(t)^2 \cdot d\omega t\right]^{1/2}$$

$$= \left[\frac{n}{(m+n)} \cdot \frac{1}{2\pi} \int_0^{\pi} I_m^2 \sin^2(\omega t)\, d\omega t\right]^{1/2}$$

$$= \left[\frac{n}{(m+n)} \cdot \frac{I_m^2}{2\pi} \int_0^{\pi} \sin^2(\omega t) \cdot d\omega t\right]^{1/2}$$

$$= \left[\frac{n}{(m+n)} \cdot \frac{I_m^2}{2\pi} \int_0^{\pi} \frac{1 - \cos 2(\omega t)}{2}\, d\omega t\right]^{1/2}$$

WKT $\boxed{\sin^2(\omega t) = \frac{1 - \cos 2(\omega t)}{2}}$

$$= \left\{\frac{n}{(m+n)} \cdot \frac{I_m^2}{2\pi} \left[\int_0^{\pi} \left(\frac{1}{2} - \frac{\cos 2(\omega t)}{2}\right) d\omega t\right]\right\}^{1/2}$$

$$= \left\{\frac{n}{(m+n)} \cdot \frac{I_m^2}{2\pi} \left[\int_0^{\pi} \frac{1}{2}\, d\omega t - \frac{1}{2} \int_0^{\pi} \cos 2(\omega t)\, d\omega t\right]\right\}^{1/2}$$

WKT $\boxed{\int_0^{\pi} \cos 2(\omega t)\, d\omega t = \frac{\sin 2(\omega t)}{2}}$

$$= \left\{\frac{n}{(m+n)} \cdot \frac{I_m^2}{4\pi} \left[\int_0^{\pi} 1\, d\omega t - \int_0^{\pi} \cos 2(\omega t)\, d\omega t\right]\right\}^{1/2}$$

$$= \left\{K \cdot \frac{I_m^2}{4\pi} \left[(\omega t)_0^{\pi} - \left(\frac{\sin 2(\omega t)}{2}\right)\right]\right\}^{1/2}$$

PTO →

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$$= \left\{ K \cdot \frac{I_m^2}{4\pi}\left[(\pi-0) - \cancelto{0}{\frac{\sin 2(\pi)}{2}} - \cancelto{0}{\frac{\sin 2(0)}{2}}\right]\right\}^{1/2}$$

$$= \left\{ K \cdot \frac{I_m^2}{4\pi} (\pi) \right\}^{1/2}$$

$$= \sqrt{K \cdot \frac{I_m^2}{4}} = \frac{I_m}{2} \cdot \sqrt{K}$$

$$\boxed{I_{rms} = \frac{I_m}{2}\sqrt{K}}$$

ON – OFF CONTROL

FORMULAE

1) ON time : $T_{on} = 2\pi n$

2) OFF time : $T_{OFF} = 2\pi m$

total time 'T' $= T_{ON} + T_{OFF}$

$$= 2\pi n + 2\pi m$$

$$\boxed{T = 2\pi(n+m)}$$

3) RMS o/p vtg

$$V_{o(rms)} = \frac{V_m}{\sqrt{2}} \sqrt{\frac{n}{(m+n)}}$$

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

$$\boxed{V_{o(rms)} = V_{s(rms)} \sqrt{K}}$$

4) $K = \frac{n}{(m+n)}$

5) $\sqrt{K} = \sqrt{\frac{n}{(m+n)}}$

6) RMS o/p voltage $V_0 = V_s \sqrt{K}$

$$V_0 = \frac{V_m}{\sqrt{2}} \sqrt{K}$$

$$V_0 = I_0 R_L$$

7) Power factor $PF = \sqrt{K}$

8) Load power $P_0 = I_0^2 R$

RMS load power $P_0 = I_0^2 R$

9) Load current or RMS load current

$$I_0 = \frac{V_0}{R}$$

10) Peak thyristor current $= I_m = \frac{V_m}{R}$

11) Peak voltage $V_m = \sqrt{2}\, V_s$

12) Average current of thyristor is

$$I_{avg} = \frac{K I_m}{\pi}$$

13) The RMS current of the thyristor is

$$I_{(rms)} = \frac{I_m}{2} \sqrt{K}$$

14) I/p power $P = V_s I_s$, $I_s = I_0$

$$\Rightarrow P = V_s I_0$$

15) $PF = \sqrt{K}$

ON-OFF Control PROBLEMS

❖ **An AC voltage controller has a resistive load of 10Ω and rms input voltage 120V, 60Hz. The thyristor switch is ON for n= 25 cycles & OFF for m= 75 cycles. Determine :**

i) RMS output voltage V_o

ii) Input power factor

iii) The average and rms current of thyristors.

June-11,6M (E&E) June-01,10M Jan-04,6M

Given :-

$R = 10\Omega$, $V_s = 120V$, $n = 25$ cycles, $m = 75$ cycles

Soln:

$$V_m = \sqrt{2} \cdot V_s = \sqrt{2} \times 120 = 169.7V$$

$$K = \frac{n}{(m+n)} = \frac{25}{(75+25)} = 0.25$$

$$\sqrt{K} = 0.5$$

a) RMS value of o/p vtg

$$V_o = V_s \sqrt{K}$$

$$= 120 \times 0.5$$

$$\boxed{V_o = 60V}$$

RMS load current

$$I_o = \frac{V_o}{R}$$

$$= \frac{60V}{10}$$

$$\boxed{I_o = 6A}$$

b) The load power

$$P_0 = I_0^2 R$$

$$= 6^2 \times 10$$

$$\boxed{P_0 = 360W}$$

The i/p power factor is

$$PF = \sqrt{K}$$

$$PF = \sqrt{0.25}$$

$$\boxed{PF = 0.5}$$

c) Peak thyristor current

$$I_m = \frac{V_m}{R}$$

$$= \frac{169.7}{10}$$

$$\boxed{I_m = 16.97\,A}$$

The average thyristor current

$$I_{T(avg)} = \frac{KI_m}{\pi} = \frac{0.25 \times 16.97}{\pi}$$

$$\boxed{I_{(avg)} = 1.33A}$$

RMS current of thyristor $I_{T(rms)}$

$$I_{T(rms)} = \frac{I_m}{2}\sqrt{K}$$

$$= \frac{16.97}{2} \cdot \sqrt{0.25}$$

$$\boxed{I_{T(rms)} = 4.24A}$$

❖ **In a ON-OFF control circuit using 1-phase, 230V, 50Hz supply the ON time is 10 cycles and OFF time is 4 cycles. Calculate the RMS value of the output voltage.**

Given :- $V_S = 230V$, $n = 10$, $m = 4$, $V_0 = ?$

Soln : $K = \frac{n}{m+n} = \frac{10}{4+10} = 0.71$

$\sqrt{K} = \sqrt{0.71}$

$\boxed{\sqrt{K} = 0.845}$

RMS value of the o/p Voltage

$V_0 = V_S\sqrt{K} = 230 \times 0.845$

$\boxed{V_0 = 194.38V}$

❖ **An ON-OFF controller with an input of 230V, 50Hz is connected to a resistive load of 20Ω, the circuit is operating with the switch ON for 30 cycles and OFF for 30 cycles.**

Determine : i) rms output current ii) input power factor

Jan-09,10M June-04,4M

Given : $V_S = 230V$, $R = 20\Omega$, $n = 30$, $m = 30$

Soln : $K = \frac{n}{(m+n)} = \frac{30}{(30+30)} = 0.5$

$\boxed{K = 0.5}$

$\sqrt{K} = \sqrt{0.5} = 0.707$

i) RMS load current :-

$$I_0 = \frac{V_0}{R}$$

$$= \frac{162 \cdot 6V}{20}$$

$$\boxed{I_0 = 8 \cdot 13A}$$

$$V_0 = \sqrt{K}\ V_s$$

$$= 0 \cdot 707 \times 230$$

$$\boxed{V_0 = 162 \cdot 6V}$$

ii) $PF = \sqrt{K}$

$$= \sqrt{0 \cdot 5}$$

$$\boxed{PF = 0 \cdot 707}$$

❖ **A single phase full wave ac voltage controller working on ON-OFF control technique has supply voltage of 230V RMS, 50Hz, Load=50Ω. The controller is ON for 30 cycles and OFF for 40 cycles. Calculate**

i) ON & OFF time intervals

ii) RMS output voltage

iii) Input PF

iv) Average and RMS thyristor currents.

Given:- $V_s = 230V$, $R = 50$, $n = 30$, $m = 40$

$$* \quad K = \frac{n}{(m+n)} = \frac{30}{30+40} = 0 \cdot 428$$

$$\boxed{K = 0 \cdot 428}$$

$$* \quad \sqrt{K} = \sqrt{0 \cdot 428} = 0 \cdot 654$$

$$\boxed{\sqrt{K} = 0 \cdot 654}$$

* $T = \frac{1}{f} = \frac{1}{50}$

$$\boxed{T = 20\,msec}$$

* $V_m = \sqrt{2}\,V_s = 325.29\,V$

$$\boxed{V_m = 325.269}$$

i) $T_{ON} = n \times T$

$= 30 \times 20\,msec$

$$\boxed{T_{ON} = 600\,msec = 0.6\,sec}$$

$T_{OFF} = m \times T$

$= 40 \times 20\,msec$

$$\boxed{T_{OFF} = 800\,msec = 0.8\,sec}$$

ii) RMS o/p vtg :-

$V_o = V_s\sqrt{K}$

$= 230\sqrt{0.4285}$

$$\boxed{V_o = 150.55\,V}$$

iii) $PF = \sqrt{K}$

$= \sqrt{0.4285}$

$$\boxed{PF = 0.6546}$$

iv) Average thyristor current

$I_{T(avg)} = K\frac{I_m}{\pi}$

$I_m = \frac{V_m}{R} = \frac{325.269}{50} = 6.5053\,A.$

$I_{T(av)} = \frac{6.5053}{\pi} \times 0.4285$

$I_{T(avg)} = 0.8872A$

RMS current of thyristor.

$$I_{T(rms)} = \frac{I_m}{2}\sqrt{K}$$

$$= \frac{6.5053}{2} \times \sqrt{0.4285}$$

$$I_{T(rms)} = 3.252 \times 0.6545$$

$$\boxed{I_T(rms) = 2.128A}$$

❖ **An AC voltage controller has a resistive load of 10Ω and rms input voltage 230V, 50Hz. The thyristor switch is ON for 25 cycles & OFF for 75 cycles.**

Determine : i) rms output voltage ii) input power factor

Jan-10,6M June-10,6M(IT) June-08,6M

Given: $n = 25$ cycles, $m = 75$ cycles, $V_s = 120V$, $R = 10\Omega$

Soln: $V_m = \sqrt{2} V_s = \sqrt{2} \times 120$

$V_m = 169.70V$

duty cycle $'K' = \frac{n}{m+n}$

$= \frac{25}{25+75}$

$K = 0.25$

$\sqrt{K} = \sqrt{0.25} = 0.5$

$\sqrt{K} = 0.5$

* RMS o/p voltage:-

$$V_0 = V_S\sqrt{K}$$

$$= 120 \times 0.5$$

$$\boxed{V_0 = 60V}$$

* RMS o/p current :-

$$I_0 = \frac{V_0}{R}$$

$$= \frac{60V}{10\Omega}$$

$$\boxed{I_0 = 6A.}$$

* $PF = \sqrt{K}$

$$\boxed{P = 0.5}$$

6> The single-phase ACVC shown in fig ① delivers a power of 5KW to the resistive load of $R = 5\Omega$. If ON-OFF control stratergy is used and the supply voltage is 230V, 50Hz, calculate

a> The RMS o/p voltage and current.

b> The duty cycle

c> The i/p power factor.

d> The RMS and average values of thyristor current.

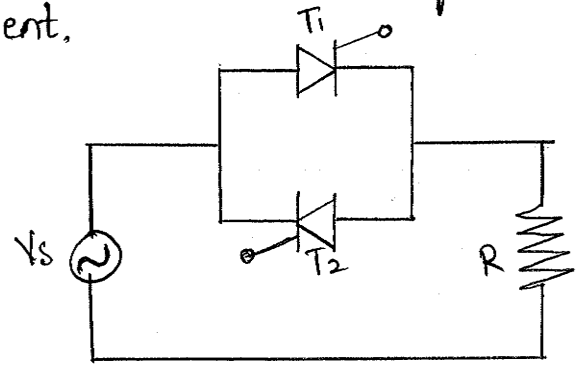


fig ①

Given : $P_0 = 5KW$, $R = 5\Omega$, $f = 50Hz$, $V_s = 230V$.

Soln :

a) The RMS o/p voltage and current :-

WKT $V_0 = \sqrt{P_0 R}$

$= \sqrt{5000 \times 5}$

$V_0 = 158.11V$

WKT $I_0 = \frac{V_0}{R}$

$= \frac{158.11}{5}$

$\boxed{I_0 = 31.62A}$

b) The duty cycle :

$K = \left(\frac{V_0}{V_s}\right)^2$

$= \left(\frac{158.11}{230}\right)^2$

$\boxed{K = 0.473}$

WKT
$V_0 = V_s\sqrt{K}$
$\sqrt{K} = \frac{V_0}{V_s}$
$K = \left(\frac{V_0}{V_s}\right)^2$

c) The i/p power factor

I - method :

$PF = \sqrt{K} = \sqrt{0.473}$

$\boxed{PF = 0.6874}$ lagging

II - method :

$PF = \frac{V_0}{V_s} = \frac{158.11}{230}$

$\boxed{PF = 0.6874}$ lagging.

d) The rms and average values of thyristor current:

The peak thyristor current:

$$I_m = \frac{V_m}{R}$$

$$V_m = \sqrt{2}\,V_s = \sqrt{2} \times 230$$

$$\boxed{V_m = 325.26\,V}$$

$$\Rightarrow I_m = \frac{V_m}{R} = \frac{325.26}{5}$$

$$\boxed{I_m = 65.05\,A}$$

The rms value of thyristor current:

$$I_{T(rms)} = \frac{I_m}{2} \cdot \sqrt{K}$$

$$= \frac{65.05}{2} \times \sqrt{0.473}$$

$$\boxed{I_{T(rms)} = 22.523\,A.}$$

The average values of thyristor current

$$I_{T(avg)} = \frac{K I_m}{\pi}$$

$$= \frac{0.473 \times 65.05A}{\pi}$$

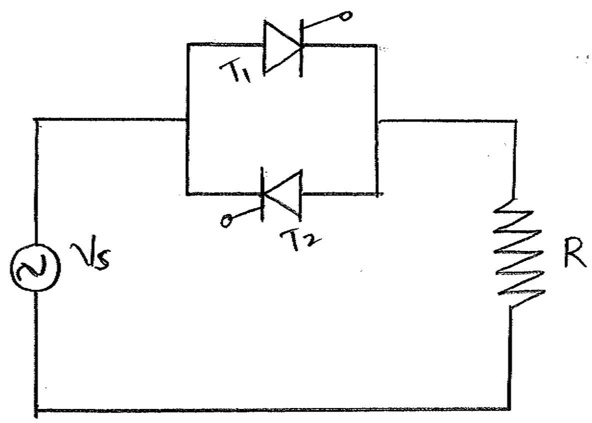
$$\boxed{I_{T(avg)} = 9.79\,A}$$

7). The ACVC shown in fig ① has $R = 20\Omega$ and the i/p ac is 230V, 50Hz. If ON-OFF control is adopted with $n = 50$ cycles and $m = 150$ cycles, Calculate

a) The rms o/p voltage,

b) The I/p power factor

c) The average and rms values of thyristor currents.



Given: $R = 20\Omega$, $V_s = 230V$, $f = 50Hz$, $n = 50$, $m = 150$.

Soln:-

a) The rms o/p voltage:-

$$V_o = V_s\sqrt{K}$$

$$K = \frac{n}{(m+n)}$$

$$= \frac{50}{50+150}$$

$$K = 0.25$$

$$V_o = 230 \times \sqrt{0.25}$$

$$\boxed{V_o = 115V}$$

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b) The i/p power factor:

$$PF = \sqrt{K}$$

$$= \sqrt{0.25}$$

$$\boxed{PF = 0.5}$$

c) The average and rms values of thyristor Currents:

* The RMS value of thyristor current:

$$I_{T(rms)} = \frac{I_m}{2}\sqrt{K}$$

$$I_m = \frac{V_m}{R}$$

$$V_m = \sqrt{2}\ V_s$$

$$= \sqrt{2} \times 230V$$

$$\boxed{V_m = 325.26V}$$

$$I_m = \frac{325.26V}{20}$$

$$I_m = 16.263A$$

$$I_{T(rms)} = \frac{I_m}{2}\sqrt{K}$$

$$= \frac{16.263}{2} \times \sqrt{0.25}$$

$$\boxed{I_{T(rms)} = 4.065A}$$

* The average value of thyristor current:

$$I_{T(avg)} = K\frac{I_m}{\pi}$$

$$= 0.25 \times \frac{16.263A}{\pi}$$

$$\boxed{I_{T(avg)} = 1.294A}$$

Principle of PHASE CONTROL AC Voltage Controller :-

Single Phase Half Wave AC voltage Controller (With R- Load) :-

OR

Unidirectional AC voltage Controller (With R- Load) :-

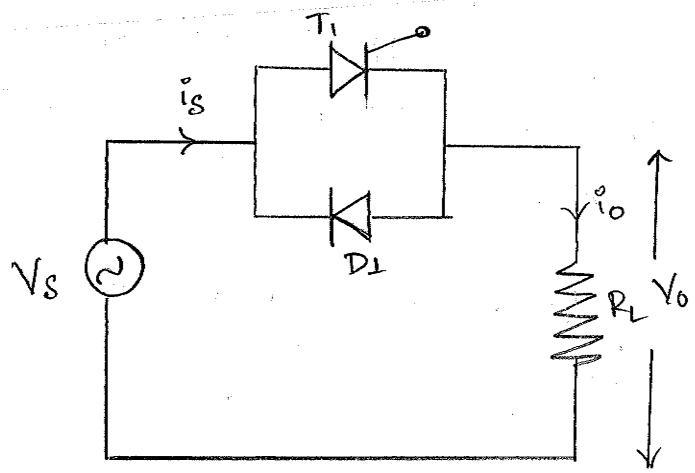


fig ①: 1φ Half wave controller (unidirectional controller).

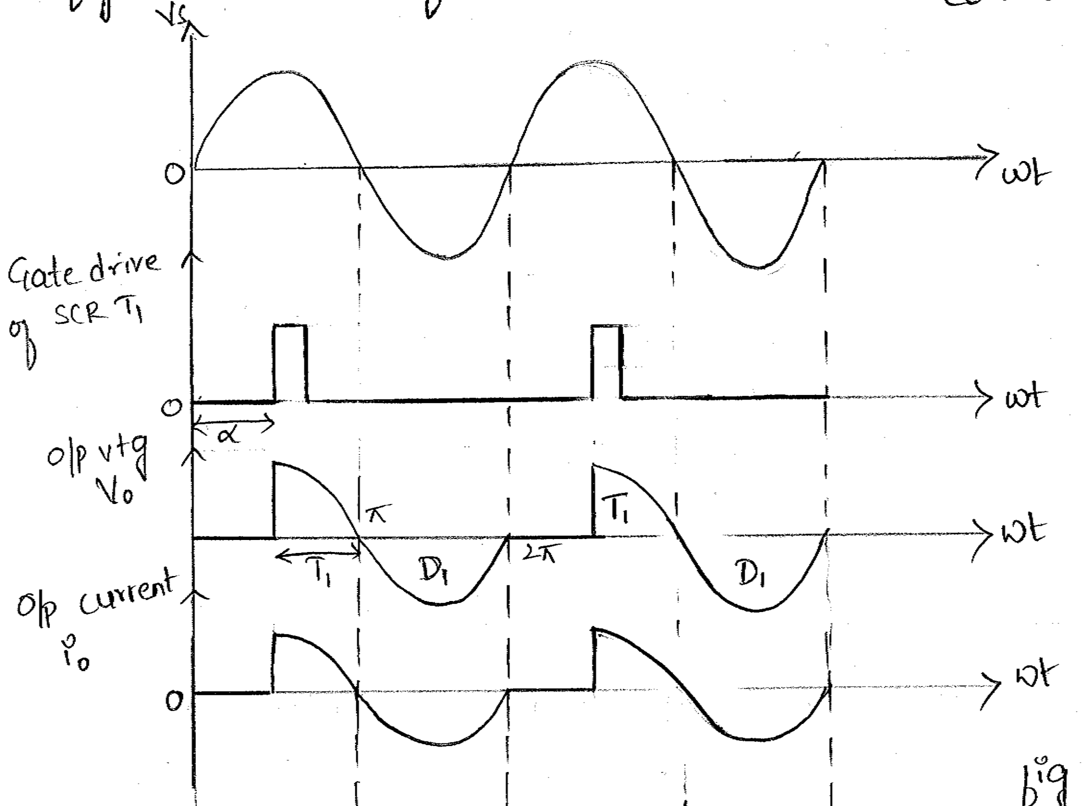


fig 1(b)

* The SCR T_1 is connected across the diode D_1 in an antiparallel configuration. Due to one SCR, only the +ve half cycle will be controlled and -ve half cycle of ac supply will appear across the load without any change as shown in fig 1(b)

Operation :

* During +ve half cycle of ac supply, SCR 'T_1' is turned ON at $\omega t = \alpha$. This will make the load voltage +ve and equal to the instantaneous ac supply voltage. The SCR will be turned OFF due to natural commutation at $\omega t = \pi$.

* During -ve half cycle of ac supply, D_1 will turn -ON at $\omega t = \pi$. Thus load voltage and current is negetive.
  Diode 'D' is turned OFF at $\omega = 2\pi$.

* Thus load voltage can be controlled by contro-lling the firing angle 'α' of the SCR.

Advantages :

1> Since there is only one SCR, the control ckt is simple.

2> The ckt is less expensive.

Disadvantages :-

1> The o/p voltage is not controlled fully, since -ve half cycle is uncontrolled due to diode 'D_1

2) The load voltage waveform is highly distorted. For large values of α, it does not resemble a sine wave at all.

Applications:

Due to the dc component in the o/p current and voltage this is used for heating and lighting applications.

Expression for rms value of o/p vtg :-

* WKT supply vtg is

$$V_s = V_m \sin\omega t.$$

* The rms value of o/p vtg is given by

$$V_0 = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} V_s^2 \, d\omega t}$$

$$V_0 = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} V_m^2 \sin^2(\omega t) \, d\omega t}$$

$$V_0 = \left\{\frac{1}{2\pi}\left[\int_\alpha^\pi V_m^2 \sin^2(\omega t)\, d\omega t + \int_\pi^{2\pi} V_m^2 \sin^2(\omega t)\, d\omega t\right]\right\}^{1/2}$$

$$V_0 = \left\{\frac{V_m^2}{2\pi}\left[\int_\alpha^\pi \sin^2(\omega t)\, d\omega t + \int_\pi^{2\pi} \sin^2(\omega t)\, d\omega t\right]\right\}^{1/2}$$

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

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

$$= \left\{ \frac{V_m^2}{4\pi} \left[\int_{\alpha}^{\pi} 1 \cdot d\omega t - \int_{\alpha}^{\pi} \cos 2\omega t \cdot d\omega t + \int_{\pi}^{2\pi} 1 \cdot d\omega t - \int_{\pi}^{2\pi} \cos 2\omega t \, d\omega t \right] \right\}^{1/2}$$

$$= \left\{ \frac{V_m^2}{4\pi} \left[(\omega t)_{\alpha}^{\pi} - \left[\frac{\sin 2\omega t}{2} \right]_{\alpha}^{\pi} + (\omega t)_{\pi}^{2\pi} - \left[\frac{\sin 2\omega t}{2} \right]_{\pi}^{2\pi} \right] \right\}^{1/2}$$

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

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

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

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

$$= \sqrt{ \frac{V_m^2}{4\pi} \left[2\pi - \alpha + \frac{\sin 2\alpha}{2} \right] }$$

$$\boxed{V_0 = \frac{V_m}{2} \sqrt{\frac{2\pi - \alpha + \frac{\sin 2\alpha}{2}}{\pi}}}$$

* RMS value of o/p current.

$$\boxed{I_0 = \frac{V_0}{R_L}}$$

Expression for average or dc value of o/p voltage:-

WKT average value of o/p voltage is given by:

$$V_{dc} = V_{o(avg)} = \frac{1}{2\pi}\int_{\alpha}^{2\pi} V_m \sin\omega t \, d\omega t$$

$$V_{o(avg)} = \frac{V_m}{2\pi}\int_{\alpha}^{2\pi} \sin\omega t \, d\omega t$$

$$V_{o(avg)} = \frac{V_m}{2\pi}\left[-\cos\omega t\right]_{\alpha}^{2\pi}$$

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

$$V_{o(avg)} = \frac{V_m}{2\pi}\left[-1 + \cos\alpha\right]$$

$$V_{o(avg)} = \frac{V_m}{2\pi}\left[\cos\alpha - 1\right]$$

$$\boxed{V_{dc} = V_{o(avg)} = \frac{\sqrt{2}\,V_s}{2\pi}\left[\cos\alpha - 1\right]}$$

Note:

$$V_o = \sqrt{\frac{V_m^2}{4\pi}\left[2\pi - \alpha + \frac{\sin 2\alpha}{2}\right]}$$

i) for $\alpha = 0$

$$V_o = \sqrt{\frac{V_m^2}{4\pi}(2\pi)}$$

$$V_o = \sqrt{\frac{V_m^2}{2}}$$

$$\boxed{V_o = \frac{V_m}{\sqrt{2}}}$$

ii) for $\alpha = 180°$

$$V_0 = \sqrt{\frac{V_m^2}{4 \times 180°}\left[2(180°) - 180 + \frac{\sin 2(180)}{2}\right]}$$

$$V_0 = \sqrt{\frac{V_m^2}{720°} \times [180°]}$$

$$\boxed{V_0 = \frac{V_m}{2}}$$

FORMULAE

1> RMS o/p voltage :-

$$V_0 = \frac{V_m}{2}\sqrt{\frac{2\pi-\alpha+\frac{\sin 2\alpha}{2}}{\pi}}$$

when $\alpha = 0°$

$$V_0 = \frac{V_m}{\sqrt{2}}$$

When $\alpha = 180°$

$$V_0 = \frac{V_m}{2}$$

2> $V_m = \sqrt{2}\,V_s$

3> RMS o/p current or rms load current.

$$I_0 = \frac{V_0}{R_L}$$

4> Average or dc o/p voltage

$$V_{dc} = \frac{\sqrt{2}\,V_s}{2\pi}\left[\cos\alpha - 1\right]$$

OR

$$V_{dc} = \frac{V_m}{2\pi}\left[\cos\alpha - 1\right]$$

5> Load power $P_0 = I_0^2 R_L$ or $P_0 = V_0 I_0 = \frac{V_0^2}{R_L}$

6> I/p current = load current

$$I_s = I_0$$

7> I/p power $P_i = V_s I_s = V_s I_0$.

8) $PF = \frac{P_o}{P_i}$

$$PF = \frac{V_o \cancel{I_o}}{V_s \cancel{I_o}}$$

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

$$= \frac{\sqrt{\frac{1}{4} \cdot \frac{2\pi - \alpha + \frac{\sin 2\alpha}{2}}{\pi}}}{\sqrt{2}}$$

9) Average o/p voltage :-

$$V_{dc} = \frac{\sqrt{2}\, V_s}{2\pi}\left[\cos\alpha - 1\right]$$

10) Average i/p current

$$I_{dc} = \frac{V_{dc}}{R}$$

11) Average thyristor current $I_{T(avg)} = \frac{I_m}{2\pi}\left[1 + \cos\alpha\right]$

12) RMS thyristor current :

$$I_{T(rms)} = \frac{I_m}{\sqrt{2}}\sqrt{\frac{1}{2\pi}\left[(\pi - \alpha) + \frac{\sin 2\alpha}{2}\right]}$$

PROBLEMS

1) A Single-Phase ac voltage controller in Fig1. Has a resistive load of R=10Ω and the input voltage is V_s=120V, 60Hz. The delay angle of thyristor T_1 is $\alpha = \pi/2$. Determine
   a) The rms value of output voltage V_o
   b) The input PF, and
   c) The average input current.

Given : $R = 10\Omega$, $V_S = 120V$, 60Hz, $\alpha = \pi/2 = 90°$

Soln:
$$V_m = \sqrt{2}\, V_S$$
$$= \sqrt{2} \times 120$$
$$V_m = 169.7V$$

a) $$V_o = \frac{V_m}{2}\sqrt{\frac{2\pi - \alpha + \frac{\sin 2(\alpha)}{2}}{\pi}}$$

$$= \frac{V_m}{2}\sqrt{\frac{2\pi - \alpha}{\pi} + \frac{\sin 2(\alpha)/2}{\pi}}$$

$$= \frac{169.7}{2}\sqrt{\frac{360° - 90°}{180°} + \frac{\sin 2(90)/2}{180°}}$$

$$= \frac{169.7}{2}\sqrt{\frac{270°}{180°}}$$

$$\boxed{V_o = 103.92V}$$

b) Input power factor:

$$PF = \frac{V_o}{V_s}$$

$$= \frac{103.92}{1}$$

$$\boxed{PF = 0.866}$$

c) Average input current:

$$I_{dc} = \frac{V_{dc}}{R}$$

$$V_{dc} = \sqrt{2} \cdot \frac{V_s}{2\pi}\left[\cos\alpha - 1\right]$$

$$= \sqrt{2}\ \frac{V_s}{2\pi}\left[\cos(\pi/2) - 1\right]$$

$$= \sqrt{2}\ \frac{V_s}{6.2831}\left[0 - 1\right]$$

$$= -\sqrt{2} \cdot \frac{120}{6.2831}$$

$$V_{dc} = -27V$$

$$\Rightarrow I_{dc} = \frac{-27}{10} = -2.7A.$$

$$\boxed{I_{dc} = -2.7A}$$

2) A Single-Phase half wave ac voltage controller has a resistance load of R=5Ω and input voltage V_s=120V, 60Hz. The delay angle of thyristor is $\alpha = \pi/3$. Calculate :

i) The RMS value of o/p voltage V_0
ii) The I/p PF &
iii) The average I/p current.

Given : $R = 5\Omega$, $V_s = 120V$, $\alpha = \pi/3$

Soln: i) $V_0 = \frac{V_m}{2}\sqrt{\frac{2\pi - \alpha + \frac{\sin 2(\alpha)}{2}}{\pi}}$

$V_m = \sqrt{2}\, V_s$

$= \sqrt{2} \times 120$

$\boxed{V_m = 169.70V}$

a) $V_0 = \frac{V_m}{2}\sqrt{\frac{(2\pi - \alpha) + \frac{\sin 2(\alpha)}{2}}{\pi}}$

$= \frac{169.70}{2}\sqrt{\frac{(2\pi - \pi/3) + \frac{\sin 2(\pi/3)}{2}}{\pi}}$

$\boxed{V_0 = 113.98V.}$

b) I/p power factor

I method : $PF = \frac{V_0}{V_s} = \frac{113.98}{120}$

$\boxed{PF = 0.9498}$ (Lagging)

II method :

$PF = \frac{P_0}{P_i}$

$$I_0 = \frac{V_0}{R}$$

$$= \frac{113.98}{5\Omega}$$

$$\boxed{I_0 = 22.796\ A}$$

$$P_0 = I_0^2 R$$

$$= (22.796)^2 \times 5$$

$$\boxed{P_0 \Rightarrow 2598.28\ W}$$

$$P_i = V_s I_s = V_s I_0$$

$$= 120 \times 22.796$$

$$\boxed{P_i = 2735.52\ W}$$

$$\Rightarrow PF = \frac{P_0}{P_i} = \frac{2598.28}{2735.52}$$

$$\boxed{PF = 0.9498}$$

c) Average input current.

$$I_{dc} = \frac{V_{dc}}{R}$$

$$V_{dc} = \frac{\sqrt{2}\, V_s}{2\pi} [\cos\alpha - 1]$$

$$= \frac{\sqrt{2} \times 120}{2\pi} [\cos(\pi/3) - 1]$$

$$\boxed{V_{dc} = -13.5\ V}$$

$$I_{dc} = \frac{-13.5}{5} = -2.7A$$

$$\boxed{I_{dc} = -2.7A.}$$

3) A single phase half-wave ac voltage controller has a load resistance R=50Ω, input ac supply voltage is 230V RMS at 50Hz. The input supply transformer has a turns ratio of 1:1. If the thyristor T1 is triggered at $\alpha = 60°$. Calculate

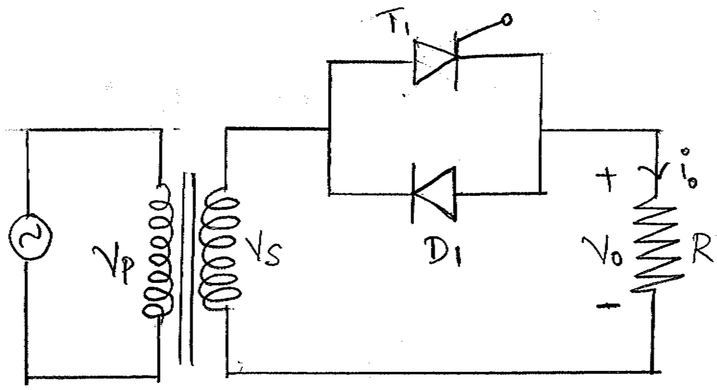
i) RMS output voltage

ii) Output power

iii) RMS load current and average load current

iv) Input power factor

v) Average and RMS thyristor current.



Given : $V_s = 230V$, $R = 50\Omega$, $\alpha = 60° = \pi/3$, $V_m = \sqrt{2}\, V_s = 325.26V.$

Soln :

i) RMS o/p voltage.

$$V_0 = \frac{V_m}{2}\sqrt{\frac{(2\pi-\alpha) + \sin 2\alpha/2}{\pi}}$$

$$= \frac{325.26}{2}\sqrt{\frac{(2\pi - \pi/3) + \frac{\sin 2(\pi/3)}{2}}{\pi}}$$

$$\boxed{V_0 = 218.46V}$$

ii) $P_0 = \frac{V_0^2}{R_L} = \frac{218.46}{50} = 954.49W$

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iii) RMS load current

$$I_0 = \frac{V_0}{R_L} = \frac{218.46}{50}$$

$$\boxed{I_0 = 4.3692A}$$

Average load current :

$$I_{dc} = \frac{V_{dc}}{R}$$

$$V_{dc} = \frac{\sqrt{2} \times V_s}{2\pi}\left[\cos\alpha - 1\right]$$

$$= \frac{\sqrt{2} \times 230}{2\pi}\left[\cos(\pi/3) - 1\right]$$

$$= 51.768 \times (-0.5)$$

$$\boxed{V_{dc} = -25.884V}$$

$$\Rightarrow \quad I_{dc} = \frac{25.884}{50} = -0.5176A.$$

$$\boxed{I_{dc} = -0.5176A}$$

iv) I/p power factor:

$$PF = \frac{P_0}{P_i}$$

$$PF = \frac{V_0}{V_s} = \frac{218.46V}{230V}$$

$$\boxed{PF = 0.9498}$$

v) Average thyristor current:

$$I_{T(avg)} = \frac{I_m}{2\pi}\left[1 + \cos\alpha\right]$$

$$I_m = \frac{V_m}{R_L} = \frac{325.269}{50}$$

$$\boxed{I_m = 6.505A}$$

$$\Rightarrow I_{T(avg)} = \frac{6.505}{2\pi}\left[1+\cos(\pi/3)\right]$$

$$= 1.035\,[1+0.5]$$

$$\boxed{I_{T(avg)} = 1.5525A}$$

RMS thyristor current:

$$I_{T(rms)} = \frac{I_m}{\sqrt{2}}\sqrt{\frac{1}{2\pi}\left[(\pi-\alpha)+\frac{\sin 2\alpha}{2}\right]}$$

$$= \frac{6.505}{\sqrt{2}}\sqrt{\frac{1}{2\pi}\left[(\pi-\pi/3)+\frac{\sin 2(\pi/3)}{2}\right]}$$

$$= 4.599\sqrt{0.159\,[2.094+0.476]}$$

$$\boxed{I_{T(rms)} = 2.917A}$$

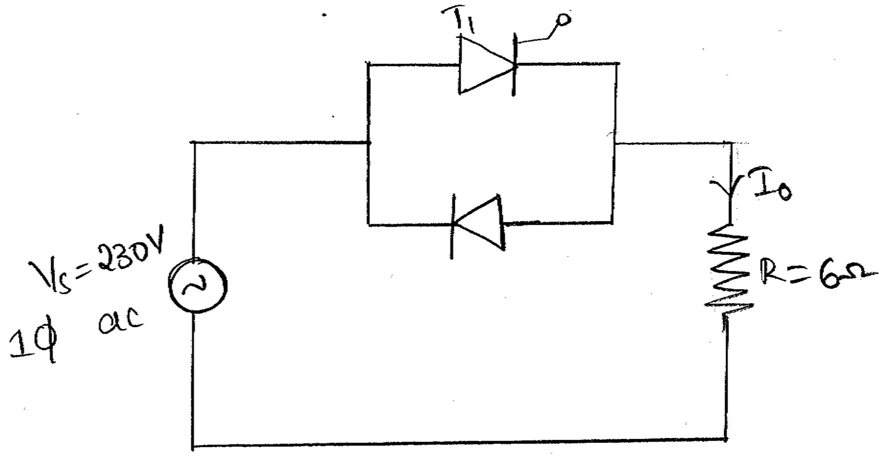
4) A Single phase half wave AC voltage controller shown in figure feeds power to a resistive load of 6Ω from 230V, 50Hz source. The firing angle of SCR is $\alpha = \pi/2$. Calculate :

i) RMS value of output voltage

ii) Input power factor

iii) Average input current

iv) Derive any formulae for atleast two sub divisions.



Given: $R = 6\Omega$, $V_s = 230V$, $\alpha = \pi/2$

Soln:

i) RMS o/p voltage:

$$V_0 = \frac{V_m}{2}\sqrt{\frac{(2\pi - \alpha) + \frac{\sin 2\alpha}{2}}{\pi}}$$

$$V_m = \sqrt{2}\, V_s$$

$$= \sqrt{2} \times 230V$$

$$\boxed{V_m = 325.2V}$$

$$\Rightarrow V_0 = \frac{325.2}{2}\sqrt{\frac{(2\pi - \frac{\pi}{2}) + \frac{\sin 2(\pi/2)}{2}}{\pi}}$$

$$= 162.6\sqrt{\frac{4.7123}{3.142}}$$

$$\Rightarrow 162.6\sqrt{1.5}$$

$$= 162.6 \times 1.2247$$

$$\boxed{V_0 = 199.1435V}$$

ii) I/p power factor:

$$PF = \frac{V_0}{V_s}$$

$$= \frac{199.1\,V}{230}$$

$$\boxed{PF = 0.865}$$

iii) Average I/p current:

$$I_{avg} = \frac{V_{dc}}{R}$$

$$V_{dc} = \frac{V_m}{2\pi}\left[\cos\alpha - 1\right]$$

$$= \frac{325.2}{2\pi}\left[\cos(\pi/2) - 1\right]$$

$$\boxed{V_{dc} = -51.72\,V}$$

$$I_{avg} = \frac{V_{dc}}{R} = \frac{-51.72}{6}$$

$$\boxed{I_{avg} = 8.62\,A}$$

PTO→.

5) A 1-Phase halfwave ac voltage controller has an input voltage of 230V, 50Hz and a load resistance of 10Ω. The firing angle of thyristor is 90° in each positive half cycle. Find :

i) Average output voltage

ii) RMS output voltage

iii) The average thyristor current

iv) The rms current value of the thyristor

v) Diode average curent

vi) Diode rms current.

Jan-11,12M

Given: $V_s = 230V$, $R = 10\Omega$, $\alpha = \pi/2 = 90°$.

Soln: $V_m = \sqrt{2} \times 230$

$$\boxed{V_m = 325.26\,V}$$

i) Average o/p voltage.

$$V_{dc} = \frac{\sqrt{2}V_s}{2\pi}[\cos\alpha - 1]$$

$$= \frac{\sqrt{2} \times 230}{2\pi}[\cos(90°) - 1]$$

$$\boxed{V_{dc} = -6.75\,V}$$

ii) RMS o/p voltage:

$$V_o = \frac{V_m}{2}\sqrt{\frac{(2\pi - \alpha) + \frac{\sin(2\alpha)}{2}}{\pi}}$$

$$= \frac{325.26}{2}\sqrt{\frac{(2\pi - \pi/2) + \frac{\sin 2(\pi/2)}{2}}{\pi}}$$

$$\boxed{V_o \cong 199.2\,V}$$

iii) The average thyristor current :

$$I_{T(avg)} = \frac{I_m}{2\pi}\left[1+\cos\alpha\right]$$

$$I_m = \frac{V_m}{R_L} = \frac{325.26}{10}$$

$$\boxed{I_m = 32.526\,A}$$

$$I_{T(avg)} = \frac{32.526}{2\pi}\left[1+\cos 90^\circ\right]$$

$$\boxed{I_{T(avg)} = 5.18A}$$

iv) The rms current value of the thyristor.

$$I_{T(rms)} = \frac{I_m}{\sqrt{2}}\sqrt{\frac{1}{2\pi}\left[(\pi-\alpha)+\frac{\sin 2\alpha}{2}\right]}$$

$$= \frac{32.526}{\sqrt{2}}\sqrt{\frac{1}{2\pi}\left[\left(\pi-\pi/2\right)+\frac{\sin 2(\pi/2)}{2}\right]}$$

$$\boxed{I_{T(rms)} = 11.5A}$$

v) Diode average current :-

$$I_{D(avg)} = \frac{I_m}{\pi}$$

$$= \frac{32.526}{\pi}$$

$$\boxed{I_{D(avg)} = 10.35A}$$

vi) Diode rms current

$$I_{d(rms)} = \frac{I_m}{2} = \frac{32.526}{2}$$

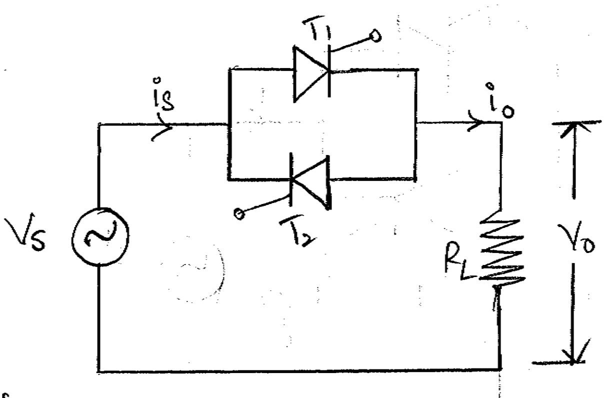
$$\boxed{I_{D(rms)} = 16.26A}$$

Single Phase FULL Wave AC voltage Controller (With R- Load) :-

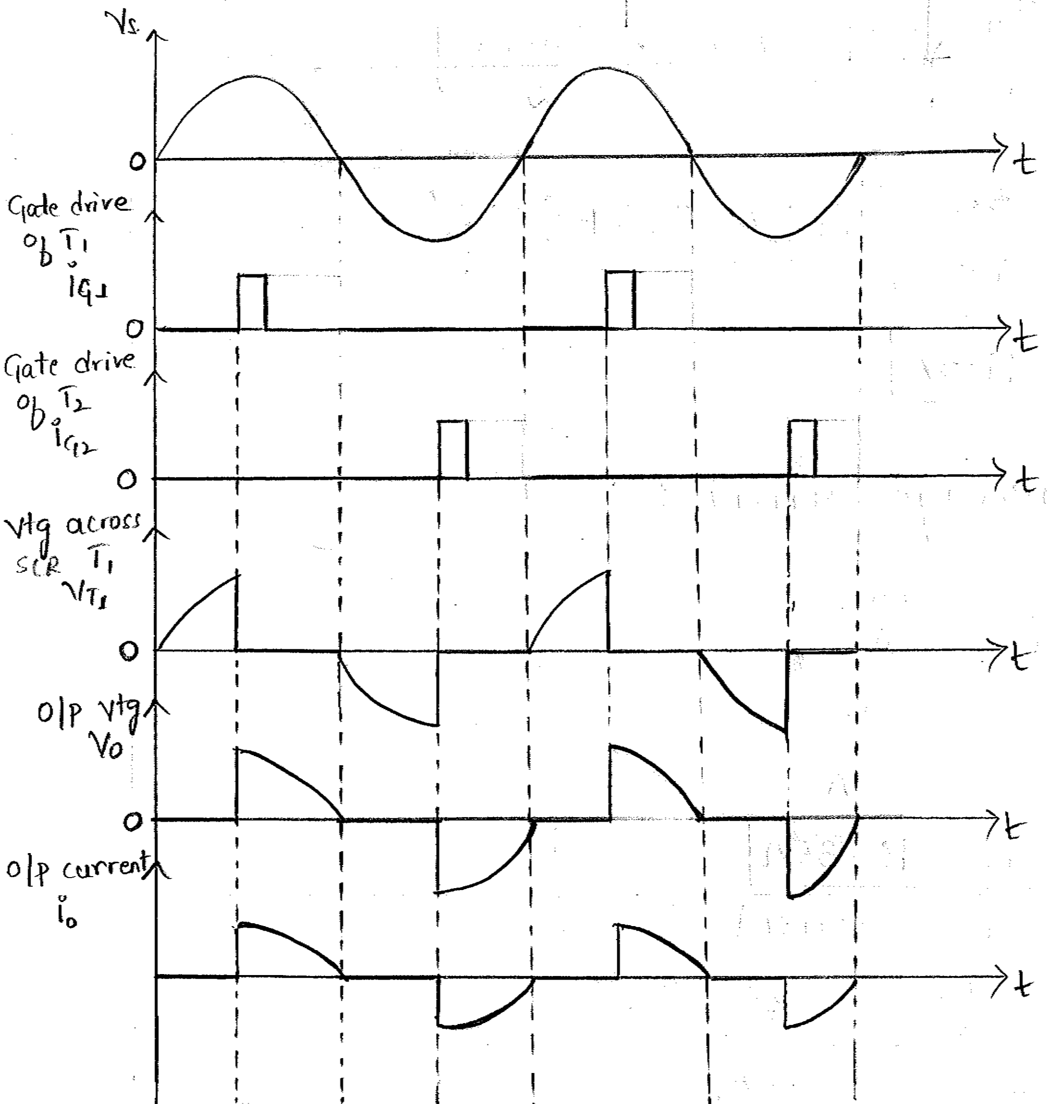
OR

Bi-directional AC voltage Controller (With R- Load) :-

❖ **Explain the operation of a single phase bidirectional controller with resistive load. Obtain the equation forms and output voltage. Show the waveforms.** **June-09,8M**



fig(1) Full wave ac vtg controller.



The ckt diagram of a single phase. Full wave ac vtg controller is as shown in fig ①

* Two SCR's are connected in the antiparallel configuration. Due to the use of two SCR's, it is possible to control the load voltage and power in both the half cycles of ac supply. Thus it is also called as a bi directional controller.

* In +ve half cycle of the supply, 'T_1' controlls the power delivered to the load and in -ve half cycle of the supply 'T_2' controls the power delivered to the load.

 Thus the RMS o/p voltage can be controlled by varying the firing angle 'α' from '0' to 180°.

* Fig ② shows the I/o waveform. The o/p vtg and current waveforms are symmetric. Hence there is no dc component in V_o & i_o

* A conducting SCR will turn OFF due to natural commutation at the end of corresponding half cycles of supply voltage.

Advantages:

1) The control of load power is possible in both the half cycle of a supply.

2) The average value of load current and supply current is zero. So there is no possibility of core saturation of induction motor used a load.

Disadvantages.

1) Due to the use of two SCR's the ckt becomes a little more complicated and expensive.

Applications:

1) Used for induction motors, pumps, fans etc...
2) As a fan regulator
3) Heater control
4) As light dimmer.

Expression for RMS value of o/p vtg for single phase full wave controller :-

WKT I/p supply vtg is given by:

$$V_s = V_m \sin\omega t \longrightarrow ①$$

The rms value of o/p vtg is given:

$$V_0 = \left[\frac{1}{T}\int_0^T V_s^2 \, d\omega t\right] \longrightarrow ②$$

$$V_0 = \left\{\frac{1}{2\pi}\left[\int_\alpha^\pi V_s^2 \, d\omega t + \int_{\pi+\alpha}^{2\pi} V_s^2 \, d\omega t\right]\right\}^{1/2}$$

$$V_0 = \left\{\frac{1}{2\pi}\left[\int_\alpha^\pi V_m^2 \sin^2(\omega t)\, d\omega t + \int_{\pi+\alpha}^{2\pi} V_m^2 \sin^2(\omega t)\, d\omega t\right]\right\}^{1/2}$$

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

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

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

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

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

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

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

$$\Rightarrow \left\{\frac{V_m^2}{4\pi}\left[2(\pi-\alpha) + \frac{\sin 2\alpha}{2} + \frac{\sin 2\alpha}{2}\right]\right\}^{1/2} \quad [\because \sin(360^\circ+\theta) = \sin\theta]$$

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

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

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

$$V_0 = \frac{V_m}{\sqrt{2}}\sqrt{\frac{\pi-\alpha+\sin 2\alpha/2}{\pi}}$$

In the eqn ③ i) when $\alpha = 0$

$$V_0 = V_m \sqrt{\frac{\pi - (0) + \sin 2(0)/2}{2\pi}}$$

$$V_0 = V_m \sqrt{\frac{\pi}{2\pi}}$$

$$\boxed{V_0 = \frac{V_m}{\sqrt{2}}}$$

ii) when $\alpha = \pi$

$$V_0 = V_m \sqrt{\frac{(\pi - \pi) + \sin 2(\pi)/2}{2\pi}}$$

$$V_0 = V_m \times 0$$

$$\boxed{V_0 = 0}$$

Average Load Voltage 'V_{dc}' :-

$$V_{dc} = \frac{1}{2\pi} \int_0^{2\pi} V_s \, d\omega t$$

$$= \frac{1}{2\pi} \left[\int_\alpha^\pi V_s \, d\omega t + \int_{\pi+\alpha}^{2\pi} V_s \, d\omega t \right]$$

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

$$= \frac{V_m}{2\pi} \left[\int_\alpha^\pi \sin \omega t \, d\omega t + \int_{\alpha+\pi}^{2\pi} \sin 2\omega t \, d\omega t \right]$$

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

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

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

$$= \frac{V_m}{2\pi}\left[\cos\alpha + \cancel{1} - \cancel{1} + \cos(\pi+\alpha)\right]$$

$\cos(A+B) = \cos A \cdot \cos B - \sin A \cdot \sin B$

$$V_{dc} = \frac{V_m}{2\pi}\left\{\cos\alpha + \cos\pi \cdot \cos\alpha - \sin\pi \cdot \sin\alpha\right\}$$

$$= \frac{V_m}{2\pi}\left[\cancel{\cos\alpha}^{\,0} - \cos\alpha\right]$$

$$\boxed{V_{dc} = 0}$$

Thus the average value of load voltage is zero.

Average load current 'I_{dc}' :-

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{0}{R_L}$$

$$\boxed{I_{dc} = 0}$$

$\therefore$ RMS value of load current (I_o)

$$\boxed{I_o = \frac{V_o}{R_L}}$$

FORMULAE

1) $V_m = \sqrt{2} V_s$

2) The rms o/p voltage V_o or $V_{o(rms)}$

i) $V_o = \dfrac{V_s}{\sqrt{2}}$

ii) $V_o = V_m \sqrt{\dfrac{(\pi - \alpha) + \frac{\sin 2\alpha}{2}}{2\pi}}$

3) The average current through thyristor I_A or $I_{T(avg)}$

$$I_A = \frac{V_m}{2\pi R}[1 + \cos\alpha]$$

4) The rms value of the thyristor current

i) $I_{T(rms)} = \dfrac{I_o}{\sqrt{2}}$

ii) $I_{T(rms)} = \dfrac{V_s}{\sqrt{2} R_L}\left[\dfrac{1}{\pi}\left(\pi - \alpha + \dfrac{\sin 2\alpha}{2}\right)\right]^{1/2}$

5) Average load voltage $V_{dc} = 0$

6) Average load current $I_{dc} = 0$

7) O/p power $P_o = \dfrac{V_o^2}{R_L} = I_o^2 R_L$

8) I/p power $P_i = V_s I_s = V_s I_o$

9) $PF = \dfrac{P_o}{P_i}$

10) RMS value of o/p current

$$I_o = \frac{V_o}{R_L}$$

PROBLEMS

1) A Single phase full wave ACVC has a resistive load of R=10Ω as shown in fig1. The input is V_s=120V(rms), 60Hz. The delay angle of thyristors T_1 and T_2 are equal to $\alpha 1 = \alpha 2 = \pi/2$. Calculate i) rms output voltage ii) the average current through thyristors I_A iii) rms current of thyristors I_R iV) the input PF.

June-11,6M

Given: $R = 10\Omega$, $V_s = 120\,V(rms)$, $60Hz$, $\alpha_1 = \alpha_2 = \pi/2$

Soln: i) $V_0 = \frac{V_s}{\sqrt{2}} = \frac{120V}{\sqrt{2}}$

$V_0 = 84.85V$

ii) I/p power factor:

$PF = \frac{P_0}{P_i}$

$P_0 = \frac{V_0^2}{R_L} = 719.95W$

$P_i = V_s I_0 = 120 \times 8.485$

$\boxed{P_i = 1018.2W}$

$I_0 = \frac{V_0}{R_L} = \frac{84.85}{10}$

$\boxed{I_0 = 8.485A}$

$\Rightarrow PF = \frac{P_0}{P_i} = \frac{719.95W}{1018.2W}$

$\boxed{PF = 0.707}$ (lagging)

iii> RMS current of thyristor:-

$$I_0 = \frac{V_0}{R_L} = \frac{84.85V}{10\Omega}$$

$$\boxed{I_0 = 8.485A}$$

$$I_{T(rms)} = \frac{I_0}{\sqrt{2}} = \frac{8.485}{\sqrt{2}}$$

$$\boxed{I_{T(rms)} = 6A}$$

iv> Average current through thyristor:-

$$I_A = \frac{V_m}{2\pi R}[1+\cos\alpha]$$

$$= \frac{169.705}{2\pi \times 10}[1+\cos(\pi/2)]$$

$$\boxed{I_A = 2.7A.}$$

2) A Single phase full wave ac voltage controller supplies a resistive load of R=10Ω from an input voltage Vs=200V, 60Hz. The delay angles of the thyristors are equal, $\alpha_1 = \alpha_2 = \pi/2$. Determine

i) The rms output voltage

ii) The input p.f

iii) Average current of thyristors &

iv) RMS current of thyristors **Jan-07,7M**

Given: $\alpha_1 = \alpha_2 = \pi/2$, $V_s = 200V$, $R = 10\Omega$

Soln: $V_m = \sqrt{2}V_s = \sqrt{2} \times 200$

$V_m = 282.84V$

ARUNKUMAR.G M.Tech, *Lecturer in E&CE dept.* S.T.J.I.T, Ranebennur.

i> $V_{o(rms)} = \frac{V_s}{\sqrt{2}} = \frac{200}{\sqrt{2}} = 141.42V$

$\boxed{V_{o(rms)} = 141.42V}$

OR

$$V_{o(rms)} = V_m \sqrt{\frac{(\pi-\alpha) + \frac{\sin 2\alpha}{2}}{2\pi}}$$

$$= 282.84V \sqrt{\frac{(\pi - \pi/2) + \frac{\sin 2(\pi/2)}{2}}{2\pi}}$$

$$= 282.84V \sqrt{\frac{1.570 + 0}{2\pi}}$$

$$= 282.84 \sqrt{0.249}$$

$\boxed{V_{o(rms)} = 141.38V}$

ii> I/p PF $= \frac{P_o}{P_i}$

$P_o = \frac{V_o^2}{R_L} = 1999.96W$

$\boxed{P_i = V_s I_o}$

$I_o = \frac{V_o}{R_L} = \frac{141.42}{10}$

$\boxed{I_o = 14.142A}$

$P_i = 200 \times 14.142$

$\boxed{P_i = 2828.4}$

$PF = P_o/P_i = 1999.96/2828.4$

$$\Rightarrow \quad PF = \frac{1999.96}{2828.4}$$

$$\boxed{PF = 0.707}$$

iii) **Average current of thyristor:**

$$I_A = \frac{V_m}{2\pi R_L}[1+\cos\alpha]$$

$$= \frac{282.84}{2\pi \times 10}\left[1+\cos(\pi/2)\right]$$

$$\boxed{I_A = 4.50A}$$

iv) To obtain RMS thyristor current:

$$I_{T(rms)} = \frac{I_o}{\sqrt{2}}$$

$$= \frac{14.142A}{\sqrt{2}}$$

$$\boxed{I_{T(rms)} = 9.99A.}$$

3) A single phase bidirectional regulator is feeding resistive load of 10Ω. The supply voltage is 230V,50Hz. If the firing angle is 45 degrees, calculate the power absorbed by the load. Derive necessary equations.

Given: $R = 10\Omega$, $V_s = 230V$, $\alpha = 45° = \pi/4$

Soln: $V_m = \sqrt{2}\, V_s = 325.26V.$

Soln: $V_m = \sqrt{2}\, V_s = 325.26V$

$$V_o = V_m \sqrt{\frac{(\pi-\alpha) + \frac{\sin 2\alpha}{2}}{2\pi}}$$

$$V_o = 325.26 \sqrt{\frac{(\pi-\pi/4) + \frac{\sin 2(\pi/4)}{2}}{2\pi}}$$

$$V_o = 325.26 \sqrt{\frac{2.356 + 0.5}{2\pi}}$$

$$V_o = 325.26 \sqrt{0.431}$$

$$\boxed{V_o = 219.21V.}$$

The power absorbed by the load is given by:-

$$P_o = \frac{V_o^2}{R_L} = \frac{(219.20V)^2}{10}$$

$$\boxed{P_o = 4.8kW}$$

4. A voltage source Vs=100sin377t supplies a resistive load of 100Ω through a pair of back to back connected thyristors (ac regulator). Calculate the average power in the load, if the thyristor's firing angle is fixed at 45° with respect to the supply voltage.

Given: $V_s = 100 \sin 377t$

$V_s = V_m \sin \omega t.$

$V_m = 100V$, $R_L = 100\Omega$, $\alpha = 45° = \pi/4.$

Soln: RMS o/p voltage:

$$V_0 = V_m \sqrt{\frac{(\pi-\alpha) + \frac{\sin 2\alpha}{2}}{2\pi}}$$

$$= 100 \sqrt{\frac{(\pi-\pi/4) + \frac{\sin 2(\pi/4)}{2}}{2\pi}}$$

$$= 100 \sqrt{\frac{2.356 + 0.5}{2\pi}}$$

$$= 100\sqrt{0.4545}$$

$$\boxed{V_0 = 67.42V}$$

Load power:

$$P_0 = \frac{V_0^2}{R} = \frac{(67.42)^2}{100} = 45.45W$$

$$\boxed{P_0 = 45.45W.}$$

5. Find the power consumed in the heater element shown in fig1, if both SCRs are triggered with delay angle of 45°. In the circuit of fig1, if the load is 2KW, 230V heater and Vs=230V, 50Hz. Calculate

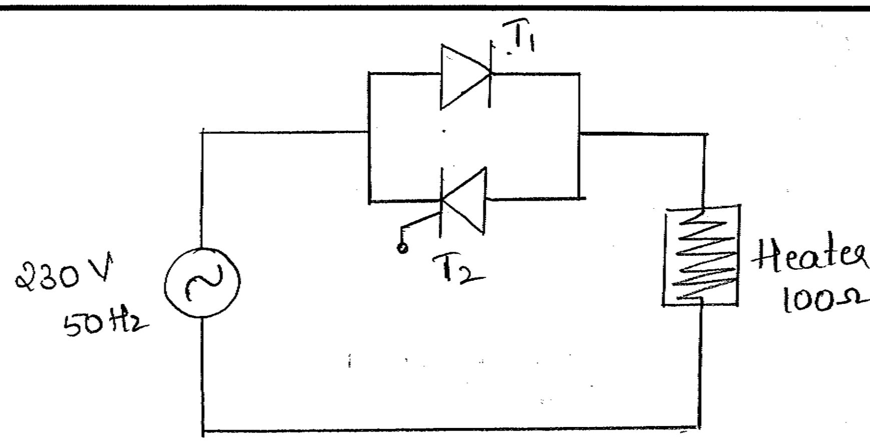
i) $V_{o(rms)}$

ii) Power dissipated in heater for α=45°.

Given: $\alpha = 45° = \pi/4$

$R = 100\Omega$

$V_s = 230V$, $P_{rated} = 2KW.$



Soln : $V_m = \sqrt{2} V_s = \sqrt{2} \times 230V$

$V_m = 325.26V$

i) RMS Value of o/p :-

$$V_o = V_m \sqrt{\frac{(\pi - \alpha) + \frac{\sin 2\alpha}{2}}{2\pi}}$$

$$= 325.26V \sqrt{\frac{(\pi - \pi/4) + \frac{\sin 2(\pi/4)}{2}}{2\pi}}$$

$$= 325.26 \sqrt{\frac{2.356 + 0.5}{2\pi}}$$

$$= 325.26 \sqrt{0.4545}$$

$$\boxed{V_o = 219.3V}$$

* Power absorbed in the load can be calculated

$$P_o = \frac{V_o^2}{R_L} = \frac{(219.3)^2}{100}$$

$$\boxed{P_o = 480.92W}$$

ii) $P_{(rated)} = \dfrac{V_{(rated)}^2}{R}$

WKT $P_{(rated)} = 2KW$ & $V_{(rated)} = 230V$

$$R = \frac{V_{rated}^2}{P_{(rated)}}$$

$$= \frac{(230)^2}{2KW}$$

$$\boxed{R = 26.45\Omega}$$

Hence power dessipation in heater is

$$P_0 = \frac{V_0^2}{R} = \frac{(219.3)^2}{26.45}$$

$$\boxed{P_0 = 1.818\,KW}$$

---

6. For the ac voltage controller shown in the following fig 1, the delay angles of thyristor are equal and $\alpha_1 = \alpha_1 = 2\pi/3$. Determine the:

i) RMS O/P voltage

ii) Input power factor

iii) Average and RMS current of the thyristors.

June-10,12M

Given : $\alpha_1 = \alpha_2 = 2\pi/3$

$\therefore \alpha = 2\pi/3$, $R = 5\Omega$

$V_s = 120\sqrt{2}\,\sin 314t$

$V_s = V_m \sin\omega t$.

$V_m = 120\sqrt{2} = 169.7V.$

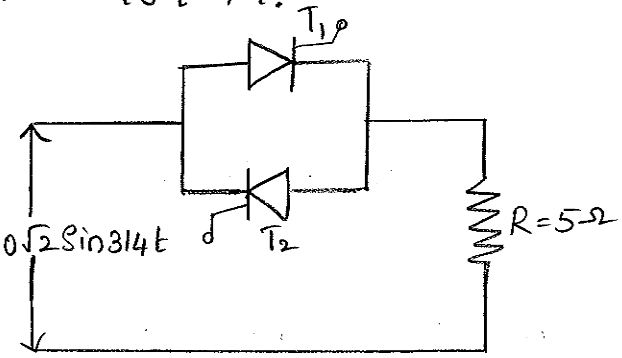


fig ①

i) RMS o/p voltage :-

$$V_0 = V_m \sqrt{\frac{(\pi-\alpha) + \frac{\sin 2\alpha}{2}}{2\pi}}$$

$$V_0 = 169.7 \sqrt{\frac{(\pi - 2\pi/3) + \frac{\sin[2(\pi/3)]}{2}}{2\pi}}$$

$$= 169.7 \sqrt{\frac{1.0471 - 0.4330}{2\pi}}$$

$$= 169.7 \sqrt{0.0977}$$

$$\boxed{V_0 = 53.05V}$$

ii) I/p power factor (PF):

WKT $V_m = \sqrt{2}\, 120$

$$V_s = \frac{V_m}{\sqrt{2}}$$

$$120V = \frac{V_m}{\sqrt{2}} \qquad \therefore V_s = 120V$$

I method: $PF = \frac{V_0}{V_s} = \frac{53.05}{120V} = \boxed{0.442}$ (lagging)

II method: $PF = \frac{P_0}{P_i}$

$P_0 = I_0^2 R_L$

$I_0 = V_0/R_L = 53/5 = \boxed{10.6A}$

$$P_0 = (10.6)^2 R_L$$

$$P_0 = 561.8W$$

$$P_i = V_s I_s \qquad \text{Where } I_s = I_0$$

$$P_i = 120 \times 10.6$$

$$P_i = 1272W$$

$$PF = \frac{P_0}{P_i} = \frac{561.8W}{1272W}$$

$$\boxed{PF = 0.4416} \text{ (lagging)}$$

iii) $$I_{T(avg)} = \frac{V_m}{2\pi R}[1+\cos\alpha]$$

$$= \frac{169.7}{2\pi \times 5}[1+\cos(2\pi/3)]$$

$$= 5.4017[1-0.5]$$

$$\boxed{I_{T(avg)} = 2.7A}$$

iv) RMS current of the thyristor :-

$$I_{T(rms)} = \frac{I_0}{\sqrt{2}}$$

$$= \frac{10.6}{\sqrt{2}}$$

$$\boxed{I_{T(rms)} = 7.49A}$$

❖ **For the A.C voltage controller shown in fig1, the delay angles of the thyristors T_1 and T_2 are equal, $\alpha_1 = \alpha_2 = 2\pi/3$. Determine:**

i) r.m.s. output voltage

ii) Input power factor

iii) Average current of thyristors and

iv) r.m.s. current of thyristors

June-06,8M

7. The single phase full wave ac voltage controller operates on a single phase voltage of 230V RMS, at 50Hz. If the triac is triggered at a delay angle of 45°, driving both the half cycles of input supply. Calculate

i) RMS value of output voltage

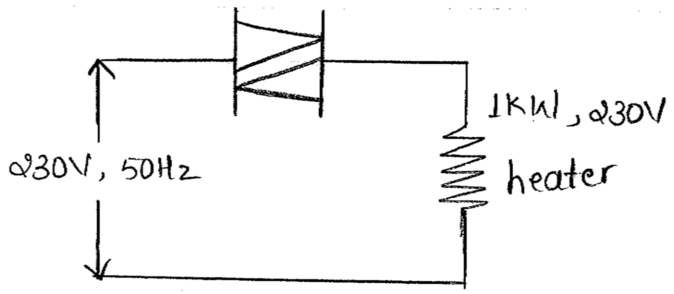
ii) RMS value of current through the heater

iii) Average value of triac current

iv) RMS value of triac current

v) Input PF.

Derive any expression used. **Jan-05,12M**



Given: $V_s = 230V$, $\alpha = 45° = \pi/4$, $P_{rated} = 1KW$, $V_{rated} = 230V$

Soln: $V_m = \sqrt{2}\,V_s = \sqrt{2} \times 230 = 325.26V$

i) RMS value of o/p vtg:

$$V_0 = V_m \sqrt{\frac{(\pi-\alpha) + \frac{\sin 2\alpha}{2}}{2\pi}}$$

$$= 325.26 \sqrt{\frac{(\pi - \pi/4) + \frac{\sin(2\pi/4)}{2}}{2\pi}}$$

$$= 325.26 \sqrt{\frac{2.356 + 0.5}{2\pi}}$$

$$= 325.26 \sqrt{0.4545}$$

$$\boxed{V_0 = 219.29V}$$

ii> **RMS value of o/p current:**

$$I_0 = \frac{V_0}{R_L}$$

$R_L = ?$

WKT $$P_{rated} = \frac{V_{rated}^2}{R_L}$$

$$R_L = \frac{V_{rated}^2}{P_{rated}}$$

$$= \frac{(230)^2}{1KW}$$

$$\boxed{R_L = 52.9\Omega}$$

$$I_0 = \frac{V_0}{R_L} = \frac{219.3}{52.9}$$

$$\boxed{I_0 = 4.145A}$$

iii> **Average value of triac current:-**

$$\boxed{I_{dc} = 0}$$

iv> **RMS value of triac:-**

The TRIAC current is same as o/p current. Hence rms value of TRIAC current will be same as o/p current i.e,

$$\boxed{I_{T(rms)} = I_0 = 4.137A}$$

v> **I/p power factor:-**

I method: $PF = \frac{V_0}{V_s} = \frac{219.29V}{230V} = \boxed{0.9534}$

II method:

$$PF = \frac{P_0}{P_i}$$

$$P_0 = I_0^2 R_L$$

$$= (4.145)^2 \times 52.9$$

$$P_0 = 908.87W$$

$$P_i = V_s I_s$$

$$= V_s I_0$$

$$P_i = 953.35$$

$$PF = \frac{908.87}{953.35}$$

$$\boxed{PF = 0.9533.}$$

❖ Single Phase FULL-Wave AC voltage controller with common Cathode :- OR

❖ Full Wave Controller with Common Cathode :-

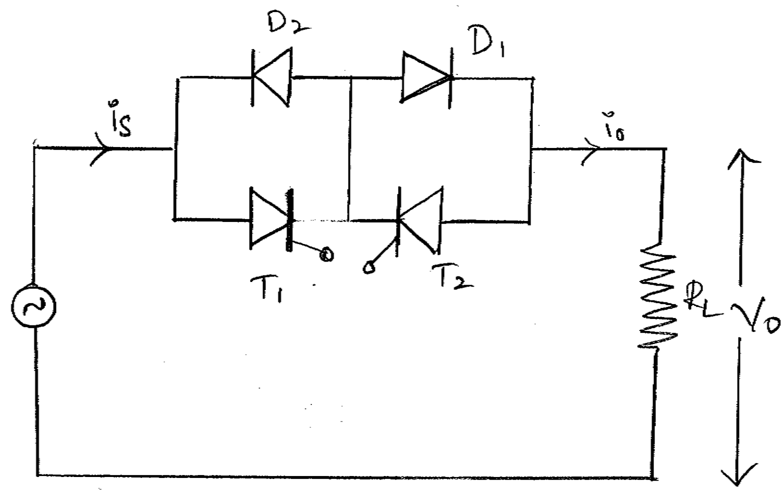


fig ① : 1ϕ full wave controller having common cathode.

fig ① shows the ckt diagram of 1ϕ full wave controller having common cathode connections of SCR's.

* The cathodes of two SCRs T_1 and T_2 are connected together. During +ve half cycle of the supply, SCR T_1 and diode D_1 conducts and in -ve half cycle SCR T_2 & diode D_2 conducts.

* In this ckt, the gate cathode drives need not be isolated. But isolation is normally provided b/w the control and power ckts.

* Four devices are required in this ckt. The efficiency of this ckt is slightly reduced due to increased power

dissipation in the devices.

I/O waveforms are same as that of full wave ac controllers.

❖ Phase Full Wave AC voltage controller with only ONE SCR :-

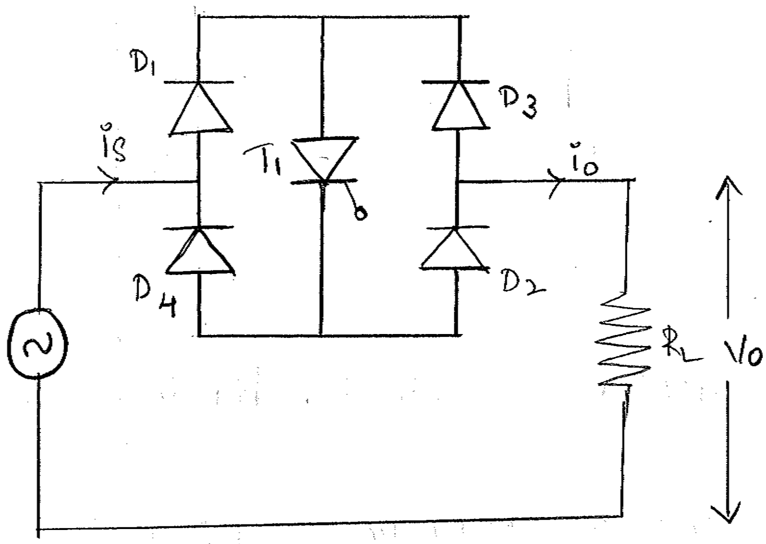


fig ①: 1φ Full wave controller with diode bridge and one SCR.

fig ① shows the ckt of 1φ full wave controller having one SCR T_1. The diode D_1, D_2, D_3 & D_4 are connected to form a bridge.

Operation:

* During +ve half cycle, SCR T_1 is triggered at $\omega t = \alpha$. The current will flow through D_1, T_1, D_2 and the load. At $\omega t = \pi$, load voltage and current reduce

to zero & SCR T_1 is turned -OFF due to natural Commutation.

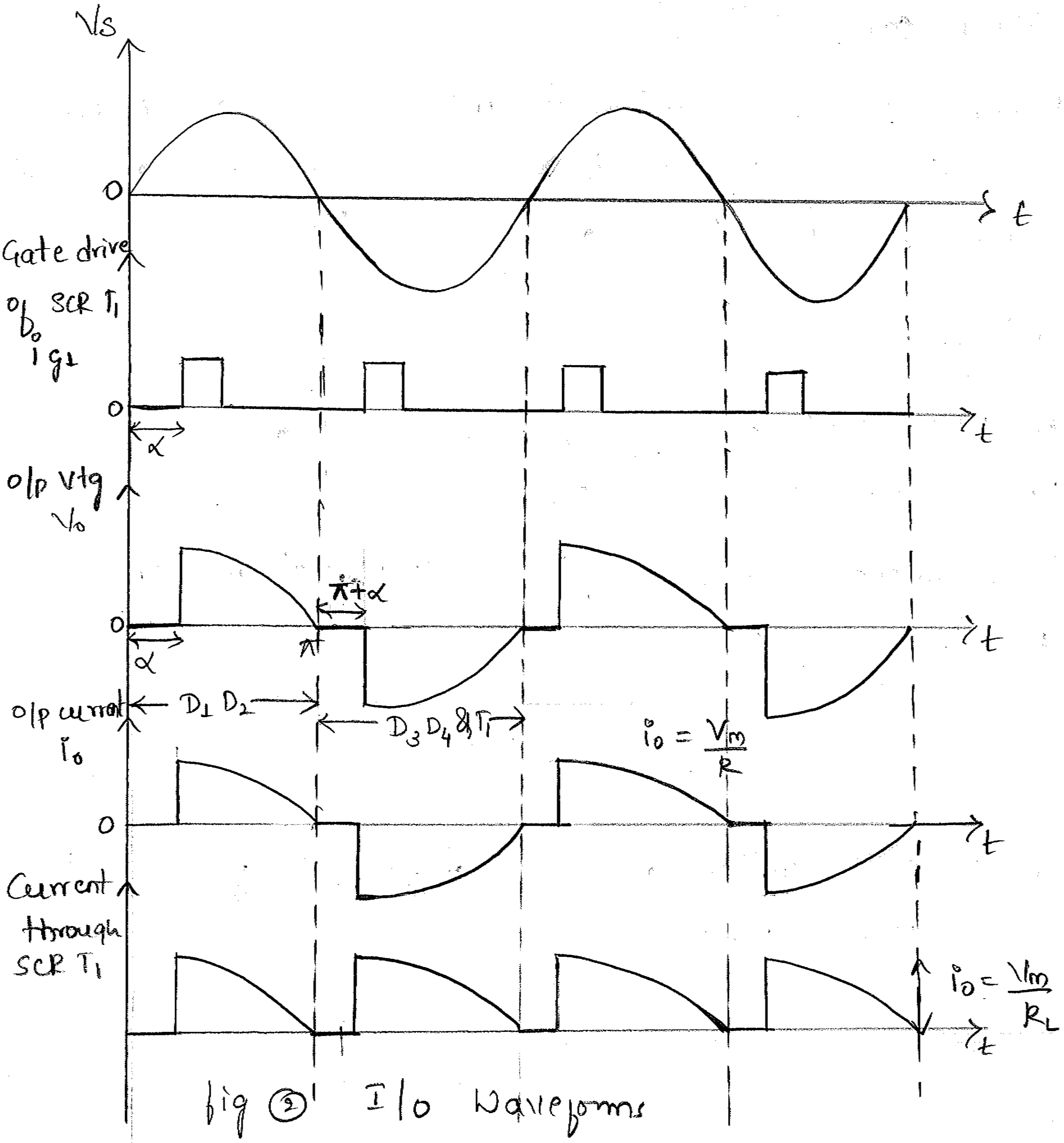


fig ② I/O Waveforms

* During -ve half cycle, SCR T_1 is triggered at $\underline{\omega t = \pi + \alpha}$. The current will flow through D_3, T_1, D_4 and the load. The load current and voltage becomes negative as shown in fig ②

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At $\omega t = 2\pi$, the load voltage and current both reduces to zero and SCR T_1 is turned OFF. due to natural commutation.

* During the time interval $\omega t = 0$ to α and π to $\pi + \alpha$, the SCR is OFF. Therefore load voltage and load current will be zero during these time interval.

Advantages:-

1) The i/p, o/p currents and voltage are symmetric. Hence there is no dc component.

2) Transformers and motors saturation problems are absent.

Applications:-

1) Full wave controller are used extensively for induction motors, pumps, fans etc...

❖ Single Phase Controller with INDUCTIVE loads :-

❖ **With a necessary waveforms, explain the operation of a single phase full wave controller with inductive load. Derive the expression for rms outputvoltage.** **June-11,8M**

❖ **With necessary circuit diagram and wavwforms, explain the operation of full wave ac voltage controller feeding on R-L load.**

June-11,8M (E&E)

❖ **With neat circuit diagram and waveforms derive an expression for the RMS valueof output voltage of single phase converter with RL load.(Assume discontinuous load current).**

Jan-09,6M

❖ **With necessary waveforms explain the operation of 1-phase full wave controller with inductive load. Derive expressions for rms output voltage and rms output current.** **June-08,10M**

❖ **Explain the operation of a single-phase phase control type of voltage controller with RL load. Give an illustration to show that for firing angle 'α' less than load angle, output voltage of the ac voltage controller cannot be regulated.**

Jan-08,8M

❖ **With necessary circuit and waveforms, explain the operation and fullwave ac voltage controller feeding an RL load.**

June-07,8M

❖ **Explain the various methods of gating an SCR. State why short duration pulses are insufficient for an ac voltage controller feeding an RL load.** **June-07,6M**

❖ **With necessary waveforms, explain the operation of a 1-phase full wave controller with inductive load. Derive the expression for rms output voltage and rms output current.** **Jan-07,10M**

Single phase controller with inductive loads :-

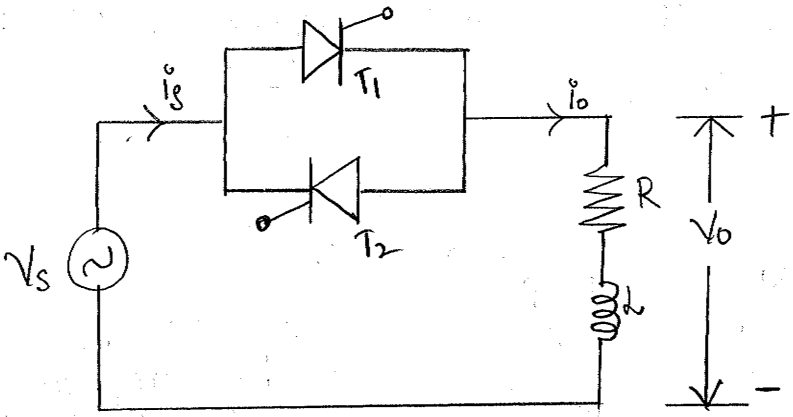
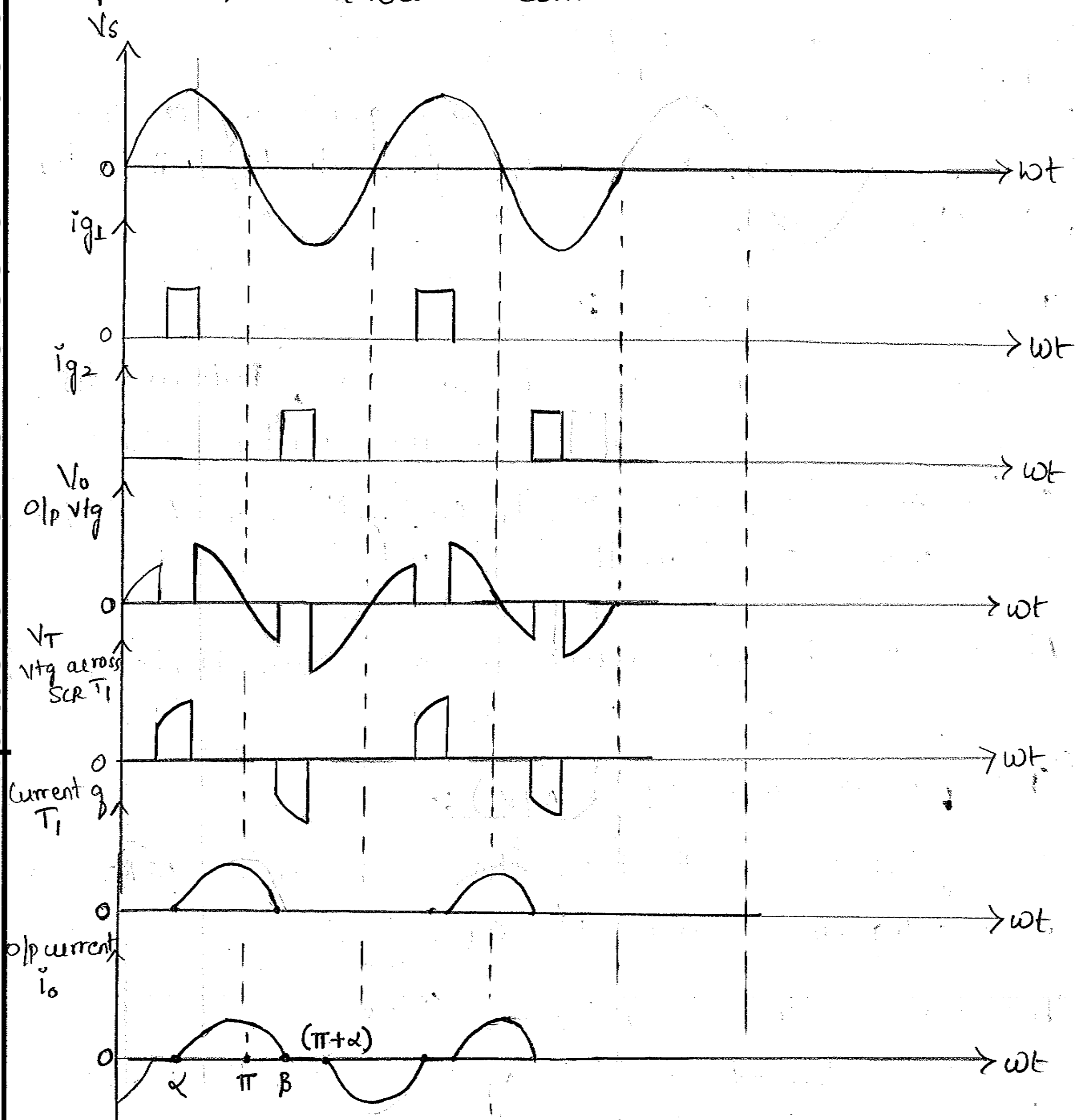


Fig ① 1φ Full wave controller with inductive load.



fig② I/O waveforms.

fig ① shows full wave ac controller using antiparallel SCR. The load is the combination of resistance and inductance ie, RL load.

Operation :

i) Interval $\omega t = \alpha$ to π :-

At $\omega t = \alpha$, SCR T_1 is turned ON. by applying a triggering pulse. The load voltage is +ve. and equal to the instantaneous supply voltage.

The load current starts increasing gradually as the load is inductive. During this interval, load inductor will store energy.

ii) Interval → $\omega t = \pi$ to β :-

At $\omega t = \pi$, the ac supply becomes −ve, But due to stored energy, the load inductance will maintain SCR 'T_1' in ON state. ie, SCR T_1 conducts from π to β. due to energy stored in the load inductance.

* At $\omega t = \beta$, the o/p current becomes zero. Hence T_1 turns OFF by natural commutation.

iii) Interval → $\omega t = (\beta$ to $\pi + \alpha)$:-

During this interval, both the SCRs remain OFF.

∴ o/p vltg and current is zero.

iv) Interval → $\omega t = (\pi + \alpha$ to $2\pi)$:-

SCR 'T_2' is turned ON at $\omega t = (\pi + \alpha)$. The load voltage becommes negative and equal to instantaneous supply vtg.

load current increases gradually in the negative direction, the load inductor will store energy. Due to this SCR T_2 continues to conduct even in next +ve half cycle as shown in fig ②.

RMS o/p voltage of 1φ full wave controller having Inductive load for discontinuous load current :-

* let supply vtg $\boxed{V_s = V_m \sin\omega t} \rightarrow ①$
* The RMS o/p vtg is given by

$$V_0 = \left[\frac{1}{T}\int_0^T V_s^2\, d\omega t\right]^{1/2}$$

$$V_0 = \left[\frac{1}{\pi}\int_\alpha^\beta V_m^2 \sin^2\omega t\, d\omega t\right]^{1/2}$$

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

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

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

$$= \left\{\frac{V_m^2}{\pi}\left[\frac{1}{2}(\beta-\alpha) - \frac{1}{4}(\sin 2\beta - \sin 2\alpha)\right]\right\}^{1/2}$$

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

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

$$= \sqrt{V_m^2 \left[\frac{(\beta-\alpha) + \frac{\sin 2\alpha}{2} - \frac{\sin 2\beta}{2}}{2\pi} \right]}$$

$$\boxed{V_o \Rightarrow V_m \sqrt{\frac{(\beta-\alpha) + \frac{\sin 2\alpha}{2} - \sin 2\beta}{2\pi}}}$$

❖ **Explain the various methods of gating an SCR. State why short duration pulses are insufficient for an ac voltage controller feeding an RL load.** **June-07,6M**

❖ **With neat waveforms, explain why short duration pulses are insufficient for an ac voltage controller feeding an R-L load.** **June-11,6M**

❖ **Why short duration gate pulses are not suitable for bi-directional ac voltage controller with inductive loads.** **Jan-07,5M**

❖ **Explain why short duration single gate pulses are not suitable for triggering thyristors in a full wave ac voltage contoller with inductive loads.** **Jan-06,6M**

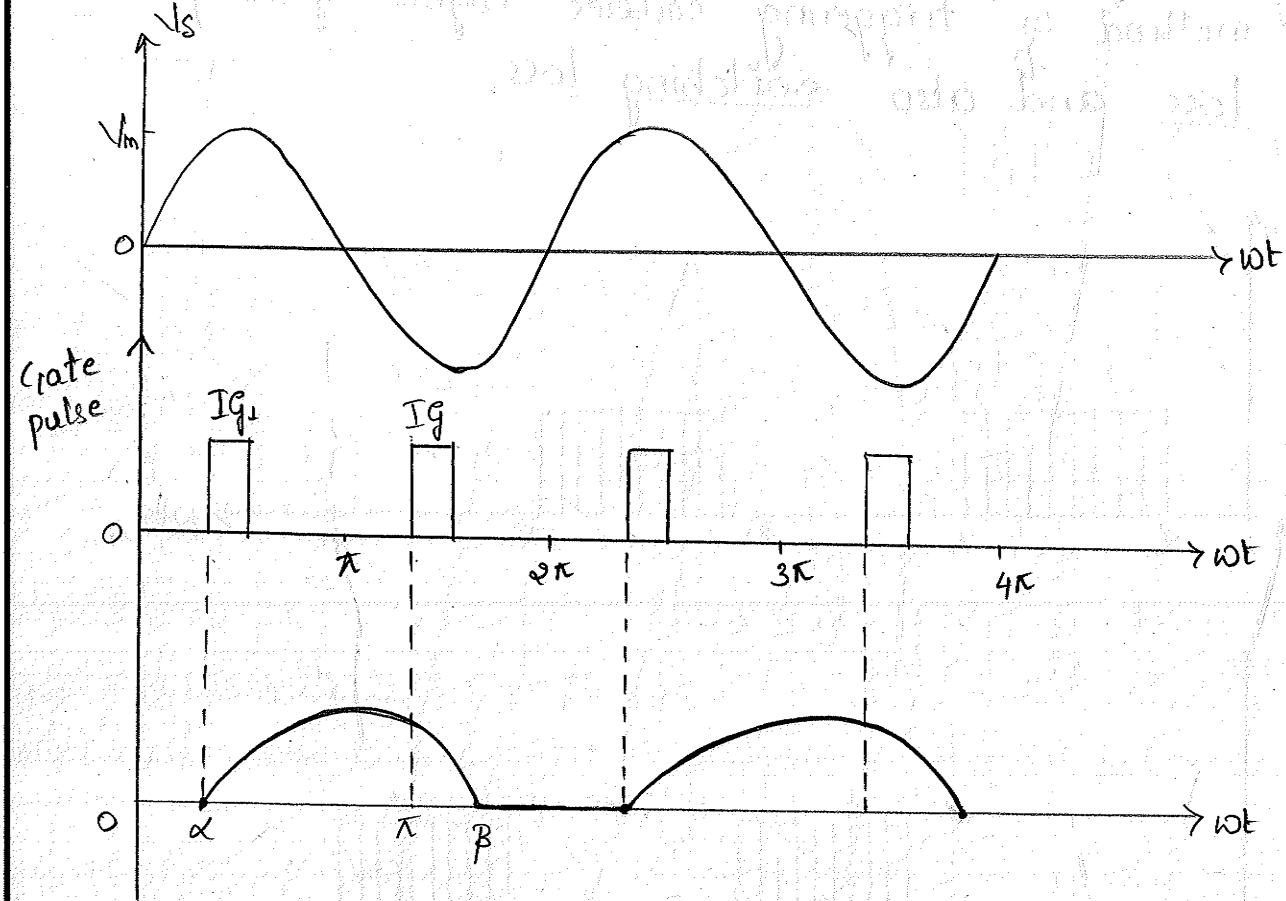
❖ **What problem is caused by sharp single pulse triggered in a single phase acvoltage controller, when the load is inductive? How can this be solved.** **June-10, 5M**

❖ **What problem is caused by sharp single pulse triggered in a single phase ac voltage controller, when the load is inductive? How can this be solved.** **June-10, 5M**

* If the load is purely resistive, then a short single gate pulse can be used to triggere each thyristor.

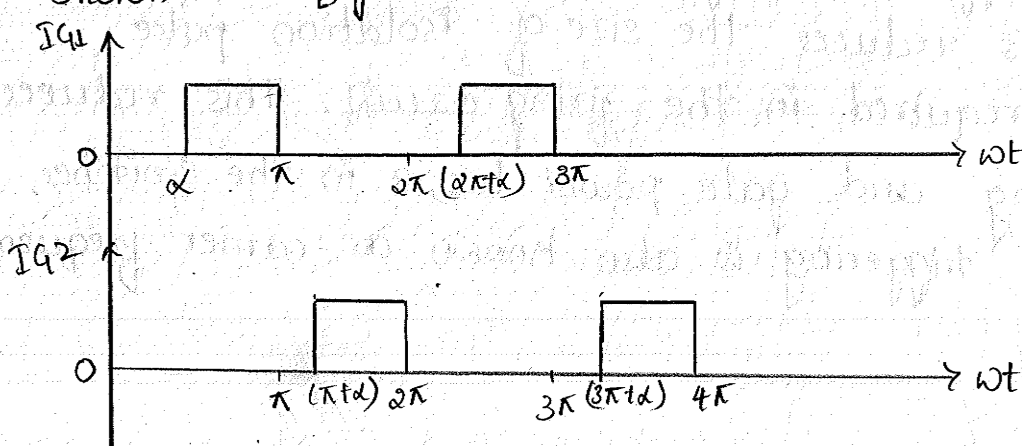
* The short duration pulse is not suitable for inductive loads. When thyristor T_2 is triggered at $\omega t = \pi + \alpha$, thyristor T_1 is still conducting due to the energy stored in the load inductance. As long as T_1 is conducting, T_2 will not forward biased. Before T_1 stops conducting at $\omega t = \beta$, the gate pulse of T_2 would have ceased.

Due to this, only T_1 will conduct during successive positive half cycles of I/p voltage causing the half wave controlled rectified instead of an ACVC



fig① short pulse triggering causing rectification

* The above explained problem can be solved by using a continuous gate pulse of duration $(\pi-\alpha)/\omega$ as shown in fig ②ⓐ.



fig②ⓐ

* As soon as T_1 current falls to zero at $\omega t = \beta$, T_2 will get forward biased and turned ON, since the gate pulse to T_2 is still available. But this method of triggering causes higher gate power loss and also switching loss.

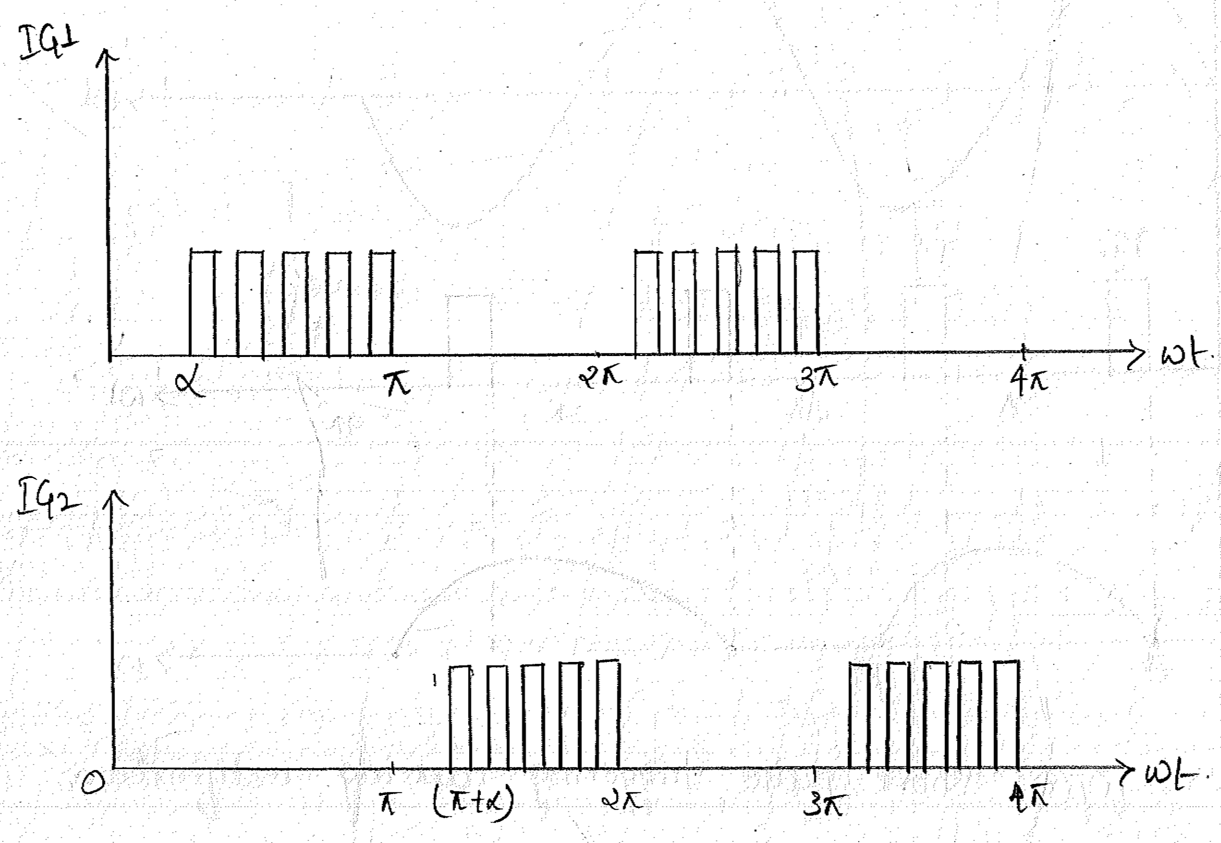


fig ③ⓐ

It is better to use a train of sharp high frequency pulses to trigger the thyristor as shown in fig 3ⓐ. Because this reduces the size of isolation pulse transformer required in the firing circuit. This reduces the switching and gate power losses in the switches. This type of triggering is also known as carrier frequency triggering.

FORMULAE

1) $\tan\theta = \frac{\omega L}{R}$ Where $\omega_L = 2\pi f L$

$\theta = \tan^{-1}\left(\frac{\omega L}{R}\right)$

2) When X_L is given, $\omega L = X_L$

$\theta = \tan^{-1}\left(\frac{X_L}{R}\right)$

3) The extinction angle β is

$$\boxed{\sin(\beta-\theta) - \sin(\alpha-\theta)\, e^{\frac{R(\alpha-\beta)}{\omega L}} = 0}$$

4) Conduction angle '∂'

$$\boxed{\partial = \beta - \alpha}$$

5) RMS o/p voltage

$$\boxed{V_o = V_m \sqrt{\frac{(\beta-\alpha) + \frac{\sin 2\alpha}{2} - \frac{\sin 2\beta}{2}}{2\pi}}}$$

6) $I_{o(rms)} = \frac{V_o}{Z}$

Where $Z = \sqrt{R^2 + (\omega L)^2}$

Where $\omega L = 2\pi f L$

7) $P_0 = I^2_{o(rms)} R_L$

$I_s = I_o$ $\quad\quad$ $I_o = I_{o(rms)}$

8) $PF = \frac{P_o}{P_i} = \frac{P_o}{I_s V_s} = \frac{P_o}{I_o V_s}$

9) $I_m = \frac{V_m}{Z}$

10) $V_m = \sqrt{2}\, V_s$.

PROBLEMS

❖ **A single phase full wave AC voltage controller has an R_L load. The input voltage is 230V, 50 Hz and the load is $R=2\Omega$ and $X_L=2\Omega$, $\alpha_1 = \alpha_2 = \pi/2$. Calculate the following :**

i) Angle until which the thyristor conducts

ii) Conduction angle of the thyristor

iii) R.m.s voltage of output. Derive the formulae you use.

Given: $V_s = 230V$, $R = 2\Omega$, $X_L = 2\Omega$, $\alpha_1 = \alpha_2 = \pi/2$

$V_m = \sqrt{2} \times 230 = 325.269 V$

Soln :

i) To determine Conduction angle β:-

WKT

$$\boxed{V_s = V_m \sin 2\omega t} \longrightarrow (1)$$

When thyristor T_1 conducts, we can write KVL as

$$V_s - i(t)R + L\frac{di(t)}{dt} = 0$$

$$V_s = i(t)R + L\frac{di(t)}{dt}$$

$$V_m \sin\omega t = i(t)R + L\frac{di(t)}{dt}$$

* Using laplace transform, above equation can be solved for $i(t)$. Hence solution is

$$\boxed{i(t) = \frac{V_m}{\sqrt{R^2 + (\omega L)^2}} \left\{ \sin(\omega t - \theta) - \sin(\alpha - \theta) e^{\frac{R(\alpha - \omega t)}{\omega L}} \right\}} \rightarrow (2)$$

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Here $\boxed{\theta = \tan^{-1} \frac{\omega L}{R}}$

From o/p current waveform, $\omega t = \beta$, $i(t) = 0$.
equation ③ becomes.

$$0 = \frac{V_m}{\sqrt{R^2 + (\omega L)^2}} \left\{ \sin(\beta - \theta) - \sin(\alpha - \theta)\, e^{\frac{R(\alpha-\beta)}{\omega L}} \right\}$$

$$\sin(\beta - \theta) - \sin(\alpha - \beta)\, e^{\frac{R(\alpha-\beta)}{\omega L}} = 0 \longrightarrow ③$$

In equation ③, if α and θ are known, solution of above equation gives β.

* Given $R = 2\Omega$

$X_L = \omega_L = 2\Omega$

$\alpha = \pi/2$

$\therefore \theta = \tan^{-1}\left[\frac{\omega L}{R}\right] = \tan^{-1}\left[\frac{2}{2}\right]$

$\boxed{\theta = 0.7853981}$

Putting the values of θ, α, R & ω_L in equation ③, we get

$$\sin(\beta - 0.7853981) - \sin(\pi/2 - 0.7853981)\, e^{\frac{2(\pi/2 - \beta)}{2}} = 0$$

$$\sin(\beta - 0.7853981) - 0.7071068\, e^{(\pi/2 - \beta)} = 0 \longrightarrow ④$$

Using bisect method, the solution of above equation at the end of 11^{th} iteration is.

$$\boxed{\beta = 3.8552772 \text{ or } 220.89}$$

Thus thyristor conducts till 220.89° due to Inductive Load.

ii) <u>To determine the conduction angle:-</u>

The SCR conducts from α to β. Hence Conduction angle is (δ)

$$\delta = \beta - \alpha = 3.8552772 - \pi/2.$$

$$\boxed{\delta = 2.2844809 \text{ or } 130.89°.}$$

iii) <u>RMS o/p vtg:-</u>

$$V_0 = V_m \sqrt{\frac{(\beta-\alpha) + \frac{\sin 2\alpha}{2} - \frac{\sin 2\beta}{2}}{2\pi}}$$

$$= 325.26 \sqrt{\frac{(3.8552 - \pi/2) + \frac{\sin[2\,\pi/2]}{2} - \frac{\sin[2(3.8552)]}{2}}{2\pi}}$$

$$= 325.26 \sqrt{\frac{2.2844 + 0 - 0.4948}{2\pi}}$$

$$= 325.26 \sqrt{0.2848}$$

$$\boxed{V_0 = 173.58V}$$

* The Single-phase full wave controller has an RL load. The i/p rms voltage is $V_s = 120V$, 60Hz. The load is such that $L = 6.5mH$ & $R = 2.5\Omega$. The delay angles of thyristor are equal : $\alpha_1 = \alpha_2 = \pi/2$. Determine.

ⓐ The conduction angle of thyristor T_1, δ;
ⓑ The rms o/p voltage V_o
ⓒ The rms o/p current I_o
ⓓ The I/p PF.

Given: $R = 2.5\Omega$, $L = 6.5mH$, $f = 60Hz$, $V_s = 120V$,

$\alpha = 90° = \pi/2$

$V_m = \sqrt{2} \times 120V = 169.705$

Soln: WKT

$$\theta = \tan^{-1}\left(\frac{WL}{R}\right)$$

$$WL = 2\pi f L = 2\pi \times 60 \times 6.5mH$$

$$WL = 2.4504\Omega$$

$$\theta = \tan^{-1}\left(\frac{2.4504}{2.5\Omega}\right)$$

$$\boxed{\theta = 0.7753}$$

ⓐ The conduction angle $\delta = \beta - \alpha$

The extinction angle β is

PTO →

$$\sin(\beta-\theta) - \sin(\alpha-\theta)\, e^{\frac{R(\alpha-\beta)}{\omega L}} = 0$$

$$\sin(\beta - 0.7753) - \sin(\pi/2 - 0.7753)\, e^{\frac{2.5(\pi/2-\beta)}{2.4504}} = 0$$

The extinction angle can be determined using bisect method, the solution of above equation is

$\boxed{\beta = 3.855}$ or $\boxed{\beta = 220.35^\circ}$

* $\delta = \beta - \alpha = 3.855 - 0.7753$

$\boxed{\delta = 3.0797.}$

(b) <u>RMS o/p voltage :-</u>

$$V_o = \frac{V_m}{} \sqrt{\frac{(\beta-\alpha) + \frac{\sin 2\alpha}{2} - \frac{\sin 2\beta}{2}}{2\pi}}$$

$$V_o = 169.7056 \sqrt{\frac{(3.855 - \pi/2) + \frac{\sin 2(\pi/2)}{2} - \frac{\sin 2(3.855)}{2}}{2\pi}}$$

$$V_o = 169.7056 \sqrt{\frac{2.2842 - 0.40057 - 0.4948}{2\pi}}$$

$\boxed{V_o = 68.09V}$

(c) <u>RMS o/p current:-</u>

$$I_o = \frac{V_o}{Z}$$

$$Z = \sqrt{R^2 + (\omega L)^2}$$

$$\Rightarrow \quad Z = \sqrt{(2.5)^2 + (2.4504)^2}$$

$$\boxed{Z = 3.5006\,\Omega}$$

$$I_o = \frac{68.09V}{3.5006}$$

$$\boxed{I_o = 19.45A}$$

(d) $$PF = \frac{P_o}{P_i}$$

$$P_o = I_o^2 R_L = (19.45)^2 \times 2.5$$

$$P_o = 945.84$$

$$P_i = I_o V_s = \boxed{2,334W}$$

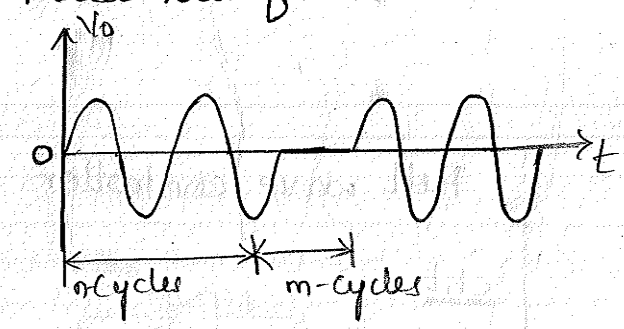
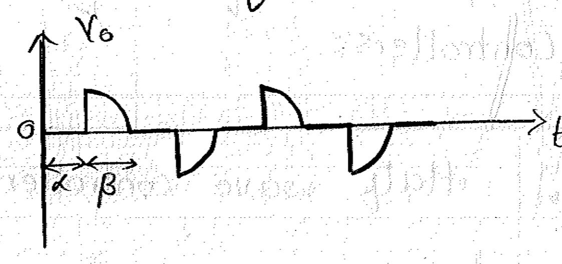
$$PF = \frac{P_o}{P_i} = \frac{945.84}{2.334}$$

$$\boxed{PF = 0.4052}$$ (lagging)

❖ **Distinguish between ON-OFF control and phase control of ac voltage controller.** **Jan-10,4M**

❖ **Compare and contrast ON-OFF control with phase control as applied to ac voltage controllers.**

June-05,6M June-10,6M(IT)

SL No	ON-OFF Control	Phase Control.
1>	O/p voltage is controlled by controlling the number of ON cycles 'n' & number of OFF cycles 'm'	O/p voltage is controlled by controlling the phase angle or firing angle α of the thyristor.
2>	Load waveform:  	Load waveform: 
3>	Thyristor conducts 180° as it is triggered at $\alpha = 0°$	Thyristor is triggered at some angle depending upon o/p power.
4>	No harmonics due to the switching at zero crossing instants.	Harmonics are present due to switching at instants other than zero crossings.
5>	Load voltage waveform is not distorted	Load voltage waveform is distorted. Distortion increases with increase in α.
6>	Average (dc) load voltage & load current is zero	Average (dc) load voltage & load current is zero.

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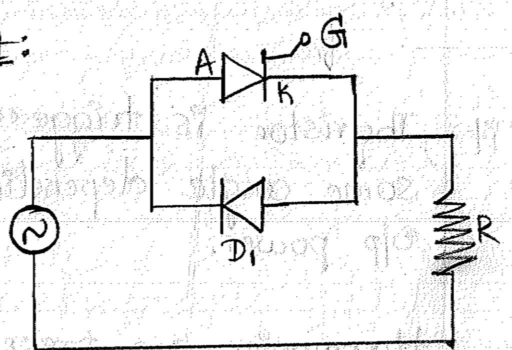
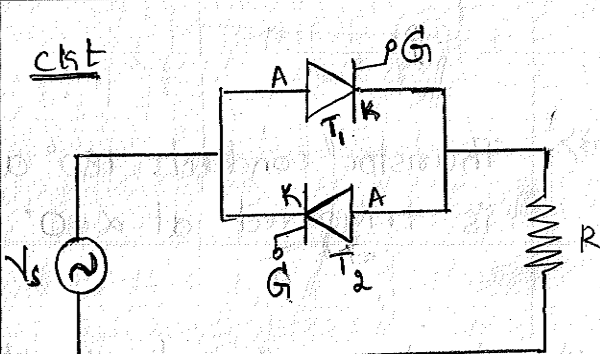
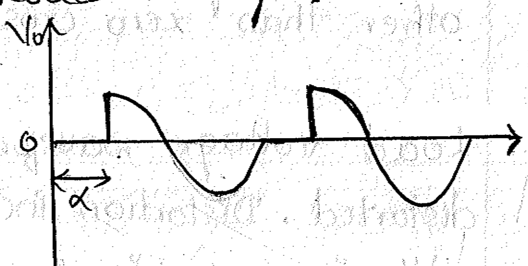
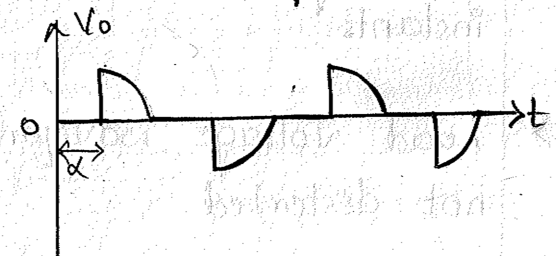
7>	Load voltage will be equal to full supply voltage or zero. Hence o/p waveform has high voltage fluctuations	Supply voltage is applied partially to load. Hence there is less voltage fluctuations.
8>	Applications : Industrial heating, speed control of induction motor. etc	Applications :- Heat control, light dimmer, fan regulators etc.

* Comparision of Half wave and full wave ac voltage controllers:

Sl No	Half wave controller	Full wave controller
1>	CKt: 	ckt 
2>	Load voltage: 	Load voltage: 
3>	Only half cycle of the supply is controlled.	Both the half cycles of the supply are controlled.

4>	Half wave controller generate asymmetric voltage and current across load.	Full wave controllers generate symmetric voltage & currents across the load.
5>	RMS load voltage $V_{o(rms)} = \frac{V_m}{2}\sqrt{\frac{(2\pi-\alpha)+\frac{\sin 2\alpha}{2}}{\pi}}$	RMS load voltage $V_o = \frac{V_m}{\sqrt{2}}\sqrt{\frac{(\pi-\alpha)+\frac{\sin 2\alpha}{2}}{\pi}}$
6>	Average (dc) load voltage $V_{dc} = \frac{V_m}{2\pi}[\cos\alpha - 1]$	Average dc load voltage $V_{dc} = 0$.
7>	Average (dc) load current $I_{dc} = \frac{V_{dc}}{R}$	Average (dc) load current $I_{dc} = 0$.
8>	Core saturation is possible due to the presence of dc value for supply and load current.	Core saturation does not take place as $I_{dc} = 0$.

❖ **What are advantages and disadvantages of ON-OFF control and phase control of ac voltage controller?** **June-10,8M**

POWER ELECTRONICS

7th Sem E&C

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DC CHOPPERS

Introduction :-

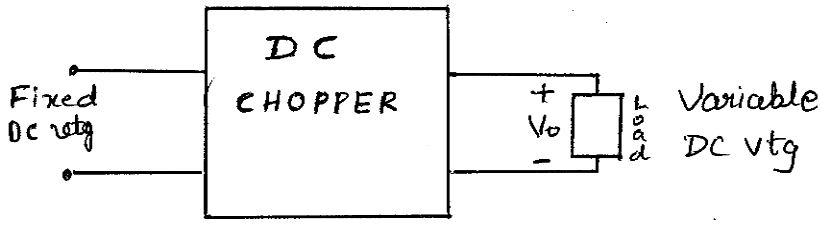


Fig. Block diagram of a chopper

- The DC Choppers convert the input DC voltage into fixed or variable DC output. Hence DC chopper is also called as dc to dc converter.
- The output 'V_o' can be greater or lesser than the input. Hence the chopper can be step-down or step-up type.

APPLICATION :-

DC traction drives, trolley cars, Marine lifts, dc voltage regulators etc.

Principle of STEP-DOWN operation (With R- Load):-

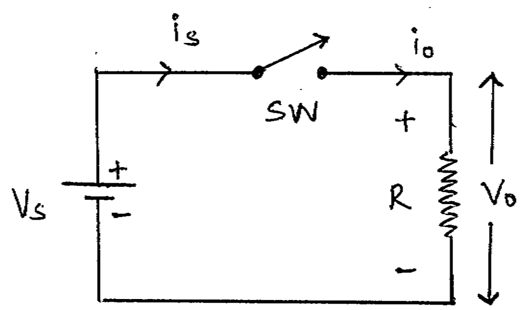
- **With the help of a circuit diagram and waveforms explain the working of a DC chopper. Derive an expression for**
  i) Output voltage ii) Output power **June-06,12M**
- **With the help of a neat circuit diagram explain the principle of a step down chopper.** **Jan-06,6M**

❖ **With the aid of a basic circuit and waveform explain the basic principles of operation of a step-down chopper with resistive load. Obtain the expressions for**

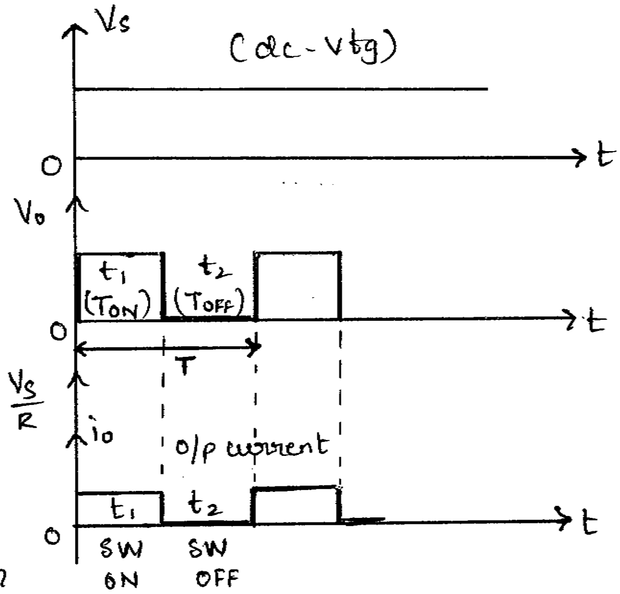
i) DC O/P voltage ii) O/P power iii) Chopper efficiency

Jan-05,10M

Principle of Step-down operation :-



ⓐ Circuit diagram



ⓑ Waveforms.

fig ⓐ shows the circuit diagram of Basic step down chopper.

The Switch (SW) can be a power transistor, SCR, GTO, power MOSFET etc.

* When the switch SW is closed for a time 't_1' the input Voltage 'V_s' appears across the load ie $\boxed{V_o = V_s}$ If the switch remains open (OFF) for a time t_2, the voltage across the load is zero ie $\boxed{V_o = 0}$

The power semiconductor devices (switch) have a finite voltage drop ranging from 0.5V to 2V, and for the sake of simplicity we shall neglect the voltage drop of these power semiconductor devices.

Average o/p Voltage :- ($V_a = V_{dc} = V_{o(av)}$)

$$V_a = \frac{1}{T}\int_0^{t_1} V_o \, dt \qquad \boxed{V_o = V_s}$$

$$= \frac{1}{T}\int_0^{t_1} V_s \cdot dt = \frac{V_s}{T}\int_0^{t_1} 1 \cdot dt$$

$$= \frac{V_s}{T}\left[t\right]_0^{t_1} = \frac{V_s}{T} \cdot t_1$$

$$= \frac{t_1}{T} \cdot V_s$$

$$\boxed{V_a = K V_s}$$

$K = \frac{t_{ON}}{t_{ON} + t_{OFF}}$

$K = \partial =$ duty cycle

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

Where T is the chopping period

$K = \frac{t_1}{T}$ is called duty cycle of the chopper

f is the chopping frequency

Average load Current (o/p current) :-

$$\boxed{I_a = \frac{V_a}{R} = \frac{KV_s}{R}}$$

RMS Value of o/p voltage :- $\boxed{V_o = V_{o(rms)}}$

$$V_{o(rms)} = \sqrt{\frac{1}{T}\int_0^{t_1} V_o^2 \cdot dt}$$

WKT $K = \frac{t_1}{T}$ $\therefore$ $\boxed{t_1 = KT}$ $\boxed{V_o = V_s}$

$$V_{o(rms)} = \sqrt{\frac{1}{T}\int_0^{KT} V_s^2 \cdot dt}$$

$$= \sqrt{\frac{V_s^2}{T}\int_0^{KT} 1 \cdot dt}$$

$$= V_s \sqrt{\frac{1}{\cancel{T}}(K\cancel{T})} = V_s\sqrt{K}$$

$$\boxed{V_{o(rms)} = \sqrt{K} \cdot V_s}$$

RMS Value of load current :-

$$\boxed{I_{(rms)} = \frac{V_{o(rms)}}{R}}$$

O/p power :-

Assuming lossless chopper, the I/p power to the Chopper is the same as o/p power & is given by

$$P_o = \frac{1}{T}\int_0^{t_1 = KT} V_o \cdot I_o \, dt$$

$$\boxed{P = VI}$$

$$P_o = \frac{1}{T}\int_0^{KT} V_o \cdot \frac{V_o}{R} \, dt$$

$$i_o = \frac{V}{R}$$

$$t_1 = KT$$

$$P_o = \frac{1}{T}\int_0^{KT} \frac{V_o^2}{R} \cdot dt$$

$$\boxed{V_o = V_s}$$

$$= \frac{V_s^2}{RT}\int_0^{KT} 1 \cdot dt = \frac{V_s^2}{RT}[KT]$$

$$\boxed{P_o = \frac{KV_s^2}{R}}$$

$$= \frac{V_s \cdot (V_s - V_{ch})}{TR} (KT)$$

$$\boxed{P_i = K \cdot \frac{V_s (V_s - V_{ch})}{R}}$$

FORMULAE

1) Average o/p Voltage

$$\boxed{V_{o(avg)} = V_a = V_{dc} = KV_s} \qquad \boxed{V_a = V_{dc} = K(V_s - V_{ch})}$$

2) Duty cycle of the chopper.

$$K = \frac{t_1}{T} = \frac{t_{ON}}{t_{ON} + t_{OFF}}$$

3) Average load current

$$\boxed{I_a = I_{dc} = \frac{V_a}{R} = \frac{KV_s}{R}} \qquad \boxed{I_{dc} = I_a = \frac{K(V_s - V_{ch})}{R}}$$

4) RMS Value of O/p Voltage :- $(V_o = V_{rms})$

$$V_{o(rms)} = \sqrt{K}\, V_s \quad \Big| \quad V_{o(rms)} = \sqrt{K} \cdot (V_s - V_{ch})$$

5) RMS Value of load current

$$I_{(rms)} = \frac{V_{o(rms)}}{R}$$

6) O/p power

i) Ideal chopper (switch) $P_o = \frac{KV_s^2}{R}$

Effective I/p Resistance :-

$$R_i = \frac{V_s}{I_a} = \frac{\cancel{V_s}}{\frac{K\cancel{V_s}}{R}}$$

$$\boxed{R_i = \frac{R}{K}}$$

O/p power :-

Let V_{ch} be the drop across the switch (chopper)

$$P_o = \frac{1}{T}\int_0^{KT} \frac{V_o^2}{R}\, dt$$

$$= \frac{1}{T}\int_0^{KT} \frac{(V_s - V_{ch})^2}{R} \cdot dt$$

$$= \frac{(V_s - V_{ch})^2}{TR}\left[t\right]_0^{KT} = \frac{(V_s - V_{ch})^2 \cdot K\cancel{T}}{\cancel{T}R}$$

$$\boxed{P_o = \frac{(V_s - V_{ch})^2 \cdot K}{R}}$$

I/p power :-

$$P_i = \frac{1}{T}\int_0^{KT} V_s \cdot i\, dt$$

$$= \frac{1}{T}\int_0^{KT} V_s \cdot \left(\frac{V_s - V_{ch}}{R}\right) \cdot dt$$

$$= \frac{V_s (V_s - V_{ch})}{TR}\int_0^{KT} 1 \cdot dt$$

$$= \frac{V_s (V_s - V_{ch})}{TR}\left[t\right]_0^{KT}$$

Ideal Switch

$$\boxed{i = \frac{V_s}{R}}$$

$$\boxed{i = \frac{V_s - V_{ch}}{R}}$$

practical switch

ii) Practical chopper (switch)
ie vtg drop across switch $P_o = \frac{K(V_s - V_{ch})^2}{R}$

7) I/p power

i) Ideal $P_i = \frac{KV_s^2}{R}$

ii) Practical $P_i = \frac{KV_s(V_s - V_{ch})^2}{R}$

8) Effective I/p resistence $\boxed{R_i = \frac{R}{K}}$

9) Chopper efficiency.

$$\eta = \frac{\text{Road Power (o/p power)}}{\text{Supply power (I/p power)}}$$

$$\eta = \frac{P_o}{P_i}$$

10) Form factor

$$FF = \frac{V_{o(rms)}}{V_{dc}}$$

11) Ripple factor

$$RF = (FF^2 - 1)^{1/2}$$

12) $T = \frac{1}{f}$

13) WKT $V_{o(av)} = V_{dc} = V_a = KV_s = \frac{T_{ON}}{T} V_s$

$$T_{ON} = \frac{V_{o(av)} \cdot T}{V_s}$$

14) DC I/p Voltage to the chopper
WKT $V_o = K(V_s - V_{ch}) \Rightarrow \frac{V_o}{K} = V_s - V_{ch}$

$$\boxed{V_s = V_o/K + V_{ch}}$$

Step Down Chopper - PROBLEMS

1) **The dc converter in fig1 has a resistive load of R=10Ω and the input voltage is Vs=220v. When the converter switch remains ON, its voltage drop is v_{ch} = 2V and the chopping frequency is f=1KHz. If the duty cycle is 50%, determine**

   a) **The average output voltage V_a**

   b) **The rms output voltage V_o**

   c) **The converter efficiency**

   d) **The effective input resistance R_i of the converter.**

Given:- $V_s = 220V$, $K = 0.5$, $R = 10\Omega$, $V_{ch} = 2V$, $f = 1KHz$

Sol:- a) $V_a = K(V_s - V_{ch}) = 0.5 \times (220-2) = 109V$

b) $V_o = \sqrt{K}\,(V_s - V_{ch}) = \sqrt{0.5} \times (220-2) = 154.15V$

c) Chopper efficiency $\eta = \frac{P_o}{P_i}$

* $P_o = \frac{K(V_s - V_{ch})^2}{R} = \frac{0.5(220-2)^2}{10\Omega}$

$\boxed{P_o = 2376.2\ W}$

* $P_i = \frac{K V_s (V_s - V_{ch})}{R} = \frac{0.5 \times 220(220-2)}{10}$

$\boxed{P_i = 2398\ W}$

$\eta\,\% = \frac{P_o}{P_i} \times 100 = \frac{2376.2}{2398} \times 100 = 99.09\%$

d) Effective I/p resistance

$R_i = \frac{R}{K} = \frac{10}{0.5}$

$\boxed{R_i = 20\Omega}$

2) A Step down dc chopper has a resistive load of R=15Ω and input voltage of Edc=200V, when the chopper remains ON, its voltage drop is 2.5V. The chopper frequency is 1KHz. If the duty cycle is 50%, determine :

i) Average output voltage

ii) RMS output voltage,

iii) Chopper efficiency

iv) Effective input resistance of chopper.

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Given :- $R = 15\Omega$, $V_s = E_{dc} = 200V$, $V_{ch} = 2.5V$, $f = 1KHz$

$K = 0.5$.

Soln :- i) Average o/p Voltage

$$V_o = V_a = K(V_s - V_{ch}) = 0.5(200V - 2.5V)$$

$$\boxed{V_o = V_a = 98.75V} \longleftarrow \text{2m}$$

ii) RMS o/p Voltage

$$V_{o(rms)} = \sqrt{K}(V_s - V_{ch}) = \sqrt{0.5} \times (200V - 2.5V)$$

$$\boxed{V_{o(rms)} = 139.653V} \longleftarrow \text{2m}$$

iii) Chopper efficiency

$$\eta\% = \frac{P_o}{P_i} \times 100$$

* $P_o = \frac{K(V_s - V_{ch})^2}{R} = \frac{0.5(200-2.5)^2}{15}$

$$\boxed{P_o = 1300.21 \text{ Watts}} \longleftarrow \text{1m}$$

* $P_i = \frac{KV_s(V_s - V_{ch})}{R} = \frac{0.5 \times 200(200-2.5)}{15}$

$$\boxed{P_i = 1316.67 \text{ watts}} \longleftarrow \text{1m}$$

$$\eta\% = \frac{P_o}{P_i} \times 100 = \frac{1300.21\,W}{1316.67\,W} \times 100$$

$$\boxed{\eta\% = 98.74}$$ ← (2m)

iv) Effective I/p resistance of the chopper

$$R_i = \frac{R}{K} = \frac{15\Omega}{0.5}$$

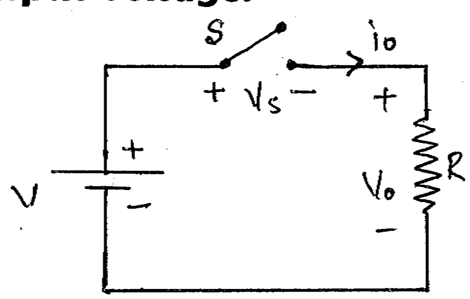
$$\boxed{R_i = 30\Omega}$$ ← (2m)

3) In the chopper circuit shown in fig1, the average output voltage is 109V. The voltage drop across chopper switch when it is ON is Vs=2v. The load resistor R=10Ω , f=1.5KHz and duty cycle ratio ∂=50%. Calculate the

i) Dc input voltage to the chopper

ii) Rms output voltage.

June-11,4M



Given :- $\partial = K = 0.5$, $V_o = 109V$, $V_s = V_{ch} = 2V$, $R = 10\Omega$, $f = 1.5\,KHz$

Soln :-

i) DC I/p Voltage to the chopper

$$V_s = \frac{V_o}{K} + V_{ch} = \frac{109V}{0.5} + 2V$$

$$\boxed{V_s = 220V}$$ ← (2m)

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ii) RMS o/p Voltage

$V_{o(rms)} = \sqrt{K}(V_s - V_{ch}) = \sqrt{0.5} \times (220V - 2V)$

$\boxed{V_{o(rms)} = 154.15V}$ ← 2m

4) **In the chopper circuit shown in fig1, the average output voltage is 109V. The voltage drop across chopper switch when it is ON is Vs=2v. The load resistor R=10Ω , f=1.5KHz and duty cycle ratio ∂=50%. Calculate the**

i) Dc input voltage to the chopper **June-09,6M**

ii) Rms output voltage.

iii) The chopper efficiency

iv) Input resistance of chopper.

Given :- $V_o = 109V$, $V_{ch} = 2V$, $R = 10\Omega$, $K = \partial = 0.5$

Soln:-

i) $V_s = \frac{V_o}{K} + V_{ch} = \frac{109V}{0.5} + 2V$

$\boxed{V_s = 220V}$ ← 1.5m

ii) $V_{o(rms)} = \sqrt{K}(V_s - V_{ch}) = \sqrt{0.5} \times (220V - 2V)$

$\boxed{V_{o(rms)} = 154.15V}$ ← 1.5m

iii) $\eta\% = \frac{P_o}{P_i} \times 100$

* $P_o = \frac{K(V_s - V_{ch})^2}{R} = \frac{0.5(220-2)^2}{10\Omega}$

$$\boxed{P_o = 2876.2W}$$

$$* \quad P_i = \frac{KV_s(V_s - V_{ch})}{R} = \frac{0.5 \times 220 \times (220-2)}{10\Omega}$$

$$\boxed{P_i = 2398\,W}$$

$$\eta\% = \frac{2876.2W}{2398\,W} \times 100$$

$$\boxed{\eta\% = 99.09\%}$$

iv) $R_i = \frac{R}{K} = \frac{10\Omega}{0.5}$

$$\boxed{R_i = 20\Omega} \longleftarrow 1.5m$$

5) In dc chopper shown in fig1 has a resistance load of 10Ω and the input voltage, Vs=200v. When the chopper switch is ON, its voltage drop is 2V and the chopping frequency is 1KHz. If the duty cycle is 50% determine

i) Average output voltage

ii) RMS output voltage

iii) The chopper efficiency

iv) The effective input resistance of the chopper.

Jan-09,8M

Given :- $K = \delta = 0.5$, $V_s = 200V$, $V_{ch} = 2V$, $R = 10\Omega$

<u>Soln</u> :-

i) $V_a = K(V_s - V_{ch}) = 0.5(200V - 2V)$

$\boxed{V_a = 99V}$ ⟵ 2m

ii) $V_{o(rms)} = \sqrt{K}(V_s - V_{ch}) = \sqrt{0.5} \times (200V - 2V)$

$\boxed{V_{o(rms)} = 140.01V}$ ⟵ 2m

iii) $P_o = \dfrac{K(V_s - V_{ch})^2}{R} = \dfrac{0.5(200-2)^2}{10}$

$\boxed{P_o = 1960.2W}$

* $P_i = \dfrac{KV_s(V_s - V_{ch})}{R} = \dfrac{0.5 \times 200(200-2)}{10\Omega}$

$\boxed{P_i = 1980 W}$

$\eta\% = \dfrac{P_o}{P_i} \times 100 = \dfrac{1960.2W}{1980} \times 100.$

$\boxed{\eta\% = 99\%}$ ⟵ 2m

iv) $R_i = \dfrac{R}{K} = \dfrac{10\Omega}{0.5}$

$\boxed{R_i = 20\Omega}$ ⟵ 2m

---

6) A dc chopper has an input voltage of 200v and a load of 8Ω resistance. The voltage drop across thyristor is 2v and the chopper frequency is 800Hz. The duty cycle α=0.4. Find

i) Average output voltage

ii) RMS output voltage

iii) Chopper efficiency.

June-07,4M

Given :- $V_s = 200V$, $R = 8\Omega$, $V_{ch} = 2V$, $\alpha = K = 0.4$

Sol :- i> $V_a = K(V_s - V_a) = 0.4\,(200 - 2V)$

$$\boxed{V_a = 79.2\,V}$$

ii> $V_{o(rms)} = \sqrt{K}\,(V_s - V_{ch}) = \sqrt{0.4} \times (200 - 2)$

$$\boxed{V_{o(rms)} = 125.22\,V}$$

iii) $P_o = \dfrac{K(V_s - V_{ch})^2}{R} = \dfrac{0.4(200-2)^2}{8\,\Omega}$

$$\boxed{P_o = 1960.2\,W}$$

$P_i = \dfrac{K V_s (V_s - V_{ch})}{R} = \dfrac{0.4 \times 200\,(200-2)}{8\,\Omega}$

$$\boxed{P_i = 1980\,W}$$

$\eta\% = \dfrac{P_o}{P_i} \times 100 = \dfrac{1960.2\,W}{1980\,W} \times 100$

$$\boxed{\eta\% = 99\%}$$

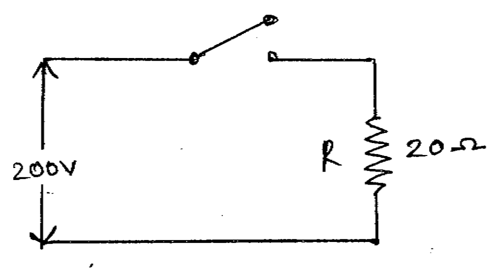
---

7) Consider the switch, to be ideal in the circuit of fig1, determine:

i) The duty cycle, K for which the output average dc voltage and rms voltage are equal

ii) The chopper efficiency.

June-04,4M



Sol :-

i> Duty cycle for which the o/p average dc Voltage and rms voltage are equal.

WKT

Average Voltage is $\boxed{V_a = K V_s} \longrightarrow (1)$

RMS Voltage is $\boxed{V_{o(rms)} = \sqrt{K}\, V_s}$ ⟶ (2)

Equating eq (1) & (2)

$$V_a = V_{o(rms)}$$

$$K V_s = \sqrt{K}\, V_s$$

$$K = \sqrt{K}$$

This is possible for $\boxed{K = 1}$ ⟵ (2m)

ii) Chopper efficiency :

The switch in fig (1) is ideal. Hence the are no losses in the chopper.

$$\boxed{\eta\,\% = 100\,\%}$$ ⟵ (2m)

Chopper Control Techniques or Methods of Chopper Control :-

❖ **Explain the different control strategies used in choppers.**

June-11,6M

1) Constant frequency Operation or Pulse width modulation (PWM)

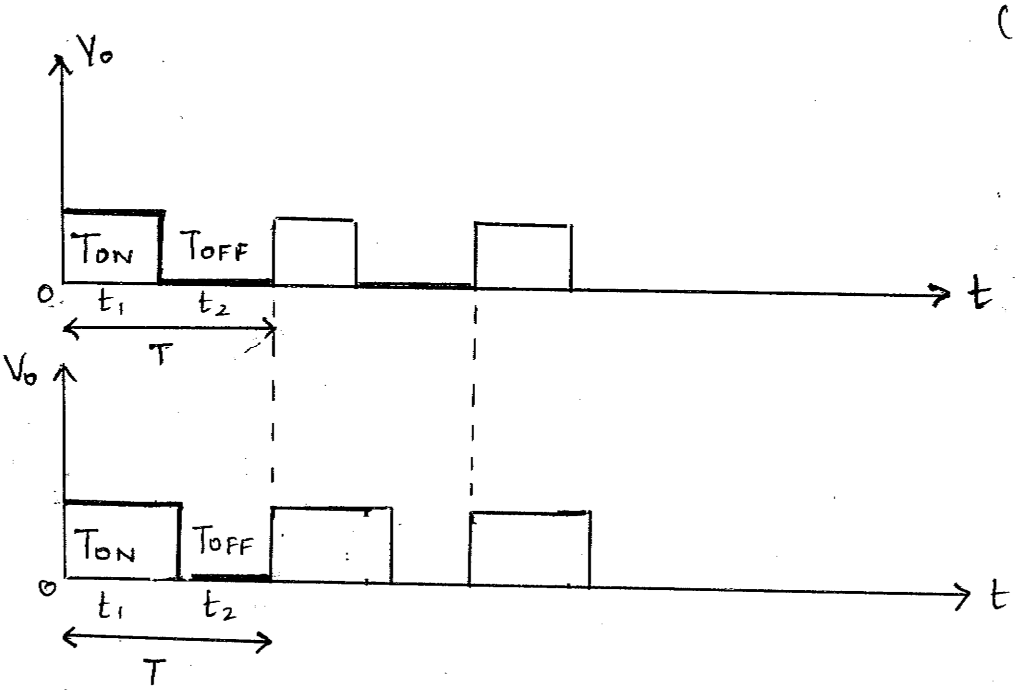


fig ⓐ : PWM Control of chopper o/p

* In this method, the chopping frequency is kept constant and the ON-time 't_1' is varied. This control is called PWM
* The total period 'T' of (one cycle) o/p waveform is constant. Therefore the chopping frequency $f = 1/T$ is also constant.

2). Variable frequency operation (Frequency Modulation)

The chopping frequency 'f' is varied keeping either t_{ON} or t_{OFF} constant. This method is also known as frequency modulation

fig ⓑ Shows the o/p vtg W/F's for a constant t_{ON} & variable chopping period 'T'.

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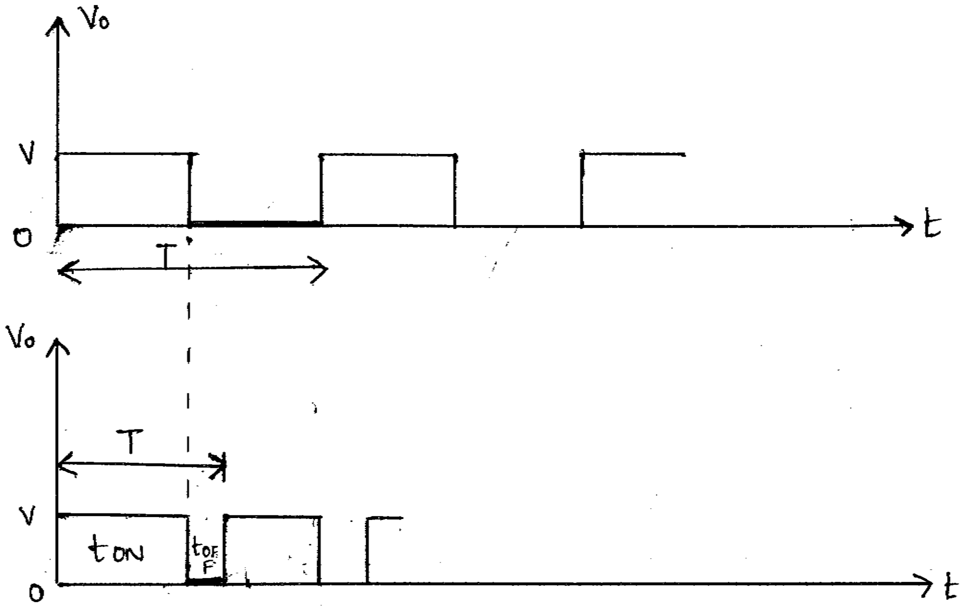


fig ⑥ Frequency control of chopper o/p

* The frequency has to be varied over a wide range to obtain full o/p voltage range.
This method produces harmonics in the o/p at unpredicted frequency & the filter design would be difficult.

STEP DOWN chopper with RL load :-

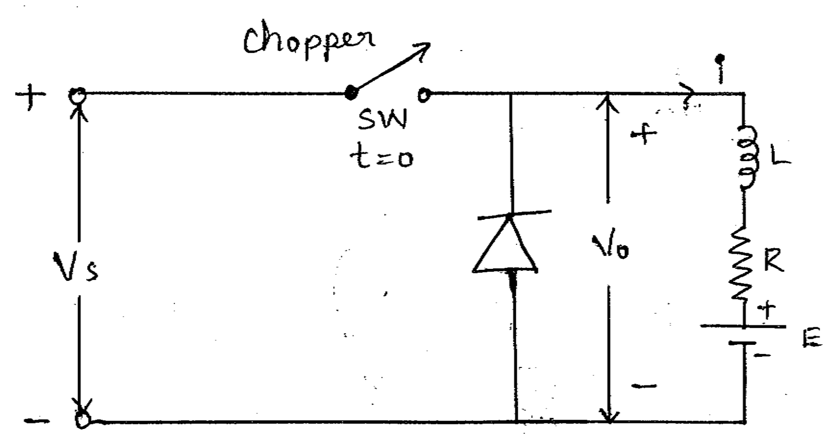
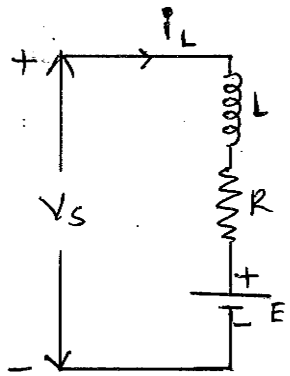


fig ⑦ : Step down chopper with RL Load.

❖ **With circuit diagram, equivalent circuit and waveforms of load voltage and load current, discuss the operation of a step down dc chopper with R-L load. Distinguish between continuous and discontinuous current modes of operation.** **June-04,10M**

Mode 1 :



Mode 2 :

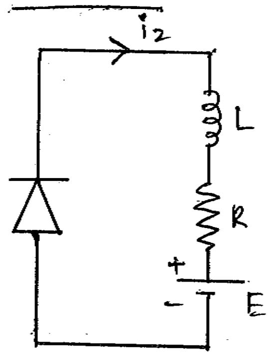


fig ② ⓐ Equivalent ckt

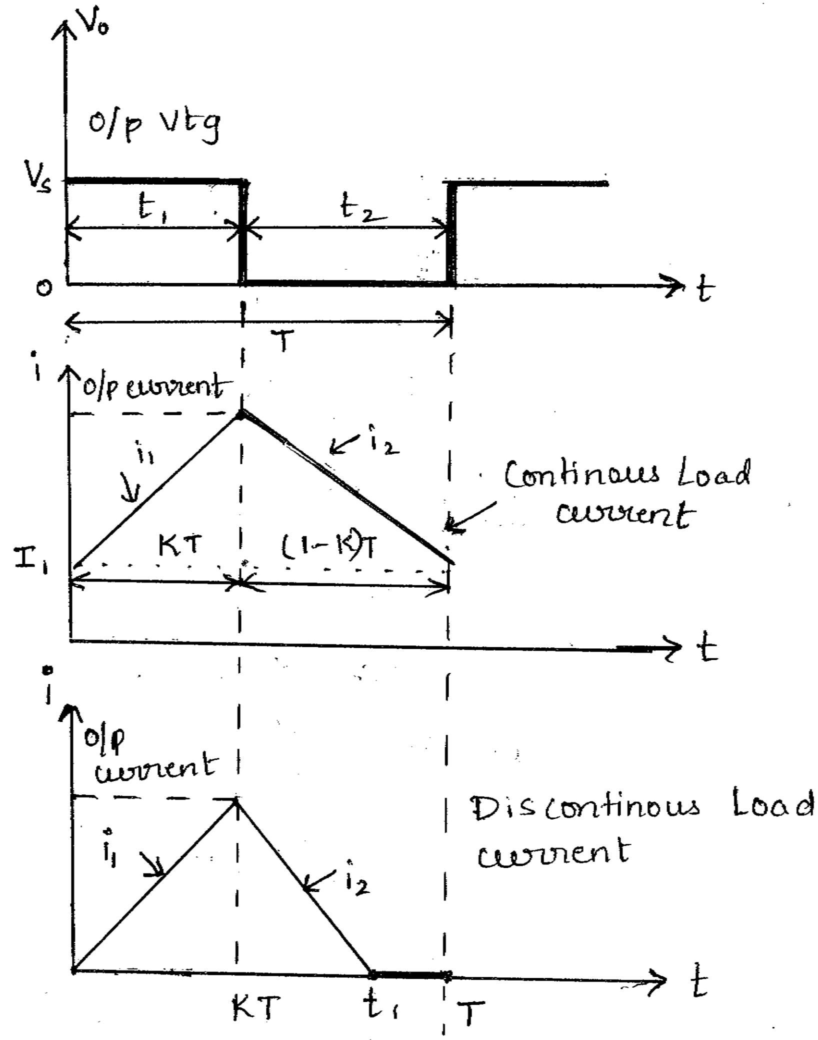


fig 2 ⓑ Waveforms

Fig ②: Equivalent ckt and waveforms of RL Load.

* WKT $K = \frac{t_1}{T}$

$\therefore \boxed{t_1 = KT}$

* WKT $T = t_1 + t_2$

$t_2 = T - t_1 = T - KT$

$\boxed{t_2 = T(1-K)}$

fig ① shows the step down chopper with RL Load.

The operation of the converters can be divided into two modes.

i) <u>Mode 1</u>: Chopper (converter) is switched ON and the current flows from the supply to the load.

ii) <u>Mode 2</u>: chopper (converter) is switche off and the load current continues to flow through free wheeling diode Dm

fig ② ⓐ shows the equivalent ckt of mode 1 & mode 2

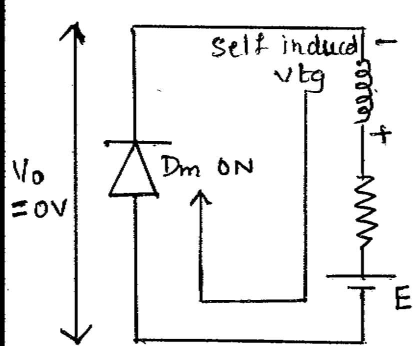
<u>Continous load current</u>

During the interval 0 to t_1, the switch 'SW' is turned ON ie closed. The o/p vtg is equal to the supply vtg ie $\boxed{V_0 = V_s}$

* The load current changes between I_1 to I_2

During the interval t_1 to t_2, the switch 'SW' is OFF. At t_1, the o/p current is at I_2. The current through L is interrupted. This will induce a self induced emf. across L.

This self reduced voltage is large enough to forward bias the free wheeling diode Dm.



Now load current decreases from I_2 to I_1 as shown in fig ② ⓑ. The o/p Vtg V_0 = 0V.

❖ **Describe the operation of step-down chopper with RL load. Derive an expression for maximum ripple of continous current.**

June-08,10M

Discontinous current :- If the inductance of the load is small then load current may be discontinous.

During the interval 0 to KT, the switch is closed & the load current starts increasing exponentially from 'zero' & current reaches to I_2 at KT.

Thus o/p vtg $\boxed{V_0 = V_s}$. The chopper switch is turned OFF at this instant.

During the interval KT to T, the switch is OFF. The freewheeling diode conducts from KT to t_1. At t_1, the load current becomes zero. The load inductance supplies the energy from KT to t_1.

The load current is zero from t_1 to T. Thus the load current is discontinous.

Thus

$V_0 = V_s$ from 0 to KT and.

$V_0 = 0$ from t_1 to T

Expression for continous load current :-

Mode 1 :-

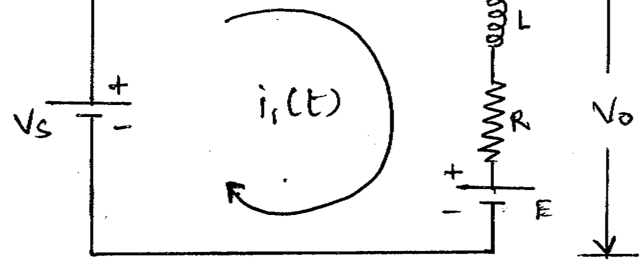


fig ①

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Applying KVL to fig ①, we get

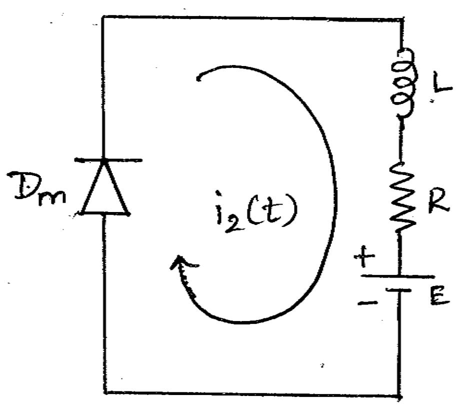
$$V_s - L\frac{di_1(t)}{dt} - i_1(t)R - E = 0$$

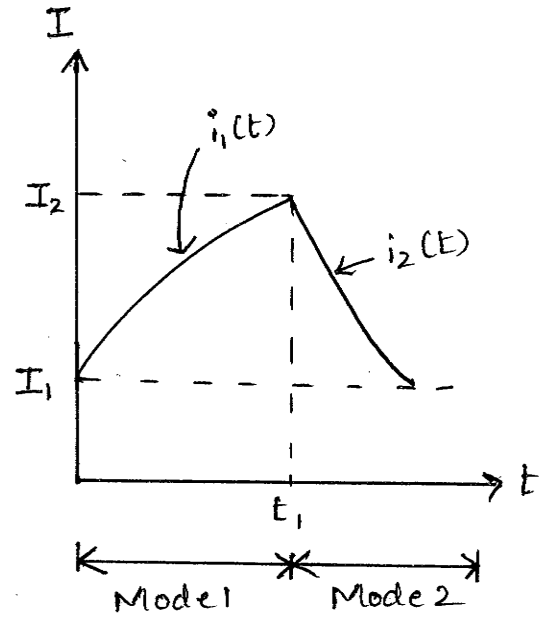
$$\boxed{V_s = L\frac{d}{dt}i_1(t) + i_1(t)R + E} \longrightarrow ①$$

Taking Laplace transform & then Inverse laplace transform of eqn ①, we get

$$\boxed{i_1(t) = I_1 e^{-tR/L} + \frac{V_s - E}{R}\left[1 - e^{-tR/L}\right]} \longrightarrow ②$$

Mode 2 :-





Applying KVL to fig ②, we get

$$\boxed{0 = L\frac{d}{dt}i_2(t) + i_2(t)R + E} \longrightarrow ③$$

Taking Laplace transform & then Inverse laplace transform we get

$$\boxed{i_2(t) = I_2 e^{-tR/L} - \frac{E}{R}\left[1 - e^{-tR/L}\right]}$$

* The minimum value of load current is

$$\boxed{I_1 = I_2 e^{-(1-K)TR/L} - \frac{E}{R}\left[1 - e^{-(1-K)TR/L}\right]}$$

* The maximum value of load current is.

$$\boxed{I_2 = I_1 e^{-tR/L} + \frac{V_S - E}{R}\left[1 - e^{-tR/L}\right]}$$

* The peak to peak load current (or ripple current) can be obtained by

$$\Delta I = I_2 - I_1$$

$$\boxed{\Delta I = \frac{V_s}{R}\left[\frac{1 - e^{-KTR/L} - e^{-(1-K)\frac{TR}{L}} + e^{-TR/L}}{1 - e^{-TR/L}}\right]}$$

Note :

* The maximum value of load current $\boxed{I_{max} = I_2}$
* The minimum value of load current $\boxed{I_{min} = I_1}$
* The peak to peak ripple current or load current

$$\boxed{\Delta I = I_{O(P-P)}}$$

❖ Expression for continuous load current :-

❖ **Prove that maximum ripple occurs in the output current of stepdown chopper when duty cycle is 0.5. And the value of maximum ripple current is given as**

$$I_{o\,max}(P-P) = \frac{V_s}{R}\tanh\left(\frac{TR}{4L}\right)$$

$$I_{o(max)}^{(P-P)} = \Delta I_{max} = \frac{V_s}{R}\tanh\left(\frac{R}{4fL}\right)$$

Soln:- WKT

$$\Delta I = \frac{V_s}{R}\frac{1}{1-e^{-TR/L}}\left(1-e^{-KTR/L}-e^{-(1-K)TR/L}+e^{-TR/L}\right) \longrightarrow (1)$$

* The condition for maximum ripple is

$$\frac{d(\Delta I)}{dK} = 0$$

$$\frac{d}{dK}\left[\frac{V_s}{R}\left[\frac{1-e^{\frac{-KTR}{L}}+e^{-TR/L}-e^{-(1-K)TR/L}}{1-e^{-\frac{TR}{L}}}\right]\right] = 0$$

$$\frac{d}{dK}\left[-e^{\frac{-KTR}{L}} - e^{\frac{-(1-K)TR}{L}}\right] = 0$$

$$-e^{-KTR/L}\cdot\left(-\frac{TR}{L}\right) - e^{-(1-K)TR/L}\cdot\left[\frac{TR}{L}\right] = 0$$

$$e^{-KTR/L}\left(\frac{T\cancel{R}}{\cancel{L}}\right) = e^{-(1-K)TR/L}\cdot\left(\frac{T\cancel{R}}{\cancel{L}}\right)$$

Applying logarithm we get

$$-\frac{KT\cancel{R}}{\cancel{L}} = -(1-K)\frac{T\cancel{R}}{\cancel{L}}$$

$$-K = -1+K$$

$$1 = K+K$$

$2K = 1$

$\boxed{K = 0.5}$

So maximum ripple current is obtained at $K = 0.5$ Then eq ① can be written as.

$$\Delta I_{(max)} = \frac{V_s}{R}\left[\frac{\left(1 - e^{-\frac{KTR}{L}}\right) - e^{-(1-K)TR/L} + e^{-TR/L}}{1 - e^{-TR/L}}\right] \quad \text{----}\rightarrow ②$$

Eq ② can be written as.

$$\Delta I_{(max)} = \frac{V_s}{R}\left[\frac{\left(1 - e^{-\frac{KTR}{L}}\right)\left(1 - e^{-\frac{(1-K)TR}{L}}\right)}{1 - e^{-\frac{TR}{L}}}\right]$$

put $\frac{TR}{L} = x$ in above equation, we get

$$\Delta I_{(max)} = \frac{V_s}{R}\left[\frac{\left(1 - e^{-Kx}\right)\left(1 - e^{-(1-K)x}\right)}{\left(1 - e^{-x}\right)}\right]$$

put $K = 0.5$

$$\Delta I_{(max)} = \frac{V_s}{R}\left[\frac{\left(1 - e^{-0.5x}\right)\left(1 - e^{-0.5x}\right)}{\left(1 - e^{-x}\right)}\right]$$

$$\Delta I_{(max)} = \frac{V_s}{R}\left[\frac{\cancel{\left(1 - e^{-0.5x}\right)}\left(1 - e^{-0.5x}\right)}{\cancel{\left(1 - e^{-0.5x}\right)}\left(1 + e^{-0.5x}\right)}\right]$$

$$\Delta I_{(max)} = \frac{V_s}{R}\left[\frac{1 - e^{-0.5x}}{1 + e^{-0.5x}}\right]$$

$$\Delta I_{(max)} = \frac{V_s}{R} \tanh\left(\frac{x}{4}\right)$$

put $x = \frac{TR}{L}$

$$\therefore \Delta I_{(max)} = V_s/R \cdot \tanh\left(TR/4L\right)$$

$$\boxed{\Delta I_{(max)} = \frac{V_s}{R} \tanh \frac{R}{4fL}} \dashrightarrow (3)$$

NOTE :-

$$(1 - e^{-x}) = (1 - e^{-0.5x})(1 + e^{-0.5x})$$

$$= 1 + \cancel{e^{-0.5x}} - \cancel{e^{-0.5x}} - e^{-0.5x} \cdot e^{-0.5x}$$

$$= 1 - e^{-0.5x} \cdot e^{-0.5x}$$

$$\boxed{(1 - e^{-x}) = (1 - e^{-x})}$$

❖ **Derive an expression for the load current of the step-down chopper with inductive load having discontinuous load current. Also obtain the time at which the load current becomes zero.**

Soln :-

The load current $i_1(t)$ derived for continous load current is also applicable to discontinous mode.

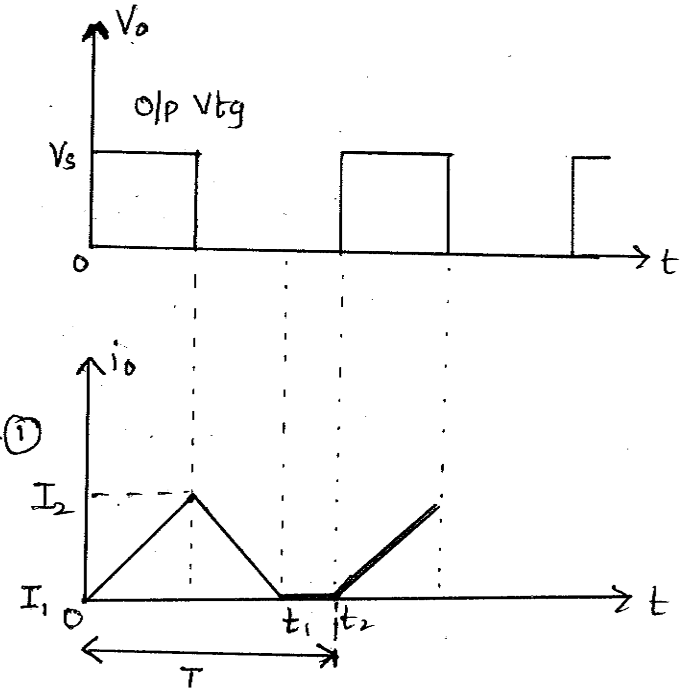


fig : Discontinous load current

WKT

$$i_1(t) = I_1 e^{-tR/L} + \frac{V_s - E}{R}\left[1 - e^{-tR/L}\right] \quad -(1)$$

In discontinous load current

$I_1 = 0$ Thus eqn (1) becomes

$$i_1(t) = 0 + \frac{V_s - E}{R}\left[1 - e^{-tR/L}\right]$$

$$i_1(t) = \frac{V_s - E}{R}\left[1 - e^{-tR/L}\right]$$

For mode 2, we have

$$i_2(t) = I_2 e^{-tR/L} - \frac{E}{R}\left(1 - e^{-tR/L}\right) \longrightarrow (2)$$

This current becomes zero at $t = t_1$, hence eqn (2) becomes

$$0 = I_2 e^{-t_1R/L} - \frac{E}{R}\left(1 - e^{-t_1R/L}\right)$$

$$I_2 e^{-t_1R/L} = \frac{E}{R}\left(1 - e^{-t_1R/L}\right)$$

$$RI_2 e^{-t_1R/L} = E\left(1 - e^{-t_1R/L}\right)$$

$$RI_2 e^{-t_1R/L} = E - Ee^{-t_1R/L}$$

$$RI_2 e^{-t_1R/L} + Ee^{-t_1R/L} = E$$

$$e^{-t_1R/L}\left[RI_2 + E\right] = E$$

$$e^{-t_1R/L} = \frac{E}{RI_2 + E}$$

$$e^{-t_1R/L} = \frac{\cancel{E}}{\cancel{E}\left[\frac{RI_2}{E} + 1\right]}$$

$$e^{-t_1R/L} = \frac{1}{1 + \frac{RI_2}{E}}$$

$$\frac{1}{e^{t_1 R/L}} = \frac{1}{1+\frac{RI_2}{E}}$$

$$1+\frac{RI_2}{E} = e^{t_1 R/L}$$

$$\frac{t_1 R}{L} = \ln\left(1+\frac{RI_2}{E}\right)$$

$$\boxed{t_1 = \frac{L}{R}\ln\left[1+\frac{RI_2}{E}\right]} \text{ sec.}$$

Step down chopper with RL load

FORMULAE

NOTE :-

$I_2 = I_{max}$ & $I_1 = I_{min}$ & Here $E = 0V$.

1) $I_{max} = I_{min}\, e^{-\frac{KTR}{L}} + \frac{V_s - E}{R}\left[1 - e^{-\frac{KTR}{L}}\right]$

2) $I_{min} = I_{max}\, e^{-\frac{(1-K)TR}{L}} - \frac{E}{R}\left[1 - e^{-\frac{(1-K)TR}{L}}\right]$

3) Maximum peak to peak ripple in load current.

$I_{o(p-p)} = I_{max} - I_{min}$ or $I_{o(p-p)} = \frac{V_s}{R}\tanh\left(\frac{R}{4fL}\right)$

4) Average value of load current

$I_{o(avg)} = \frac{I_{max} + I_{min}}{2}$

5) RMS load current

$I_{o(rms)} = \left\{I_{min}^2 + \frac{I_{o(p-p)}^2}{3} + I_{min} \cdot I_{o(p-p)}\right\}^{1/2}$

6) Effective I/p resistance of chopper

$$R_i = \frac{V_s}{I_{s(avg)}}$$

The average source current

$$I_{s(avg)} = K I_{o(avg)}$$

7) RMS chopper current

i) $$I_{T(RMS)} = \sqrt{K}\left\{ I_{min}^2 + \frac{I_{o(P-P)}^2}{3} + I_{min} \times I_{o(P-P)} \right\}^{1/2}$$

OR

ii) $$I_{T(RMS)} = \sqrt{K}\, I_{o(rms)}$$

When E is finite value

1) $$I_{max} = \frac{V_s}{R}\left(\frac{1 - e^{-KTR/L}}{1 - e^{-TR/L}}\right) - \frac{E}{R}$$

2) $$I_{min} = \frac{V_s}{R}\left(\frac{1 - e^{KTR/L}}{1 - e^{TR/L}}\right) - \frac{E}{R}$$

3) Average O/p current

$$I_{o(avg)} = \frac{KV_s - E}{R}$$

4) Check for continous conversion

$$K' = \frac{L}{T} \ln\left[1 - \frac{E}{V_s}\left(1 - e^{T/L}\right)\right]$$

for continous conversion → $\boxed{K > K'}$

PROBLEMS

1) A Chopper is feeding an RL load as shown in fig1. The chopper frequency is 1KHz and duty cycle K=0.5. Calculate :

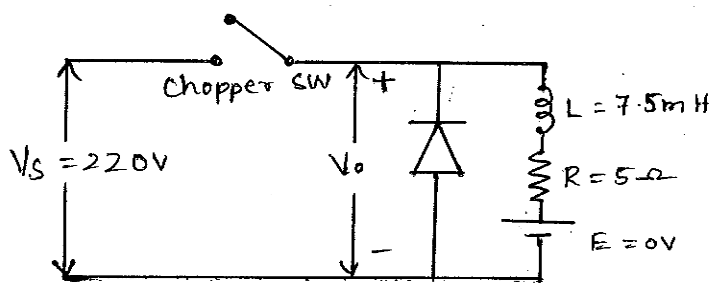
i) The minimum instantaneous load current I_1

ii) The peak instantaneous load current I_2

iii) The average value of load current I_a

iv) The rms load current I_0

Jan-11,8M



Given :- $V_S = 220V$, $L = 7.5mH$, $R = 50\Omega$, $E = 0V$, $K = 0.5$

$$T = \frac{1}{f} = \frac{1}{1KHz} = 1m\,sec$$

Soln :-

$$I_2 = I_1 e^{-\frac{KTR}{L}} + \frac{V_S - E}{R}\left[1 - e^{-\frac{KTR}{L}}\right]$$

$$= I_1 e^{-(0.5 \times 1 \times 10^{-3} \times 5)/7.5mH} + \frac{220V - 0}{5}\left[1 - e^{-\frac{(0.5 \times 1 \times 10^{-3} \times 5)}{7.5mH}}\right]$$

$$= I_1 e^{-0.333} + 44\left[1 - e^{-0.333}\right]$$

$$I_2 = I_1 \times 0.716770 + 44\left[1 - 0.716770\right]$$

$$= 0.716770\, I_1 + 44\,(0.283)$$

$$\boxed{I_2 = 0.716770\, I_1 + 12.462} \longrightarrow (1)$$

$$I_1 = I_2 e^{\frac{-(1-K)TR}{L}} - \frac{E}{R}\left[1 - e^{-(1-K)TR/L}\right]$$

$$I_1 = I_2 e^{[-(1-0.5)1\times10^{-3}\times5]/7.5\times10^{-3}} - \frac{0}{R}\left[1 - e^{\{-(1-0.5)\times1\times10^{-3}\times5\}/7.5\times10^{-3}}\right]$$

$$I_1 = I_2 e^{[-0.5\times10^{-3}\times5]/7.5\times10^{-3}} - 0$$

$$I_1 = I_2 e^{-0.333}$$

$$\boxed{I_1 = 0.716770\, I_2} \longrightarrow (2)$$

Substituting eq (2) in eq (1), we get

$$I_2 = 0.716770(0.716770\, I_2) + 12.462$$

$$I_2 = 0.51875\, I_2 + 12.462$$

$$I_2 - 0.51875\, I_2 = 12.462$$

$$0.486\, I_2 = 12.462$$

$$I_2 = \frac{12.462}{0.486}$$

$$\boxed{I_{max} = I_2 = 25.63\text{ A}} \longrightarrow (3)$$

Substituting eqn (3) in eq (2), we get

$$\boxed{I_1 = 18.36\text{ A}}$$

iii) Maximum peak to peak load ripple current :

I st method :

$$I_{O(p-p)} = I_2 - I_1 = 25.63\text{A} - 18.36\text{ A}$$

$$\boxed{I_{O(p-p)} = 7.27\text{ A}}$$

II nd Method :-

$$I_{o(max)(p-p)} = \frac{V_s}{R}\tanh\left(\frac{R}{4fL}\right)$$

$$= \frac{220}{5}\tanh\left(\frac{5\Omega}{4\times 1KHz\times 7.5\times 10^{-3}}\right)$$

$$= 44\tanh(0.1666)$$

$$\boxed{I_{o(max)(p-p)} = 7.263\text{ A}}$$

NOTE :- 1st press hyp & tan → tanh

iv) Average value of load current :

$$I_{o(avg)} = \frac{I_{max} + I_{min}}{2} = \frac{25.63 + 18.36}{2}$$

$$\boxed{I_{o(avg)} = 21.995\text{ A}}$$

v) RMS load current :-

$$I_{o(rms)} = \left\{I_{min}^2 + \frac{I_{o(p-p)}^2}{3} + I_{min}\, I_{o(p-p)}\right\}^{1/2}$$

$$= \left\{(18.36)^2 + \frac{(7.27)^2}{3} + 18.36\times 7.27\right\}^{1/2}$$

$$\boxed{I_{o(rms)} = 22.095\text{A}}$$

vi) Effective I/p resistance :-

$$I_{s(avg)} = K\, I_{o(avg)} = 0.5\times 22\text{ A}$$

$$\boxed{I_{s(avg)} = 11\text{A}}$$

$$R_i = \frac{V_s}{I_{s(avg)}} = \frac{220\text{V}}{11\text{A}}$$

$$\boxed{R_i = 20\Omega}$$

vii) RMS chopper current

I[st] Method :-

$$I_{T(rms)} = \sqrt{K}\, I_{O(rms)} = \sqrt{0.5} \times 22.095$$

$$\boxed{I_{T(rms)} = 15.62\,A}$$

II[nd] Method :-

$$I_{T(rms)} = \sqrt{K} \left\{ I_{min}^2 + \frac{I_{O(P-P)}^2}{3} + I_{min} I_{O(P-P)} \right\}^{1/2}$$

$$I_{T(rms)} = \sqrt{0.5} \left\{ (18.36)^2 + \frac{(7.27)^2}{3} + 18.36 \times 7.27 \right\}^{1/2}$$

$$\boxed{I_{T(rms)} = 15.62\,A}$$

2) A chopper is feeding an RL load as shown in fig1. The chopper frequency is 1KHz and duty cycle K=0.5. Calculate

i) The minimum instantaneous load current

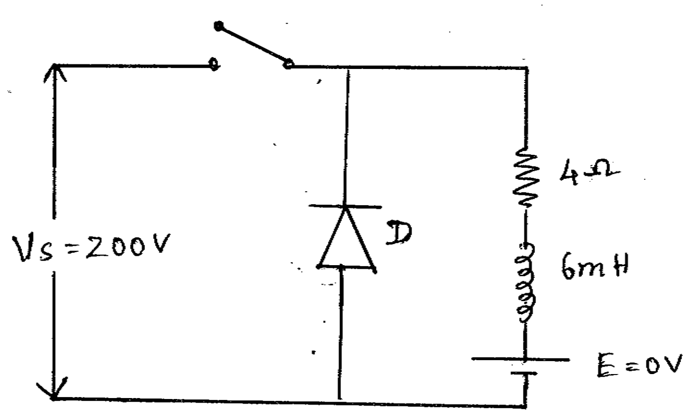
ii) The peak instantaneous value of load current

iii) The average value of load current

iv) The RMS load current

v) The RMS chopper input current.

Jan-08,10M



Given :- $V_S = 200V$, $R = 4\,\Omega$, $L = 6mH$, $f = 1KHz$, $K = 0.5$, $E = 0V$

$$T = \frac{1}{f} = \frac{1}{1KHz} = 1msec$$

Soln :- i & ii) The maximum and peak instantaneous load current :-

$$I_{min} = I_{max} e^{-(1-K)TR/L} - \frac{E}{R}\left[1 - e^{-(1-K)TR/L}\right]$$

$$= I_{max} e^{\frac{\left[-(1-0.5)\times 1\times 10^{-3}\times 4\right]}{6\times 10^{-3}}} - \frac{0}{4}\left[1 - e^{\frac{\left[-(1-0.5)1\times 10^{-3}\times 4\right]}{6\times 10^{-3}}}\right]$$

$$\boxed{I_{min} = 0.7165313 I_{max}} \quad --- \; (1)$$

$$I_{max} = I_{min} e^{-\frac{KTR}{L}} + \frac{V_S - E}{R}\left(1 - e^{-\frac{KTR}{L}}\right)$$

$$= I_{min} e^{-\left[\frac{0.5\times 1msec\times 4}{6mH}\right]} + \frac{200-0}{4\Omega}\left[1 - e^{-\left[\frac{0.5\times 1msec\times 4}{6mH}\right]}\right]$$

$$\boxed{I_{max} = I_{min}\, 0.7165313 + 14.17343} \longrightarrow (2)$$

Substituting eq (2) in eq (1), we get

$$I_{min} = 0.7165313(I_{min}\, 0.7165313 + 14.17343)$$

$$I_{min} = 0.5134\, I_{min} + 10.1557$$

$$I_{min} - 0.5134 I_{min} = 10.1557$$

$$0.4866 I_{min} = 10.1557$$

$$I_{min} = \frac{10.1557}{0.4866}$$

$$\boxed{I_{min} = 20.871A} \longrightarrow (3)$$

Substituting eq (3) in eq (2), we get

$$I_{max} = 20.871A \times 0.7165313 + 14.17343$$

$$\boxed{I_{max} = 29.128A}$$

iii) Average value of load current :-

$$I_{o(avg)} = \frac{I_{max} + I_{min}}{2} = \frac{29.128A + 20.871A}{2}$$

$$\boxed{I_{o(avg)} = 25A}$$

iv) RMS load current :-

$$I_{o(rms)} = \left\{ I_{min}^2 + \frac{I_{o(p-p)}^2}{3} + I_{min} I_{o(p-p)} \right\}^{1/2}$$

$$I_{o(p-p)} = I_{max} - I_{min} = 29.128A - 20.871A$$

$$\boxed{I_{o(p-p)} = 8.257A}$$

$$\therefore I_{o(rms)} = \left\{ (20.871)^2 + \frac{(8.257A)^2}{3} + 20.871 \times 8.257 \right\}^{1/2}$$

$$\boxed{I_{o(rms)} = 25.12A}$$

v) RMS chopper current :-

$$I_{T(rms)} = \sqrt{K} \times I_{o(rms)}$$

$$= \sqrt{0.5} \times 25.112 A$$

$$\boxed{I_{T(rms)} = 17.757A}$$

3) In a step down chopper, the source voltage is 220v dc. The load circuit parameters are R=10Ω and L=5mH. If the chopper is operating at a frequency of 200Hz and the ON/OFF ratio of the chopper is 2:1, calculate:

i) The average load current

ii) The maximum and minimum values if instantaneous load current under steady state cinditions.

Jan-06,7M

Given :- $V_S = 220V$, $f = 200Hz$, $T = \frac{1}{f} = 5msec$, $R = 10\Omega$,

$L = 5mH$, $\frac{ON}{OFF} = \frac{2}{1}$ ON = 2 OFF = 1

Duty cycle $K = \frac{ON}{ON+OFF} = \frac{2}{2+1} = \frac{2}{3}$

$$\boxed{K = 0.66667}$$

Soln :- i) Average lod current

$V_o(avg) = KV_S = 0.6667 \times 220V$

$$\boxed{V_o(avg) = 146.7V}$$

$I_o(avg) = \frac{V_o(avg)}{R} = \frac{146.7V}{10}$

$$\boxed{I_o(avg) = 14.67V}$$

ii) Imax and Imain :-

$$I_{min} = I_{max} e^{-(1-K)TR/L} - \frac{E}{R}\left[1 - e^{-\frac{(1-K)RT}{L}}\right]$$

$$= I_{max} e^{\left[-\frac{(1-0.6666)\,5msec \times 10}{5mH}\right]} - \frac{0}{10}\left[1 - e^{\left[-\frac{(1-0.666)\,5msec \times 10}{5mH}\right]}\right]$$

$$= I_{max} \times 0.0357 - 0$$

$$\boxed{I_{min} = 0.0357\, I_{max}} \longrightarrow (i)$$

$$I_{max} = I_{min} e^{-KTR/L} + \frac{V_S - E}{R}\left[1 - e^{-\frac{KTR}{L}}\right]$$

$$= I_{min} e^{-\frac{(0.66 \times 5msec \times 10)}{5mH}} + \frac{220 - 0}{10}\left[1 - e^{-\frac{(0.666 \times 5msec \times 10)}{5mH}}\right]$$

$$= I_{min}\, 1.281 \times 10^{-3} + 22\left[1 - 1.281 \times 10^{-3}\right]$$

$$\boxed{I_{max} = I_{min} \times 1.281 \times 10^{-3} + 21.9718} \rightarrow (2)$$

Substituting eq (1) in eq (2), we get

$$I_{max} = (0.0357 I_{max})\, 1.281 \times 10^{-3} + 21.9718$$

$$I_{max} = 4.573 \times 10^{-5} I_{max} + 21.9718$$

$$I_{max} - 4.573 \times 10^{-5} I_{max} = 21.9718$$

$$0.99954\, I_{max} = 21.9718$$

$$I_{max} = \frac{21.9718}{0.99954}$$

$$\boxed{I_{max} = 21.972\,A}$$

$$* \; I_{min} = 0.0357 \times I_{max} = 0.0357 \times 21.972\,A$$

$$\boxed{I_{min} = 0.7844\,A}$$

---

4) For a type A chopper circuit, Edc=220v, f=500Hz. Duty cycle K=0.3 and load R=1Ω , L=3mH and E=23 volts. Compare the following quantities.

i) Check whether the conversion is continuous or not

ii) Average output current

iii) I_{max} and I_{min}

June-05,6M

Given :- $V_s = E_{dc} = 220V$, $E = 23V$, $K = 0.3$, $R = 1\Omega$

$L = 3mH$, $f = 500Hz$, $T = \frac{1}{f} = \frac{1}{500Hz}$

$T = 2msec$

iii) $$I_{min} = \frac{V_s}{R}\left[\frac{1 - e^{\frac{KTR}{L}}}{1 - e^{TR/L}}\right] - \frac{E}{R}$$

$$= \frac{220}{1\Omega}\left[\frac{1 - e^{(0.3\times 2msec \times 1\Omega)/3mH}}{1 - e^{(2msec\times 1\Omega/3mH}}\right] - \frac{23}{1}$$

$$= 220V\left[\frac{1-e^{0.2}}{1-e^{0.666}}\right] - 23 = 220V\left[\frac{1-1.22V}{1-1.946V}\right] - 23$$

$$= 220\left[\frac{-0.22}{-0.946}\right] - 23$$

$$= 220[0.2325] - 23$$

$$= 51.162 - 23$$

$$\boxed{I_{min} = 28.39A}$$

$$I_{max} = \frac{V_s}{R}\left[\frac{1 - e^{-\frac{KTR}{L}}}{1 - e^{-\frac{TR}{L}}}\right] - \frac{E}{R}$$

$$= \frac{220}{1}\left[\frac{1 - e^{-\frac{(0.3\times 2msec\times 1)}{3mH}}}{1 - e^{-\frac{(2msec\times 1)}{3mH}}}\right] - \frac{23}{1}$$

$$= \frac{220}{1}\left[\frac{1-e^{-0.22}}{1-e^{-0.666}}\right] - 23$$

$$= 220\left[\frac{1-0.8025}{1-0.5137}\right] - 23$$

$$= 220\left[\frac{0.1975}{0.4865}\right] - 23$$

$$= 220[0.40612] - 23$$

$$= 89.34 - 23$$

$$\boxed{I_{max} = 66.34A}$$

ii> Average o/p current

$$I_{o(avg)} = \frac{KV_s - E}{R} = \frac{(0.3 \times 220) - 23}{1}$$

$$\boxed{I_{o(avg)} = 43A}$$

i> Check for conversion is continoues or not

$$K' = \frac{L}{T} \ln\left[1 - \frac{E}{V_s}\left(1 - e^{T/L}\right)\right]$$

$$= \frac{3mA}{2msec} \ln\left[1 - \frac{23}{220}\left(1 - e^{2msec/3msec}\right)\right]$$

$$= 1.5 \ln\left[1 - 0.1045\left(1 - e^{0.666}\right)\right]$$

$$= 1.5 \ln\left[1 - 0.1045\left(1 - 1.94643\right)\right]$$

$$= 1.5 \ln\left[1 - 0.1045(-0.9464)\right]$$

$$= 1.5 \ln\left[1 - 0.09890\right]$$

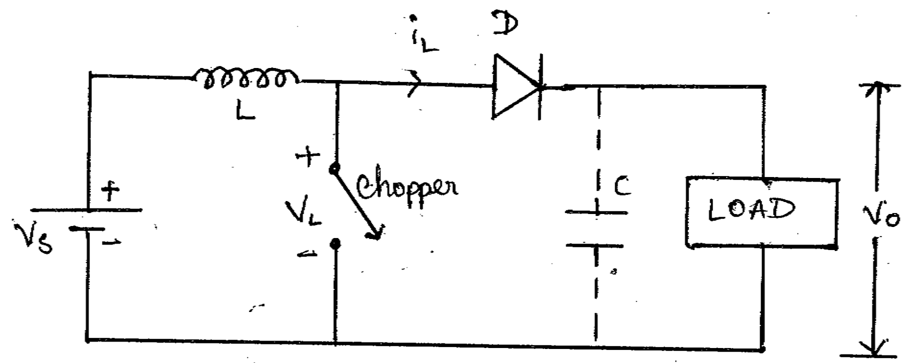
$$= 1.5 \ln\left[0.90109\right]$$

$K' = -10.156$

$K > K'$ ∴ Conversion is continoues.

Principle of STEP UP chopper :-

- **What is chopper? Explain the principle of step-up chopper with relevant equations.** **June-10,10M**
- **Explain the principle of operation of a step up chopper with suitable circuit diagram and waveforms. Derive the expression for average output voltage to step up chopper.** **Jan-10,10M**
- **Obtain an expression for the output voltage for a step up chopper. Explain how duty cycle is controlled.** **June-10,10M(IT)**
- **Obtain expression for the output voltage for a step up chopper. Explain how duty cycle is controlled.** **June-07,8M**
- **Explain the principle of operation of a step up chopper.** **Jan-07,6M**



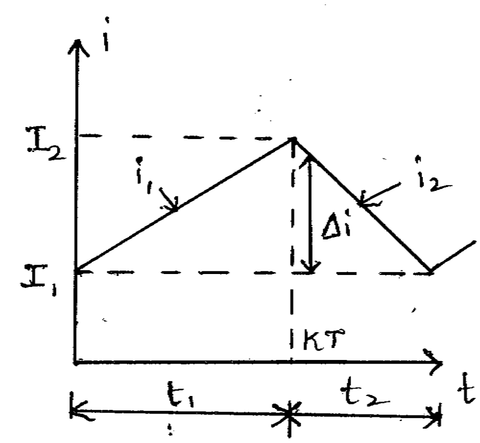


fig ⓑ : Current W/F

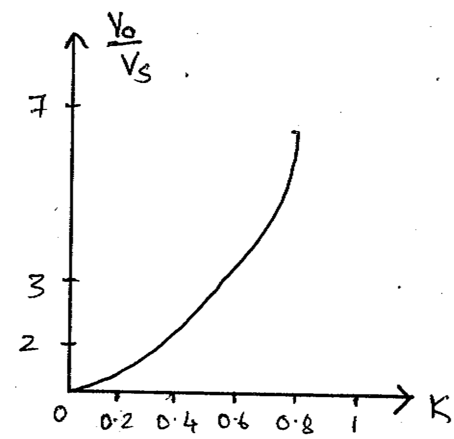


fig ⓒ : O/p Voltage

Mode I

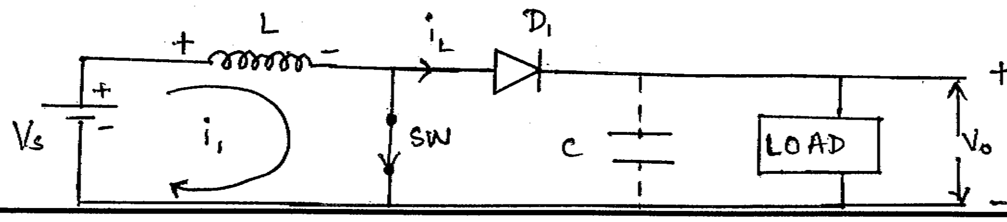


fig 2ⓐ Equivalent ckt

Fig ① a shows the ckt diagram of the step up chopper. A switch is connected across inductance & supply. A filter capacitor 'C' is used across the load to make V_o smooth.

The diode D_1 blocks the reverse flow of o/p current when switch is turned ON.

When the switch 'SW' is closed for time t_1 the current flows through the inductance from the supply. The inductor current rises and energy is stored in the inductor 'L'.

Now the o/p Voltage $\boxed{V_o = 0}$

MODE - 2 :-

If the switch is opened for time t_2, then the energy stored in the inductor is transferred to load through diode D_1 & inductor current.

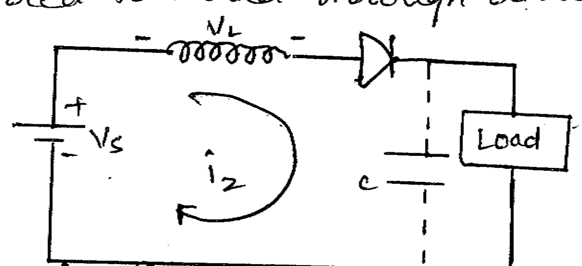


fig 2 ⓑ Equivalent ckt

Now the diode D_1 is forward biased & $V_o = V_s$

Assuming continous current flow, the wave form for the inductor current is shown in fig 1 ⓑ

* When the chopper is ON, voltage across L is

$$V_L = L \cdot \frac{di}{dt} \longrightarrow ①$$

ie $V_L = V_s$ $dt = t_1$ & $di_L = \Delta I$

Eq ① becomes

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

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

Where ΔI is called peak to peak ripple current

* The instantaneous o/p voltage is

$$\boxed{V_o = V_s + L\frac{\Delta I}{t_2}} \longrightarrow (3)$$

Sub eq (2) in eq (3), we get

$$V_o = V_s + \frac{\cancel{L}}{t_2} \cdot \frac{V_s t}{\cancel{L}}$$

$$= V_s + \frac{V_s t_1}{t_2}$$

$$V_o = V_s\left[1 + \frac{t_1}{t_2}\right]$$

$$V_o = V_s\left[\frac{t_2 + t_1}{t_2}\right]$$

$$\boxed{V_o = V_s \cdot \frac{1}{1-K}} \longrightarrow (4)$$

WKT

$$K = \frac{t_1}{t_1+t_2}$$

$$1-K = 1 - \frac{t}{t_1+t_2}$$

$$1-K = \frac{t_1+t_2-t_1}{t_1+t_2}$$

$$1-K = \frac{t_2}{t_1+t_2}$$

$$\boxed{\frac{1}{(1-K)} = \frac{t_1+t_2}{t_2}}$$

* The instantaneous load Voltage will be dependent on duty cycle K.

for	$K = 0$,	$V_o = V_s$ &
for	$K = 1$,	$V_o = \infty$

* If a large Capacitor 'C' is connected across the load, the o/p Voltage will be continous & V_o would become equal ~~to~~ the average Value 'V_a' (V_{dc})

Average o/p Voltage :-

$$V_a = V_{dc} = V_L = \frac{1}{T}\int_0^T V_L(t) \cdot dt$$

$$= \frac{1}{T}\int_0^T L \cdot \frac{di_L(t)}{\cancel{dt}} \cdot \cancel{dt}$$

$$V_L = \frac{L}{T}\int_0^T di_L(t)$$

The above integration is wrt, inductance current $di_L(t)$

, hence we should change the limits

At $t=0$ (lower limit), $i_L(t) = I_{min}$

& at $t=T$ (upper limit), $i_L(t) = I_{min}$

$$V_L = \frac{L}{T}\int_{I_{min}}^{I_{min}} di_L(t)$$

$$= \frac{L}{T}\left[i_L(t)\right]_{I_{min}}^{I_{min}}$$

$$= \frac{L}{T}\left[\cancel{I_{min} - I_{min}}\right]^{0}$$

$$\boxed{V_L = 0}$$

Thus the average voltage across the inductance is zero. The inductances stores the energy when the switch is 'ON' & supplies the energy to the load when the switch is OFF.

Voltage across Switch :-

$$\boxed{V_{AB} = \frac{1}{T}\int_0^T V_{AB}(t).\,dt} \longrightarrow (1)$$

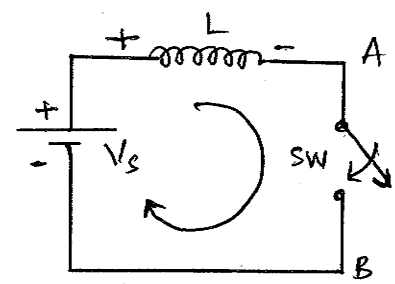


fig (1)

WKT

$V_{AB}(t) = V_{o(av)}$ from KT to T & rest of the period it is zero. Hence eqn (1) becomes

$$V_{AB} = \frac{1}{T}\int_{KT}^{T} V_{o(av)}\,dt$$

$$= \frac{V_{o(av)}}{T}\int_{KT}^{T} 1.\,dt = \frac{V_{o(av)}}{T}\left[t\right]_{KT}^{T}$$

$$= \frac{V_{o(av)}}{T}\left[T - KT\right]$$

$$= \frac{V_{o(avg)}}{T} \cdot T(1-K)$$

$$\boxed{V_{AB} = V_{o(avg)}(1-K)}$$

Applying KVL to fig ①, we get

$$V_S - V_L - V_{AB} = 0$$

$$V_S = V_L + V_{AB}$$

$$V_S = V_L + V_{AB}$$

$$V_S = 0 + V_{o(av)}(1-K)$$

$$\boxed{V_{o(av)} = \frac{V_S}{(1-K)}}$$

Use of step-up operation for energy Transfer :-

❖ **Explain how the principle of a step-up chopper can be used to transfer energy from a low voltage dc source to a high voltage dc source.** **Jan-06,7M**

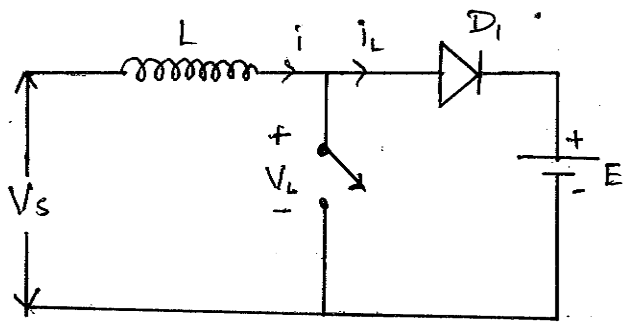
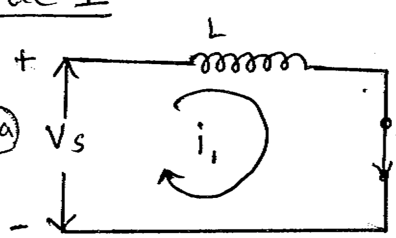


fig ①: use of step up operation

The principle of step up chopper can be applied to transfer energy from one voltage source to another shown in fig ①

Mode 1

fig (2a)



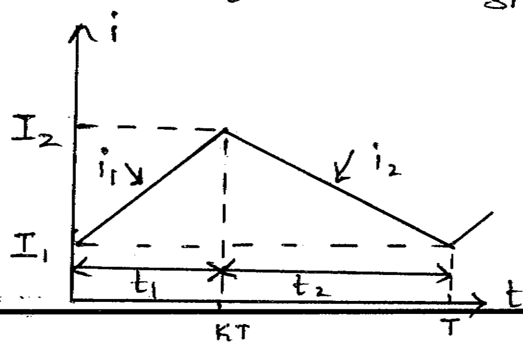


fig (c)

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Inductor current for mode 1 is given by

$$V_s = L\frac{di_1}{dt}$$

$$V_s\,dt = L\,di_1 \Rightarrow i_1 = \frac{V_s}{L}t + I_1$$

Integrating above eqn wrt t

$$\therefore di_1 = \frac{V_s}{L}dt \qquad \because I_1 \text{ is a constant}$$

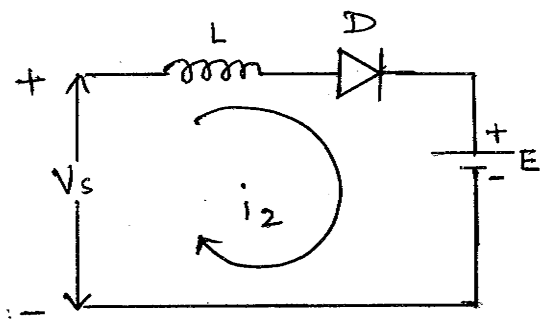
$$i_1 = \frac{V_s}{L}t + I_1$$

Where I_1 is the initial current through inductor

* During mode 1, the current must rise and necessary condition is

$$\boxed{\frac{di_1}{dt} > 0} \quad \text{or} \quad \boxed{V_s > 0}$$

Mode 2



Switch is OFF

Applying KVL to above ckt we get

$$V_s = L\frac{di_2}{dt} + E$$

$$V_s - E = L\frac{di_2}{dt}$$

$$\frac{di_2}{dt} = \frac{V_s - E}{L}$$

$$di_2 = \left(\frac{V_s - E}{L}\right)dt$$

Where I_2 is initial current for mode 2

for stabe system, the current must fall & the necessary condition is

$$\boxed{\frac{di_2}{dt} < 0} \quad \text{or} \quad \boxed{V_s < E}$$

∴ The condition for controllable power transfer is

$$\boxed{0 < V_s < E}$$

$V_s < E$, to permit transfer of power from fixed or variable source to fixed dc Vtg.

When the chopper is turned ON, energy is transferred from source V_s to inductor L. If the chopper is then turned OFF, a magnitude of energy stored in the inductor is forced to battery E.

❖ Performance parameters :-

The performance of choppers is affected by many parameters. These parameter are listed below:

1> Duty cycle 'K' :

The duty cycle of the chopper controls its o/p Vtg. The value of duty cycle lies b/w 0 and 1.

∴ The duty cycle 'K' can be controlled b/w a minimum value K_{min} and a maximum value.

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Kmax, thereby limiting the minimum & maximum value of o/p Vtg.

2) Chopping frequency 'f' :-

The frequency of the chopper is $f = \frac{1}{T}$, where 'T' is the period of o/p Vtg waveform.

The frequency should be as high as possible to reduce the load ripple current and to minimize the size of series inductor in the load ckt.

3) Operating speed of switch :-

The operating speed of the devices used in the chopper depends upon turn ON & turn OFF times of the switch. Hence switching frequency of the chopper depends upon the the speed of the switching device

(* MOSFET have very small turn-ON & turn-OFF times. Hence operates at very high speed).

❖ List the performance parameter of the step-up and step down converters.

The performance parameters of the step-up and step down converters are as follows.

1) Ripple current of the inductor 'ΔI_L'
2) Maximum switching frequency 'f_{max}'
3) Conditions for continous or discontinous inductor current.
4) Maximum value of inductor to maintain continous inductor current.

Classification of Choppers :-

- **Give the classification of chopper. Explain briefly each one of them.** **June-10,10M**
- **Explain how the choppers are classified with reference to load voltage and load current.** **Jan-106M June-06,8M**
- **What is chopper? Classify and explain the different types of chopper with each circuit diagrams.** **June-09,6M**
- **Explain brefly how choppers are classified.** **Jan-09,4M**
- **Explain in detail how choppers are classified.** **June-08,10M June-05,10M**
- **Classify the choppers and explain the different types of chopper circuits.** **Jan-08,10M**
- **Explain how the DC choppers are classified, with reference to load voltage and load current, write the circuit of class-B,class-C and class-D choppers and briefly explain to show the type of load voltage and load current waveform they give.** **Jan-05,10M**

Depending on the direction of current & voltage flow choppers can be classified as.

i> Class A chopper
ii> Class B chopper
iii> Class C chopper
iv> Class D chopper
v> Class E chopper

i> Class A chopper :-

The figures below shows the ckt diagram & VI characteristics of class A chopper.

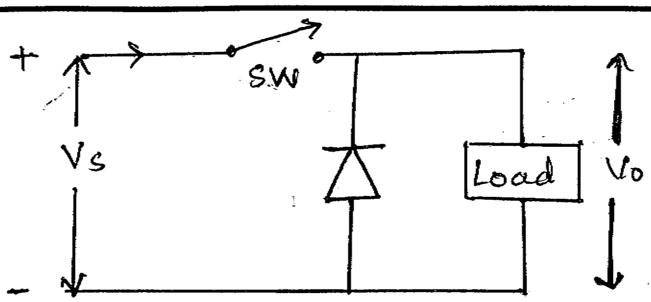


fig: ⓐ Class A chopper

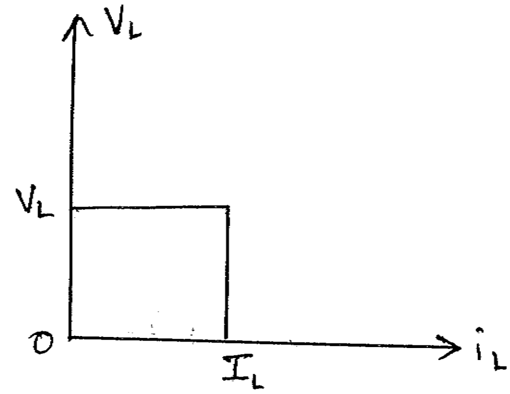


fig ⓑ: V-I characteristics

The load current flows into the load. Both the load current and load voltage are positive. This is also called as I quadrant chopper & is said to be operated as rectifier.

The step down chopper is basically class-A chopper

ii) Class - B chopper :

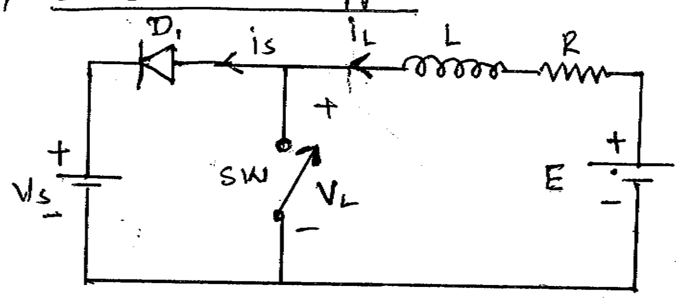


Fig ⓐ : Ckt

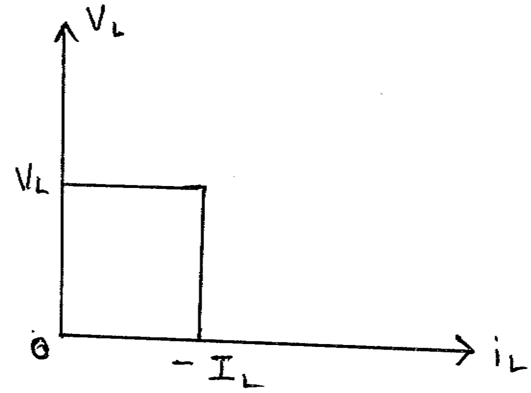
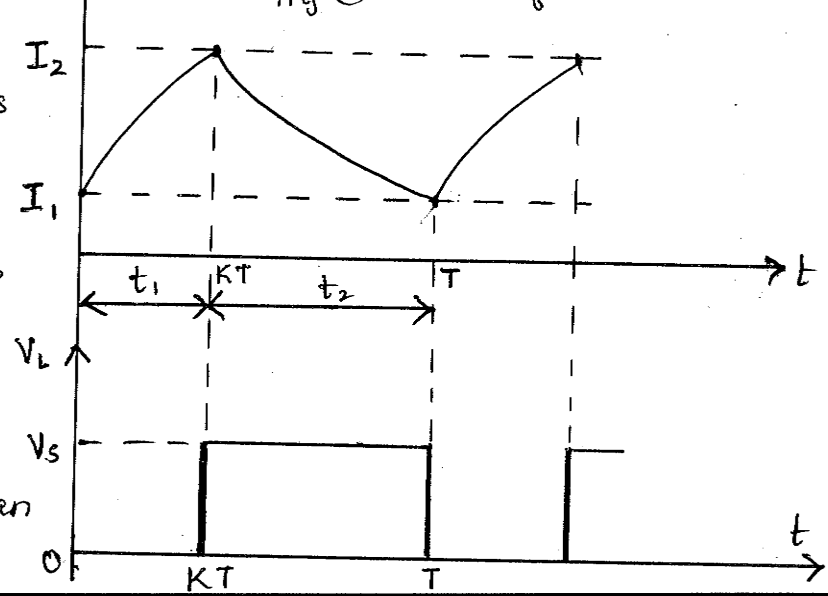


Fig ⓑ : VI characteristics

Fig ⓒ : Waveforms.



* In class B chopper the load current flows out of the load. The load voltage is +ve and load current is -ve as shown in fig ⓑ. The load is R-L-E

A class B chopper is said to be operated as an inverter.

Operation :-

When the chopper (SW) is ON, the voltage E drives current through inductor L & store energy in L & the load voltage $\boxed{V_L = 0}$

When the switch (chopper) SW is OFF, the energy stored in inductor 'L' is returned to supply 'V_s' through diode D_1 & load current i_L falls.

When chopper is ON :

The load current is given by

$$\boxed{0 = L\frac{di_L}{dt} + Ri_L + E} \longrightarrow (1)$$

With an initial current $i_L(t=0) = I_1$, the solution for the above equation is given by:

$$i_L(t) = I_1 e^{-tR/L} - \frac{E}{R}\left[1 - e^{-tR/L}\right] \longrightarrow (2)$$

* The above equation is valid for $0 \le t \le t_1 [= KT]$
At time $t = t_1 = KT$, the load current I_L becomes,

$$i_L[t = t_1 = KT] = I_2$$

When chopper is OFF :

In this mode, load current falls & the load current I_L is given by

$$\boxed{V_s = L\frac{d}{dt}i_L + Ri_L + E} \longrightarrow (2)$$

With an initial current $i_L[t = t_1] = I_2$ the solution for eqn (2) is given by

$$i_2(t) = I_2 e^{-tR/L} + \frac{V_s - E}{R}\left[1 - e^{-tR/L}\right] \longrightarrow (3)$$

Eq (3) is valid for $0 \le t \le t_2 \left[= (1-K)T\right]$

iii) <u>class - C chopper</u> :-

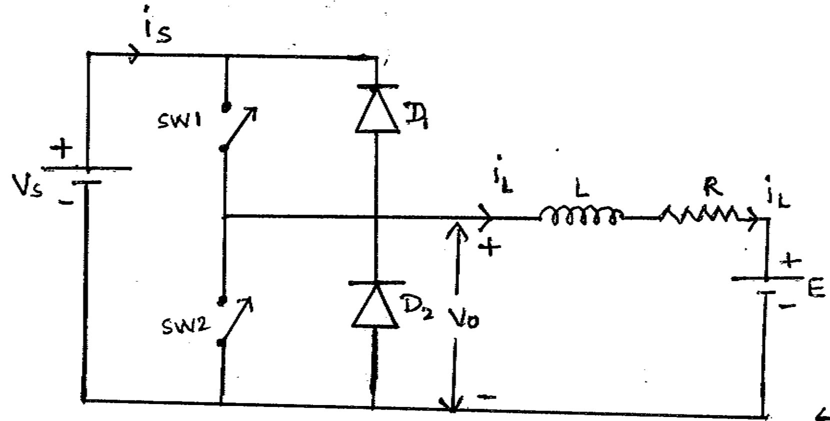


fig (1)(a) ckt diagram

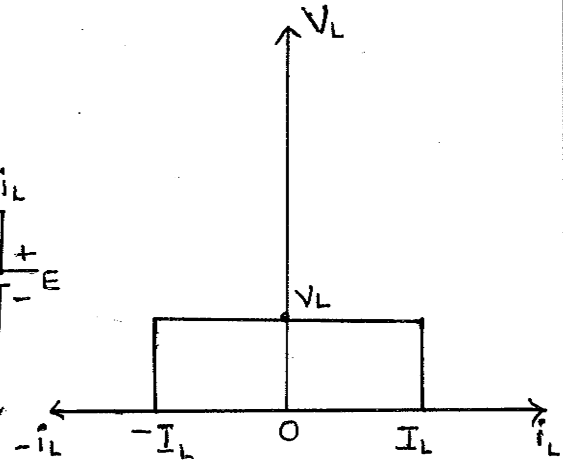


fig 1 (b) V-I characteristics

* In class - c chopper, the <u>load current</u> is <u>either</u> <u>+ve</u> or <u>-ve</u> but <u>load voltage</u> is always <u>positive</u>.

Class C chopper is also known as two - quadrant chopper.

* Class A & Class B choppers are combined to form Class C choppers as shown in fig 1(a).

Here i) S_1 & D_2 operates as class A chopper

ii) S_2 & D_1 operates as class B chopper

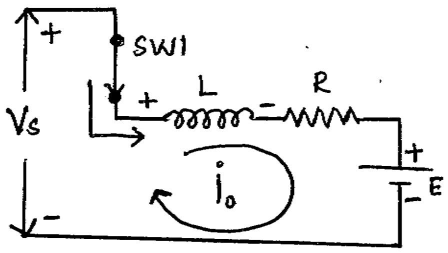
<u>Operation</u>

* For Ist quadrant operation S_1 & D_1 operate & the S_2 & D_2 donot conduct

* For IInd quadrant operation S_2 & D_2 operate & the S_1 & D_1 donot conduct.

Initially when both choppers are OFF both diodes D_1 & D_2 are also OFF & therefore load is isolated from supply.

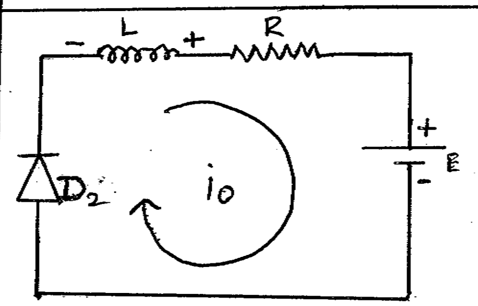
i) Mode 1 - SW1 turned ON :

Conducting device	Equivalent ckt	o/p vtg	o/p current	Operation
SW1		$V_0 = V_s$	+ve	Forward Motoring or Rectifying (load stores energy)

When SW1 is turned ON, the dc supply gets connected across the load making the load voltage +ve $\boxed{V_0 = +V_s}$
The load current flows from the DC supply to the load.

Thus load voltage & load current both are +ve & load receives power from the source.

ii) Mode 2 - SW1 turned OFF / D₂ starts conducting

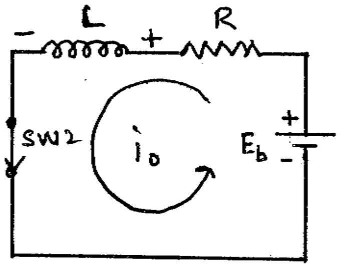
Conducting device	Equivalent ckt	o/p vtg	o/p current	Operation
D_2		0	Negetive (-ve)	Freewheeling Inductance Supplies energy to the load.

When SW1 is turned OFF, a -ve self inductance EMF appears across the load. This will forward bias diode D_2 & free wheeling takes place through it.

After some time the free wheeling current reduces to zero, and D_2 turns -OFF.

Thus load vtg is zero & load current is +ve

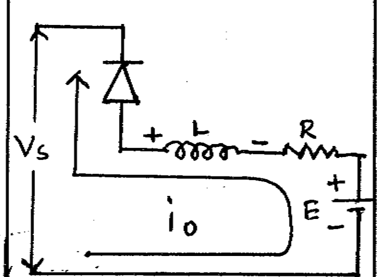
iii) Mode 3. D_2 turn OFF., SW2 is turned ON :

Conducting devices	Equivalent ckt	o/p Vtg	o/p current	Operation
SW2		0	Negetive (−ve)	Freewheeling

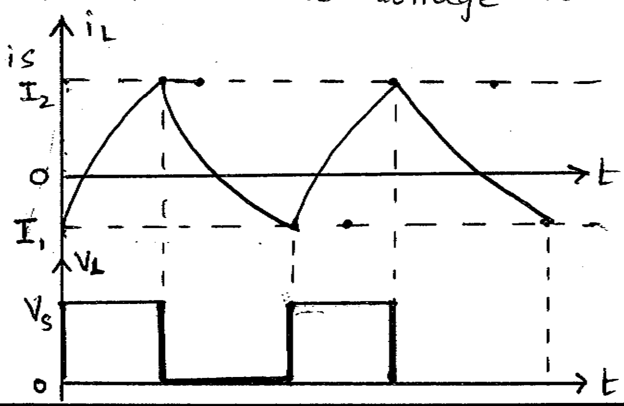
SW2 can be turned ON only after D_2 goes out of conduction. SW2 can be turned ON due to the presence of Back EMF in the circuit.

The load Vtg is zero and load current becomes −ve in this mode of operation.

iv) Mode 4 :- SW2 is turned OFF & D_1 starts conducting

Conducting device	Equivalent ckt	o/p Vtg.	o/p current	Operation
D_1		$+V_s$	−ve (Negetive)	Regenerative Braking (load returns energy back)

* D_1 comes into conduction as soon as SW2 is turned OFF. The stored energy is returned back. The load voltage is +ve ie $V_0 = V_s$. but load current is −ve



iv) class - D chopper :-

* In class D chopper, load current is always +ve. The load vtg is +ve or -ve as shown in fig 1 ⓑ.
* A class D chopper can operate as a rectifier. The ckt diagram is shown in fig 1 ⓐ.

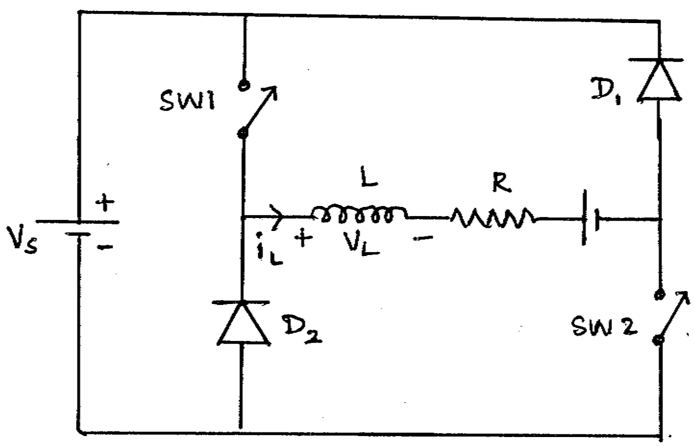


fig 1 ⓐ : ckt diagram

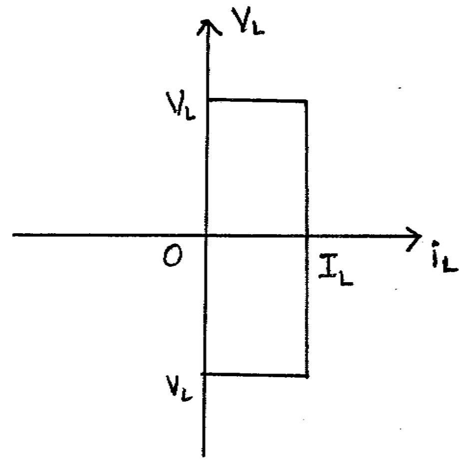


fig ①ⓑ : V-I characteristics

* When both switches (choppers) SW1 & SW2 are turned ON the o/p vtg is $V_o = V_s$ & the load current is +ve.

If SW1 & SW2 are turned OFF load current i_L will remain +ve and continues to flow through a highly inductive load since both diodes D_1 & D_2 are in conducting state. So the diode provides a path for a load current.

As the diode starts conducting the load vtg is reversed. so load current i_L is always +ve whether V_L is +ve or -ve.

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CLASS-E CHOPPER :-

- **Explain the working principle of a four quadrant chopper with the necessary circuit diagram.** **June-10,10M(IT)**
- **With the help of a ciruit and quadrantal diagrams, explain the working of a class-E chopper. Mention the devices that gives path for the current in each quadrant.** **June-09,8M**
- **With the help of circuit and quadrantal diagrams, explain the working of a class-E chopper. Mention the devices that provide path for the current in each quadrant.** **Jan-08,10M**
- **Draw the schematic circuit of a class-E four quadrant dc chopper and mention the devices that provide the path for current in the first and third quadrants of operation.** **June-04,6M**

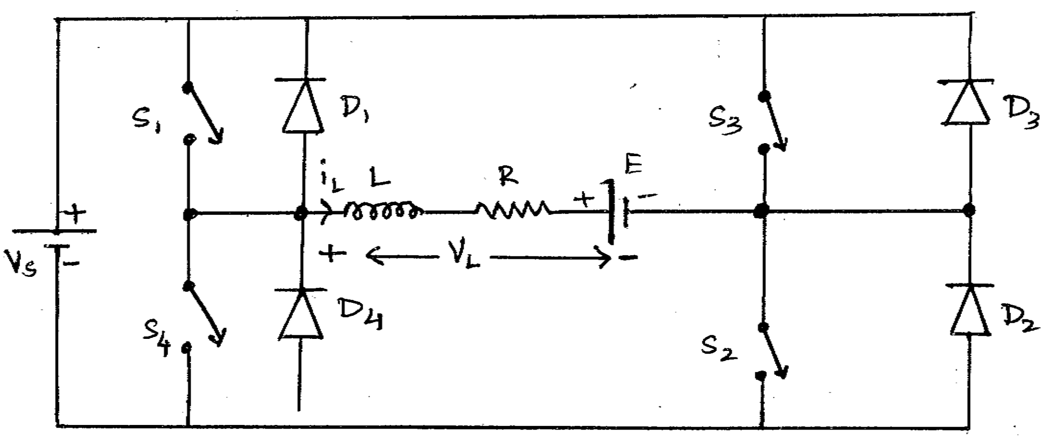
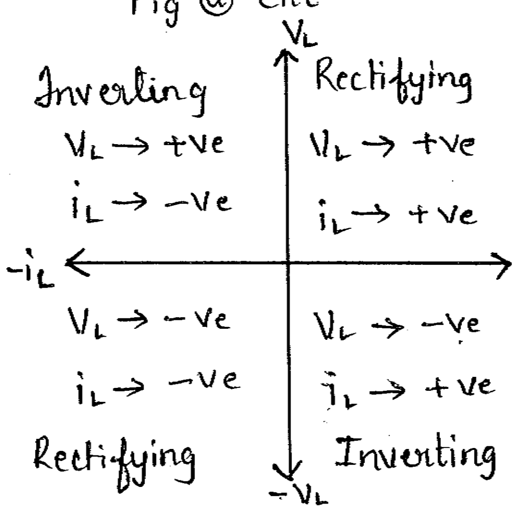
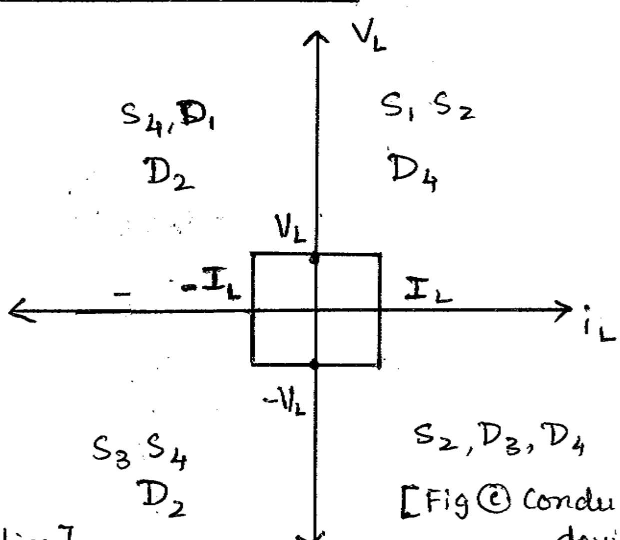


Fig (a) Ckt



[Fig (b) Polarities]



[Fig (c) Conducting devices]

In fig 1 (a) shown, S_1, S_2, D_3 & D_4 constitute one class C chopper & S_3, S_4, D_1 & D_2 form another class - C chopper

<u>Operation</u> :

i> <u>I - Quadrant</u> :-

The load vtg & load current wave forms are as shown in fig 1 (a)

The load vtg is either <u>+ve or zero</u>. The instantaneous load current is also always +ve.

In I^{st} quadrant switches S_1 & S_2 are ON & diode D_4 is ON. The power flow takes place from source to load.

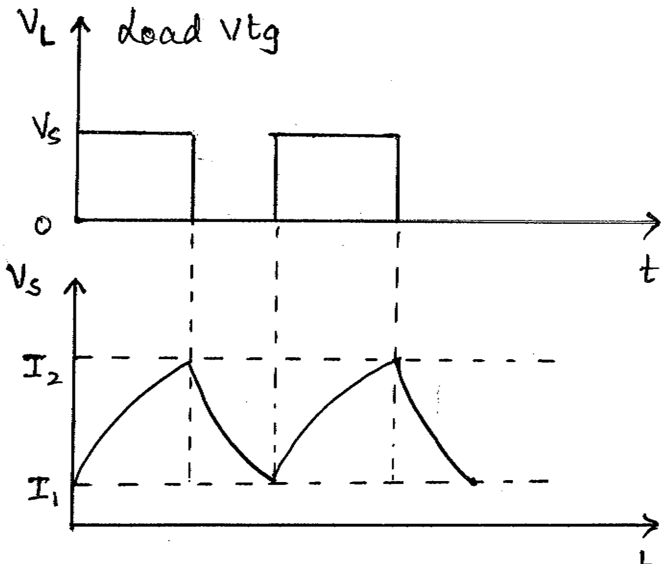
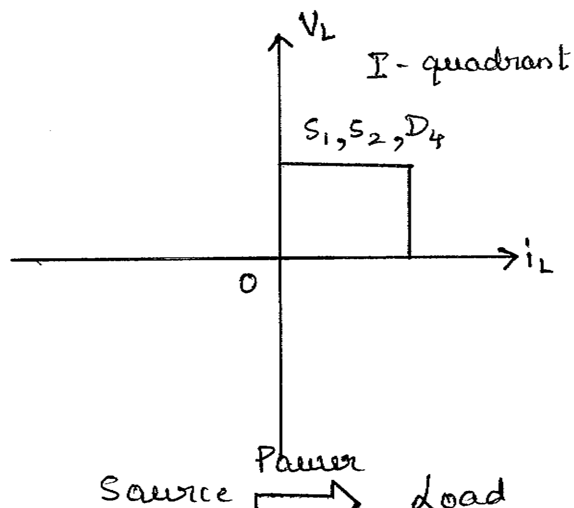
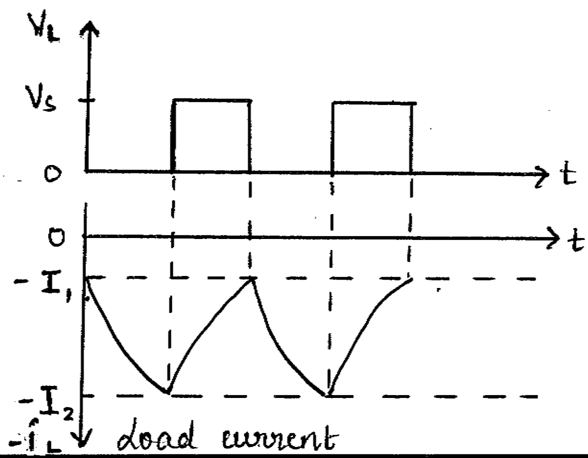


fig 1 (a) W/F



ii> <u>II - Quadrant</u> :→



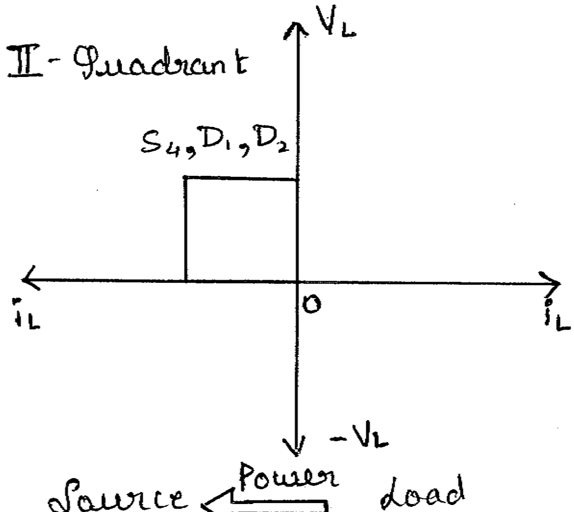


fig 2@ W/F's

* The load current & load Voltage waveforms are as shown in fig 2@.

* The o/p Vtg is either zero or positive. The instantaneous load current is always −ve. Hence the chopper will operate in the second quadrant. In second quadrant switch S_4 & diode D_1 & D_2 are ON.

* The power flow takes place from load to source

iii) III - Quadrant :-

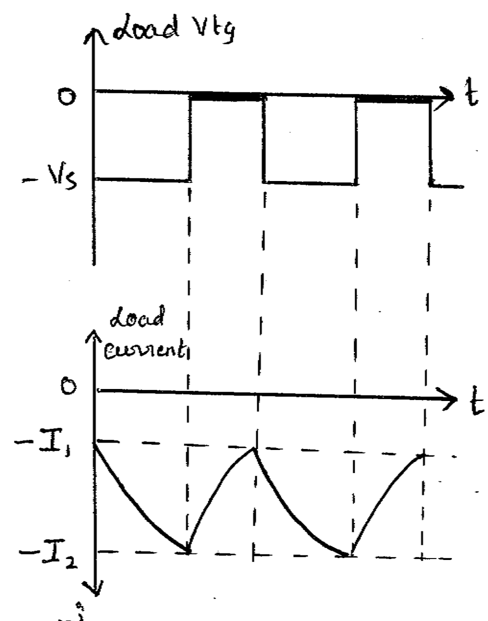
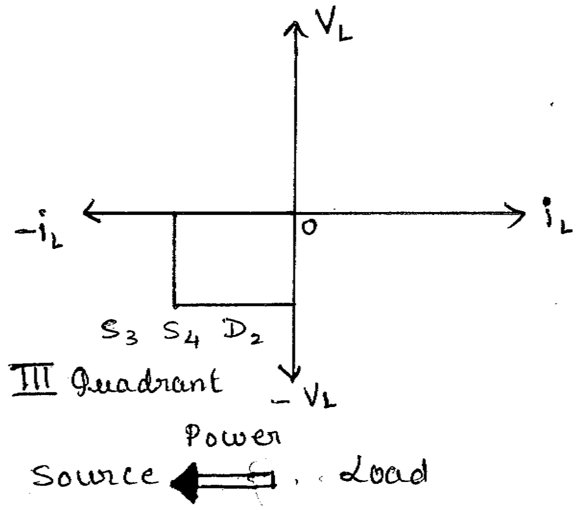


fig 3@ W/F's

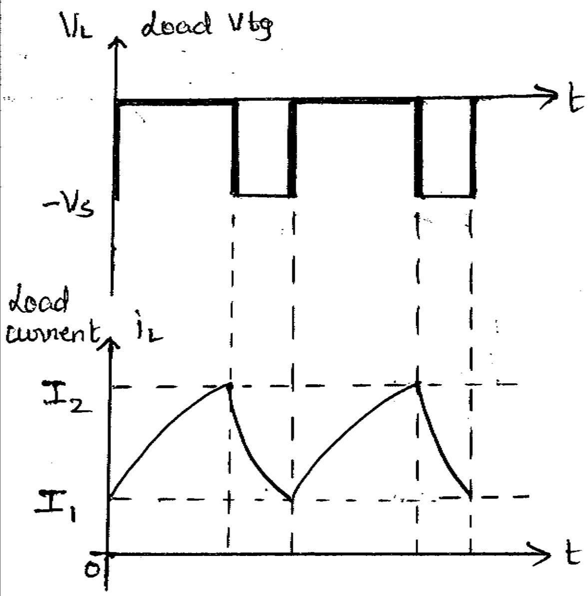


* The load current and load voltage waveforms are as Shown in fig 3@

* The o/p voltage is either zero or −ve. The instantaneous load current is always −ve.
Hence the chopper operates in the third quadrant.
The switches S_3 & S_4, diode D_2 are ON.

* The power flow takes place from source to load

iv) IV - Quadrant :



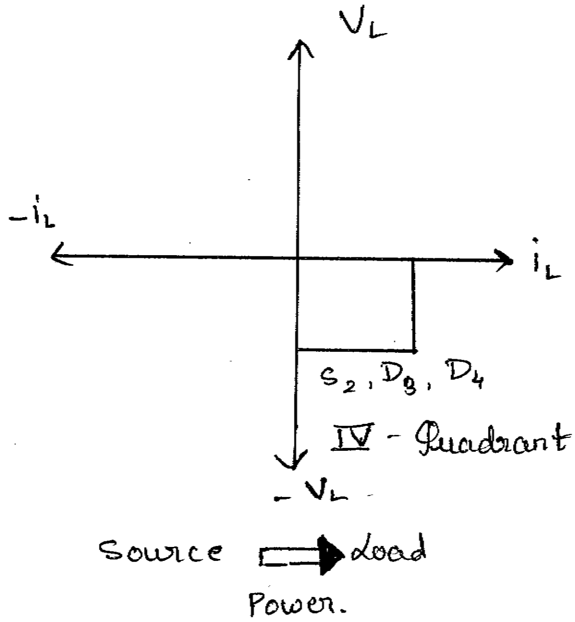


fig 4 ⓐ : W/F's

* The load voltage and load current waveforms are as shown in fig 4 ⓐ.

* The load voltage is either zero or -ve. The load current will be always +ve

Hence the chopper operates in the fourth quadrant. The switch S_2, diodes D_3 & D_4 are ON.

* The power flow takes place from load to source

❖ Thyristor Chopper circuit :-

A thyristor chopper circuit uses a fast turn-OFF thyristor as a switch and rewuires commutation circuitry to turn it OFF.

There are two types of circuits:

1) **Impulse commutated chopper**
2) **Resonant pulse chopper**

Impulse commutated chopper :-

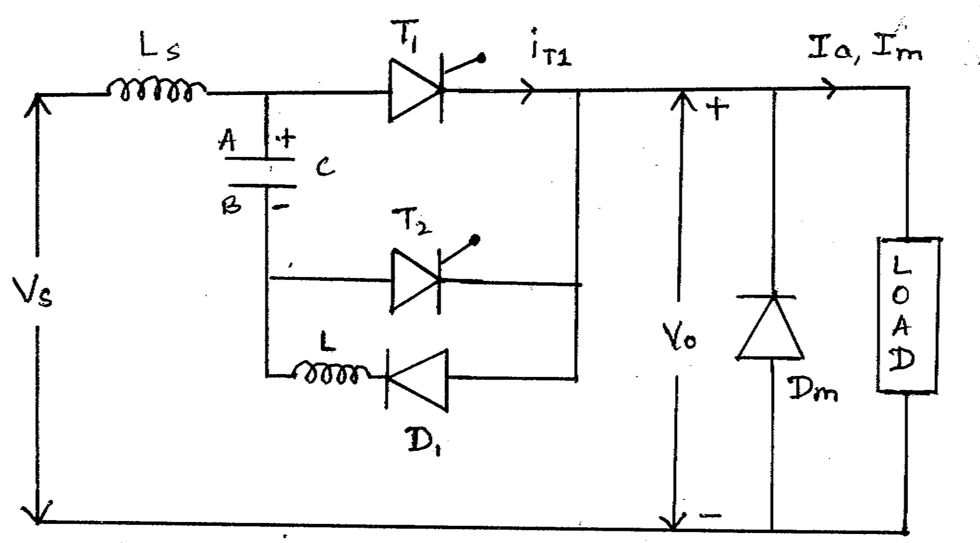
❖ **Explain the working principle of IMPULSE commutated thyristor chopper with necessary circuit diagrams and waveforms**

June-10,10M(IT)

❖ **With neat circuit, explain the working principle of impulse commutated thristor chopper.** **Jan-09,8M**

❖ **With the help of necessary mode equivalent circuits and waveforms, explain the operation of an impulse commutated chopper.**

Jan-07,14M



fig① Impulse Commutated chopper

The impulse commutated chopper with two thyristor ie 2SCR's T_1 & T_2 as shown in figure ① & is also called classical chopper

The ckt operation can be divided into 5 modes & equivalent ckts are as shown.

At the beginning of operation, the Thyristor T_2 is fixed and capacitor 'C' is charged with the polarity as shown in the fig ①.

The ckt operation is divided into five modes, also we redefine the time origin at $t=0$, at the beginning of each mode.

Mode 1 : (T_1 is ON)

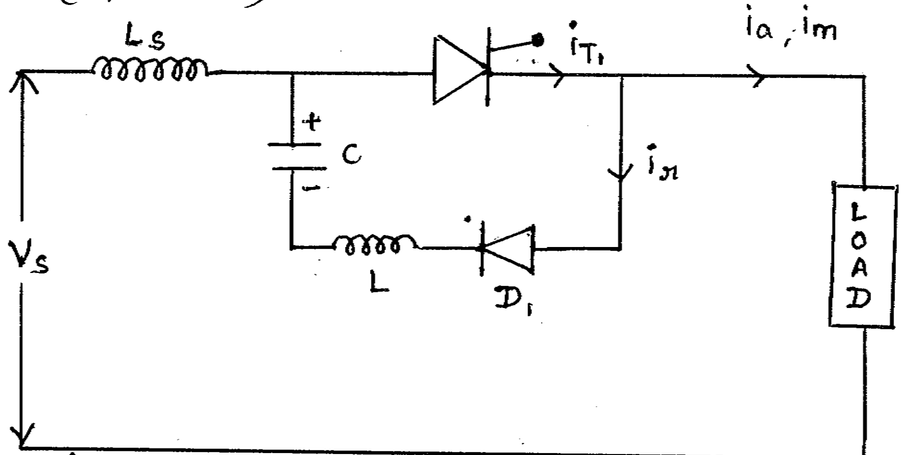


fig ② :- ckt diagram for mode 1

Mode 1 begins with T_1 is fired & the load is connected to the supply. Now commutation capacitor 'C' reverses its charge through the resonant reversing ckt formed by T_1, D_1 & L.

* The resonant current is given by :

$$\boxed{i_r = V_c\sqrt{C/L}\ \sin\omega_m t} \longrightarrow ①$$

* The peak value of resonant current is

$$\boxed{I_p = V_c\sqrt{\frac{C}{L}}} \longrightarrow ②$$

& Capacitor Voltage '$V_c(t)$' is given by

$$\boxed{V_c(t) = V_c \cos \omega_m t} \longrightarrow (3)$$

Where $\omega_m = \frac{1}{\sqrt{LC}}$

After time $t = \pi\sqrt{LC}$, the capacitor voltage is reversed to $-V_c$. This is called as commutation readiness of the chopper.

Mode 2 :- (T_2 is ON)

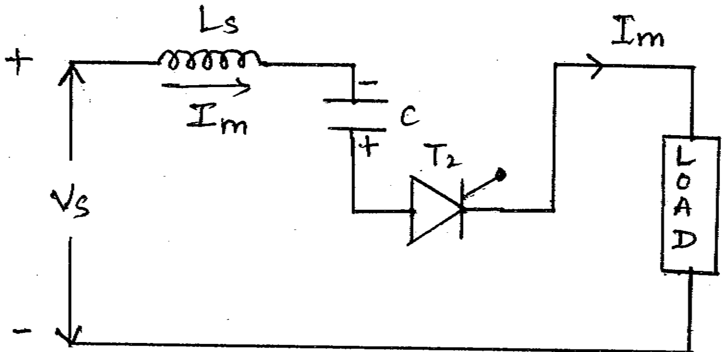


fig (3)

Mode 2 begins when the commutation thyristor 'T_2' is fired. A reverse voltage of V_s is applied across Thyristo T_1 & T_1 is turned - OFF.

* Now the capacitor 'C' discharges through the load from '$-V_c$' to zero & this discharging time is called as turn-OFF time or available turn-OFF time & is given by

$$\boxed{t_{off} = \frac{V_c \cdot C}{I_m}} \longrightarrow (4)$$

Where, I_m is peak load current

* The ckt turn-OFF time 't_{OFF}' must be greater than the turn-OFF time of the thyristor.

* The time required for the capacitor to recharge back to the supply voltage is called recharging time & is given by

$$\boxed{t_d = \frac{V_s \cdot C}{I_m}} \longrightarrow (5)$$

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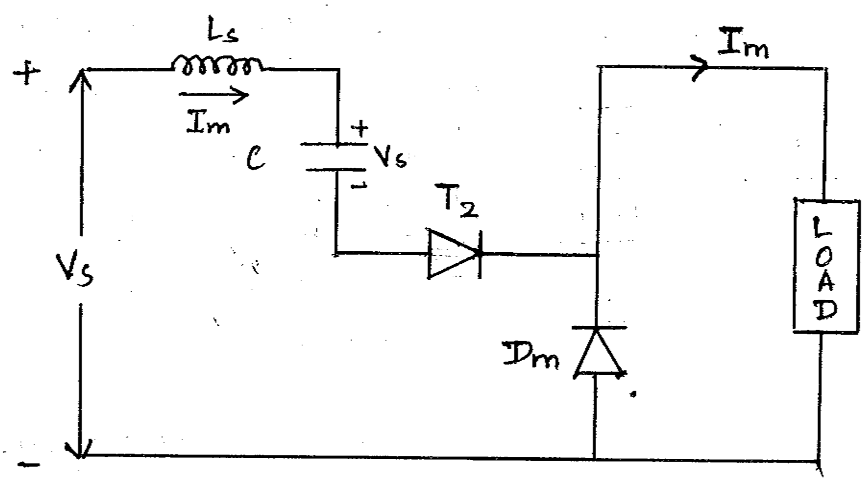
* Thus the total time necessary for the capacitor to discharge & recharge is the commutation time & is given by

$$\boxed{t_c = t_{OFF} + t_d} \longrightarrow (6)$$

* Mode 2 ends at $t = t_c$ when the commutation capacitor 'C' recharges to V_s & the freewheeling diode D_m starts conducting.

Mode 3 :- (D_m is ON)



Mode 3 begins when the free-wheeling diode D_m starts conducting & the load current decays. Now the energy stored in the source inductance L_s is transferred into the capacitor.

* The current is given by

$$\boxed{i_s(t) = I_m \cos\omega_s t} \longrightarrow (7)$$

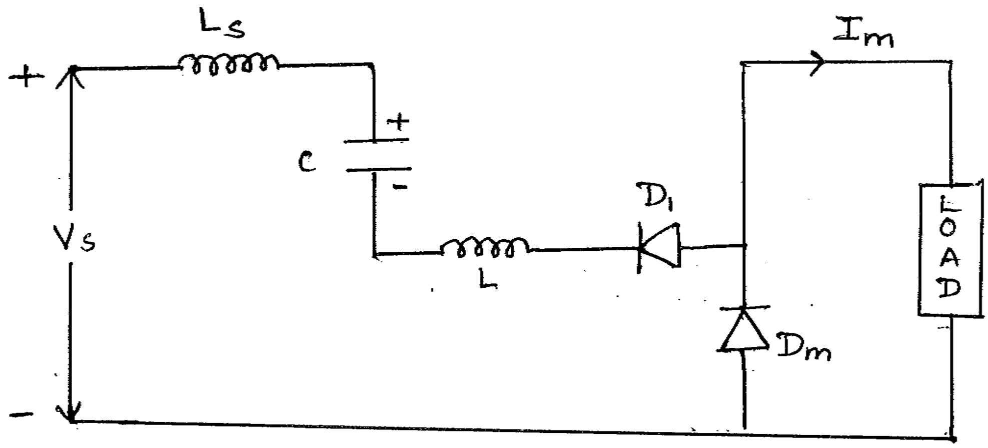
Where $\omega_s = \frac{1}{\sqrt{L_s C}}$

* The instantaneous capacitor voltage is

$$\boxed{V_c(t) = V_s + I_m\sqrt{\frac{L_s}{C}}\,\sin\omega_s t} \longrightarrow (8)$$

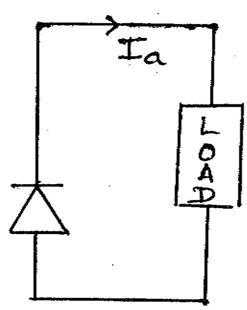
Mode 4 :- (D_1 ON & T_2 - OFF)

Mode 4 begins when overcharging is complete & the load current continues to decay.



This mode exists due to diode D_1 since it allows the resonant oscillation in mode 3 to continue through the ckt formed by D_m, D_1, C & the supply.

Mode 5 :- (Only D_m is ON)



Mode 5 begins when both thyristors are OFF & the load current continues to decay through the diode D_m.

Mode-5 ends When the main thyristor T_1 is refired at the beginning of the next cycle. The different waveforms for the currents & voltage are as shown in fig ⑥ → (See next page)

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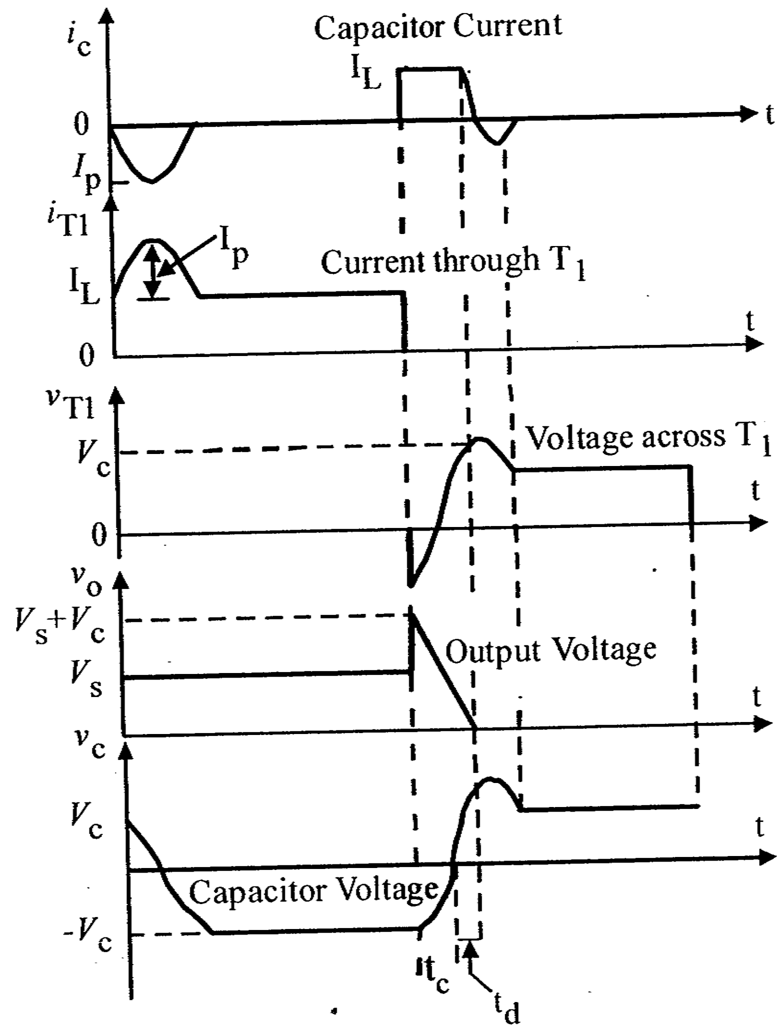

http://arunkumarnotes.ezimbo.com/

Advantages

1) Ckt is simple and requires two thyristors and one diode

2) At higher frequency, the load ripple currents & supply harmonic current become smaller, hence size of the I/p filter is reduced.

Disadvantages

1) The main SCR T_1 has to carry the resonant reversal current, hence its peak current rating is increased & limiting $V_{o\,min}$.

2) The discharging & charging time of commutation capacitor are dependent on load current & this limits HF operation, especially at low load current (Peak load current I_m)

3) This chopper cannot be tested without connecting the load.

POWER ELECTRONICS

7th Sem E&C

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AC VOLTAGE CONTROLLER

Introduction :-

❖ What is an ac voltage controller?

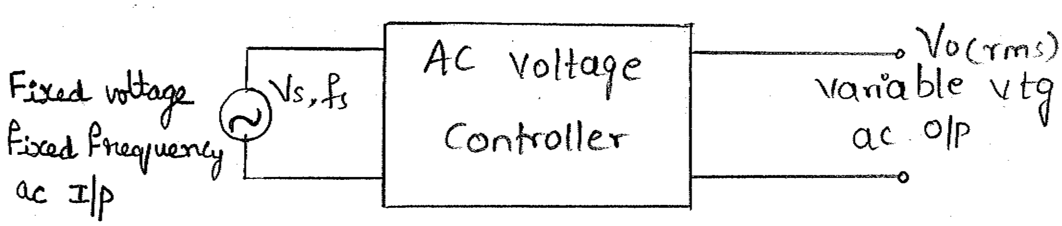


Fig. AC Voltage Controller

- ❖ AC voltage controller converts fixed ac signal into variable (Controlled) ac output voltage. The RMS value of the ac output voltage and the ac power flow to the load is controlled by varying (Adjusting) the triggering angle ‘ α’.
- ❖ These ac voltage controllers are used in speed control of ac motors, induction motors, fan regulators, light controllers etc.
- ❖ The main advantages of ac voltage controllers are high efficiency, compact in size, flexibility in control and simple circuitry.

Drawbacks :-

AC voltage controllers generates **HARMONICS.**

Types of AC voltage controllers :-

1) ON-OFF Control

2) Phase Control.

Principle of ON-OFF Control OR Integral Cycle control OR Zero Voltage Switching :-

- Draw the circuit diagram of a single phase AC voltage controller and explain the principle of ON-OFF control, with the help of relevant waveforms. Derive the expression for rms output voltage interms of rms supply voltage and duty cycle of the operation of the controller.

  June-10,6M Jan-04,10M

- What is an ac voltage regulator(controller)? With the help of waveforms, explain ON-OFF control and phase control.

  June-09,6M

- With a circuit diagram and waveforms of gating pulses and output voltage, explain the operation of 1-phase ON-OFF type ac voltage controller. Derive an expression for Vo(rms).

  June-08,10M

- Derive an expression for the rms value of the output voltage f a bi-directional ac voltage controller, employing ON-OFF control.

  Jan-08,6M

- Draw the circuit of a single phase ac voltage controller and explain the principle of ON-OFF control, with the help of relevant waveforms. Derive the expression for the RMS output voltage in terms of the RMS supply voltage and the duty cycle of operation of the controller.

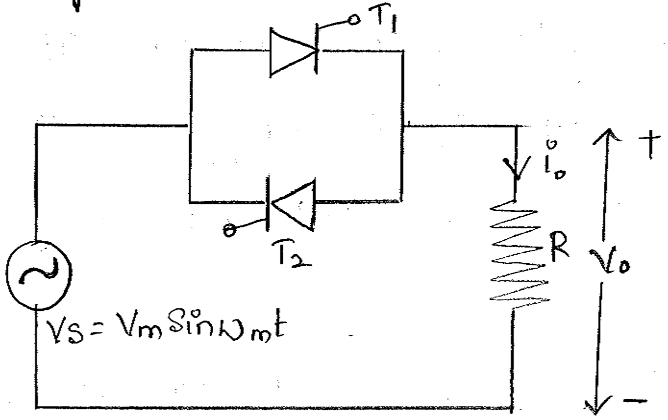
  Jan-05,8M

- What is an ac voltage controller? With the help of circuit diagram and waveform, explain the principle of phase control. June-11,6M

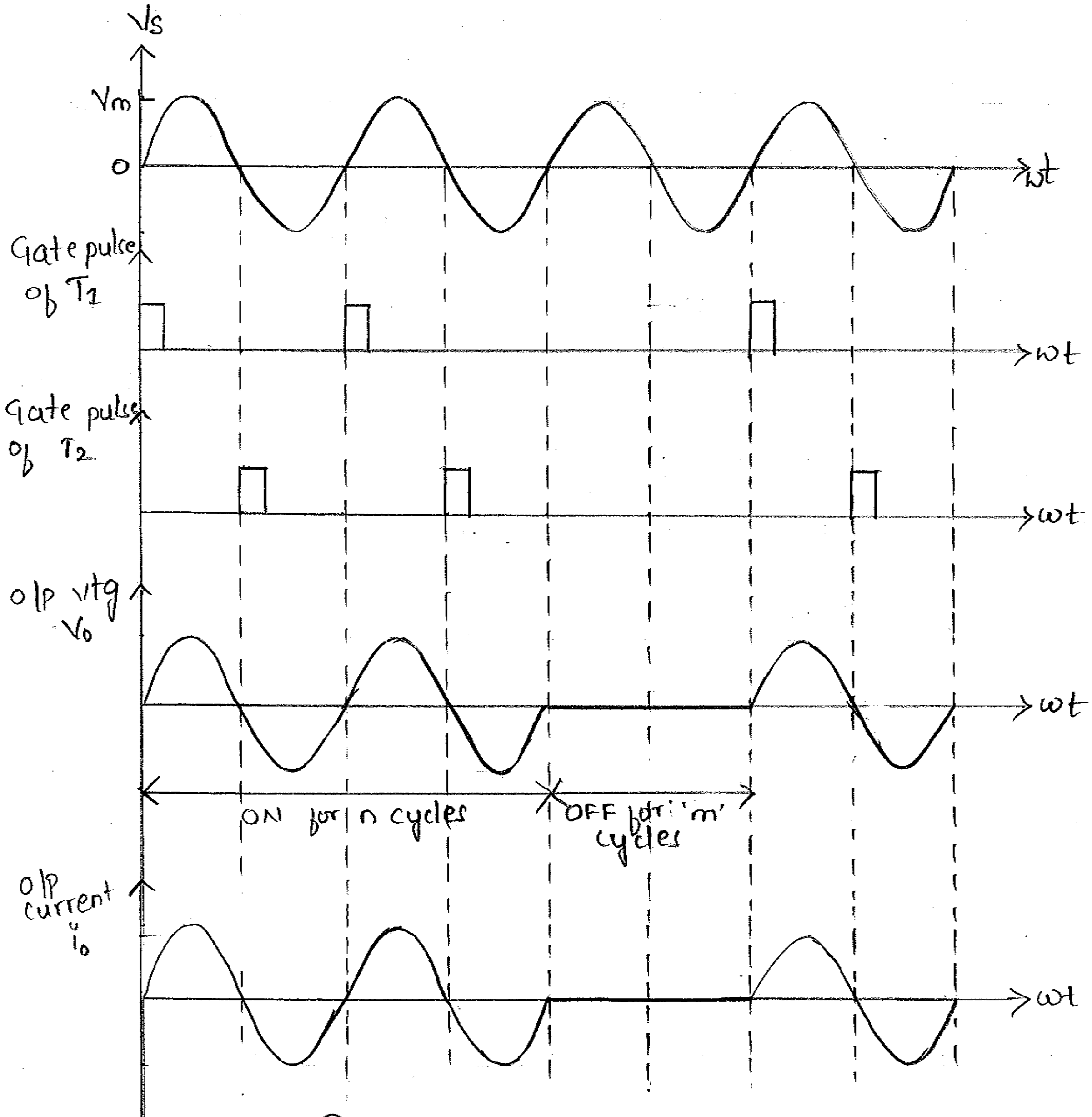
Principle of ON - OFF Control :-

(OR)

Integral cycle control or Zero vtg switching :-



ⓐ ckt.



ⓑ Waveforms

* ON-OFF Controller uses 2 SCR's connected in antiparallel as shown in fig ⓐ.

* During +ve half cycle of the ac i/p at the instant $\omega t = 0, 2\pi, 4\pi \ldots$ SCR 'T_1' is triggered at $\alpha = 0$. Thus SCR 'T_1' conducts and +ve half cycles appears across the load.

* During −ve half cycle of the ac i/p at instants $\omega t = \pi, 3\pi, 5\pi, \ldots$ SCR 'T_2' is triggered at $\alpha = 0$. Thus SCR 'T_2' conducts and the −ve half cycles appears across the load.

* When gate pulses are removed, both the SCR's are OFF. Thus no o/p appears across the load.
  ∴ SCR's conducts for 'n' number of cycles and they are 'OFF' for 'm' number of cycles.
  Hence the name ON-OFF control.

* Fig ⓑ shows the i/p and o/p waveforms for resistive load.

(Note: In place of the antiparallel SCRs a triac can be used)

Advantages :-

1) The SCRs are switch ON at zero crossings. Hence the harmonics due to switching actions are reduced.

2) Electromagnetic interference to neighbouring electronic ckts is minimized.

Disadvantages :-

1) O/p will be discontinuous, hence the load has to sustain these variations.

2) Since the thyristors are triggered at zero crossing, their conducting is not being exploited.

Expression for RMS value of load voltage ($V_{o(rms)}$) :-

The o/p RMS voltage is given by:

$$V_{o(rms)} = \sqrt{\frac{1}{T}\int_0^{2\pi} V_s^2 \, d\omega t} \longrightarrow ①$$

Let the supply voltage is

$$\boxed{V_s = V_m \sin(\omega t)} \longrightarrow ②$$

Substitute eq ② in eq ①, we get.

$$V_{o(rms)} = \sqrt{\frac{n}{n+m} \cdot \frac{1}{2\pi}\int_0^{2\pi} V_m^2 \sin^2(\omega t)\, d\omega t}$$

PTO →

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

WKT $\quad \sin^2(\omega t) = \dfrac{1-\cos 2(\omega t)}{2}$

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

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

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

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

$$\because \boxed{\int_0^{2\pi} \cos 2(\omega t)\, d\omega t = \frac{\sin 2(\omega t)}{2}}$$

$$= \left\{\frac{n}{(m+n)} \cdot \frac{V_m^2}{2\pi}\left[\left(\frac{2\pi}{2} - \frac{0}{2}\right) - \frac{1}{2}\left[\frac{\sin 2(2\pi)}{2} - \frac{\sin 2(0)}{2}\right]\right]\right\}^{1/2}$$

$$= \left\{\frac{n}{(m+n)} \cdot \frac{V_m^2}{2\pi}\left[(\pi) - \frac{1}{2}(0-0)\right]\right\}^{1/2}$$

$$\because \boxed{\begin{array}{l} \sin 2(2\pi) = 0 \\ \sin(0) = 0 \end{array}}$$

$$= \left\{ \frac{n}{(m+n)} \cdot \frac{V_m^2}{2\pi} (\pi) \right\}^{1/2}$$

$$= \left[\frac{n}{(m+n)} \cdot \frac{V_m^2}{2} \right]^{1/2}$$

$$= \sqrt{\frac{n}{(m+n)} \cdot \frac{V_m^2}{2}}$$

$$V_{o(rms)} = \frac{V_m}{\sqrt{2}} \sqrt{\frac{n}{(m+n)}}$$

$$V_{o(rms)} = \frac{V_m}{\sqrt{2}} \sqrt{K}$$ Where $K = \frac{n}{(m+n)}$

WKT $\boxed{V_{s(rms)} = \frac{V_m}{\sqrt{2}}}$

$$\therefore \boxed{V_{o(rms)} = V_{s(rms)} \sqrt{K}}$$

Average thyristor Current :-

The average value of current in a thyristor T_1 is given by

$$I_{T1(avg)} = \frac{n}{(m+n)} \left\{ \frac{1}{2\pi} \int_0^{\pi} i(t)\, d\omega t \right\} \longrightarrow (1)$$

The current can be expressed as

$$\boxed{i(t) = I_m \sin(\omega t)} \longrightarrow (2)$$

WKT
$$V_{s(rms)} = \frac{V_m}{\sqrt{2}}$$
$$\boxed{V_m = \sqrt{2}\, V_{s(rms)}}$$

WKT
$$I_m = \frac{V_m}{R}$$
$$\therefore I_m = \frac{V_{s(rms)} \sqrt{2}}{R}.$$

Substituting eq② in eq①, we get.

$$I_{T1(avg)} = \frac{n}{(m+n)} \left\{ \frac{1}{2\pi} \int_0^{\pi} I_m \sin(\omega t)\, d\omega t \right\}$$

$$= \frac{n}{(m+n)} \left\{ \frac{I_m}{2\pi} \int_0^{\pi} \sin(\omega t).d\omega t \right\}$$

$$= \frac{n}{(m+n)} \left\{ \frac{I_m}{2\pi} \left[-\cos(\omega t) \right]_0^{\pi} \right\} \quad \because \int_0^{\pi} \sin(\omega t) d\omega t = -\cos\omega t.$$

$$= \frac{n}{(m+n)} \left\{ \frac{I_m}{2\pi} \left[-\cos(\pi) - (-\cos(0)) \right] \right\}$$

$$= \frac{n}{(m+n)} \left\{ \frac{I_m}{2\pi} \left[-(-1) - (-1) \right] \right\}$$

$$= \frac{n}{(m+n)} \left\{ \frac{I_m}{2\pi} (2) \right\}$$

$$= \frac{n}{(m+n)} \cdot \frac{I_m}{\pi}$$

$$\boxed{I_{T1(avg)} = K \cdot \frac{I_m}{\pi}}$$

WKT

$$I_m = \frac{\sqrt{2}\, V_{s(rms)}}{R}$$

$$\therefore \boxed{I_{T1(avg)} = K \cdot \frac{\sqrt{2}\, V_{s(rms)}}{\pi R}}$$

Note: Since both the thyristors share the load current equally their avg currents will be same ie.

$$\boxed{I_T = I_{T1} = I_{T2}}$$

RMS Current of thyristor $I_{(rms)}$:-

$$I_{(rms)} = \left[\frac{n}{(m+n)} \cdot \frac{1}{2\pi} \int_0^{\pi} i(t)^2 \cdot d\omega t\right]^{1/2}$$

$$= \left[\frac{n}{(m+n)} \cdot \frac{1}{2\pi} \int_0^{\pi} I_m^2 \sin^2(\omega t)\, d\omega t\right]^{1/2}$$

$$= \left[\frac{n}{(m+n)} \cdot \frac{I_m^2}{2\pi} \int_0^{\pi} \sin^2(\omega t) \cdot d\omega t\right]^{1/2}$$

$$= \left[\frac{n}{(m+n)} \cdot \frac{I_m^2}{2\pi} \int_0^{\pi} \frac{1 - \cos 2(\omega t)}{2}\, d\omega t\right]^{1/2}$$

WKT $\boxed{\sin^2(\omega t) = \frac{1 - \cos 2(\omega t)}{2}}$

$$= \left\{\frac{n}{(m+n)} \cdot \frac{I_m^2}{2\pi} \left[\int_0^{\pi} \left(\frac{1}{2} - \frac{\cos 2(\omega t)}{2}\right) d\omega t\right]\right\}^{1/2}$$

$$= \left\{\frac{n}{(m+n)} \cdot \frac{I_m^2}{2\pi} \left[\int_0^{\pi} \frac{1}{2}\, d\omega t - \frac{1}{2} \int_0^{\pi} \cos 2(\omega t)\, d\omega t\right]\right\}^{1/2}$$

WKT $\boxed{\int_0^{\pi} \cos 2(\omega t)\, d\omega t = \frac{\sin 2(\omega t)}{2}}$

$$= \left\{\frac{n}{(m+n)} \cdot \frac{I_m^2}{4\pi} \left[\int_0^{\pi} 1\, d\omega t - \int_0^{\pi} \cos 2(\omega t)\, d\omega t\right]\right\}^{1/2}$$

$$= \left\{K \cdot \frac{I_m^2}{4\pi} \left[(\omega t)_0^{\pi} - \left(\frac{\sin 2(\omega t)}{2}\right)\right]\right\}^{1/2}$$

PTO →

$$= \left\{ K \cdot \frac{I_m^2}{4\pi} \left[(\pi - 0) - \cancel{\frac{\sin 2(\pi)}{2}}^{0} - \cancel{\frac{\sin 2(0)}{2}}^{0} \right] \right\}^{1/2}$$

$$= \left\{ K \cdot \frac{I_m^2}{4\pi} (\pi) \right\}^{1/2}$$

$$= \sqrt{K \cdot \frac{I_m^2}{4}} = \frac{I_m}{2} \cdot \sqrt{K}$$

$$\boxed{I_{rms} = \frac{I_m}{2} \sqrt{K}}$$

ON – OFF CONTROL

FORMULAE

1) ON time : $T_{on} = 2\pi n$

2) OFF time : $T_{OFF} = 2\pi m$

total time 'T' $= T_{ON} + T_{OFF}$

$= 2\pi n + 2\pi m$

$$\boxed{T = 2\pi(n+m)}$$

3) RMS o/p vtg

$$V_{o(rms)} = \frac{V_m}{\sqrt{2}} \sqrt{\frac{n}{(m+n)}}$$

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

$$\boxed{V_{o(rms)} = V_{s(rms)} \sqrt{K}}$$

4) $K = \frac{n}{(m+n)}$

5) $\sqrt{K} = \sqrt{\frac{n}{(m+n)}}$

6) RMS o/p voltage $V_0 = V_s \sqrt{K}$

$$V_0 = \frac{V_m}{\sqrt{2}} \sqrt{K}$$

$$V_0 = I_0 R_L$$

7) Power factor $PF = \sqrt{K}$

8) Load power $P_0 = I_0^2 R$

RMS load power $P_0 = I_0^2 R$

9) Load current or RMS load current

$$I_0 = \frac{V_0}{R}$$

10) Peak thyristor current $= I_m = \frac{V_m}{R}$

11) Peak voltage $V_m = \sqrt{2} V_s$

12) Average current of thyristor is

$$I_{avg} = \frac{K I_m}{\pi}$$

13) The RMS current of the thyristor is

$$I_{(rms)} = \frac{I_m}{2} \sqrt{K}$$

14) I/p power $P = V_s I_s$, $I_s = I_0$

$$\Rightarrow P = V_s I_0$$

15) $PF = \sqrt{K}$

ON-OFF Control PROBLEMS

❖ **An AC voltage controller has a resistive load of 10Ω and rms input voltage 120V, 60Hz. The thyristor switch is ON for n= 25 cycles & OFF for m= 75 cycles. Determine :**

i) RMS output voltage V_o

ii) Input power factor

iii) The average and rms current of thyristors.

June-11,6M (E&E) June-01,10M Jan-04,6M

Given :-

$R = 10\Omega$, $V_s = 120V$, $n = 25$ cycles, $m = 75$ cycles

Soln: $V_m = \sqrt{2} \cdot V_s = \sqrt{2} \times 120 = 169.7V$

$$K = \frac{n}{(m+n)} = \frac{25}{(75+25)} = 0.25$$

$$\sqrt{K} = 0.5$$

a) RMS value of o/p vtg

$$V_o = V_s \sqrt{K}$$

$$= 120 \times 0.5$$

$$\boxed{V_o = 60V}$$

RMS load current

$$I_o = \frac{V_o}{R}$$

$$= \frac{60V}{10}$$

$$\boxed{I_o = 6A}$$

b) The load power

$$P_0 = I_0^2 R$$

$$= 6^2 \times 10$$

$$\boxed{P_0 = 360W}$$

The i/p power factor is

$$PF = \sqrt{K}$$

$$PF = \sqrt{0.25}$$

$$\boxed{PF = 0.5}$$

c) Peak thyristor current

$$I_m = \frac{V_m}{R}$$

$$= \frac{169.7}{10}$$

$$\boxed{I_m = 16.97 A}$$

The average thyristor current

$$I_{T(avg)} = \frac{K I_m}{\pi} = \frac{0.25 \times 16.97}{\pi}$$

$$\boxed{I_{(avg)} = 1.33A}$$

RMS current of thyristor $I_{T(rms)}$

$$I_{T(rms)} = \frac{I_m}{2} \sqrt{K}$$

$$= \frac{16.97}{2} \cdot \sqrt{0.25}$$

$$\boxed{I_{T(rms)} = 4.24A}$$

❖ **In a ON-OFF control circuit using 1-phase, 230V, 50Hz supply the ON time is 10 cycles and OFF time is 4 cycles. Calculate the RMS value of the output voltage.**

Given :- $V_S = 230V$, $n = 10$, $m = 4$, $V_o = ?$

Soln : $K = \frac{n}{m+n} = \frac{10}{4+10} = 0.71$

$\sqrt{K} = \sqrt{0.71}$

$\boxed{\sqrt{K} = 0.845}$

RMS value of the o/p Voltage

$V_o = V_S\sqrt{K} = 230 \times 0.845$

$\boxed{V_o = 194.38V}$

❖ **An ON-OFF controller with an input of 230V, 50Hz is connected to a resistive load of 20Ω, the circuit is operating with the switch ON for 30 cycles and OFF for 30 cycles.**

Determine : i) rms output current ii) input power factor

Jan-09,10M June-04,4M

Given : $V_S = 230V$, $R = 20\Omega$, $n = 30$, $m = 30$

Soln : $K = \frac{n}{(m+n)} = \frac{30}{(30+30)} = 0.5$

$\boxed{K = 0.5}$

$\sqrt{K} = \sqrt{0.5} = 0.707$

i) RMS load current :-

$$I_0 = \frac{V_0}{R}$$

$$= \frac{162.6V}{20}$$

$$\boxed{I_0 = 8.13A}$$

$$V_0 = \sqrt{K}\ V_s$$

$$= 0.707 \times 230$$

$$\boxed{V_0 = 162.6V}$$

ii) $PF = \sqrt{K}$

$$= \sqrt{0.5}$$

$$\boxed{PF = 0.707}$$

❖ **A single phase full wave ac voltage controller working on ON-OFF control technique has supply voltage of 230V RMS, 50Hz, Load=50Ω. The controller is ON for 30 cycles and OFF for 40 cycles. Calculate**

i) ON & OFF time intervals

ii) RMS output voltage

iii) Input PF

iv) Average and RMS thyristor currents.

Given:- $V_s = 230V$, $R = 50$, $n = 30$, $m = 40$

* $K = \frac{n}{(m+n)} = \frac{30}{30+40} = 0.428$

$$\boxed{K = 0.428}$$

* $\sqrt{K} = \sqrt{0.428} = 0.654$

$$\boxed{\sqrt{K} = 0.654}$$

* $T = \frac{1}{f} = \frac{1}{50}$

$$\boxed{T = 20\,msec}$$

* $V_m = \sqrt{2}\,V_s = 325.29\,V$

$$\boxed{V_m = 325.269}$$

i) $T_{ON} = n \times T$

$= 30 \times 20\,msec$

$$\boxed{T_{ON} = 600\,msec = 0.6\,sec}$$

$T_{OFF} = m \times T$

$= 40 \times 20\,msec$

$$\boxed{T_{OFF} = 800\,msec = 0.8\,sec}$$

ii) RMS o/p vtg :-

$V_0 = V_s \sqrt{K}$

$= 230\sqrt{0.4285}$

$$\boxed{V_0 = 150.55\,V}$$

iii) $PF = \sqrt{K}$

$= \sqrt{0.4285}$

$$\boxed{PF = 0.6546}$$

iv) Average thyristor current

$I_{T(avg)} = K\frac{I_m}{\pi}$

$I_m = \frac{V_m}{R} = \frac{325.269}{50} = 6.5053\,A.$

$I_{T(av)} = \frac{6.5053}{\pi} \times 0.4285$

$$I_{T(avg)} = 0.8872A$$

RMS current of thyristor.

$$I_{T(rms)} = \frac{I_m}{2}\sqrt{K}$$

$$= \frac{6.5053}{2} \times \sqrt{0.4285}$$

$$I_{T(rms)} = 3.252 \times 0.6545$$

$$\boxed{I_T(rms) = 2.128A}$$

❖ **An AC voltage controller has a resistive load of 10Ω and rms input voltage 230V, 50Hz. The thyristor switch is ON for 25 cycles & OFF for 75 cycles.**

Determine : i) rms output voltage ii) input power factor

Jan-10,6M June-10,6M(IT) June-08,6M

Given: $n = 25$ cycles, $m = 75$ cycles, $V_s = 120V$, $R = 10\Omega$

Soln: $V_m = \sqrt{2}V_s = \sqrt{2} \times 120$

$$V_m = 169.70V$$

duty cycle $'K' = \frac{n}{m+n}$

$$= \frac{25}{25+75}$$

$$K = 0.25$$

$$\sqrt{K} = \sqrt{0.25} = 0.5$$

$$\sqrt{K} = 0.5$$

* RMS o/p voltage:-

$$V_0 = V_S\sqrt{K}$$
$$= 120 \times 0.5$$
$$\boxed{V_0 = 60V}$$

* RMS o/p current :-

$$I_0 = \frac{V_0}{R}$$
$$= \frac{60V}{10\Omega}$$
$$\boxed{I_0 = 6A.}$$

* $PF = \sqrt{K}$

$$\boxed{P = 0.5}$$

6) The single-phase ACVC shown in fig ① delivers a power of 5KW to the resistive load of $R = 5\Omega$. If ON-OFF control stratergy is used and the supply voltage is 230V, 50Hz, calculate

a) The RMS o/p voltage and current.
b) The duty cycle
c) The i/p power factor.
d) The RMS and average values of thyristor current.

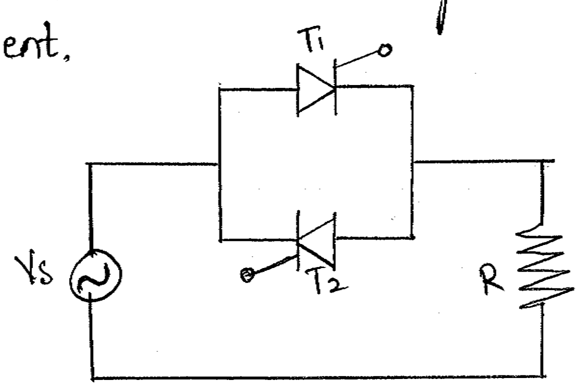


fig ①

Given: $P_0 = 5KW$, $R = 5\Omega$, $f = 50Hz$, $V_s = 230V$.

Soln:

a) The RMS o/p voltage and current :-

WKT $V_0 = \sqrt{P_0 R}$

$= \sqrt{5000 \times 5}$

$V_0 = 158.11V$

WKT $I_0 = \frac{V_0}{R}$

$= \frac{158.11}{5}$

$\boxed{I_0 = 31.62A}$

b) The duty cycle:

$K = \left(\frac{V_0}{V_s}\right)^2$

$= \left(\frac{158.11}{230}\right)^2$

$\boxed{K = 0.473}$

WKT
$V_0 = V_s\sqrt{K}$
$\sqrt{K} = \frac{V_0}{V_s}$
$K = \left(\frac{V_0}{V_s}\right)^2$

c) The i/p power factor

I- method:

$PF = \sqrt{K} = \sqrt{0.473}$

$\boxed{PF = 0.6874}$ lagging

II - method:

$PF = \frac{V_0}{V_s} = \frac{158.11}{230}$

$\boxed{PF = 0.6874}$ lagging.

d) The rms and average values of thyristor current:

The peak thyristor current :

$$I_m = \frac{V_m}{R}$$

$$V_m = \sqrt{2}\, V_S = \sqrt{2} \times 230$$

$$\boxed{V_m = 325.26V}$$

$$\Rightarrow I_m = \frac{V_m}{R} = \frac{325.26}{5}$$

$$\boxed{I_m = 65.05A}$$

The rms value of thyristor current :

$$I_{T(rms)} = \frac{I_m}{2} \cdot \sqrt{K}$$

$$= \frac{65.05}{2} \times \sqrt{0.473}$$

$$\boxed{I_{T(rms)} = 22.523A.}$$

The average values of thyristor current

$$I_{T(avg)} = \frac{K I_m}{\pi}$$

$$= \frac{0.473 \times 65.05A}{\pi}$$

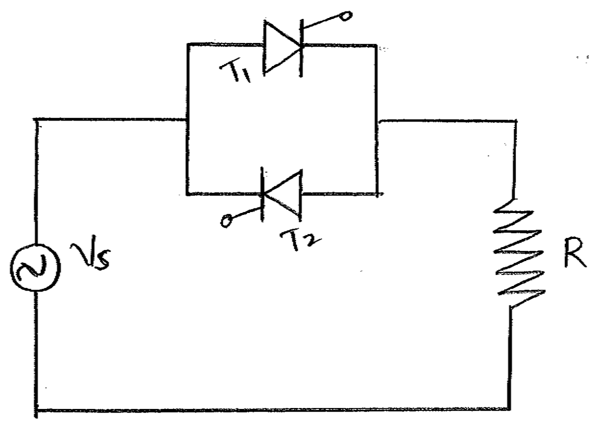
$$\boxed{I_{T(avg)} = 9.79A}$$

7). The ACVC shown in fig ① has $R = 20\Omega$ and the i/p ac is 230V, 50Hz. If ON-OFF control is adopted with n=50 cycles and m=150 cycles, Calculate

a) The rms o/p voltage,

b) The I/p power factor

c) The average and rms values of thyristor currents.



Given: $R = 20\Omega$, $V_s = 230V$, $f = 50Hz$, $n = 50$, $m = 150$.

Soln:-

a) The rms o/p voltage:-

$$V_o = V_s\sqrt{K}$$

$$K = \frac{n}{(m+n)}$$

$$= \frac{50}{50+150}$$

$$K = 0.25$$

$$V_o = 230 \times \sqrt{0.25}$$

$$\boxed{V_o = 115V}$$

b) The i/p power factor:

$$PF = \sqrt{K}$$

$$= \sqrt{0.25}$$

$$\boxed{PF = 0.5}$$

c) The average and rms values of thyristor Currents:

* The RMS value of thyristor current:

$$I_{T(rms)} = \frac{I_m}{2}\sqrt{K}$$

$$I_m = \frac{V_m}{R}$$

$$V_m = \sqrt{2}\ V_s$$

$$= \sqrt{2} \times 230V$$

$$\boxed{V_m = 325.26V}$$

$$I_m = \frac{325.26V}{20}$$

$$I_m = 16.263A$$

$$I_{T(rms)} = \frac{I_m}{2}\sqrt{K}$$

$$= \frac{16.263}{2} \times \sqrt{0.25}$$

$$\boxed{I_{T(rms)} = 4.065A}$$

* The average value of thyristor current:

$$I_{T(avg)} = K\frac{I_m}{\pi}$$

$$= 0.25 \times \frac{16.263A}{\pi}$$

$$\boxed{I_{T(avg)} = 1.294A}$$

Principle of PHASE CONTROL AC Voltage Controller :-

Single Phase Half Wave AC voltage Controller (With R- Load) :-

OR

Unidirectional AC voltage Controller (With R- Load) :-

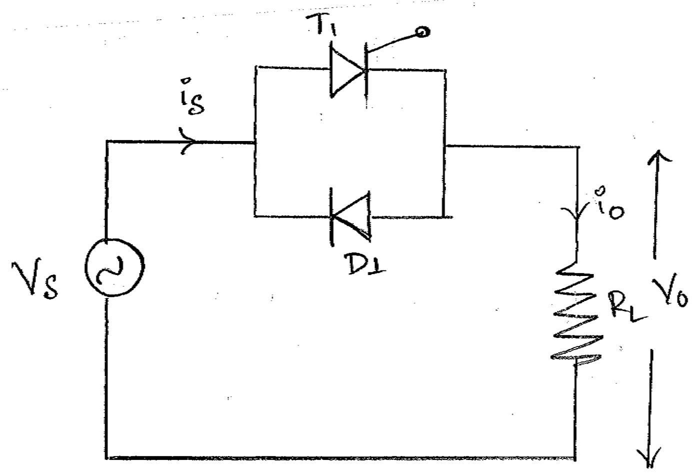


fig ①: 1φ Half wave controller (unidirectional controller).

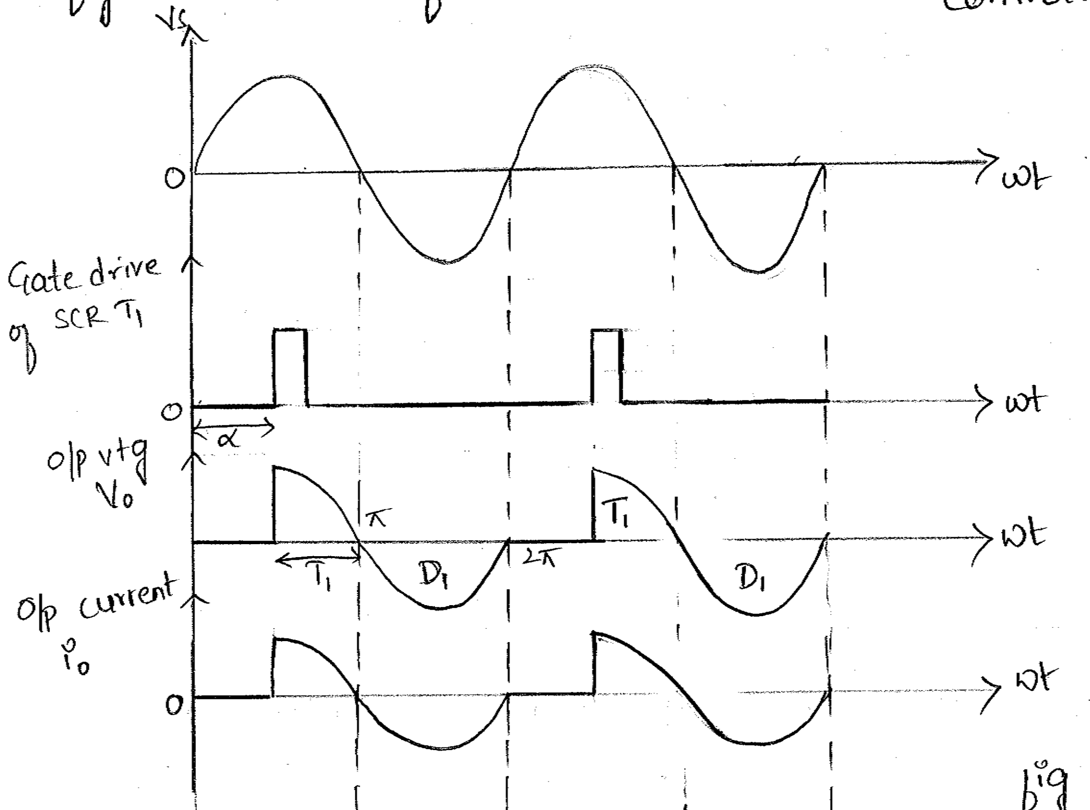


fig 1 (b)

* The SCR T_1 is connected across the diode D_1 in an antiparallel configuration. Due to one SCR, only the +ve half cycle will be controlled and -ve half cycle of ac supply will appear across the load without any change as shown in fig 1(b)

Operation :

* During +ve half cycle of ac supply, SCR 'T_1' is turned ON at $\omega t = \alpha$. This will make the load voltage +ve and equal to the instantaneous ac supply voltage. The SCR will be turned OFF due to natural commutation at $\omega t = \pi$.

* During -ve half cycle of ac supply, D_1 will turn -ON at $\omega t = \pi$. Thus load voltage and current is negetive.
  Diode 'D' is turned OFF at $\omega = 2\pi$.

* Thus load voltage can be controlled by contro-lling the firing angle 'α' of the SCR.

Advantages :

1> Since there is only one SCR, the control ckt is simple.
2> The ckt is less expensive.

Disadvantages :-

1> The o/p voltage is not controlled fully, since -ve half cycle is uncontrolled due to diode 'D_1

2) The load voltage waveform is highly distorted. For large values of α, it does not resemble a sine wave at all.

Applications:

Due to the dc component in the o/p current and voltage this is used for heating and lighting appli-cations.

Expression for rms value of o/p vtg :-

* WKT supply vtg is

$$V_s = V_m \sin\omega t.$$

* The rms value of o/p vtg is given by

$$V_0 = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} V_s^2 \, d\omega t}$$

$$V_0 = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} V_m^2 \sin^2(\omega t)\, d\omega t}$$

$$V_0 = \left\{\frac{1}{2\pi}\left[\int_\alpha^{\pi} V_m^2 \sin^2(\omega t)\, d\omega t + \int_\pi^{2\pi} V_m^2 \sin^2(\omega t)\, d\omega t\right]\right\}^{1/2}$$

$$V_0 = \left\{\frac{V_m^2}{2\pi}\left[\int_\alpha^{\pi} \sin^2(\omega t)\, d\omega t + \int_\pi^{2\pi} \sin^2(\omega t)\, d\omega t\right]\right\}^{1/2}$$

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

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

$$= \left\{ \frac{V_m^2}{4\pi} \left[\int_{\alpha}^{\pi} 1 \cdot d\omega t - \int_{\alpha}^{\pi} \cos 2\omega t \cdot d\omega t + \int_{\pi}^{2\pi} 1 \cdot d\omega t - \int_{\pi}^{2\pi} \cos 2\omega t \, d\omega t \right] \right\}^{1/2}$$

$$= \left\{ \frac{V_m^2}{4\pi} \left[(\omega t)_{\alpha}^{\pi} - \left[\frac{\sin 2\omega t}{2} \right]_{\alpha}^{\pi} + (\omega t)_{\pi}^{2\pi} - \left[\frac{\sin 2\omega t}{2} \right]_{\pi}^{2\pi} \right] \right\}^{1/2}$$

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

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

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

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

$$= \sqrt{ \frac{V_m^2}{4\pi} \left[2\pi - \alpha + \frac{\sin 2\alpha}{2} \right] }$$

$$\boxed{V_0 = \frac{V_m}{2} \sqrt{ \frac{2\pi - \alpha + \frac{\sin 2\alpha}{2}}{\pi} }}$$

* RMS value of o/p current.

$$\boxed{I_0 = \frac{V_0}{R_L}}$$

Expression for average or dc value of o/p voltage:-

WKT average value of o/p voltage is given by:

$$V_{dc} = V_{o(avg)} = \frac{1}{2\pi}\int_{\alpha}^{2\pi} V_m \sin\omega t \, d\omega t$$

$$V_{o(avg)} = \frac{V_m}{2\pi}\int_{\alpha}^{2\pi} \sin\omega t \, d\omega t$$

$$V_{o(avg)} = \frac{V_m}{2\pi}\left[-\cos\omega t\right]_{\alpha}^{2\pi}$$

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

$$V_{o(avg)} = \frac{V_m}{2\pi}\left[-1 + \cos\alpha\right]$$

$$V_{o(avg)} = \frac{V_m}{2\pi}\left[\cos\alpha - 1\right]$$

$$\boxed{V_{dc} = V_{o(avg)} = \frac{\sqrt{2}\,V_s}{2\pi}\left[\cos\alpha - 1\right]}$$

Note:

$$V_o = \sqrt{\frac{V_m^2}{4\pi}\left[2\pi - \alpha + \frac{\sin 2\alpha}{2}\right]}$$

i) for $\alpha = 0$

$$V_o = \sqrt{\frac{V_m^2}{4\pi}(2\pi)}$$

$$V_o = \sqrt{\frac{V_m^2}{2}}$$

$$\boxed{V_o = \frac{V_m}{\sqrt{2}}}$$

ii) for $\alpha = 180°$

$$V_o = \sqrt{\frac{V_m^2}{4 \times 180°}\left[2(180°) - 180 + \frac{\sin 2(180)}{2}\right]}$$

$$V_o = \sqrt{\frac{V_m^2}{720°} \times [180°]}$$

$$\boxed{V_o = \frac{V_m}{2}}$$

FORMULAE

1> RMS o/p voltage :-

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

when $\alpha = 0°$

$$V_o = \frac{V_m}{\sqrt{2}}$$

When $\alpha = 180°$

$$V_o = \frac{V_m}{2}$$

2> $V_m = \sqrt{2}\, V_s$

3> RMS o/p current or rms load current.

$$I_o = \frac{V_o}{R_L}$$

4> Average or dc o/p voltage

$$V_{dc} = \frac{\sqrt{2}\, V_s}{2\pi}\left[\cos\alpha - 1\right]$$

OR

$$V_{dc} = \frac{V_m}{2\pi}\left[\cos\alpha - 1\right]$$

5> Load power $P_o = I_o^2 R_L$ or $P_o = V_o I_o = \frac{V_o^2}{R_L}$

6> I/p current = load current

$$I_s = I_o$$

7> I/p power $P_i = V_s I_s = V_s I_o$.

8) $PF = \frac{P_o}{P_i}$

$$PF = \frac{V_o \cancel{I_o}}{V_s \cancel{I_o}}$$

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

$$= \frac{\sqrt{\frac{1}{4}\cdot\frac{2\pi-\alpha+\frac{\sin 2\alpha}{2}}{\pi}}}{\sqrt{2}}$$

9) Average o/p voltage :-

$$V_{dc} = \frac{\sqrt{2}\,V_s}{2\pi}\left[\cos\alpha - 1\right]$$

10) Average i/p current

$$I_{dc} = \frac{V_{dc}}{R}$$

11) Average thyristor current $I_{T(avg)} = \frac{I_m}{2\pi}\left[1+\cos\alpha\right]$

12) RMS thyristor current :

$$I_{T(rms)} = \frac{I_m}{\sqrt{2}}\sqrt{\frac{1}{2\pi}\left[(\pi-\alpha)+\frac{\sin 2\alpha}{2}\right]}$$

PROBLEMS

1) A Single-Phase ac voltage controller in Fig1. Has a resistive load of R=10Ω and the input voltage is V_s=120V, 60Hz. The delay angle of thyristor T_1 is $\alpha = \pi/2$. Determine

a) The rms value of output voltage V_o

b) The input PF, and

c) The average input current.

Given: $R = 10\Omega$, $V_s = 120V$, $60Hz$, $\alpha = \pi/2 = 90°$

Soln: $V_m = \sqrt{2}\, V_s$

$= \sqrt{2} \times 120$

$V_m = 169.7V$

a) $$V_0 = \frac{V_m}{2}\sqrt{\frac{2\pi - \alpha + \frac{\sin 2(\alpha)}{2}}{\pi}}$$

$$= \frac{V_m}{2}\sqrt{\frac{2\pi-\alpha}{\pi} + \frac{\sin 2(\alpha)/2}{\pi}}$$

$$= \frac{169.7}{2}\sqrt{\frac{360°-90°}{180°} + \frac{\sin 2(90)/2}{180°}}$$

$$= \frac{169.7}{2}\sqrt{\frac{270°}{180°}}$$

$$\boxed{V_0 = 103.92V}$$

b) Input power factor:

$$PF = \frac{V_0}{V_s}$$

$$= \frac{103.92}{1}$$

$$\boxed{PF = 0.866}$$

c) Average input current:

$$I_{dc} = \frac{V_{dc}}{R}$$

$$V_{dc} = \sqrt{2} \cdot \frac{V_s}{2\pi} \left[\cos\alpha - 1\right]$$

$$= \sqrt{2} \frac{V_s}{2\pi} \left[\cos(\pi/2) - 1\right]$$

$$= \sqrt{2} \frac{V_s}{6.2831} \left[0 - 1\right]$$

$$= -\sqrt{2} \cdot \frac{120}{6.2831}$$

$$V_{dc} = -27V$$

$$\Rightarrow I_{dc} = \frac{-27}{10} = -2.7A.$$

$$\boxed{I_{dc} = -2.7A}$$

2) A Single-Phase half wave ac voltage controller has a resistance load of R=5Ω and input voltage V_s=120V, 60Hz. The delay angle of thyristor is $\alpha = \pi/3$. Calculate :

i) The RMS value of o/p voltage V_o
ii) The I/p PF &
iii) The average I/p current.

Given : $R = 5\Omega$, $V_s = 120V$, $\alpha = \pi/3$

Soln: i) $V_o = \frac{V_m}{2}\sqrt{\frac{2\pi - \alpha + \frac{\sin 2(\alpha)}{2}}{\pi}}$

$V_m = \sqrt{2}\, V_s$

$= \sqrt{2} \times 120$

$$\boxed{V_m = 169.70V}$$

a) $V_o = \frac{V_m}{2}\sqrt{\frac{(2\pi - \alpha) + \frac{\sin 2(\alpha)}{2}}{\pi}}$

$= \frac{169.70}{2}\sqrt{\frac{(2\pi - \pi/3) + \frac{\sin 2(\pi/3)}{2}}{\pi}}$

$$\boxed{V_o = 113.98V.}$$

b) I/p power factor

I method : $PF = \frac{V_o}{V_s} = \frac{113.98}{120}$

$$\boxed{PF = 0.9498} \quad \text{(Lagging)}$$

II method :

$PF = \frac{P_o}{P_i}$

$$I_0 = \frac{V_0}{R}$$

$$= \frac{113.98}{5\Omega}$$

$$\boxed{I_0 = 22.796\ A}$$

$$P_0 = I_0^2 R$$

$$= (22.796)^2 \times 5$$

$$\boxed{P_0 \Rightarrow 2598.28\ W}$$

$$P_i = V_s I_s = V_s I_0$$

$$= 120 \times 22.796$$

$$\boxed{P_i = 2735.52\ W}$$

$$\Rightarrow PF = \frac{P_0}{P_i} = \frac{2598.28}{2735.52}$$

$$\boxed{PF = 0.9498}$$

c) Average input current.

$$I_{dc} = \frac{V_{dc}}{R}$$

$$V_{dc} = \frac{\sqrt{2}\, V_s}{2\pi} [\cos\alpha - 1]$$

$$= \frac{\sqrt{2} \times 120}{2\pi} \left[\cos(\pi/3) - 1\right]$$

$$\boxed{V_{dc} = -13.5\ V}$$

$$I_{dc} = \frac{-13.5}{5} = -2.7A$$

$$\boxed{I_{dc} = -2.7A.}$$

3) A single phase half-wave ac voltage controller has a load resistance R=50Ω, input ac supply voltage is 230V RMS at 50Hz. The input supply transformer has a turns ratio of 1:1. If the thyristor T1 is triggered at α= 60°. Calculate

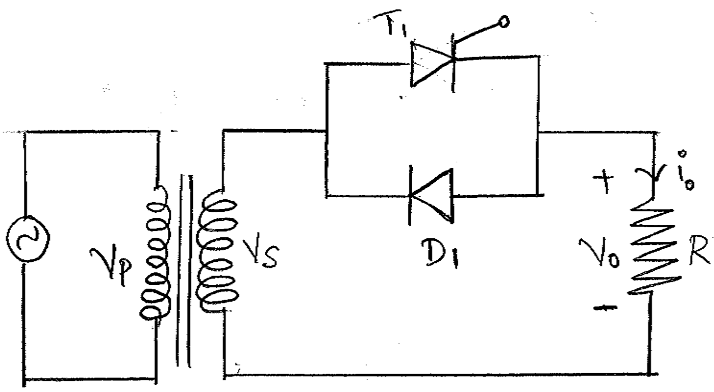
i) RMS output voltage

ii) Output power

iii) RMS load current and average load current

iv) Input power factor

v) Average and RMS thyristor current.



Given: $V_s = 230V$, $R = 50\Omega$, $\alpha = 60° = \pi/3$, $V_m = \sqrt{2}\, V_s$
$= 325.26V.$

Soln:

i) RMS o/p voltage.

$$V_0 = \frac{V_m}{2}\sqrt{\frac{(2\pi-\alpha) + \sin 2\alpha/2}{\pi}}$$

$$= \frac{325.26}{2}\sqrt{\frac{(2\pi - \pi/3) + \frac{\sin 2(\pi/3)}{2}}{\pi}}$$

$$\boxed{V_0 = 218.46V}$$

ii) $P_0 = \frac{V_0^2}{R_L} = \frac{218.46}{50} = 954.49W$

iii) RMS load current

$$I_0 = \frac{V_0}{R_L} = \frac{218.46}{50}$$

$$\boxed{I_0 = 4.3692A}$$

Average Load current :

$$I_{dc} = \frac{V_{dc}}{R}$$

$$V_{dc} = \frac{\sqrt{2} \times V_s}{2\pi} [\cos\alpha - 1]$$

$$= \frac{\sqrt{2} \times 230}{2\pi} [\cos(\pi/3) - 1]$$

$$= 51.768 \times (-0.5)$$

$$\boxed{V_{dc} = -25.884V}$$

$$\Rightarrow \quad I_{dc} = \frac{25.884}{50} = -0.5176A.$$

$$\boxed{I_{dc} = -0.5176A}$$

iv) I/p power factor:

$$PF = \frac{P_0}{P_i}$$

$$PF = \frac{V_0}{V_s} = \frac{218.46V}{230V}$$

$$\boxed{PF = 0.9498}$$

v) Average thyristor current :

$$I_{T(avg)} = \frac{I_m}{2\pi} [1 + \cos\alpha]$$

$$I_m = \frac{V_m}{R_L} = \frac{325.269}{50}$$

$$\boxed{I_m = 6.505A}$$

$$\Rightarrow I_{T(avg)} = \frac{6.505}{2\pi}\left[1+\cos(\pi/3)\right]$$

$$= 1.035\left[1+0.5\right]$$

$$\boxed{I_{T(avg)} = 1.5525A}$$

RMS thyristor current :

$$I_{T(rms)} = \frac{I_m}{\sqrt{2}}\sqrt{\frac{1}{2\pi}\left[(\pi-\alpha)+\frac{\sin 2\alpha}{2}\right]}$$

$$= \frac{6.505}{\sqrt{2}}\sqrt{\frac{1}{2\pi}\left[(\pi-\pi/3)+\frac{\sin 2(\pi/3)}{2}\right]}$$

$$= 4.599\sqrt{0.159\left[2.094+0.476\right]}$$

$$\boxed{I_{T(rms)} = 2.917A}$$

---

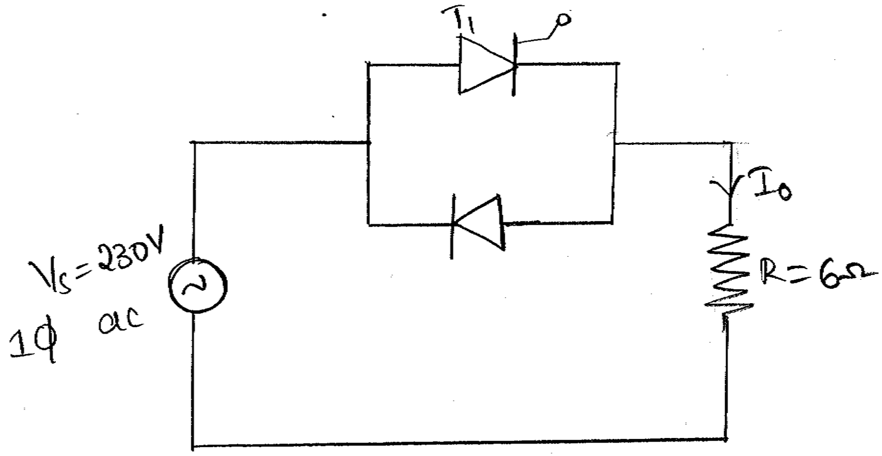
4) A Single phase half wave AC voltage controller shown in figure feeds power to a resistive load of 6Ω from 230V, 50Hz source. The firing angle of SCR is $\alpha = \pi/2$. Calculate :

i) RMS value of output voltage

ii) Input power factor

iii) Average input current

iv) Derive any formulae for atleast two sub divisions.



Given: $R = 6\Omega$, $V_s = 230V$, $\alpha = \pi/2$

Soln:

i) RMS o/p voltage:

$$V_o = \frac{V_m}{2}\sqrt{\frac{(2\pi - \alpha) + \frac{\sin 2\alpha}{2}}{\pi}}$$

$$V_m = \sqrt{2}\,V_s$$

$$= \sqrt{2} \times 230V$$

$$\boxed{V_m = 325.2V}$$

$$\Rightarrow V_o = \frac{325.2}{2}\sqrt{\frac{(2\pi - \frac{\pi}{2}) + \frac{\sin 2(\pi/2)}{2}}{\pi}}$$

$$= 162.6\sqrt{\frac{4.7123}{3.142}}$$

$$\Rightarrow 162.6\sqrt{1.5}$$

$$= 162.6 \times 1.2247$$

$$\boxed{V_o = 199.1435V}$$

ii> I/p power factor:

$$PF = \frac{V_0}{V_s}$$

$$= \frac{199.1V}{230}$$

$$\boxed{PF = 0.865}$$

iii> Average I/p current:

$$I_{avg} = \frac{V_{dc}}{R}$$

$$V_{dc} = \frac{V_m}{2\pi}\left[\cos\alpha - 1\right]$$

$$= \frac{325.2}{2\pi}\left[\cos(\pi/2) - 1\right]$$

$$\boxed{V_{dc} = -51.72V}$$

$$I_{avg} = \frac{V_{dc}}{R} = \frac{-51.72}{6}$$

$$\boxed{I_{avg} = 8.62A}$$

PTO→.

5) A 1-Phase halfwave ac voltage controller has an input voltage of 230V, 50Hz and a load resistance of 10Ω. The firing angle of thyristor is 90° in each positive half cycle. Find :

i) Average output voltage

ii) RMS output voltage

iii) The average thyristor current

iv) The rms current value of the thyristor

v) Diode average curent

vi) Diode rms current.

Jan-11,12M

Given: $V_s = 230V$, $R = 10\Omega$, $\alpha = \pi/2 = 90^\circ$.

Soln: $V_m = \sqrt{2} \times 230$

$$\boxed{V_m = 325.26\,V}$$

i) Average o/p voltage.

$$V_{dc} = \frac{\sqrt{2}\,V_s}{2\pi}[\cos\alpha - 1]$$

$$= \frac{\sqrt{2} \times 230}{2\pi}[\cos(90^\circ) - 1]$$

$$\boxed{V_{dc} = -6.75\,V}$$

ii) RMS o/p voltage:

$$V_o = \frac{V_m}{2}\sqrt{\frac{(2\pi - \alpha) + \frac{\sin(2\alpha)}{2}}{\pi}}$$

$$= \frac{325.26}{2}\sqrt{\frac{(2\pi - \pi/2) + \frac{\sin 2(\pi/2)}{2}}{\pi}}$$

$$\boxed{V_o = 199.2\,V}$$

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iii) The average thyristor current :

$$I_{T(avg)} = \frac{I_m}{2\pi}[1+\cos\alpha]$$

$$I_m = \frac{V_m}{R_L} = \frac{325.26}{10}$$

$$\boxed{I_m = 32.526\,A}$$

$$I_{T(avg)} = \frac{32.526}{2\pi}[1+\cos 90^\circ]$$

$$\boxed{I_{T(avg)} = 5.18A}$$

iv) The rms current value of the thyristor.

$$I_{T(rms)} = \frac{I_m}{\sqrt{2}}\sqrt{\frac{1}{2\pi}\left[(\pi-\alpha) + \frac{\sin 2\alpha}{2}\right]}$$

$$= \frac{32.526}{\sqrt{2}}\sqrt{\frac{1}{2\pi}\left[(\pi-\pi/2) + \frac{\sin 2(\pi/2)}{2}\right]}$$

$$\boxed{I_{T(rms)} = 11.5A}$$

v) Diode average current :-

$$I_{D(avg)} = \frac{I_m}{\pi}$$

$$= \frac{32.526}{\pi}$$

$$\boxed{I_{D(avg)} = 10.35A}$$

vi) Diode rms current

$$I_{d(rms)} = \frac{I_m}{2} = \frac{32.526}{2}$$

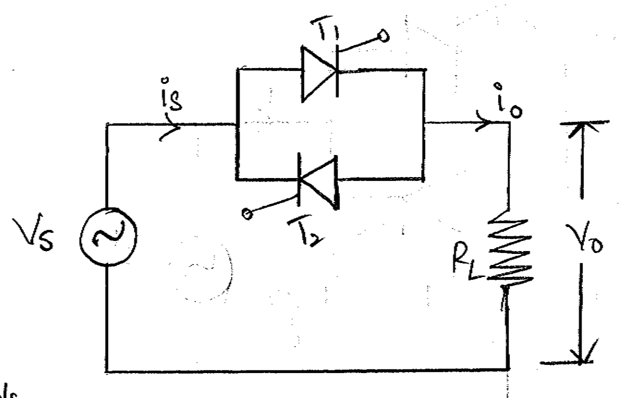
$$\boxed{I_{D(rms)} = 16.26A}$$

Single Phase FULL Wave AC voltage Controller (With R- Load) :-

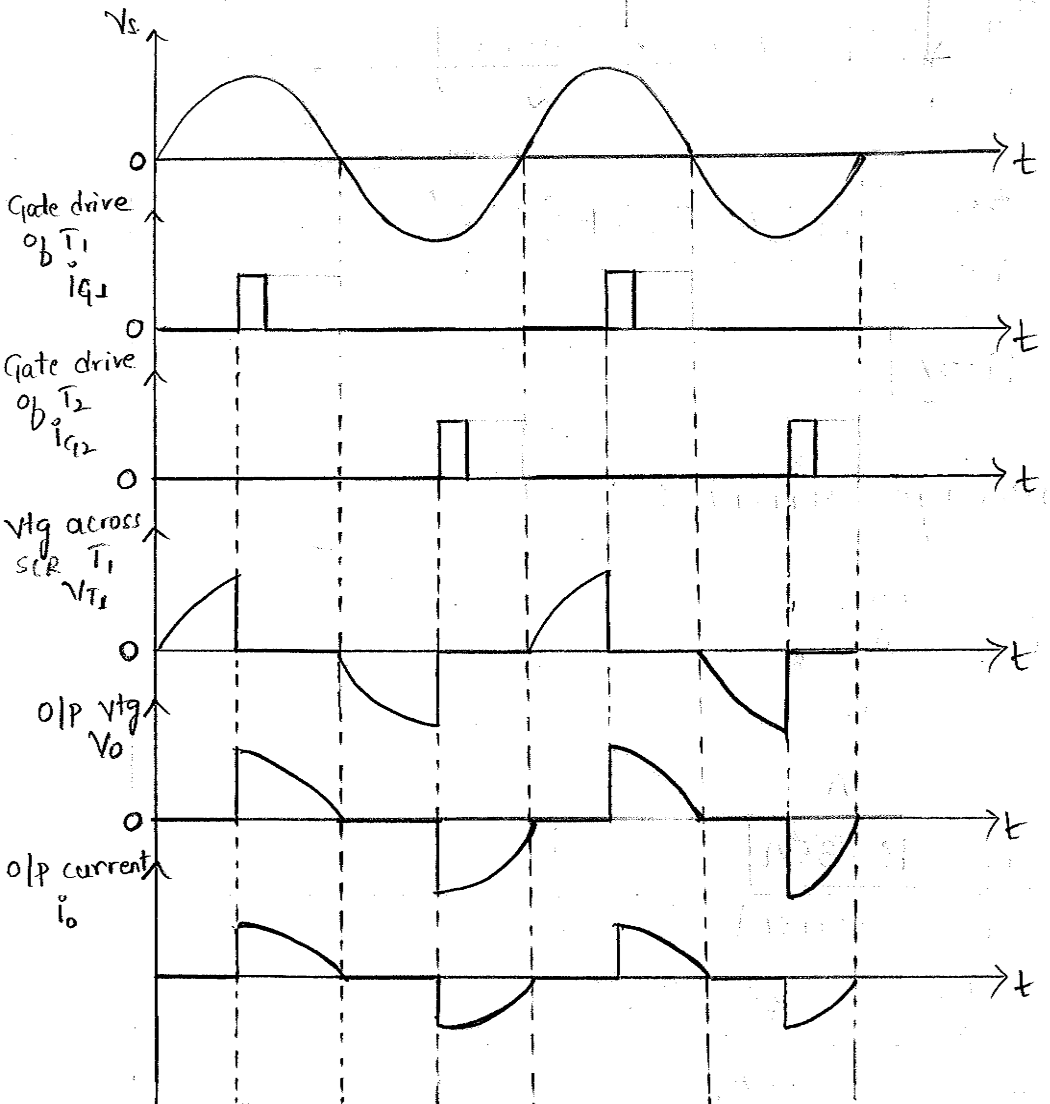
OR

Bi-directional AC voltage Controller (With R- Load) :-

❖ **Explain the operation of a single phase bidirectional controller with resistive load. Obtain the equation forms and output voltage. Show the waveforms.** **June-09,8M**



fig(1) Full wave ac vtg controller.



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The ckt diagram of a single phase. Full wave ac vtg controller is as shown in fig ①

* Two SCR's are connected in the antiparallel configuration. Due to the use of two SCR's, it is possible to control the load voltage and power in both the half cycles of ac supply. Thus it is also called as a bi directional controller.

* In +ve half cycle of the supply, 'T_1' controlls the power delivered to the load and in -ve half cycle of the supply 'T_2' controls the power delivered to the load.

  Thus the RMS o/p voltage can be controlled by varying the firing angle 'α' from '0' to 180°.

* Fig ② shows the I/o waveform. The o/p vtg and current waveforms are symmetric. Hence there is no dc component in V_o & i_o

* A conducting SCR will turn OFF due to natural commutation at the end of corresponding half cycles of supply voltage.

Advantages:

1> The control of load power is possible in both the half cycle of a supply.

2> The average value of load current and supply current is zero. So there is no possibility of core saturation of induction motor used a load.

Disadvantages.

1) Due to the use of two SCR's the ckt becomes a little more complicated and expensive.

Applications:

1) Used for induction motors, pumps, fans etc...
2) As a fan regulator
3) Heater control
4) As light dimmer.

Expression for RMS value of o/p vtg for single phase full wave controller :-

WKT I/p supply vtg is given by:

$$V_s = V_m \sin\omega t \longrightarrow (1)$$

The rms value of o/p vtg is given:

$$V_o = \left[\frac{1}{T}\int_0^T V_s^2\, d\omega t\right] \longrightarrow (2)$$

$$V_o = \left\{\frac{1}{2\pi}\left[\int_\alpha^\pi V_s^2\, d\omega t + \int_{\pi+\alpha}^{2\pi} V_s^2\, d\omega t\right]\right\}^{1/2}$$

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

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

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

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

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

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

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

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

$$\Rightarrow \left\{\frac{V_m^2}{4\pi}\left[2(\pi-\alpha) + \frac{\sin 2\alpha}{2} + \frac{\sin 2\alpha}{2}\right]\right\}^{1/2} \quad \left[\because \sin(360^\circ+\theta) = \sin\theta\right]$$

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

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

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

$$V_0 = \frac{V_m}{\sqrt{2}}\sqrt{\frac{\pi-\alpha+\sin 2\alpha/2}{\pi}}$$

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In the eqn ③ i) when $\alpha = 0$

$$V_0 = V_m \sqrt{\frac{\pi - (0) + \sin 2(0)/2}{2\pi}}$$

$$V_0 = V_m \sqrt{\frac{\pi}{2\pi}}$$

$$\boxed{V_0 = \frac{V_m}{\sqrt{2}}}$$

ii) when $\alpha = \pi$

$$V_0 = V_m \sqrt{\frac{(\pi - \pi) + \sin 2(\pi)/2}{2\pi}}$$

$$V_0 = V_m \times 0$$

$$\boxed{V_0 = 0}$$

Average Load Voltage 'V_{dc}' :-

$$V_{dc} = \frac{1}{2\pi}\int_0^{2\pi} V_s \, d\omega t$$

$$= \frac{1}{2\pi}\left[\int_\alpha^{\pi} V_s \, d\omega t + \int_{\pi+\alpha}^{2\pi} V_s \, d\omega t\right]$$

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

$$= \frac{V_m}{2\pi}\left[\int_\alpha^{\pi} \sin\omega t \, d\omega t + \int_{\alpha+\pi}^{2\pi} \sin 2\omega t \, d\omega t\right]$$

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

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

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

$$= \frac{V_m}{2\pi}\left[\cos\alpha + \cancel{1} - \cancel{1} + \cos(\pi+\alpha)\right]$$

$$\cos(A+B) = \cos A \cdot \cos B - \sin A \cdot \sin B$$

$$V_{dc} = \frac{V_m}{2\pi}\left\{\cos\alpha + \cos\pi \cdot \cos\alpha - \sin\pi \cdot \sin\alpha\right\}$$

$$= \frac{V_m}{2\pi}\left[\cancel{\cos\alpha} - \cos\alpha\right]^{0}$$

$$\boxed{V_{dc} = 0}$$

Thus the average value of load voltage is zero.

Average load current 'I_{dc}' :-

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{0}{R_L}$$

$$\boxed{I_{dc} = 0}$$

$\therefore$ RMS value of load current (I_o)

$$\boxed{I_o = \frac{V_o}{R_L}}$$

FORMULAE

1) $V_m = \sqrt{2} V_s$

2) The rms o/p voltage V_o or $V_{o(rms)}$

i) $V_o = \frac{V_s}{\sqrt{2}}$

ii) $V_o = V_m \sqrt{\frac{(\pi - \alpha) + \frac{\sin 2\alpha}{2}}{2\pi}}$

3) The average current through thyristor I_A or $I_{T(avg)}$

$$I_A = \frac{V_m}{2\pi R} [1 + \cos\alpha]$$

4) The rms value of the thyristor current

i) $I_{T(rms)} = \frac{I_o}{\sqrt{2}}$

ii) $I_{T(rms)} = \frac{V_s}{\sqrt{2} R_L} \left[\frac{1}{\pi} \left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)\right]^{1/2}$

5) Average load voltage $V_{dc} = 0$

6) Average load current $I_{dc} = 0$

7) o/p power $P_o = \frac{V_o^2}{R_L} = I_o^2 R_L$

8) I/p power $P_i = V_s I_s = V_s I_o$

9) $PF = \frac{P_o}{P_i}$

10) RMS value of o/p current

$$I_o = \frac{V_o}{R_L}$$

PROBLEMS

1) **A Single phase full wave ACVC has a resistive load of R=10Ω as shown in fig1. The input is V_s=120V(rms), 60Hz. The delay angle of thyristors T_1 and T_2 are equal to $\alpha 1= \alpha 2=\pi/2$. Calculate i) rms output voltage ii) the average current through thyristors I_A iii) rms current of thyristors I_R iV) the input PF.**

June-11,6M

Given: $R=10\Omega$, $V_s=120V(rms)$, $60Hz$, $\alpha_1=\alpha_2=\pi/2$

Soln: i) $V_o = \frac{V_s}{\sqrt{2}} = \frac{120V}{\sqrt{2}}$

$V_o = 84.85V$

ii) I/p power factor:

$PF = \frac{P_o}{P_i}$

$P_o = \frac{V_o^2}{R_L} = 719.95W$

$P_i = V_s I_o = 120 \times 8.485$

$\boxed{P_i = 1018.2W}$

$I_o = \frac{V_o}{R_L} = \frac{84.85}{10}$

$\boxed{I_o = 8.485A}$

$\Rightarrow PF = \frac{P_o}{P_i} = \frac{719.95W}{1018.2W}$

$\boxed{PF = 0.707}$ (lagging)

iii) RMS current of thyristor:-

$$I_0 = \frac{V_0}{R_L} = \frac{84.85V}{10\Omega}$$

$$\boxed{I_0 = 8.485A}$$

$$I_{T(rms)} = \frac{I_0}{\sqrt{2}} = \frac{8.485}{\sqrt{2}}$$

$$\boxed{I_{T(rms)} = 6A}$$

iv) Average current through thyristor:-

$$I_A = \frac{V_m}{2\pi R}[1+\cos\alpha]$$

$$= \frac{169.705}{2\pi \times 10}[1+\cos(\pi/2)]$$

$$\boxed{I_A = 2.7A.}$$

---

2) A Single phase full wave ac voltage controller supplies a resistive load of R=10Ω from an input voltage Vs=200V, 60Hz. The delay angles of the thyristors are equal, $\alpha_1 = \alpha_2 = \pi/2$. Determine

i) The rms output voltage

ii) The input p.f

iii) Average current of thyristors &

iv) RMS current of thyristors **Jan-07,7M**

Given: $\alpha_1 = \alpha_2 = \pi/2$, $V_s = 200V$, $R = 10\Omega$

Soln: $V_m = \sqrt{2}V_s = \sqrt{2} \times 200$

$V_m = 282.84V$

i> $V_{o(rms)} = \frac{V_s}{\sqrt{2}} = \frac{200}{\sqrt{2}} = 141.42V$

$$\boxed{V_{o(rms)} = 141.42V}$$

OR

$$V_{o(rms)} = V_m \sqrt{\frac{(\pi-\alpha) + \frac{\sin 2\alpha}{2}}{2\pi}}$$

$$= 282.84V \sqrt{\frac{(\pi - \pi/2) + \frac{\sin 2(\pi/2)}{2}}{2\pi}}$$

$$= 282.84V \sqrt{\frac{1.570 + 0}{2\pi}}$$

$$= 282.84 \sqrt{0.249}$$

$$\boxed{V_{o(rms)} = 141.38V}$$

ii> I/p PF $= \frac{P_o}{P_i}$

$P_o = \frac{V_o^2}{R_L} = 1999.96W$

$$\boxed{P_i = V_s I_o}$$

$I_o = \frac{V_o}{R_L} = \frac{141.42}{10}$

$$\boxed{I_o = 14.142A}$$

$P_i = 200 \times 14.142$

$$\boxed{P_i = 2828.4}$$

$PF = P_o/P_i = 1999.96/2828.4$

$$\Rightarrow \quad PF = \frac{1999.96}{2828.4}$$

$$\boxed{PF = 0.707}$$

iii> **Average current of thyristor:**

$$I_A = \frac{V_m}{2\pi R_L}[1+\cos\alpha]$$

$$= \frac{282.84}{2\pi \times 10}\left[1+\cos(\pi/2)\right]$$

$$\boxed{I_A = 4.50A}$$

iv> To obtain RMS thyristor current:

$$I_{T(rms)} = \frac{I_o}{\sqrt{2}}$$

$$= \frac{14.142A}{\sqrt{2}}$$

$$\boxed{I_{T(rms)} = 9.99A.}$$

3) A single phase bidirectional regulator is feeding resistive load of 10Ω. The supply voltage is 230V,50Hz. If the firing angle is 45 degrees, calculate the power absorbed by the load. Derive necessary equations.

Given: $R = 10\Omega$, $V_s = 230V$, $\alpha = 45° = \pi/4$

Soln: $V_m = \sqrt{2}V_s = 325.26V$.

Soln: $V_m = \sqrt{2}\, V_s = 325.26V$

$$V_0 = V_m \sqrt{\frac{(\pi-\alpha) + \frac{\sin 2\alpha}{2}}{2\pi}}$$

$$V_0 = 325.26 \sqrt{\frac{(\pi-\pi/4) + \frac{\sin 2(\pi/4)}{2}}{2\pi}}$$

$$V_0 = 325.26 \sqrt{\frac{2.356 + 0.5}{2\pi}}$$

$$V_0 = 325.26 \sqrt{0.431}$$

$$\boxed{V_0 = 219.21 V.}$$

The power absorbed by the load is given by :-

$$P_0 = \frac{V_0^2}{R_L} = \frac{(219.20V)^2}{10}$$

$$\boxed{P_0 = 4.8kW}$$

4. A voltage source Vs=100sin377t supplies a resistive load of 100Ω through a pair of back to back connected thyristors (ac regulator). Calculate the average power in the load, if the thyristor's firing angle is fixed at 45° with respect to the supply voltage.

Given: $V_s = 100 \sin 377t$

$V_s = V_m \sin \omega t.$

$V_m = 100V$, $R_L = 100\Omega$, $\alpha = 45° = \pi/4.$

Soln: RMS o/p voltage:

$$V_0 = V_m \sqrt{\frac{(\pi-\alpha) + \frac{\sin 2\alpha}{2}}{2\pi}}$$

$$= 100 \sqrt{\frac{(\pi - \pi/4) + \frac{\sin 2(\pi/4)}{2}}{2\pi}}$$

$$= 100 \sqrt{\frac{2.356 + 0.5}{2\pi}}$$

$$= 100 \sqrt{0.4545}$$

$$\boxed{V_0 = 67.42V}$$

Load power:

$$P_0 = \frac{V_0^2}{R} = \frac{(67.42)^2}{100} = 45.45W$$

$$\boxed{P_0 = 45.45W.}$$

5. Find the power consumed in the heater element shown in fig1, if both SCRs are triggered with delay angle of 45°. In the circuit of fig1, if the load is 2KW, 230V heater and Vs=230V, 50Hz. Calculate

i) $V_{o(rms)}$

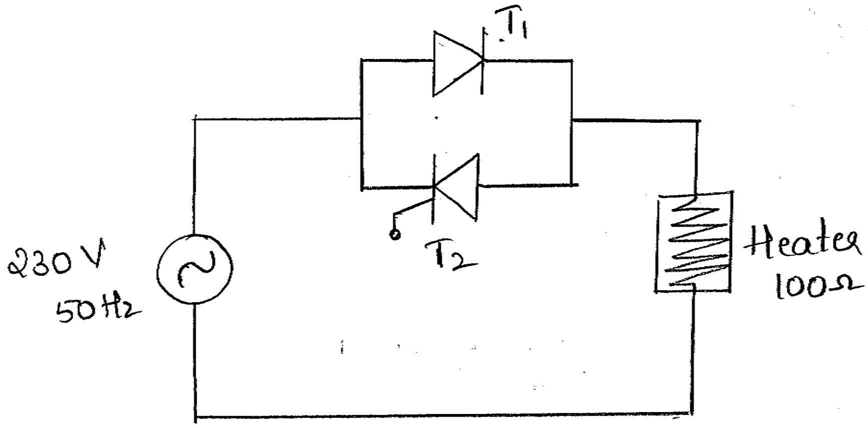
ii) Power dissipated in heater for α=45°.

Given: $\alpha = 45° = \pi/4$

$R = 100\Omega$

$V_s = 230V$, $P_{rated} = 2KW$.

ARUNKUMAR.G M.Tech, *Lecturer in E&CE dept.* **S.T.J.I.T, Ranebennur.**



Soln : $V_m = \sqrt{2} V_s = \sqrt{2} \times 230V$

$V_m = 325.26V$

i) RMS Value of o/p :-

$$V_o = V_m \sqrt{\frac{(\pi - \alpha) + \frac{\sin 2\alpha}{2}}{2\pi}}$$

$$= 325.26V \sqrt{\frac{(\pi - \pi/4) + \frac{\sin 2(\pi/4)}{2}}{2\pi}}$$

$$= 325.26 \sqrt{\frac{2.356 + 0.5}{2\pi}}$$

$$= 325.26 \sqrt{0.4545}$$

$$\boxed{V_o = 219.3V}$$

* Power absorbed in the load can be calculated

$$P_o = \frac{V_o^2}{R_L} = \frac{(219.3)^2}{100}$$

$$\boxed{P_o = 480.92W}$$

ii) $P_{(rated)} = \frac{V_{(rated)}^2}{R}$

WKT $P_{(rated)} = 2KW$ & $V_{(rated)} = 230V$

$$R = \frac{V_{rated}^2}{P_{(rated)}}$$

$$= \frac{(230)^2}{2KW}$$

$$\boxed{R = 26.45\Omega}$$

Hence power dessipation in heater is

$$P_0 = \frac{V_0^2}{R} = \frac{(219.3)^2}{26.45}$$

$$\boxed{P_0 = 1.818\ KW}$$

6. For the ac voltage controller shown in the following fig 1, the delay angles of thyristor are equal and $\alpha_1 = \alpha_1 = 2\pi/3$. Determine the:

i) RMS O/P voltage

ii) Input power factor

iii) Average and RMS current of the thyristors.

June-10,12M

Given : $\alpha_1 = \alpha_2 = 2\pi/3$

$\therefore \alpha = 2\pi/3$, $R = 5\Omega$

$V_s = 120\sqrt{2}\sin 314t$

$V_s = V_m \sin\omega t.$

$V_m = 120\sqrt{2} = 169.7V.$

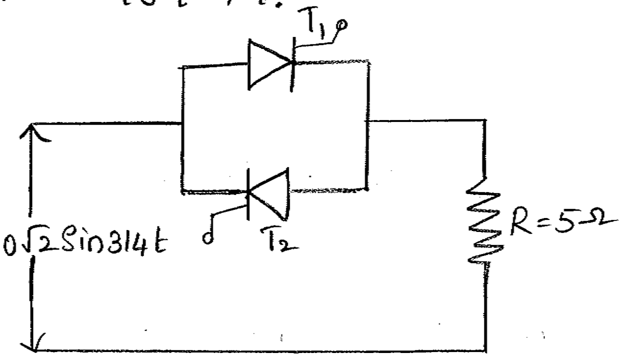


fig ①

i) **RMS o/p voltage :-**

$$V_0 = V_m \sqrt{\frac{(\pi-\alpha) + \frac{\sin 2\alpha}{2}}{2\pi}}$$

$$V_0 = 169.7 \sqrt{\frac{(\pi - 2\pi/3) + \frac{\sin[2(\pi/3)]}{2}}{2\pi}}$$

$$= 169.7 \sqrt{\frac{1.0471 - 0.4330}{2\pi}}$$

$$= 169.7 \sqrt{0.0977}$$

$$\boxed{V_0 = 53.05V}$$

ii) **I/P power factor (PF):**

WKT $\quad V_m = \sqrt{2}\ 120$

$$V_s = \frac{V_m}{\sqrt{2}}$$

$$120V = \frac{V_m}{\sqrt{2}} \qquad \therefore V_s = 120V$$

I method: $\quad PF = \frac{V_0}{V_s} = \frac{53.05}{120V} = \boxed{0.442}$ (lagging)

II method: $\quad PF = \frac{P_0}{P_i}$

$P_0 = I_0^2 R_L$

$I_0 = V_0/R_L = 53/5 = \boxed{10.6A}$

http://arunkumarnotes.ezimbo.com/

$P_o = (10.6)^2 R_L$

$P_o = 561.8W$

$P_i = V_S I_S$ where $I_S = I_O$

$P_i = 120 \times 10.6$

$P_i = 1272W$

$PF = \frac{P_o}{P_i} = \frac{561.8W}{1272W}$

$\boxed{PF = 0.4416}$ (lagging)

iii) $I_{T(avg)} = \frac{V_m}{2\pi R}[1 + \cos\alpha]$

$= \frac{169.7}{2\pi \times 5}[1 + \cos(2\pi/3)]$

$= 5.4017[1 - 0.5]$

$\boxed{I_{T(avg)} = 2.7A}$

iv) RMS current of the thyristor :-

$I_{T(rms)} = \frac{I_o}{\sqrt{2}}$

$= \frac{10.6}{\sqrt{2}}$

$\boxed{I_{T(rms)} = 7.49A}$

❖ **For the A.C voltage controller shown in fig1, the delay angles of the thyristors T_1 and T_2 are equal, $\alpha_1 = \alpha_2 = 2\pi/3$. Determine:**

i) r.m.s. output voltage

ii) Input power factor

iii) Average current of thyristors and

iv) r.m.s. current of thyristors

June-06,8M

7. The single phase full wave ac voltage controller operates on a single phase voltage of 230V RMS, at 50Hz. If the triac is triggered at a delay angle of 45°, driving both the half cycles of input supply. Calculate

i) RMS value of output voltage

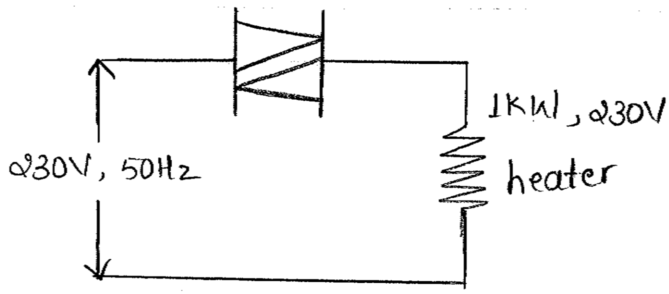
ii) RMS value of current through the heater

iii) Average value of triac current

iv) RMS value of triac current

v) Input PF.

Derive any expression used. **Jan-05,12M**



Given: $V_s = 230V$, $\alpha = 45° = \pi/4$, $P_{rated} = 1KW$, $V_{rated} = 230V$

Soln: $V_m = \sqrt{2} V_s = \sqrt{2} \times 230 = 325.26V$

i) RMS value of o/p vtg:

$$V_0 = V_m \sqrt{\frac{(\pi - \alpha) + \frac{\sin 2\alpha}{2}}{2\pi}}$$

$$= 325.26 \sqrt{\frac{(\pi - \pi/4) + \frac{\sin(2\pi/4)}{2}}{2\pi}}$$

$$= 325.26 \sqrt{\frac{2.356 + 0.5}{2\pi}}$$

$$= 325.26 \sqrt{0.4545}$$

$$\boxed{V_0 = 219.29V}$$

ii) RMS value of o/p current:

$$I_o = \frac{V_o}{R_L}$$

$R_L = ?$

WKT $$P_{rated} = \frac{V_{rated}^2}{R_L}$$

$$R_L = \frac{V_{rated}^2}{P_{rated}}$$

$$= \frac{(230)^2}{1KW}$$

$$\boxed{R_L = 52.9\,\Omega}$$

$$I_o = \frac{V_o}{R_L} = \frac{219.3}{52.9}$$

$$\boxed{I_o = 4.145A}$$

iii) Average value of triac current:-

$$\boxed{I_{dc} = 0}$$

iv) RMS value of triac:-

The TRIAC current is same as o/p current. Hence rms value of TRIAC current will be same as o/p current i.e,

$$\boxed{I_{T(rms)} = I_o = 4.137A}$$

v) I/p power factor:-

I method: $PF = \frac{V_o}{V_s} = \frac{219.29V}{230V} = \boxed{0.9534}$

II method :

$$PF = \frac{P_o}{P_i}$$

$$P_o = I_o^2 R_L$$

$$= (4.145)^2 \times 52.9$$

$$P_o = 908.87W$$

$$P_i = V_s I_s$$

$$= V_s I_o$$

$$P_i = 953.35$$

$$PF = \frac{908.87}{953.35}$$

$$\boxed{PF = 0.9533.}$$

❖ Single Phase FULL-Wave AC voltage controller with common Cathode :- OR

❖ Full Wave Controller with Common Cathode :-

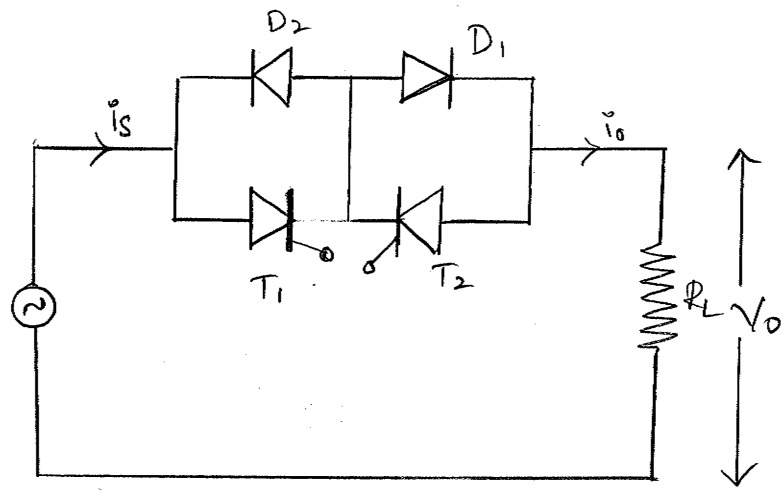


fig ① : 1ϕ full wave controller having common cathode.

fig ① shows the ckt diagram of 1ϕ full wave controller having common cathode connections of SCR's.

* The cathodes of two SCRs T_1 and T_2 are connected together. During +ve half cycle of the supply, SCR T_1 and diode D_1 conducts and in -ve half cycle SCR T_2 & diode D_2 conducts.

* In this ckt, the gate cathode drives need not be isolated. But isolation is normally provided b/w the control and power ckts.

* Four devices are required in this ckt. The efficiency of this ckt is slightly reduced due to increased power

dissipation in the devices.

I/o waveforms are same as that of full wave ac controllers.

❖ Phase Full Wave AC voltage controller with only ONE SCR :-

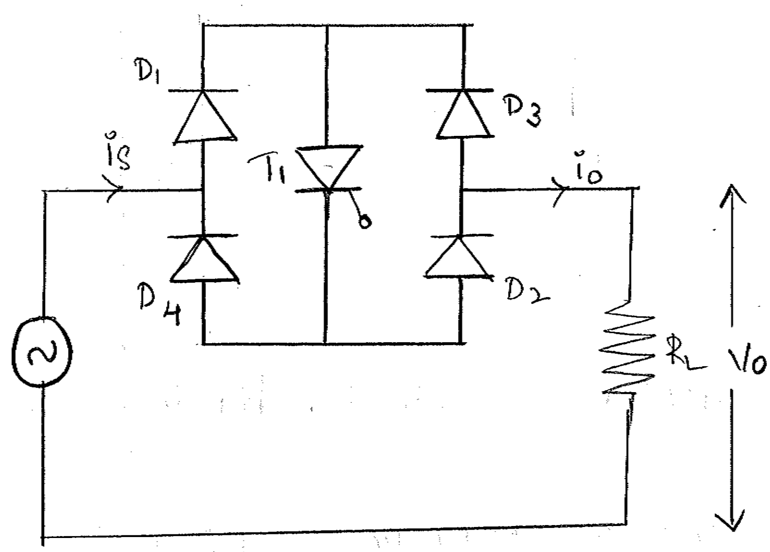


fig ①: 1φ Full wave controller with diode bridge and one SCR.

fig ① shows the ckt of 1φ full wave controller having one SCR T_1. The diode D_1, D_2, D_3, & D_4 are connected to form a bridge.

Operation:

* During +ve half cycle, SCR T_1 is triggered at $\omega t = \alpha$. The current will flow through D_1, T_1, D_2 and the load. At $\omega t = \pi$, load voltage and current reduce

to zero & SCR T_1 is turned -OFF due to natural Commutation.

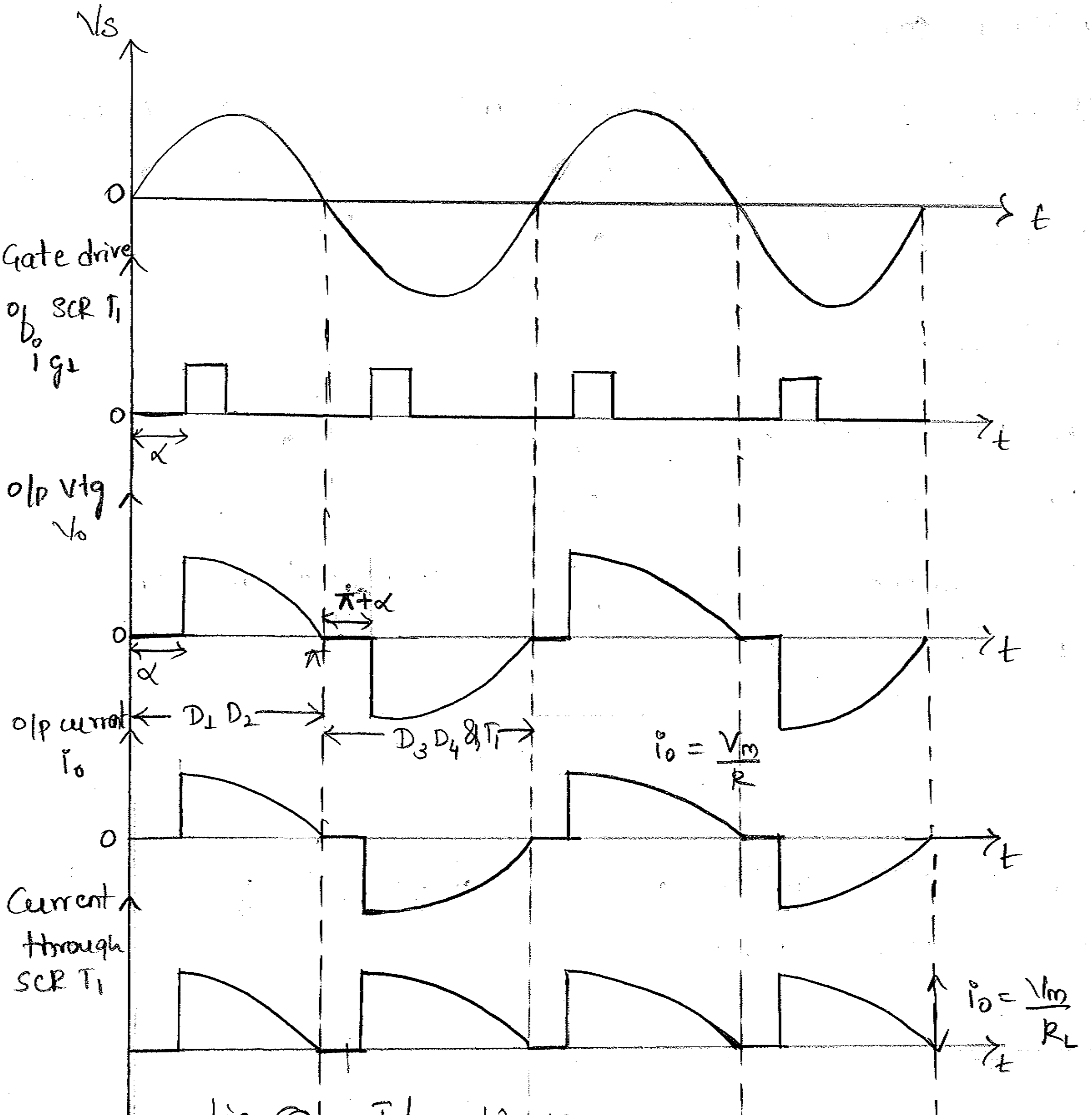


fig ② I/O Waveforms

* During -ve half cycle, SCR T_1 is triggered at $\omega t = \pi + \alpha$. The current will flow through D_3, T_1, D_4 and the load. The Load current and voltage becomes negative as shown in fig ②

At $\omega t = 2\pi$, the load voltage and current both reduces to zero and SCR T_1 is turned OFF. due to natural commutation.

* During the time interval $\omega t = 0$ to α and π to $\pi+\alpha$, the SCR is OFF. Therefore load voltage and load current will be zero during these time interval.

Advantages:-

1) The i/p, o/p currents and voltage are symmetric. Hence there is no dc component.

2) Transformers and motors saturation problems are absent.

Applications:-

1) Full wave controller are used extensively for induction motors, pumps, fans etc...

- **Single Phase Controller with INDUCTIVE loads :-**
- **With a necessary waveforms, explain the operation of a single phase full wave controller with inductive load. Derive the expression for rms outputvoltage.** **June-11,8M**
- **With necessary circuit diagram and wavwforms, explain the operation of full wave ac voltage controller feeding on R-L load.**

  June-11,8M (E&E)
- **With neat circuit diagram and waveforms derive an expression for the RMS valueof output voltage of single phase converter with RL load.(Assume discontinuous load current).**

  Jan-09,6M
- **With necessary waveforms explain the operation of 1-phase full wave controller with inductive load. Derive expressions for rms output voltage and rms output current.** **June-08,10M**
- **Explain the operation of a single-phase phase control type of voltage controller with RL load. Give an illustration to show that for firing angle 'α' less than load angle, output voltage of the ac voltage controller cannot be regulated.**

  Jan-08,8M
- **With necessary circuit and waveforms, explain the operation and fullwave ac voltage controller feeding an RL load.**

  June-07,8M
- **Explain the various methods of gating an SCR. State why short duration pulses are insufficient for an ac voltage controller feeding an RL load.** **June-07,6M**
- **With necessary waveforms, explain the operation of a 1-phase full wave controller with inductive load. Derive the expression for rms output voltage and rms output current.** **Jan-07,10M**

Single phase controller with inductive loads :-

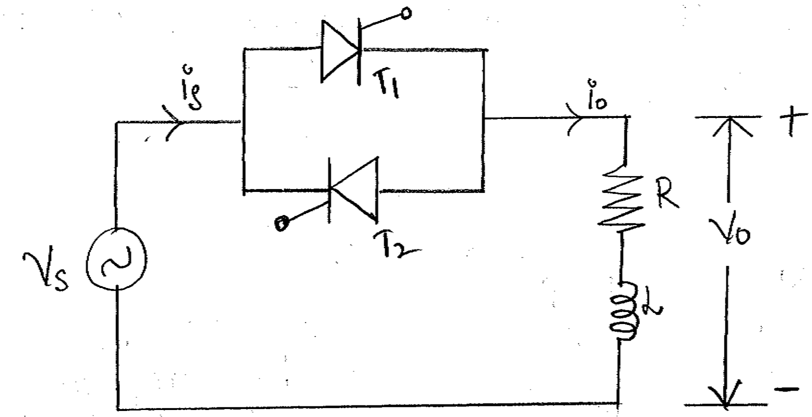
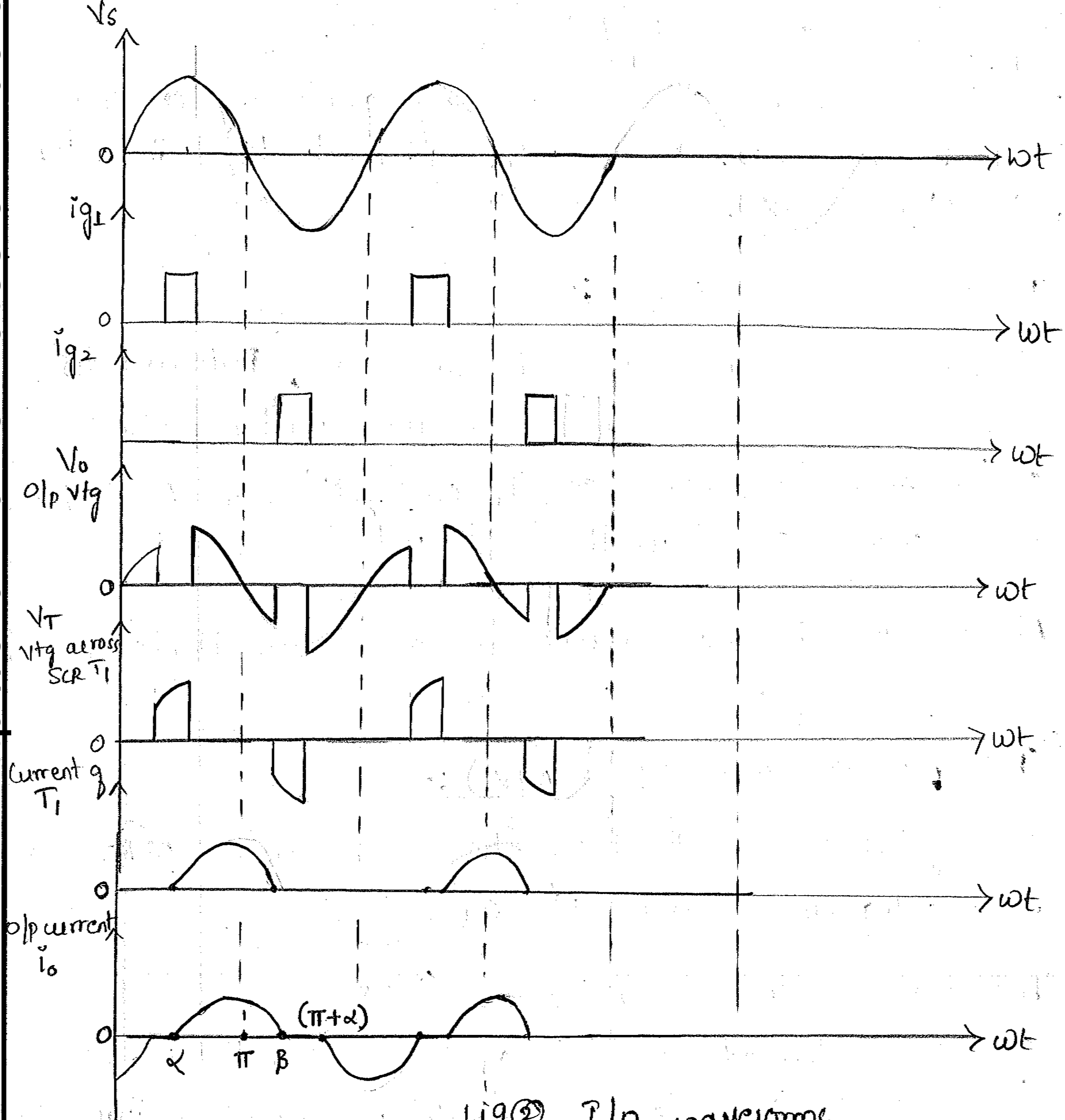


Fig ① 1ϕ Full wave controller with inductive load.



fig② I/O waveforms.

fig ① shows full wave ac controller using antiparallel SCR. The load is the combination of resistance and inductance ie, RL load.

Operation :

i> Interval $\omega t = \alpha$ to π :-

At $\omega t = \alpha$, SCR T_1 is turned ON. by applying a triggering pulse. The load voltage is +ve. and equal to the instantaneous supply voltage.

The load current starts increasing gradually as the load is inductive. During this interval, load inductor will store energy.

ii> Interval → $\omega t = \pi$ to β :-

At $\omega t = \pi$, the ac supply becomes -ve, But due to stored energy, the load inductance will maintain SCR 'T_1' in ON state. ie, SCR T_1 conducts from π to β. due to energy stored in the load inductance.

* At $\omega t = \beta$, the o/p current becomes zero. Hence T_1 turns OFF by natural commutation.

iii> Interval → $\omega t = (\beta$ to $\pi + \alpha)$:-

During this interval, both the SCRs remain OFF.

∴ o/p vltg and current is zero.

iv> Interval → $\omega t = (\pi + \alpha$ to $2\pi)$:-

SCR 'T_2' is turned ON at $\omega t = (\pi + \alpha)$. The load voltage becommes negative and equal to instantaneous supply vtg.

load current increases gradually in the negative direction, the load inductor will store energy. Due to this SCR T_2 continues to conduct even in next +ve half cycle as shown in fig ②.

RMS o/p voltage of 1φ full wave controller having Inductive load for discontinuous load current :-

* let supply vtg $\boxed{V_s = V_m \sin\omega t}$ → ①

* The RMS o/p vtg is given by

$$V_0 = \left[\frac{1}{T}\int_0^T V_s^2 \, d\omega t\right]^{1/2}$$

$$V_0 = \left[\frac{1}{\pi}\int_\alpha^\beta V_m^2 \sin^2\omega t \, d\omega t\right]^{1/2}$$

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

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

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

$$= \left\{\frac{V_m^2}{\pi}\left[\frac{1}{2}(\beta-\alpha) - \frac{1}{4}(\sin 2\beta - \sin 2\alpha)\right]\right\}^{1/2}$$

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

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

$$= \sqrt{V_m^2 \left[\frac{(\beta - \alpha) + \frac{\sin 2\alpha}{2} - \frac{\sin 2\beta}{2}}{2\pi} \right]}$$

$$\boxed{V_0 \Rightarrow V_m \sqrt{\frac{(\beta - \alpha) + \frac{\sin 2\alpha}{2} - \sin 2\beta}{2\pi}}}$$

- **Explain the various methods of gating an SCR. State why short duration pulses are insufficient for an ac voltage controller feeding an RL load.** **June-07,6M**
- **With neat waveforms, explain why short duration pulses are insufficient for an ac voltage controller feeding an R-L load.** **June-11,6M**
- **Why short duration gate pulses are not suitable for bi-directional ac voltage controller with inductive loads.** **Jan-07,5M**
- **Explain why short duration single gate pulses are not suitable for triggering thyristors in a full wave ac voltage contoller with inductive loads.** **Jan-06,6M**
- **What problem is caused by sharp single pulse triggered in a single phase acvoltage controller, when the load is inductive? How can this be solved.** **June-10, 5M**

- **What problem is caused by sharp single pulse triggered in a single phase ac voltage controller, when the load is inductive? How can this be solved.** **June-10, 5M**

* If the load is purely resistive, then a short single gate pulse can be used to triggere each thyristor.

* The short duration pulse is not suitable for inductive loads. When thyristor T_2 is triggered at $\omega t = \pi + \alpha$, thyristor T_1 is still conducting due to the energy stored in the Load inductance. As long as T_1 is conducting, T_2 will not forward biased. Before T_1 stops conducting at $\omega t = \beta$, the gate pulse of T_2 would have ceased.

Due to this, only T_1 will conduct during successive positive half cycles of I/p voltage causing the half wave controlled rectified instead of an ACVC

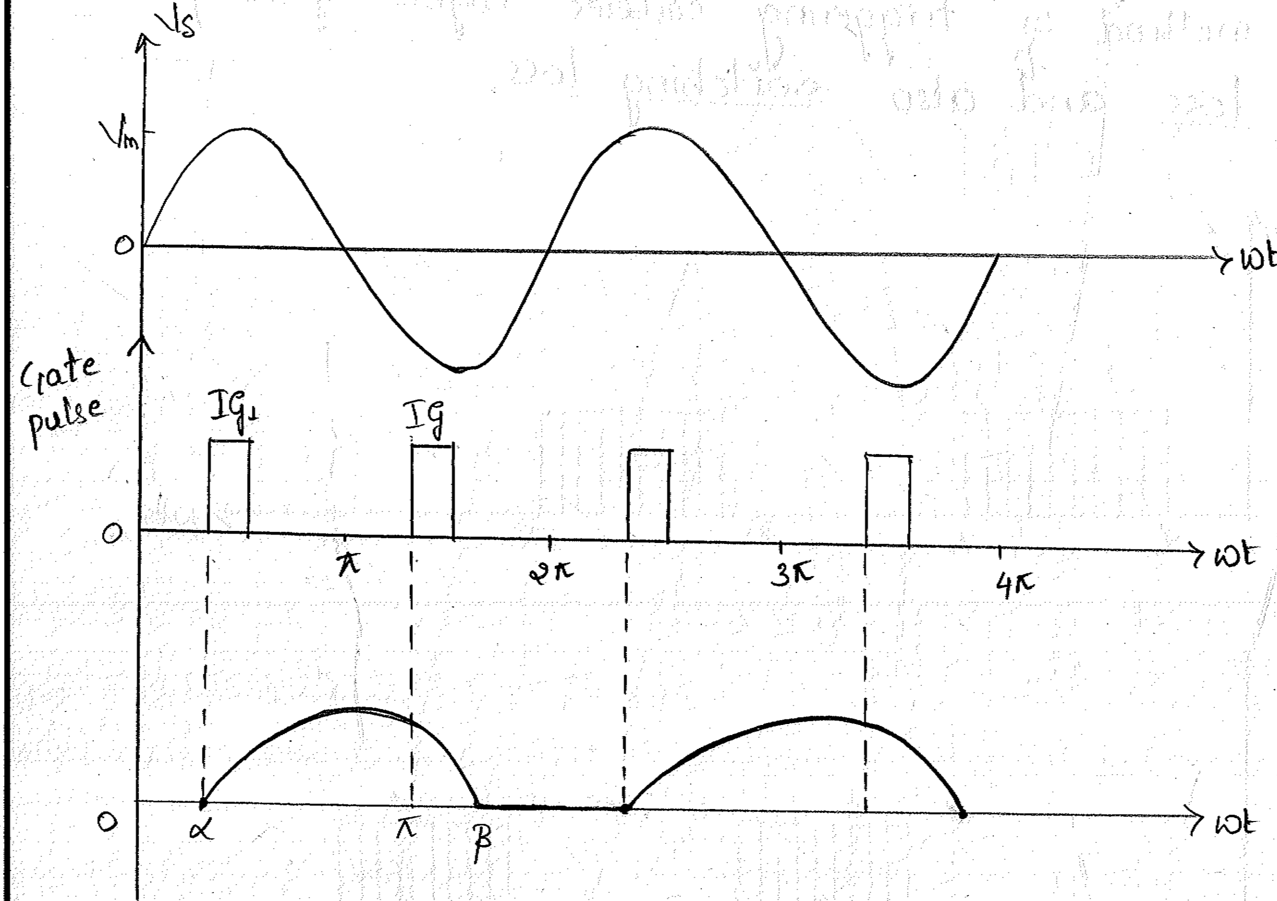


fig ① short pulse triggering causing rectification

* The above explained problem can be solved by using a continuous gate pulse of duration $(\pi-\alpha)/\omega$ as shown in fig ②ⓐ.

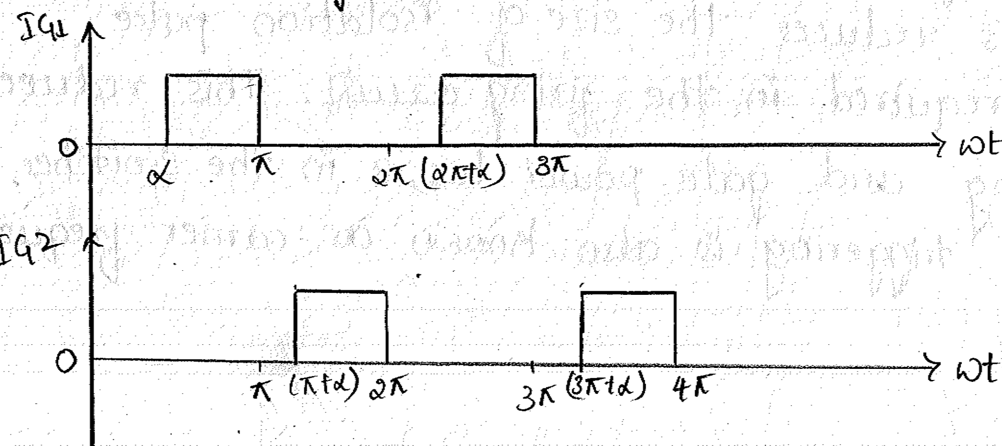


fig ②ⓐ

* As soon as T_1 current falls to zero at $\omega t = \beta$, T_2 will get forward biased and turned ON, since the gate pulse to T_2 is still available. But this method of triggering causes higher gate power loss and also switching loss.

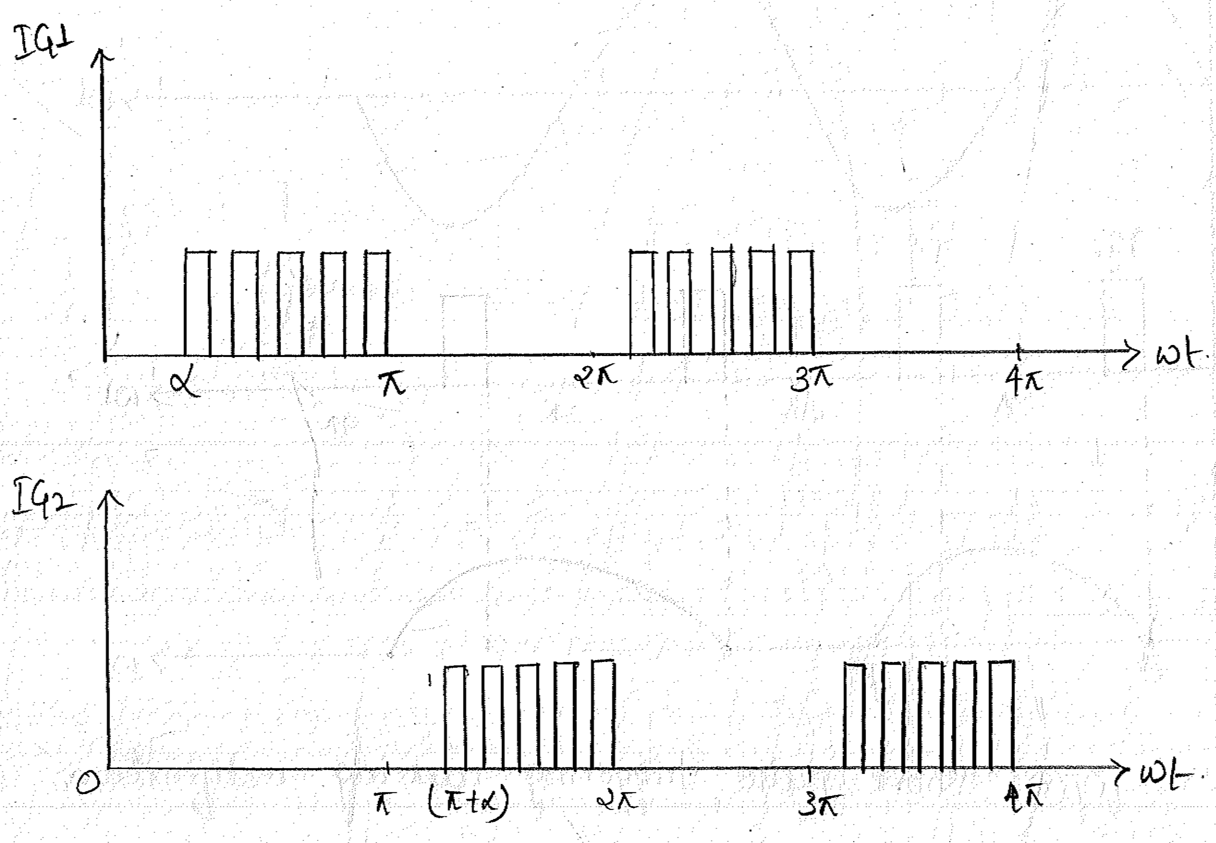


fig 3(a)

It is better to use a train of sharp high frequency pulses to trigger the thyristor as shown in fig 3(a). Because this reduces the size of isolation pulse transformer required in the firing circuit. This reduces the switching and gate power losses in the switches. This type of triggering is also known as carrier frequency triggering.

FORMULAE

1> $\tan\theta = \frac{\omega L}{R}$ Where $\omega_L = 2\pi f L$

$$\theta = \tan^{-1}\left(\frac{\omega L}{R}\right)$$

2> When X_L is given, $\omega L = X_L$

$$\theta = \tan^{-1}\left(\frac{X_L}{R}\right)$$

3> The extinction angle β is

$$\boxed{\sin(\beta-\theta) - \sin(\alpha-\theta)\, e^{\frac{R(\alpha-\beta)}{\omega L}} = 0}$$

4> Conduction angle '∂'

$$\boxed{\partial = \beta - \alpha}$$

5> RMS o/p voltage

$$\boxed{V_o = V_m \sqrt{\frac{(\beta-\alpha) + \frac{\sin 2\alpha}{2} - \frac{\sin 2\beta}{2}}{2\pi}}}$$

6> $I_{o(rms)} = \frac{V_o}{Z}$

Where $Z = \sqrt{R^2 + (\omega L)^2}$

Where $\omega L = 2\pi f L$

7) $P_o = I_{o(rms)}^2 R_L$

$I_s = I_o$ $\qquad$ $I_o = I_{o(rms)}$

8) $PF = \frac{P_o}{P_i} = \frac{P_o}{I_s V_s} = \frac{P_o}{I_o V_s}$

9) $I_m = \frac{V_m}{Z}$

10) $V_m = \sqrt{2}\, V_s.$

PROBLEMS

❖ **A single phase full wave AC voltage controller has an R_L load. The input voltage is 230V, 50 Hz and the load is R=2Ω and X_L=2Ω, $\alpha_1 = \alpha_2 = \pi/2$. Calculate the following :**

i) Angle until which the thyristor conducts

ii) Conduction angle of the thyristor

iii) R.m.s voltage of output. Derive the formulae you use.

Given: $V_s = 230V$, $R = 2\Omega$, $X_L = 2\Omega$, $\alpha_1 = \alpha_2 = \pi/2$

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

Soln:

i) To determine Conduction angle β:-

WKT

$$\boxed{v_s = V_m \sin 2\omega t} \longrightarrow (1)$$

When thyristor T_1 conducts, we can write KVL as

$$V_s - i(t)R + L\frac{di(t)}{dt} = 0$$

$$V_s = i(t)R + L\frac{di(t)}{dt}$$

$$V_m \sin\omega t = i(t)R + L\frac{di(t)}{dt}$$

* Using laplace transform, above equation can be solved for $i(t)$. Hence solution is

$$\boxed{i(t) = \frac{V_m}{\sqrt{R^2 + (\omega L)^2}}\left\{\sin(\omega t - \theta) - \sin(\alpha - \theta)\, e^{\frac{R(\alpha - \omega t)}{\omega L}}\right\}} \rightarrow (2)$$

Here $\boxed{\theta = \tan^{-1}\frac{\omega L}{R}}$

From o/p current waveform, $\omega t = \beta$, $i(t) = 0$.
equation ③ becomes.

$$0 = \frac{V_m}{\sqrt{R^2 + (\omega L)^2}} \left\{ \sin(\beta - \theta) - \sin(\alpha - \theta)\, e^{\frac{R(\alpha-\beta)}{\omega L}} \right\}$$

$$\sin(\beta-\theta) - \sin(\alpha-\beta)\, e^{\frac{R(\alpha-\beta)}{\omega L}} = 0 \longrightarrow ③$$

In equation ③, if α and θ are known, solution of above equation gives β.

* Given $R = 2\Omega$

$X_L = \omega_L = 2\Omega$

$\alpha = \pi/2$

$\therefore \theta = \tan^{-1}\left[\frac{\omega L}{R}\right] = \tan^{-1}\left[\frac{2}{2}\right]$

$\boxed{\theta = 0.7853981}$

Putting the values of θ, α, R & ω_L in equation ③, we get

$$\sin(\beta - 0.7853981) - \sin(\pi/2 - 0.7853981)\, e^{\frac{2(\pi/2-\beta)}{2}} = 0$$

$$\sin(\beta - 0.7853981) - 0.7071068\, e^{(\pi/2 - \beta)} = 0 \longrightarrow ④$$

Using bisect method, the solution of above equation at the end of 11^{th} iteration is.

$$\boxed{\beta = 3.8552772 \text{ or } 220.89}$$

Thus thyristor conducts till 220.89° due to Inductive Load.

ii) To determine the conduction angle:-

The SCR conducts from α to β. Hence Conduction angle is (δ)

$$\delta = \beta - \alpha = 3.8552772 - \pi/2.$$

$$\boxed{\delta = 2.2844809 \text{ or } 130.89^\circ.}$$

iii) RMS o/p vtg:-

$$V_o = V_m \sqrt{\frac{(\beta-\alpha) + \frac{\sin 2\alpha}{2} - \frac{\sin 2\beta}{2}}{2\pi}}$$

$$= 325.26 \sqrt{\frac{(3.8552 - \pi/2) + \frac{\sin[2\,\pi/2]}{2} - \frac{\sin[2(3.8552)]}{2}}{2\pi}}$$

$$= 325.26 \sqrt{\frac{2.2844 + 0 - 0.4948}{2\pi}}$$

$$= 325.26 \sqrt{0.2848}$$

$$\boxed{V_o = 173.58V}$$

* The Single-phase full wave controller has an RL load. The i/p rms voltage is $V_s = 120V$, 60Hz. The load is such that $L = 6.5mH$ & $R = 2.5\Omega$. The delay angles of thyristor are equal : $\alpha_1 = \alpha_2 = \pi/2$. Determine.

ⓐ The conduction angle of thyristor T_1, δ;

ⓑ The rms o/p voltage V_o

ⓒ The rms o/p current I_o

ⓓ The I/p PF.

Given: $R = 2.5\Omega$, $L = 6.5mH$, $f = 60Hz$, $V_s = 120V$,

$\alpha = 90° = \pi/2$

$V_m = \sqrt{2} \times 120V = 169.705$

Soln: WKT

$$\theta = \tan^{-1}\left(\frac{\omega L}{R}\right)$$

$$\omega L = 2\pi f L = 2\pi \times 60 \times 6.5mH$$

$$\omega L = 2.4504\Omega$$

$$\theta = \tan^{-1}\left(\frac{2.4504}{2.5\Omega}\right)$$

$$\boxed{\theta = 0.7753}$$

ⓐ The conduction angle $\delta = \beta - \alpha$

The extinction angle β is

PTO →

$$\sin(\beta-\theta) - \sin(\alpha-\theta)\, e^{\frac{R(\alpha-\beta)}{\omega L}} = 0$$

$$\sin(\beta - 0.7753) - \sin(\pi/2 - 0.7753)\, e^{\frac{2.5(\pi/2-\beta)}{2.4504}} = 0$$

The extinction angle can be determined using bisect method, the solution of above equation is

$\boxed{\beta = 3.855}$ or $\boxed{\beta = 220.35^\circ}$

* $\gamma = \beta - \alpha = 3.855 - 0.7753$

$\boxed{\gamma = 3.0797.}$

ⓑ <u>RMS o/p voltage :-</u>

$$V_o = V_m \sqrt{\frac{(\beta-\alpha) + \frac{\sin 2\alpha}{2} - \frac{\sin 2\beta}{2}}{2\pi}}$$

$$V_o = 169.7056 \sqrt{\frac{(3.855 - \pi/2) + \frac{\sin 2(\pi/2)}{2} - \frac{\sin 2(3.855)}{2}}{2\pi}}$$

$$V_o = 169.7056 \sqrt{\frac{2.2842 - 0.40057 - 0.4948}{2\pi}}$$

$\boxed{V_o = 68.09V}$

ⓒ <u>RMS o/p current:-</u>

$$I_o = \frac{V_o}{Z}$$

$$Z = \sqrt{R^2 + (\omega L)^2}$$

$$\Rightarrow Z = \sqrt{(2.5)^2 + (2.4504)^2}$$

$$\boxed{Z = 3.5006\,\Omega}$$

$$I_o = \frac{68.09V}{3.5006}$$

$$\boxed{I_o = 19.45A}$$

(d) $PF = \frac{P_o}{P_i}$

$$P_o = I_o^2 R_L = (19.45)^2 \times 2.5$$

$$P_o = 945.84$$

$$P_i = I_o V_s = \boxed{2,334W}$$

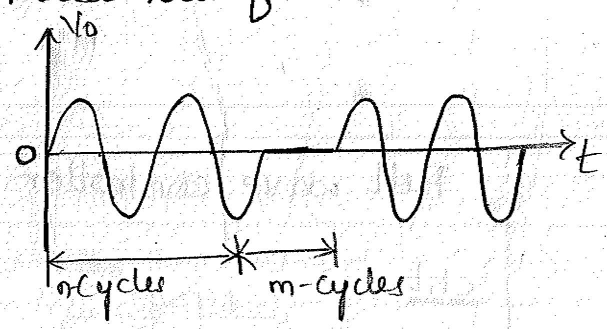
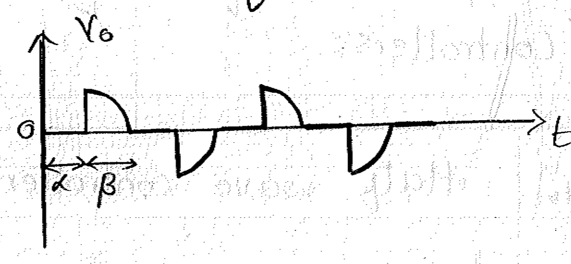
$$PF = \frac{P_o}{P_i} = \frac{945.84}{2,334}$$

$\boxed{PF = 0.4052}$ (lagging)

❖ Distinguish between ON-OFF control and phase control of ac voltage controller. **Jan-10,4M**

❖ Compare and contrast ON-OFF control with phase control as applied to ac voltage controllers.

June-05,6M June-10,6M(IT)

SL No	ON-OFF Control	Phase Control.
1>	O/p voltage is controlled by controlling the number of ON cycles 'n' & number of OFF cycles 'm'	O/p voltage is controlled by controlling the phase angle or firing angle α of the thyristor.
2>	Load waveform: 	Load waveform: 
3>	Thyristor conducts 180° as it is triggered at α=0°	Thyristor is triggered at some angle depending upon o/p power.
4>	No harmonics due to the switching at zero crossing instants.	Harmonics are present due to switching at instants other than zero crossings.
5>	Load voltage waveform is not distorted	Load voltage waveform is distorted. Distortion increases with increase in α.
6>	Average (dc) load voltage & load current is zero	Average (dc) load voltage & load current is zero.

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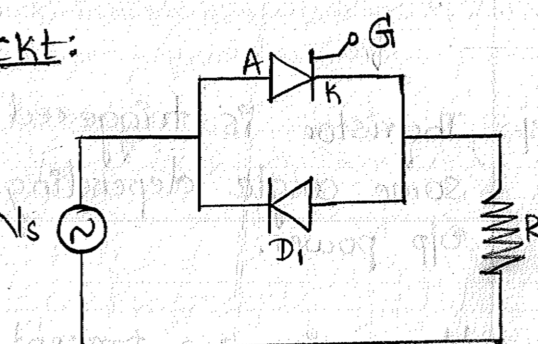
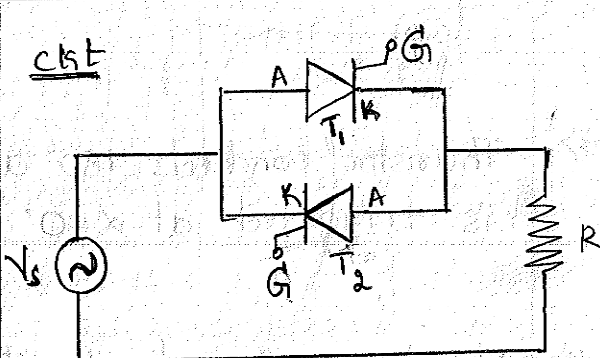
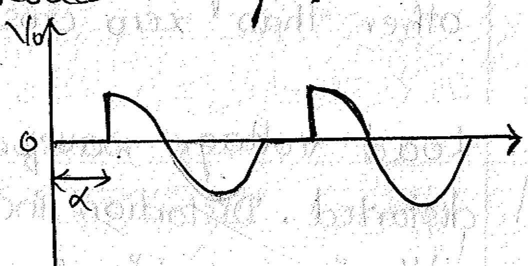
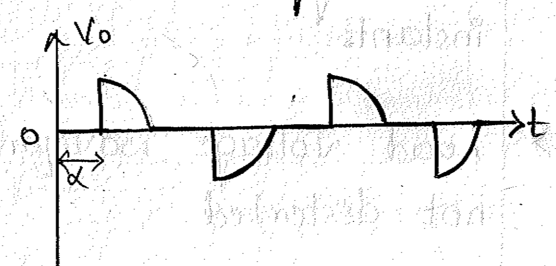
7>	Load voltage will be equal to full supply voltage or zero Hence o/p waveform has high voltage fluctuations	Supply voltage is applied partially to load. Hence there is less voltage fluctuations.
8>	Applications : Industrial heating, speed control of induction motor. etc	Applications :- Heat control, light dimmer, fan regulators etc..

*

Comparision of Half wave and full wave ac voltage Controllers:

Sl No	Half wave controller	Full wave controller
1>	CKt: 	ckt 
2>	Load voltage: 	Load voltage: 
3>	Only half cycle of the supply is controlled.	Both the half cycles of the supply are controlled.

4)	Half wave controller generate asymmetric voltage and current across load.	Full wave controllers generate symmetric voltage & currents across the load.
5)	RMS load voltage $V_{o(rms)} = \frac{V_m}{2}\sqrt{\frac{(2\pi-\alpha)+\frac{\sin 2\alpha}{2}}{\pi}}$	RMS load voltage $V_o = \frac{V_m}{\sqrt{2}}\sqrt{\frac{(\pi-\alpha)+\frac{\sin 2\alpha}{2}}{\pi}}$
6)	Average (dc) Load voltage $V_{dc} = \frac{V_m}{2\pi}[\cos\alpha - 1]$	Average dc load voltage $V_{dc} = 0$.
7)	Average (dc) load current $I_{dc} = \frac{V_{dc}}{R}$	Average (dc) load current $I_{dc} = 0$.
8)	Core saturation is possible due to the presence of dc value for supply and load current.	Core saturation does not take place as $I_{dc} = 0$.

❖ **What are advantages and disadvantages of ON-OFF control and phase control of ac voltage controller?** **June-10,8M**

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THYRISTORS

SCR :-

❖ **With neat sketch, explain the static V-I characteristics of an SCR? What are the significance of Latching current, Holding current and Break over voltage.** **Jan-09,8M Jan-05,8M**

❖ **Sketch the static V-I characteristics of an SCR and explain :**

i) Latching current **iii) Break over voltage**

ii) Holding current

June-10,8M(IT) June-08,7M June-07M

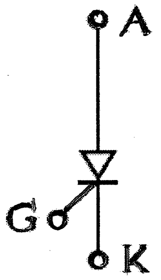
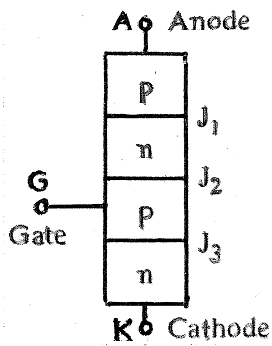


Fig a.: Symbol



A thyristor is a four (4) layer, three junction, three terminal semiconductor device. The terminals are **Anode (A)**, **Cathode (K)** and **Gate (G)**. Thyristors are operated as bistable switches, operating from OFF state to ON state. Thyristor is also called as **Silicon Controlled Rectifier (SCR)**.

Characteristics of Thyristor :-

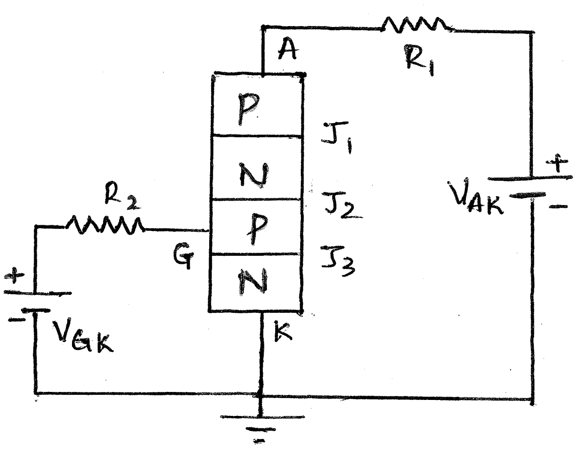


Fig 2a. Circuit Diagram.

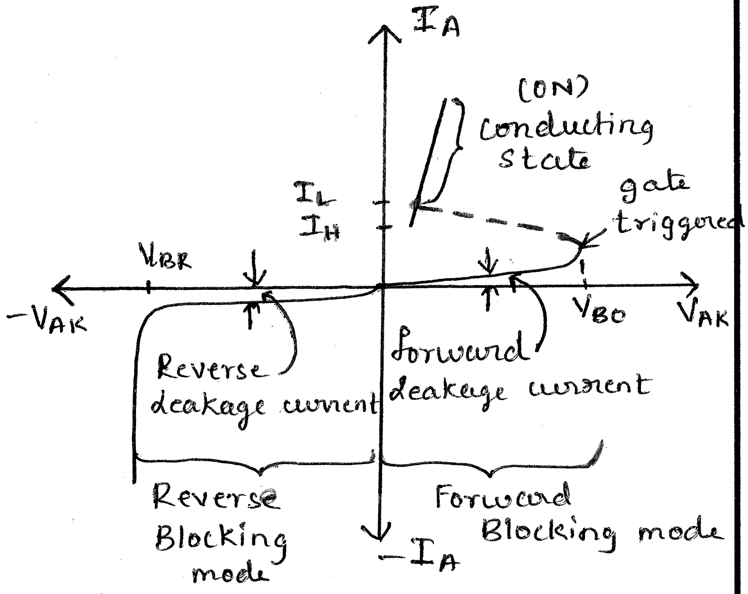


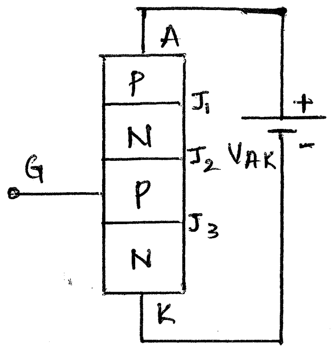
Fig 2b. V-I Characteristics

* When the anode voltage is made +ve wrt to the cathode, the junction J_1 & J_3 are forward biased The junction J_2 is reverse biased. Hence forward Vtg is to be hold by junction J_2.

  A very small current flows from anode to cathode. This current is called as forward leakage current The thyristor is then said to be in forward blocking mode.
  The thyristar is treated as an open switch.

* A thyristor can be turned ON by applying a gate pulse between gate & cathode and is called as forward conduction mode.

  In this mode thyristor is in ON condition and behaves as a closed switch.



* When anode vtg is made -ve wrt to cathode, the thyristor is reverse biased Junction J_1 & J_3 are reverse biased where as Junction J_2 is forward biased.

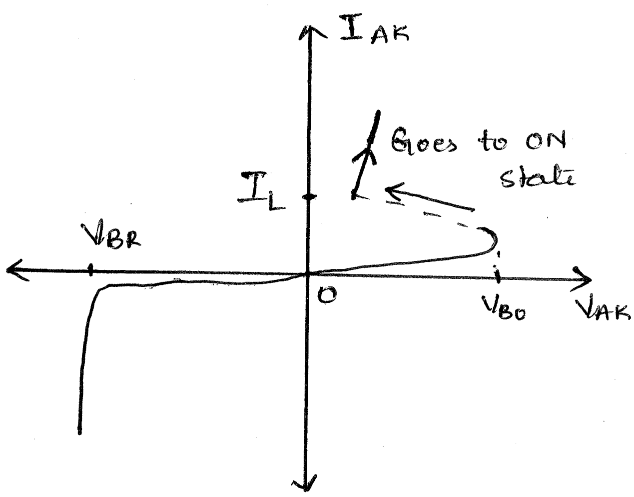
A very small current flows from cathode to Anode. This current is called <u>reverse leakage current</u> & this mode is called <u>reverse blocking mode</u>.

* At reverse breakdown vtg (V_{BR}), the reverse current increases rapidly. At the same time reverse break-down, the high vtg is present across the thyristor & heavy current flows through it. Hence large power dissipation takes place in the thyristor. Due to this dissipation the thyristor will damage.

During reverse blocking mode, the +ve gate signal should not be applied. If the +ve signal is applied between gate and cathode, junction J_3 is forward biased hence current starts flowing through it.

<u>Latching Current</u> :-

Latching current is the minimum forward current that flows through the thyristor to keep it in forward conduction mode (ie ON state) at the time of Triggering.



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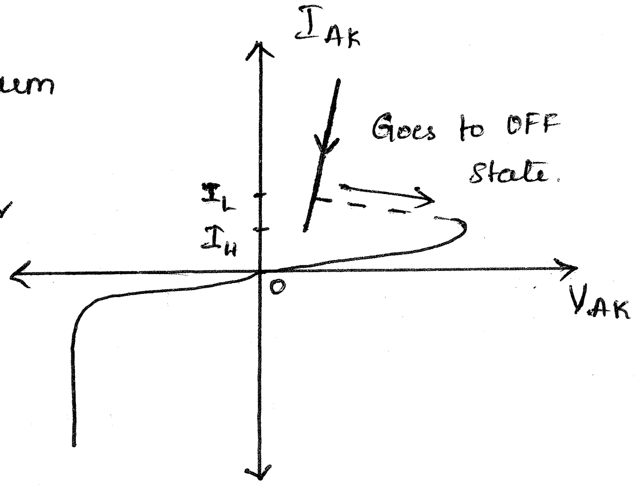
* If forward current is less than latching current, thyristor doesnot turn-ON.

ie $I_{AK} < I_L$

After triggering $I_{AK} \geq I_L$ for thyristor to remain in ON state. The latching current is of the order of 10 to 15mA.

Holding Current :-



* Holding current is minimum forward current that flows through the thyristor to keep it in forward conduction mode. When forward current reduces below holding current. thyristor turns-OFF

* The holding current of the thyristor is of order 8 to 10mA.

Break over Voltage (V_{BO}) :-

When gate is open & if anode to cathode voltage exceeds forward Breakover voltage 'V_{BO}', the SCR is driven into forward conduction.

In other words V_{BO} is the maximum vtg that SCR can withstand in forward direction.

❖ Comparision between holding and latching currents :-

1) Latching current is effective at the time of turning ON whereas holding current is effective at the time of turning - OFF the thyristor.

2) Latching current is the maximum current that should flow at the time of triggering to turn ON the thyristor.

Whereas once the thyristor is already in ON - state its current should not reduce below holding current otherwise it turns - OFF

3) Latching current is greater than holding current even though their magnitude are much related.

❖ TWO TRANSISTOR ANALOGY of SCR

❖ **Using two transistor models, explain how a small gate current can turn on a SCR when blocking forward voltage.** **June-11,6M (E&E)**

❖ **Explain the turn-on mechanism of a thyristor using two transistor analogy and derive an expression for the anode current in terms of transistor parameters.** **Jan-10,8M**

❖ **Usingthe Two transistor model, explain how a small gate current can turn on an SCR**

June-10,6M June-08,6M June-04,6M

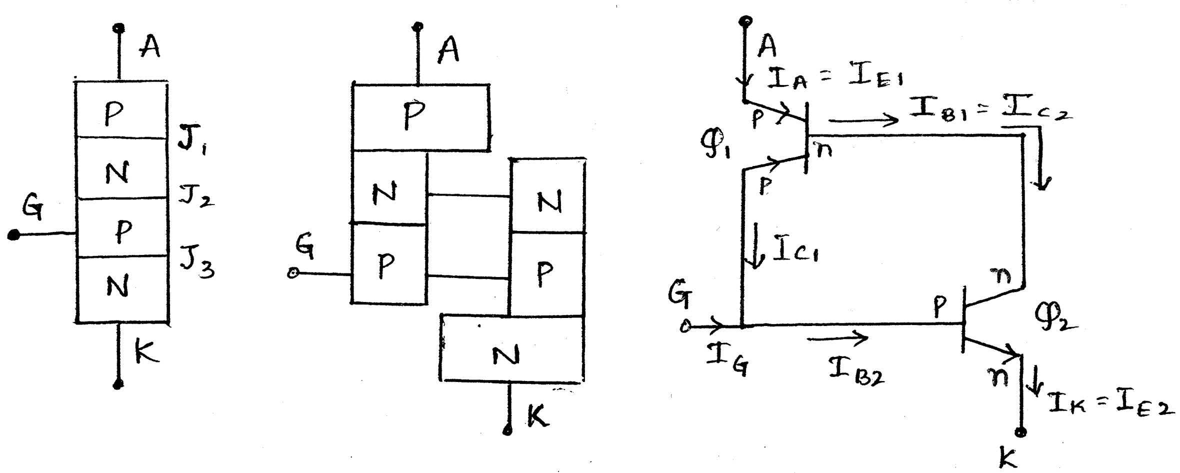
❖ **With help of two transistor model of an SCR, derive the expression for anode current. There from explain the switching action and significance of Gate control.** **June-09,8M**

❖ **Using two transistor analogy, derive an expression for anode current of SCR.** **Jan-09,8M**

❖ **Explain the principle of an SCR using two transistor model.** **Jan-07,6M June-08,6M**

❖ **Using two transistor model, explain the switching action of a thyistor and significance of gate control. Also derive an expression for the anode current.** **Jan-08,8M**

❖ **Using two transistor model, explain the the turn-ON mechanism of a SCR. Derive an expression for anode current in terms of transistor parameters.** **June-06,8M**



a) Four layer Structure of Thyristor b) Two transistor model c)

* The operation of the thyristor can be explained with the help of two transistor model as shown in fig b. The middle two layers are split into two seperate parts. Because of this the two transistors are formed. The transistor Q_1 is PNP & Q_2 is NPN.

* The Base of Q_1 is connected to collector of Q_2. Similarly base of Q_2 is connected to collector of Q_1.

* These transistors are in common base (CB) configuration. In general the relationship between collector current 'I_c', emitter current 'I_E' & leakage current I_{CBO} of a transistor is

$$\boxed{I_C = \alpha I_E + I_{CBO}} \longrightarrow (1)$$

Where $\alpha = \frac{I_c}{I_E}$, common base current gain

* For transistor Q_1

$$\boxed{I_{C1} = \alpha I_{E1} + I_{CBO1}} \longrightarrow (2)$$

from fig ©, $I_{E1} = I_A$

Substituting I_{E1} value in eqn (2), we get

$$\boxed{I_{C1} = \alpha I_A + I_{CBO1}} \longrightarrow (3)$$

Where α_1 is CB current gain of Q_1
I_{CBO} is CB leakage current of Q_1

* Similarly for transistor Q_2

$$\boxed{I_{C2} = \alpha_2 I_{E2} + I_{CBO2}} \rightarrow (4)$$

from fig (C), $I_{E2} = I_K$

Substituting I_{E2} value in eq (4), we get

$$\boxed{I_{C2} = \alpha_2 I_K + I_{CBO2}} \rightarrow (5)$$

Where α_2 is CB current gain of Q_2

I_{CBO2} is CB leakage current of Q_2

From fig (C), it is clear that

$$\boxed{I_A = I_{C1} + I_{C2}} \rightarrow (6)$$

Substituting eqn (3) & (5) in eqn (6), we get

$$I_A = \alpha I_A + I_{CBO1} + \alpha_2 I_K + I_{CBO2}$$

from fig (C) $\boxed{I_K = I_A + I_G}$

$$I_A = \alpha_1 I_A + I_{CBO1} + \alpha_2 [I_A + I_G] + I_{CBO2}$$

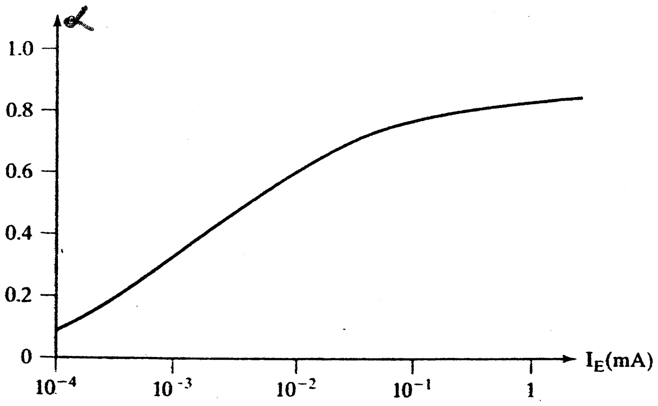
$$I_A = \underline{\alpha_1 I_A} + I_{CBO1} + \underline{\alpha_2 I_A} + \alpha_2 I_G + I_{CBO2}$$

$$I_A - \alpha_1 I_A - \alpha_2 I_A = I_{CBO1} + I_{CBO2} + \alpha_2 I_G$$

$$I_A [1 - \alpha_1 - \alpha_2] = I_{CBO1} + I_{CBO2} + \alpha_2 I_G$$

$$I_A = \frac{I_{CBO1} + I_{CBO2} + \alpha_2 I_G}{1 - \alpha_1 - \alpha_2}$$

$$\boxed{I_A = \frac{I_{CBO1} + I_{CBO2} + \alpha_2 I_G}{1 - (\alpha_1 + \alpha_2)}} \rightarrow (7)$$



FIGURE

Typical variation of current gain with emitter current.

* The current gain α_1 varies with the emitter current $I_A = I_{E1}$ & α_2 varies with $I_K = I_A + I_G$

  A typical variation of current gain α with the emitter current I_E is shown in fig 2

* If the gate current I_G is suddenly increased say (0 to 1mA) this immediately increases anode current I_A, which would further increase α_1 & α_2.

  If $(\alpha_1+\alpha_2)$ tends to be unity, then denominator of eq 7 approaches zero, resulting in a large value of anode current I_A & the thyristor turns ON with a small gate current.

❖ Methods of SCR Turn-ON :

❖ **Explain the different types of turn-ON methods(triggering mechanisms) used to switch-ON a thyristor device. Use the two transistor model of a thyristor as the basis to explain the switching behaviour of the thyristor.**

Jan-05,10M

❖ **Explain the various methods of turn-ON of our SCR**

June-10,6M(IT)

❖ **Mention the different turn-ON methods employed to switch-ON SCR. Explain with waveforms, the resistancetriggering circuit to Turn-ON the SCR in the phase control circuit.**

June-09,10M

❖ **Explain the various methods of Turn-ON of an SCR and mention the advantages of gate triggering.** **June-07,8M**

With anode +ve wrt cathode, a thyristor can be turned ON by one of the following techniques :

1) Thermals or High temperature triggering
2) Light triggering
3) High voltage (Forward Vbo) triggering
4) dv/dt triggering
5) Gate triggering

P.T.O

1) Thermals or High temperature triggering

If the temperature of a thyristor is high, there is an increase in the number of electron hole pairs, which increases the leakage current. This increase in current causes α_1 & α_2 to increase so $(\alpha_1+\alpha_2)$ may tend to be unity & the thyristor may be turned ON

This type of turn ON May cause thermal runaway & it normally avoided

2) Light triggering :-

If light is allowed to strike the gate to cathode junction of the thyristor, the electron-hole pairs increase and the thyristor may be turned ON.

3) High Voltage (High forward Voltage) :-

If the forward anode-to-cathode voltage is greater than the forward breakdown vtg ie $V_{AK} > V_{BO}$, sufficient leakage current flows to initiate regenerate turn-ON

This type of turn ON may be destructive & should be avoided

4) $\frac{dv}{dt}$:- If the rate of rise of anode-cathode voltage is high, the charging current of the capacitive junction may be sufficient enough to turn-ON the thyristor

A high value of charging current may damage the thyristor & device must be protected against high $\frac{dv}{dt}$

5) Gate triggering :-

If a thyristor is forward biased, the injection of the gate current by applying +ve gate vtg b/w the gate and cathode terminal & turns ON the thyristor.

As the gate current is increased, the forward blocking vtg is decreased as shown in fig (1)

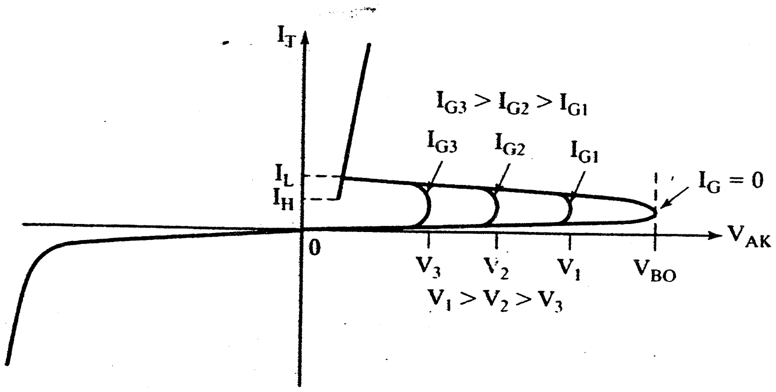


FIGURE (1)
Effects of gate current on forward blocking voltage.

❖ Switching Characteristics of Thyristor (SCR) :-

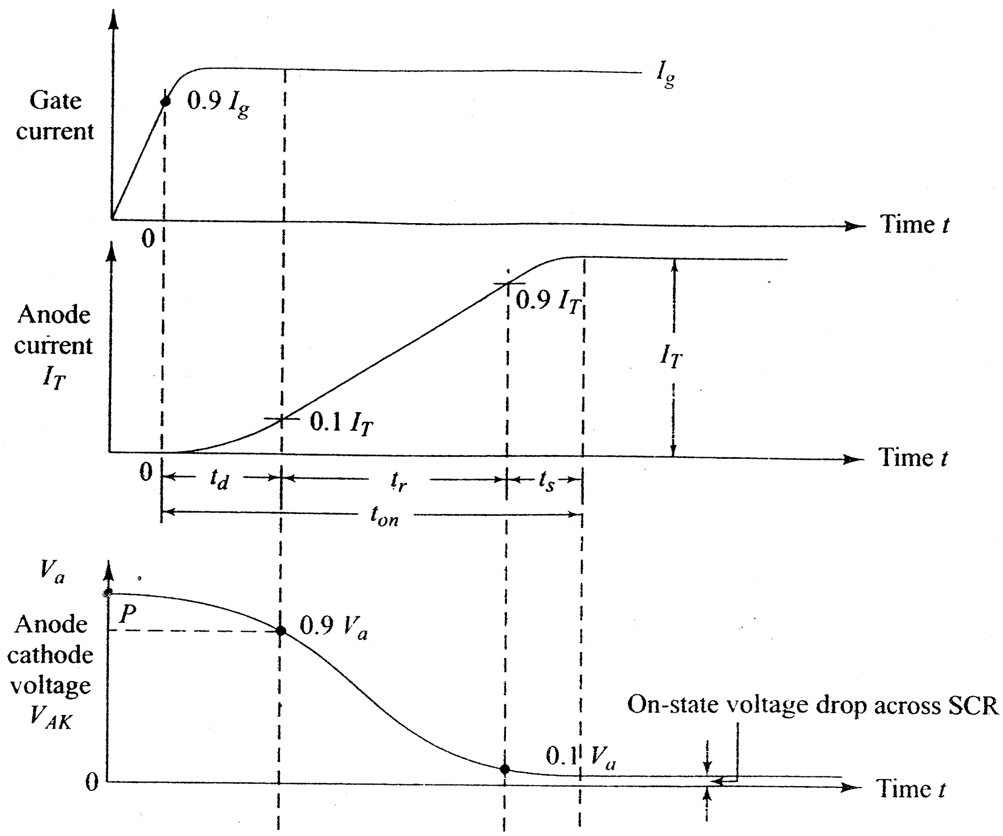
OR

❖ SCR Turn-ON and Turn-OFF Characteristics

❖ **Explain the turn-ON and turn-OFF characteristics of the SCR**

June-05,8M

Dynamic turn-ON switching characteristics :



The turn ON time 't_{ON}' of the SCR is subdivided into three distinct periods

i> Delay time 't_d'

ii> Rise time 't_r'

iii> Spread time 't_s'

i> <u>Delay time</u> :-

This is the time between the instant a which the gate current reaches to 90% of its final value (from 0 to 90% I_g) & the instant at which the anode current reaches 10% of its final value (ie 10% I_A)

It can also be defined as the time during which anode vtg fall from 100% of V_{AK} to 90% of V_{AK} as shown in fig.

ii) Rise time 't_r':-

This is the time required for the anode current to rise from 10 to 90% of its final value.

It is also defined as the time during which anode vtg (V_{AK}) falls from 90% of V_{AK} to 10% of V_{AK}.

During rise time, turn-ON losses are the highest due to high anode vtg V_{AK} & large anode current I_A, occuring together in the thyristor. Hence large dissipation takes place in the thyristor.

ie $$\boxed{P = V_A \cdot I_A}$$

This power dessipation is called switching losses of Thyristor.

iii) Spread-time 't_s':-

The spread time is the time required for the anode voltage V_{AK} to fall from 10% V_{AK} to the ON-state vtg drop (1V to 1.5V)

After spread time, anode current attains steady state values & the vtg drop across the SCR is equal to the ON-State vtg drop of the order of 1V to 1.5V.

* The turn ON Time of thyristor is given by

$$\boxed{t_{ON} = t_d + t_r + t_s}$$

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Turn-OFF characteristics :

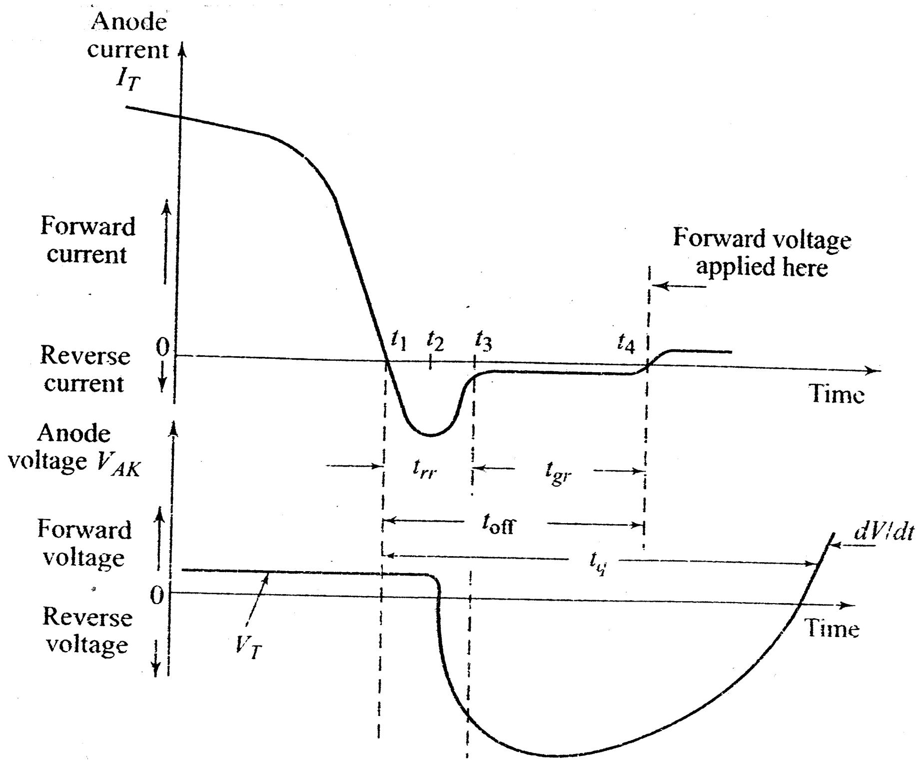

Fig. *Waveforms during SCR turn-off*

Once thyristor is ON. gate looses its control.
The thyristor can be turned OFF by reducing the anode current below holding current ie $I_A < I_H$.

Turn-OFF time is divided into
i) Reverse recovery time 't_{rr}'
ii) Gate recovery time 't_{gr}'.

i) Reverse Recovery time 't_{rr}' :-

Once anode current is zero, the device start to turn OFF but not immediately & it will take some time to turn OFF

* The time taken by the minority carriers present in the PN-junction to recombine with the opposite charges & to be neutralized. This time is called Reverse recovery time 't_{rr}'.

ii) Gate recovery time 't_{gr}':-

The Time taken by charges for the recombination when reverse vtg is maintained across the thyristor.

The time taken by the thyristor to change state from ON state to OFF-state is called turn-OFF state

Turn-OFF time is the sum of t_{rr} & t_{gr}.

$$\boxed{t_{OFF} = t_{rr} + t_{gr}}$$

* The turn-OFF time of the thyristor varies from 50μsec to 100μsec

❖ **Define turn-OFF time of thyristor and mention any two factors that affect it.** **Jan-06,3M**

❖ Inverter Grade Thyristors :-

- The thyristor with **FAST turn-OFF time** i.e. **3 to 50 μsec** are called Inverter grade SCR's.
- Inverter grade thyristors are costlier and are used in INVERTERS and CHOPPERS.

❖ Converter Grade Thyristors :-

- Thyristor with **SLOW turn-OFF time** i.e. **50 to 100 μsec** are called Converter grade thyristors.
- These are cheaper and are used in Phase-Controlled rectifiers, ac voltage controllers, cyclo-converters etc.

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❖ Thyristor Gate Characteristics :-

❖ Sketch the gate characteristics of an SCR and explain the different regions of gate characteristics. Also indicate different voltages and different currents on the gate characteristics.

June-11,10M

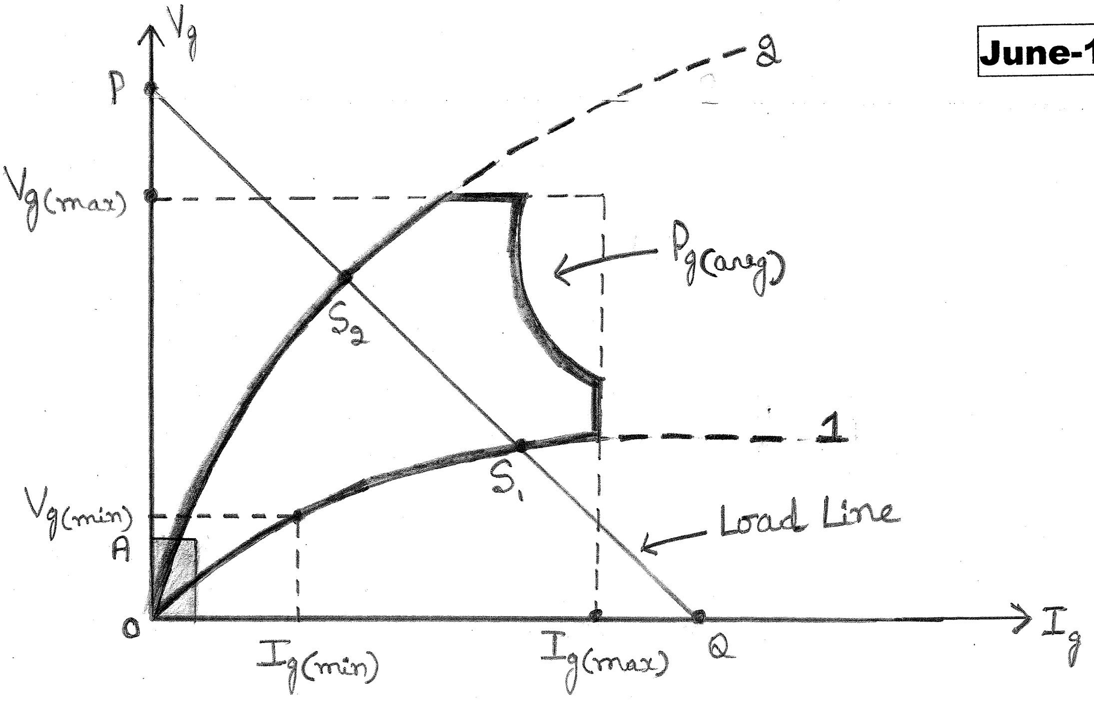


Fig ① shows the gate characteristics of a thyristor. Here, +ve gate cathode voltage Vg and +ve gate to cathode current Ig represents dc values.

* For a particular type of SCRs Vg - Ig characteristics has a spread b/w curves 1 & 2 as shown in fig ①. This spread or scatter of gate characteristics is due to difference in low doping levels of p and n layers.

* Curve 1 represents the lowest voltages values that must be applied to turn-ON the SCR & curve 2 gives the highest possible voltage values that can be safely applied to gate circuit.

* Each thyristor has maximum limits as Vg(max) for voltage and Ig(max) for gate current. There is also a limit on the maximum gate Power dessipation

($P_{g(max)} = V_g I_g$)

These limits should not be exceeded in order to avoid permanent damage of junction J_3.

* There are also minimum limits for V_g & I_g for reliable turn-ON, these are represented by $V_{g(min)}$ & $V_{g(max)}$ as shown in fig (1).

* If $V_{g(max)}$, $I_{g(max)}$ & $P_{g(any)}$ are exceeded, the thyristor can be destroyed.

There are three important regions:

1) The first region 'OA' lies the origin and is defined by the maximum gate voltage that will not trigger any device. The gate must be operated in this region whenever forward bias is applied across the thyristor & triggering is not necessary. (This region sets a limit on the maximum false signals that can be tolerated in the gate firing circuit)

2) The second region is the minimum value of gate -voltage & current required to trigger the SCR.

3) The third region is the largest limits on the gate - signals for reliable firing. For applications, where fast turn - ON is required, a hard firing signal is needed.

* A thyristor may be considered to be a charged controlled device. Thus, higher the magnitude of gate current pulse lesser is the time needed to inject the required. charge for turning ON the thyristor. Therefore the SCR turn - ON time can reduced by using gate current of higher magnitude.

❖ Thyristor FIRING circuits or SCR FIRING or TRIGGERING circuits :-

❖ Thyristor can be turned ON by many methods like, overvoltage turn-ON, dv/dt turn-ON, temperature turn-ON, light turn-ON and gate turn-ON.

❖ The most commonly employed method to turn-ON thyristor is gate turn-ON. In this method a gate pulse is used to turn-ON thyristor and a circuit used to generate gate pulse is called firing or triggering circuit.

The different firing or triggering circuits are :

1) Resistance firing circuit (R-Firing)

2) RC triggering circuit and

3) UJT relaxation oscillator.

❖ Resistance firing circuit (R-Firing) :-

❖ **With a neat circuit diagram and waveforms, explain the resistor triggering circuit.**

June-11, 6M

❖ **Mention the different turn-ON methods employed to switch ON SCR. Explain with waveforms, the resistance triggering circuits to turn-ON SCR in the phase control circuit.** **Jan-09,10M**

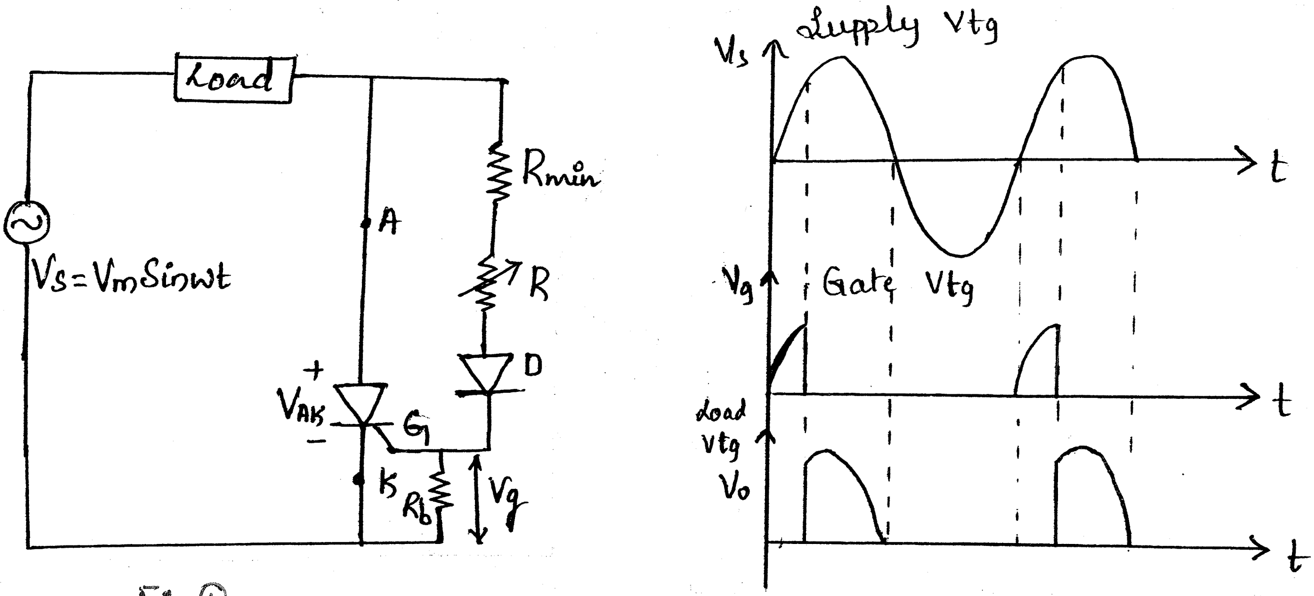


Fig ①

* Resistance firing is the simplest & most economi-cal, but it has limited range of firing angle control ie 0° to 90°.

Fig ① a shows the basic resistance ckt. R is variable resistance, R_b is the stablizing resistance. The function of R_{min} is to limit the gate current to a safe value when R is zero.

(This current should not exceed maximum permissible gate current I_{gm}).

* The value of R_{min} can be calculated from to eq

$$\boxed{\frac{V_m}{R_{min}} \leq I_{gm}} \quad \text{or} \quad \boxed{R_{min} \geq \frac{V_m}{I_{gm}}}$$

Where V_m is the maximum value of source vtg.

* The Stablization resistor R_b should have such a value that the maximum vtg drop across it does not exceed maximum possible gate vtg $V_{g(max)}$.

This can happen only when R is zero under this condition

$$\boxed{IR_b \leq V_{g(max)}}$$

$$\frac{V_m}{R_{min}+R_b} \cdot R_b \leq V_{g(max)}$$

$$V_m R_b \leq (R_{min}+R_b) V_{g(max)}$$

$$V_m R_b \leq R_{min} V_{g(max)} + R_b V_{g(max)}$$

$$R_b (V_m - V_{g(max)}) \leq R_{min} V_{g(max)}$$

$$\boxed{R_b \leq \frac{R_{min} V_{g(max)}}{V_m - V_{g(max)}}}$$

Drawbacks

1) Firing angle is limited to 0 to 90°.

❖ Resistance-Capacitance (RC) firing circuit :-

OR

❖ RC Half wave firing :-

❖ **With the help of neat circuit diagram and waveforms, explain RC firing circuit used with half controlled rectifier**

June-10,6M

❖ **With a circuit diagram and waveforms explain RC-triggering circuit.**

June-06,4M

❖ **With circuit diagrams and waveforms, discuss the operation of RC firing circuit for a half wave SCR controlled rectifier.**

June-04,8M

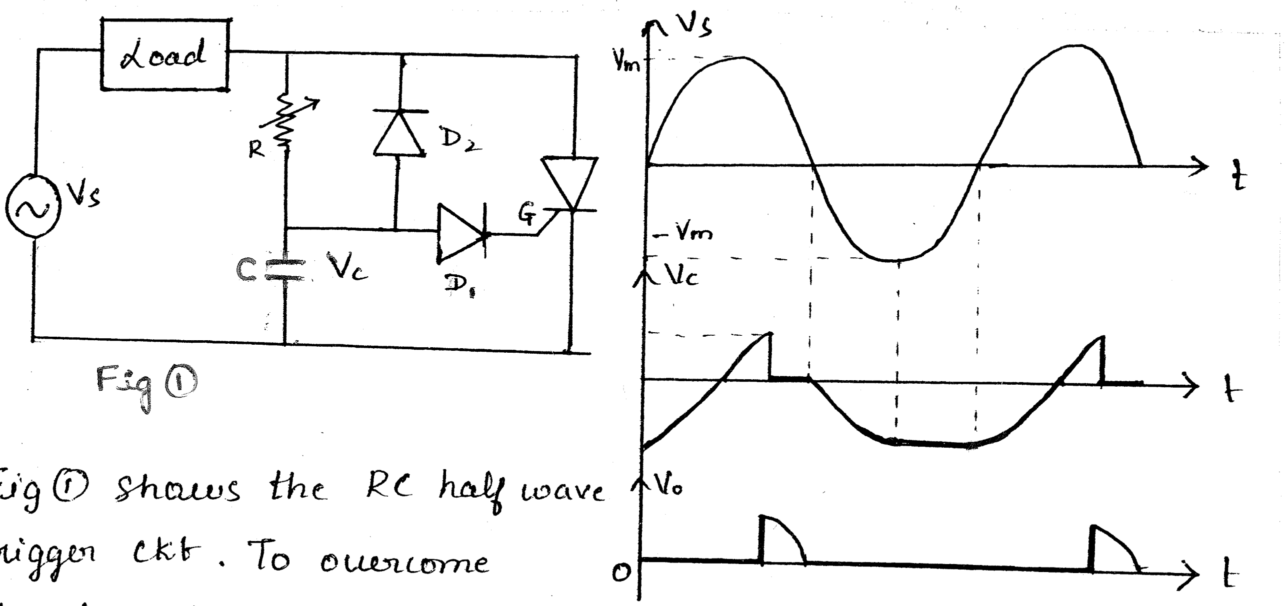


Fig ①

Fig ① shows the RC half wave trigger ckt. To overcome the drawback of R-firing circuit, RC firing circuits are used.

Operation :-

* During each -ve half cycle of I/p voltage, the capacitor charges to the peak supply voltage through diode 'D1' with lower plate positive wrt to the top plate

The diode D_1 is provided in order to by pass 'R' during each negetive half cycle of the supply vtg. so that the capacitor charges fast to the negetive peak value of the supply vtg $-V_m$.

This capacitor voltage remains at $-V_m$ until supply voltage attains zero value ($V_s = 0$).

* When the SCR anode Voltage becomes +ve, the capacitor starts charging through the resistor R.

When the capacitor charging voltage becomes equal to $V_{gt} + V_d$, the SCR turns ON

* In fig (1), diode D_1 is used to prevent the breakdown of gate to cathode junction.

The value of RC for zero o/p voltage is given by

$$\boxed{RC \geq \frac{1.3T}{2}}$$

Where $T = \frac{1}{f}$

* The SCR will trigger when

$$\boxed{V_c = V_{gt} + V_d} \longrightarrow (1)$$

The maximum value of R is given by

$$\boxed{V_s \geq I_{gt} R + V_c} \longrightarrow (2)$$

Substituting eq (1) in (2), we get

$$\boxed{V_s \geq I_{gt} R + V_{gt} + V_d}$$

$$V_s - V_{gt} - V_d \geq I_{gt} R$$

$$\frac{V_s - V_{gt} - V_d}{I_{gt}} \geq R$$

$$\boxed{R \leq \frac{V_s - V_{gt} - V_d}{I_{gt}}}$$

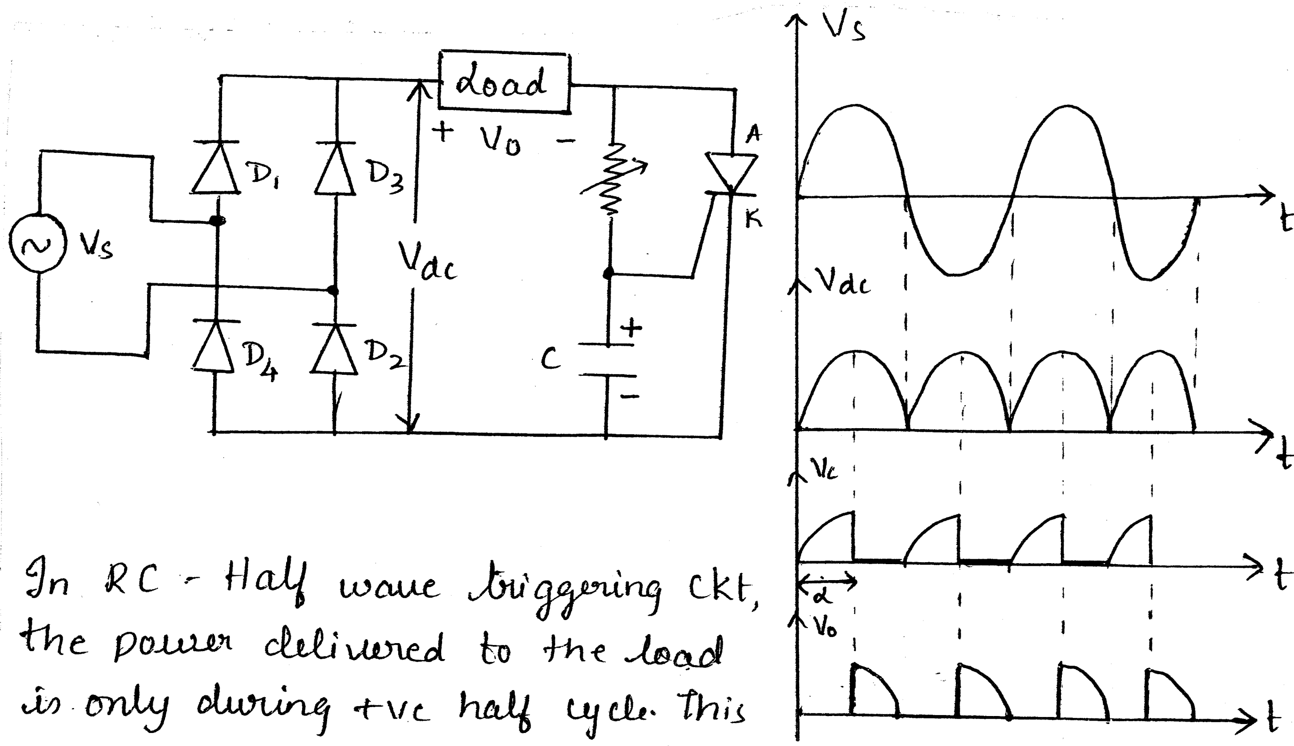
Where $V_d \rightarrow$ Voltage drop across D_2

$V_{gt} \rightarrow$ Minimum gate turn-ON voltage

$I_{gt} \rightarrow$ Gate turn ON current

* By varying 'R', the firing angle can be varied from 0° to 180°.

❖ RC - FULL wave triggering circuit :-



In RC - Half wave triggering ckt, the power delivered to the load is only during +ve half cycle. This limitation can be overcome by using Full wave RC triggering ckt.

Here AC I/p Signal 'Vs' is converted into pulsating dc by full wave bridge rectifier ckt. This allows the SCR to be triggered on for both half cycle of the AC i/p voltage, which doubles the power delivered to the load.

* When the capacitor charges to a voltage equal to V_{gt}, SCR triggers & rectified vtg V_{dc} appears across load as V_O. The value of RC is obtained from the following relation

$$\boxed{RC \geqslant \frac{50T}{2}}$$

For the ckt 'R' can be calculated as

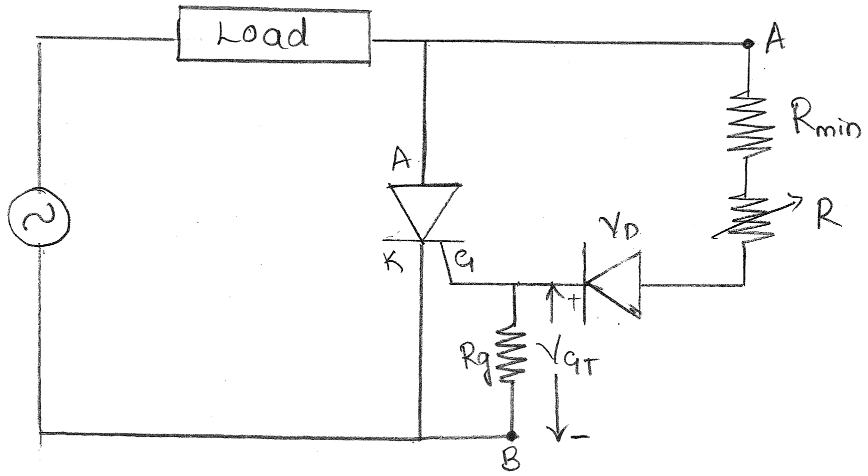
$$V_s = I_{gt} R + V_C$$

$$V_s = I_{gt} R + V_{gt}$$

$$= V_s - V_{gt}$$

$$\boxed{R = \frac{V_s - V_{gt}}{I_{gt}}}$$

❖ **For the thyristor in the circuit of fig1, the gate voltage required to trigger is V_{GT}=0.6V and the corresponding gate current is I_{GT}=250μA. The diode used is of silicon material and the input voltage is V=100sinwt. Find the firing angle α at which the thyristor will turn ON if R_{min}=10KΩ, R=220KΩ.**



Given : $V_{GT} = 0.6V$, $I_{GT} = 250\mu A$, $V = 100 \sin \omega t$, $R_{min} = 10K\Omega$, $R = 220K\Omega$, $V_m = 100V$, Assuming $V_D = 0.7V$.

Soln :- Applying KVL from V, A & B, we get

$$V - I_{GT} R_{min} - I_{GT} R - V_D - {}_{GT} R_g = 0$$

$$V - I_{GT}(R_{min} + R) - V_D - V_{GT} = 0$$

$$V = I_{GT}(R_{min} + R) + V_D + V_{GT}$$

$$V = 250 \times 10^{-6}(10K\Omega + 220K\Omega) + 0.7 + 0.6$$

$$\boxed{V = 58.8\,V}$$

WKT $V = V_m \sin\alpha$

$$\frac{V}{V_m} = \sin\alpha$$

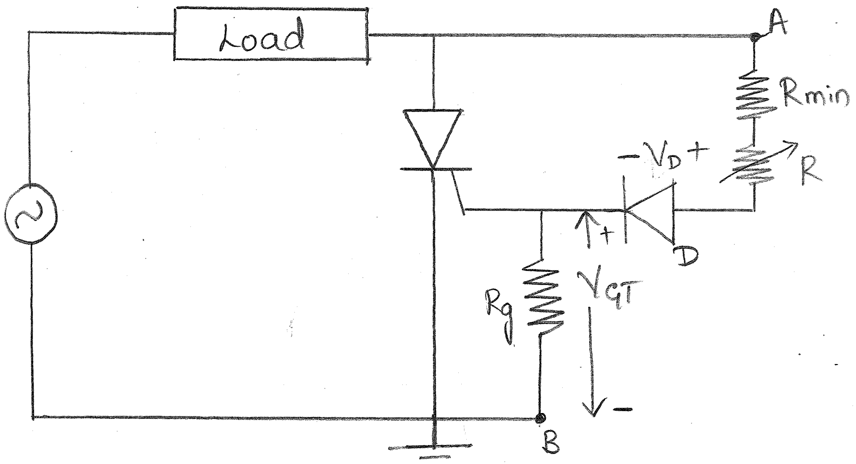
PTO →

$$\alpha = \sin^{-1}\left(\frac{V}{V_m}\right)$$

$$= \sin^{-1}\left(\frac{58.8}{100}\right)$$

$$\boxed{\alpha = 36.01^{\circ}}$$

❖ **The circuit of fig1 uses an SCR with $I_{g(min)}$=0.1mA and $V_{g(min)}$=0.5v. The diode is silicon and the peak amplitude of the input is 24volts. Determine the trigger angle α for R=100KΩ and Rmin=10KΩ.**



Given: $V_{g(min)} = 0.5V$, $I_{g(min)} = 0.1mA$, $V_m = 24V$,
$R = 100k\Omega$, $R_{min} = 10k\Omega$, Assuming $V_D = 0.7V$.

Soln: Applying KVL from V, A & B we get

$$V - I_{gt}R_{min} - I_{gt}R - V_D - V_{gt} = 0$$

$$V - I_{gt}(R_{min} + R) - V_D - V_{gt} = 0$$

$$V = I_{gt}(R_{min} + R) + V_D + V_{gt}$$

$$V = 0.1mA\,(10k\Omega + 100k\Omega) + 0.7V + 0.5V$$

$$\boxed{V = 12.2V}$$

WKT,

$$V = V_m \sin\alpha$$

$$\alpha = \sin^{-1}\left(\frac{V}{V_m}\right)$$

$$= \sin^{-1}\left(\frac{12.2}{24}\right)$$

$$\boxed{\alpha = 30.6^\circ}$$

❖ **The ON-State voltage drop across the thyristor in the circuit of fig1 is 0.8v. The thyristor has a holding current of 15mA with I_G=0. If the thyristor is turned ON by a momentary pulse of gate current. Determine the value of voltage V below which the thyristor will turn-OFF.**

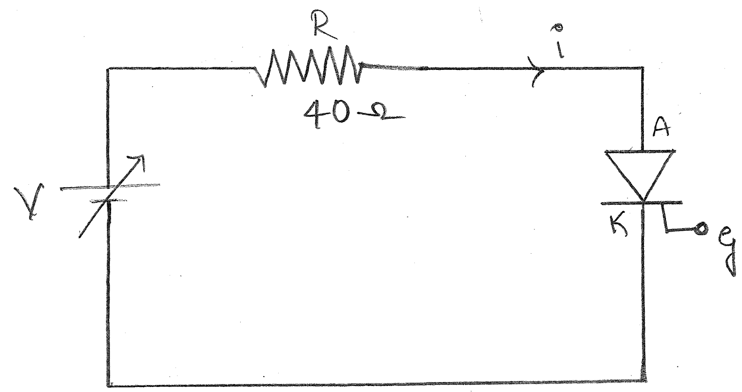


fig ①

Given : $V_{AK} = 0.8V$, $I_H = 15mA$, $R = 40\Omega$

Soln: Applying KVL to the ckt, we get

$$V - IR - V_{AK} = 0$$

$$V = IR + V_{AK}$$

$$= 15mA \times 40\Omega + 0.8V$$

$$\boxed{V = 1.4V}$$

When $V = 1.4V$, the current equal to I_H. Hence to turn OFF the thyristor, 'V' must be reduced below 1.4V

❖ **Design a suitable RC half wave triggering circuit for a thyristorised network operation on a 220V,50Hz supply. The specifications of SCR are $V_{gt(min)}$=5V and $I_{gt(max)}$=30mA.**

Given : $V_{gt(min)} = 5V$, $I_{gt(max)} = 30mA$, $V_s = 220V$,

$f = 50Hz$, $T = \frac{1}{f} = \frac{1}{50Hz}$

$$\boxed{T = 20mSec}$$

Assuming : $V_D = 0.7V$

Soln: WKT

$$R = \frac{V_s - V_{gt} - V_D}{I_{gt}}$$

$$= \frac{220V - 5V - 0.7}{30mA}$$

$$\boxed{R = 7.1433 K\Omega}$$

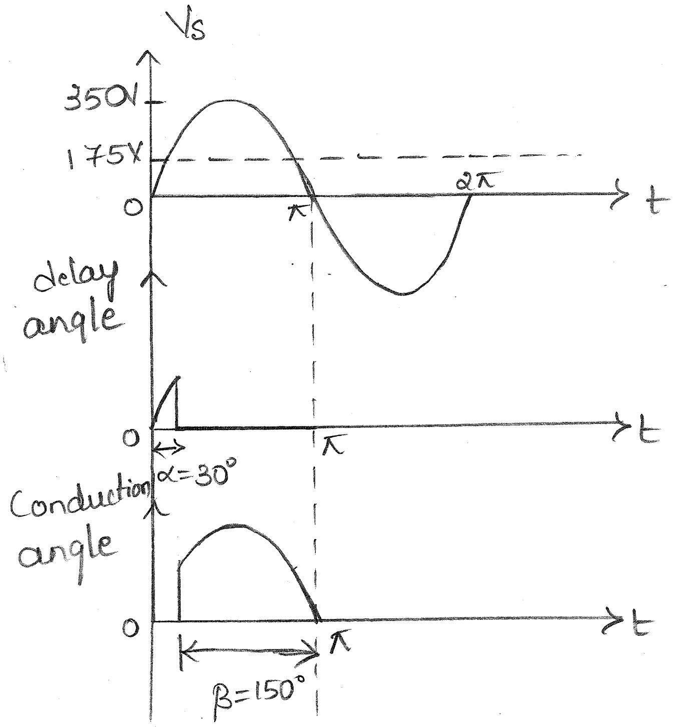
WKT $RC \geq \frac{1.3T}{2}$

$$C \geq \frac{1.3 \times 20\,msec}{2 \times 7.1433\,K\Omega}$$

$$\boxed{C \geq 1.8199\,\mu F}$$

❖ **A thyristor has the forward breakover voltage of 175V when gate pulse of 2mA is made to flow. Find the delay angle and conduction angle if a sine wave of 350V peak is applied.**

Given: $V_{BO} = V_S = 175V$, $I_g = 2mA$, $V_m = 350V$, $\alpha = ?$ & $\beta = ?$



Soln: WKT

$$V_S = V_m \sin\alpha$$

$$\alpha = \sin^{-1}\left(\frac{V_S}{V_m}\right)$$

$$\alpha = \sin^{-1}\left(\frac{175}{350}\right)$$

∴ Delay angle 'α' is

$$\boxed{\alpha = 30°}$$

WKT $\pi = \alpha + \beta$

$$\beta = \pi - \alpha$$

$$\beta = 180° - 30°$$

∴ Conduction angle is

$$\boxed{\beta = 150°}$$

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Firing Angle Problems - FORMULAE

1) $V_{BO} = V_m \sin\alpha$

Where $V_m = \sqrt{2}\, V_{rms}$

2) $\alpha = \sin^{-1}\left(\frac{V_{BO}}{V_m}\right)$

3) Delay angle or Firing angle

$$\boxed{\alpha = 180^\circ - \beta}$$

4) Conduction angle

$$\boxed{\beta = 180^\circ - \alpha}$$

❖ **A thyristor is supplied from 230V,50Hz mains. If the conduction angle is 120°, determine the voltage at which the thyristor is triggered.**

Jan11-4M

Given :- $V_{rms} = 230V, \quad \beta = 120^\circ$

Sol :- $V_m = \sqrt{2}\, V_{rms}$

$= \sqrt{2} \times 230V$

$$\boxed{V_m = 325.26V}$$

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* Firing angle

$$\alpha = 180^\circ - \beta$$

$$\alpha = 180^\circ - 120^\circ$$

$$\boxed{\alpha = 60^\circ}$$

* $V_{BO} = V_m \sin\alpha$

$$= 325.26V \times \sin(60^\circ)$$

$$\boxed{V_{BO} = 281.68V}$$

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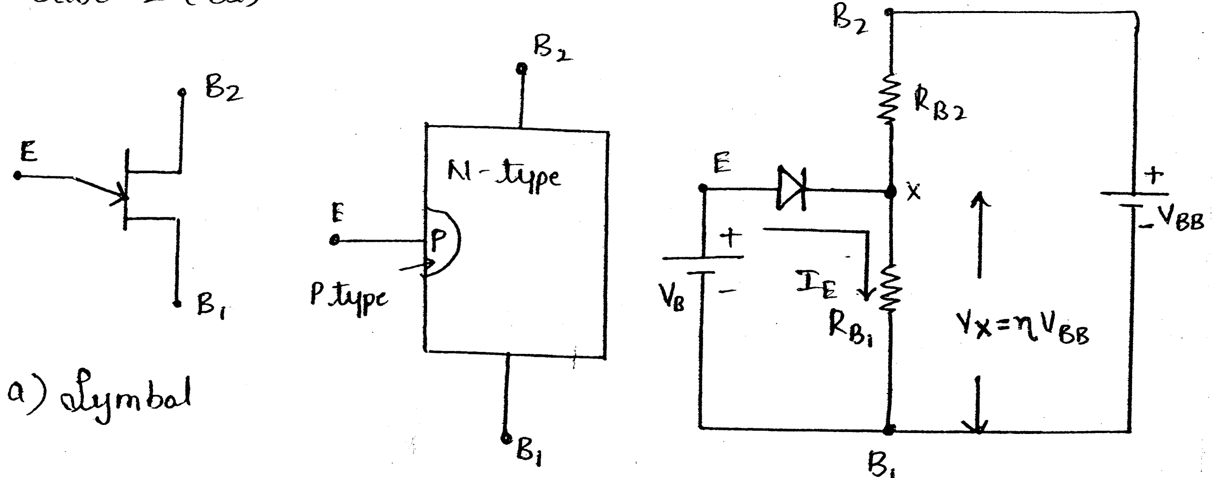
❖ UNIJUNCTION Transistor :-

* The drawback with R-firing & RC-firing is that power dissipation in the gate ckt is more, to overcome this drawback, UJT firing ckt is used.

* UJT is an abbrevation for unijunction transistor made up of n type silicon material to which P-type emitter is fixed

UJT has 3 terminals namely Emitter (E) Base-1 (B1) & Base-2 (B2)



a) Symbol

b) Structure

c) Equivalent ckt.

* R_{B1} & R_{B2} are the internal resistance respectively from Bases B_1 & B_2 to x-point.

When a voltage V_{BB} is applied across the two base terminals B_1 & B_2, the potential of point x wrt B_1 is given by

$$V_X = I R_{B1}$$

$$= \frac{V_{BB}}{R_{B1} + R_{B2}} \cdot R_{B1}$$

$$= \frac{R_{B1}}{R_{B1}+R_{B2}} V_{BB}$$

$$V_x = \eta V_{BB}$$

where $\eta = \frac{R_{B1}}{R_{B1}+R_{B2}}$

* $R_{BB} = R_{B1} + R_{B2} \quad \therefore \eta = \frac{R_{B1}}{R_{BB}}$.

Where η is the internal UJT vtg divider ratio & is called the intrinsic stand off ratio.

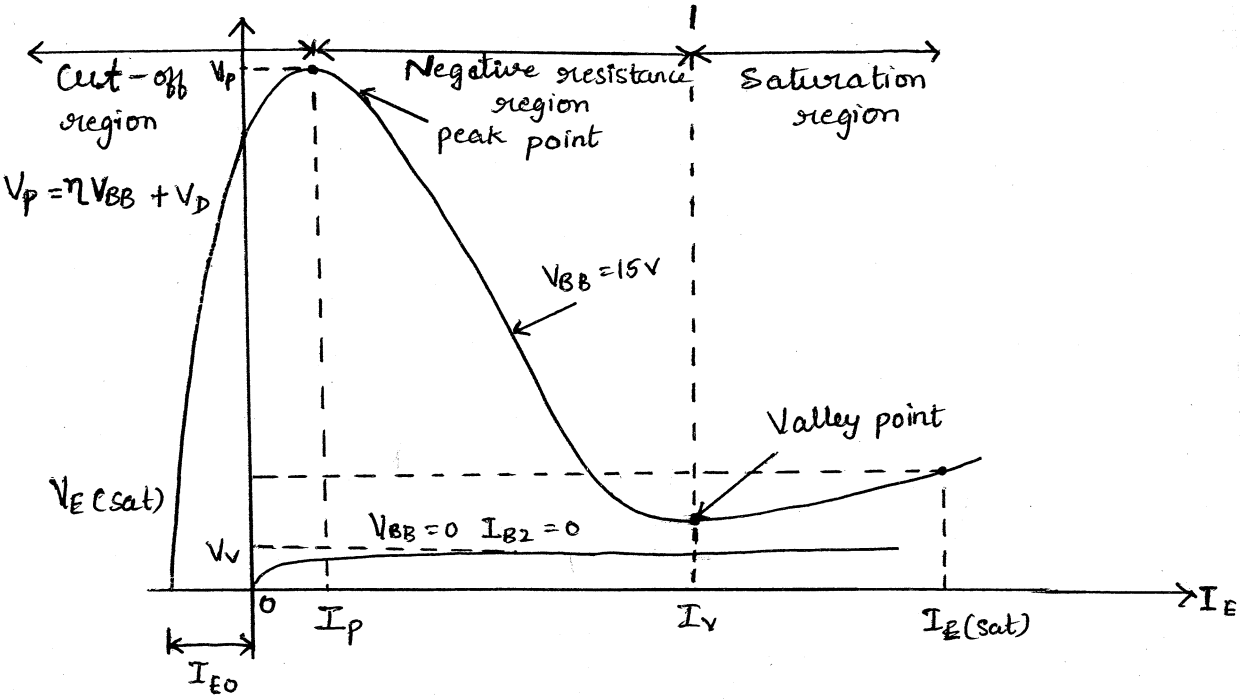


fig:- Characteristics for $V_{BB} = 0$ & $V_{BB} = 15V$.

The characteristics can be divided into three main regions

1) Cut-off region :-

When the emitter voltage V_E is less than V_P, the p-n junction is reverse biased. A small amount of reverse saturation current I_{EO} flows through the device.

2) <u>Negetive resistance region</u>:-

When the emitter voltage V_E becomes equal to V_P, the p-n junction becomes forward biased and I_E starts flowing. The voltage across the device decreases in this region, though the current through the devices increases. Hence the region is called <u>negetive resistance</u> region. This decreases the resistance R_{B1}. This region continues till valley point.

3) <u>Saturation region</u>:-

The further increase in the 'I_E' beyond the valley point current 'I_V' drives the device in the saturation region. The voltage corresponding to the valley point is called Valley point voltage denoted as V_V.

❖ UJT-Relaxation oscillator :-

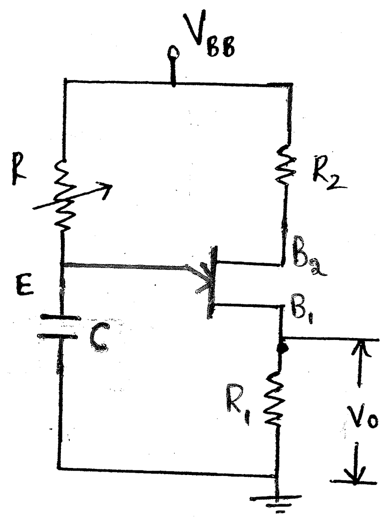
❖ **With relevant circuit diagram and waveforms, explain the UJT relaxation oscillator.**

Jan-10,6M

❖ **Brief the working principle of a UJT relaxation oscillator with the help of a circuit diagram and show period of oscillation**

T= RC $\log_e(1/1-n)$.

June-08,6M



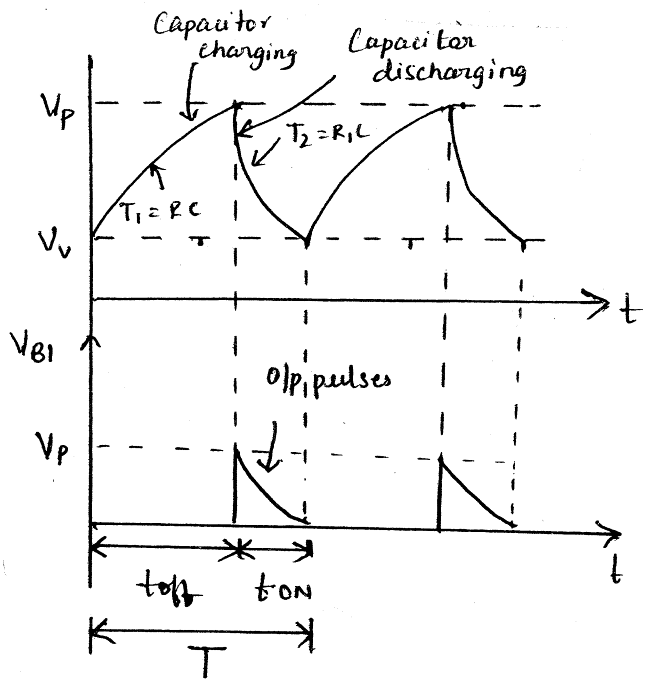


Fig ① shows a **UJT** relaxation oscillator.
When dc supply 'V_{BB}' is applied, Capacitor 'C' begins to charge through R exponentially toward V_{BB}. During this charging, emitter ckt of UJT is an open ckt

* The control Vtg $V_C = V_E$ is given by

$$V_C = V_E = V_{BB}(1 - e^{-t/RC})$$

* The charging time constant is given by

$$\boxed{\tau_1 = RC}$$

* When this emitter voltage $V_E = V_C$ reaches the peak point vtg $V_P = \eta V_{BB} + V_D$, the UJT turns ON & Capacitor 'C' discharges through low resistance R_1.

* The discharging time constant is given by

$$\boxed{\tau_2 = R_1 C}$$

Hence τ_2 is much smaller than τ_1

* When discharging vtg dropped to 'V_V', UJT turns OFF. The charging & discharging process of capacitor repeats for each period T & is given by

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

* R_2 is used for thermal stability of V_P, the value of R_2 can be calculated by using formula.

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

* The maximum value of R is determined by

$$R_{max} = \frac{V_{BB} - V_P}{I_P} = \frac{V_{BB} - (\eta V_{BB} + V_D)}{I_P}$$

The minimum value of R is given by

$$R_{min} = \frac{V_{BB} - V_V}{I_V}$$

* R_1 can be calculated as

$$\boxed{R_1 = \frac{V_{BB}}{\text{leakage current}} - R_2 - R_{B1} - R_{B2}}$$

Derive the expression for Periodic time 'T' of the UJT relaxation oscillator

Soln:- The voltage across the Capacitor is given by

$$V_P = V_{BB}(1 - e^{-t/RC})$$

When $V_P = \eta V_{BB} + V_D$, the capacitor will discharge through R_1

Substituting 'V_P' value in eq ①, we get

$$\eta V_{BB} + V_D = V_{BB}(1 - e^{-t/RC})$$

Since $V_{BB} >> V_D$, neglecting V_D

$$\eta V_{BB} = V_{BB}(1 - e^{-t/RC})$$

$$\eta = 1 - e^{-t/RC}$$

$$e^{-t/RC} = 1 - \eta$$

$$\frac{1}{e^{-t/RC}} = \frac{1}{1-\eta}$$

$$e^{t/RC} = \frac{1}{1-\eta}$$

Taking $\log_e$ on both side we get

$$\frac{t}{RC} = \log_e\left(\frac{1}{1+\eta}\right)$$

put $\boxed{t = T}$ is above equation

$$\boxed{T = RC \log_e\left(\frac{1}{1-\eta}\right)}$$

The frequency of oscillation 'f'

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

$$\boxed{f = \frac{1}{RC \log_e\left(\frac{1}{1-\eta}\right)}}$$

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UJT-Relaxation Oscillator Formulae :

1) Capacitor voltage $V_C = V_E$ is

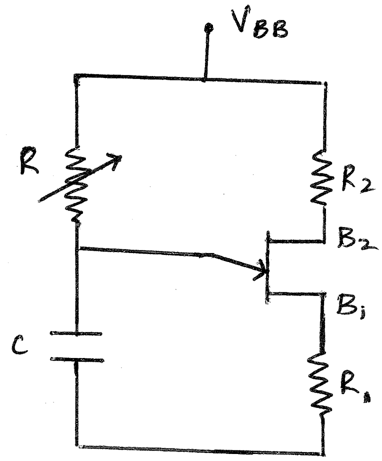
$$\boxed{V_C = V_E = V_{BB}\left(1 - e^{-t/RC}\right)}$$

2) Charging time constant

$$\boxed{\tau_1 = RC}$$

3) Discharging time constant

$$\tau_2 = R_1 C$$



4) $T = \tau_1 + \tau_2$ &

$$\boxed{T = RC \ln\left(\frac{1}{1-\eta}\right)}$$

5) $R_2 = \frac{10^4}{\eta V_{BB}}$ or $\boxed{R_2 = \frac{0.7\,(R_{B1} + R_{B2})}{\eta V_{BB}}}$

6) $$R_1 = \frac{V_{BB}}{\text{leakage current}} - R_2 - R_{B1} - R_{B2}$$

or

$$R_1 = \frac{V_{gt}}{I_{leakage}}$$

7) $$R_{max} = \frac{V_{BB} - V_P}{I_P}$$

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8) $R_{min} = \frac{V_{BB} - V_V}{I_V}$

9) $T = 1/f$

10) $V_P = \eta V_{BB} + V_D$

det $V_D = 0.8V$

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

PROBLEMS

1) A UJT is used to trigger the thyristor whose minimum gate triggering voltage is 6.2V, the UJT ratings are : η=0.66, I_P=3mA, I_V =0.5mA, $R_{B1}+R_{B2}$ = 5KΩ, leakage current = 3.2mA, V_P=14V and V_V=1V. Oscillator frequency is 2KHz and capacitor C=0.04μf. Design the complete circuit.

Soln :- Assume $V_D = 0.8V$

$$T = \frac{1}{f} = \frac{1}{2\times10^3}$$

WKT $$T = RC \ln\left(\frac{1}{1-\eta}\right)$$

$$\frac{1}{2\times10^3} = R\times 0.04\mu F\left(\frac{1}{1-0.66}\right)$$

$$\boxed{R = 11.6k\Omega}$$

* The peak voltage is given by

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

$$V_{BB} = \frac{V_P - V_D}{\eta} = \frac{14V - 0.8V}{0.66}$$

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

* $$R_2 = \frac{0.7(R_{B1}+R_{B2})}{\eta V_{BB}} = \frac{0.7(5\times10^3)}{0.66\times20}$$

$$\boxed{R_2 = 265.15\Omega}$$

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

$20V = 3.2 \times 10^{-3}(R_1 + 265 + 5 \times 10^3)$

$\frac{20V}{3.2 \times 10^{-3}} = R_1 + 5.265\,k\Omega$

$R_1 = 625 - 5.265\,k\Omega$

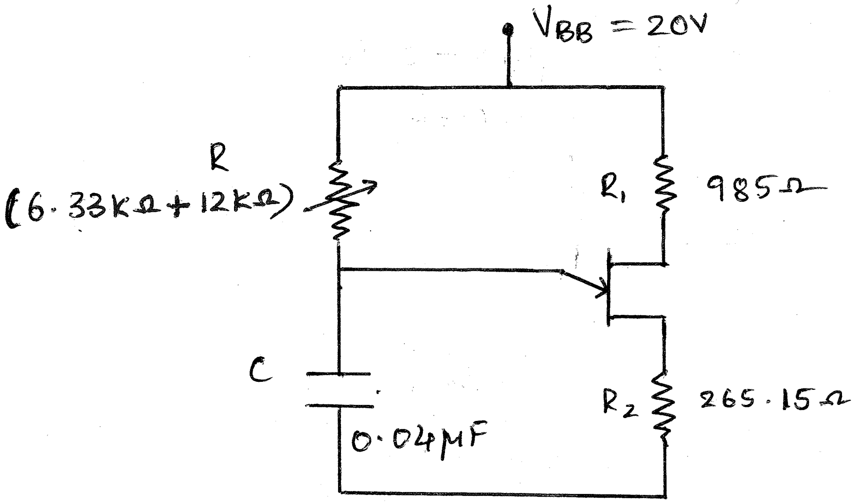
$\boxed{R_1 = 985\,\Omega}$

* $R_{(max)} = \frac{V_{BB} - V_P}{I_P} = \frac{20V - 14V}{0.5 \times 10^{-3}}$

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

* $R_{(min)} = \frac{V_{BB} - V_V}{I_V} = \frac{20V - 1V}{3 \times 10^{-3}}$

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



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2) Design the UJT triggering circuit for SCR. Given V_{BB}=20V, η=0.6, I_P=10A, V_V=2V, I_V=10mA. The frequency of oscillation is 100HZ. The triggering pulse width should be 50μsec.

Given :- $V_{BB} = 20V$, $\eta = 0.6$, $I_P = 10\mu A$, $V_V = 2V$,

$I_V = 10mA$, $f = 100Hz$, $\tau_2 = 50\mu sec$.

Soln :- $T = \frac{1}{f} = \frac{1}{100Hz}$

WKT $T = RC \ln\left(\frac{1}{1-\eta}\right)$

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

$$RC = 0.0109135$$

Assuming $C = 1\mu F$

$$R = \frac{0.0109135}{1\mu F}$$

$$\boxed{R_C = 10.91K\Omega}$$

* Peak Voltage

$$V_P = \eta V_{BB} + V_D \qquad (\text{Take } V_D = 0.8V)$$

$$= 0.6 \times 20V + 0.8V$$

$$\boxed{V_P = 12.8V}$$

* $R_{(min)} = \frac{V_{BB} - V_V}{I_V} = \frac{20V - 2V}{10 \times 10^{-3}}$

$$\boxed{R_{(min)} = 1.8K\Omega}$$

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

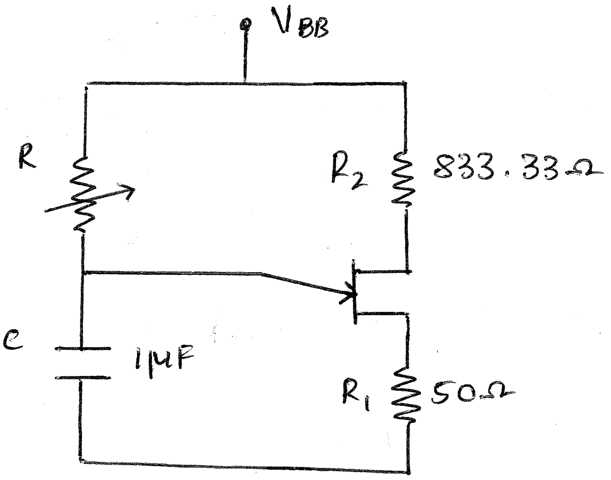
$\boxed{R_2 = 833.33\,\Omega}$

* The given pulse width $\tau_2 = 50\mu sec$

WKT $\tau_2 = R_1 C$

$R_1 = \frac{\tau_2}{C_1} = \frac{50\mu sec}{1\mu F}$

$\boxed{R_1 = 50\,\Omega}$



3) An UJT used in a relaxation oscillator circuit is having η=0.7, V_V=1V and the supply voltage to the circuit is 15V. Design the suitable values of R and C given that the frequency of oscillation is 1KHz. Peak current is 1mA and valley current is 8mA.

Sol: Given :- $V_{BB} = 15V$, $\eta = 0.7V$, $V_V = 1V$, $f = 1KHz$,

$I_P = 1mA$, $I_V = 8mA$

Assume $V_D = 0.8V$

Soln :- Peak Voltage

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

$$= 0.7 \times 15V + 0.8V$$

$$\boxed{V_p = 11.3V}$$

* The period of oscillation

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

$$\frac{1}{1KH_z} = RC \ln\left(\frac{1}{1-0.7}\right)$$

$$RC = 8.3058 \times 10^{-4}$$

Assume $C = 1\mu F$

$$R = \frac{8.3058 \times 10^{-4}}{1\mu F}$$

$$\boxed{R = 830.58\Omega}$$

* $$R_{(max)} = \frac{V_{BB} - V_p}{I_p} = \frac{15V - 11.3V}{1 \times 10^{-3}}$$

$$\boxed{R_{(max)} = 3700\Omega}$$

* $$R_{(min)} = \frac{V_{BB} - V_v}{I_v} = \frac{15V - 1V}{8 \times 10^{-3}}$$

$$\boxed{R_{(min)} = 1750\Omega}$$

❖ **An UJT triggering circuit is connected across a 20V zener. The valley and peak point voltages are 1V and 15V respectively. The intrinsic stand-off ratio is 0.75. It operates at a frequency of 1200Hz. Find the charging capacitor if R=5.6KΩ.**

Given :- $V_{BB} = 20V$, $V_V = 1V$, $V_P = 15V$, $\eta = 0.75$,
$f = 1200 Hz$, $R = 5.6 K\Omega$ $T = \frac{1}{f}$

Sol :-
The period of UJT relaxation oscillator is

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

$$\frac{1}{1200} = 5.6 \times 10^3 \cdot C \cdot \ln\left(\frac{1}{1-0.75}\right)$$

$$\boxed{C = 0.107\,\mu F}$$

Design a UJT relaxation oscillator for triggering a thyristor. The following data is given for UJT η=0.6, I_P=50μA, V_V=2V, VBB=10V and R_{BB}=6KΩ. The leakage current is 4mA. The triggering frequency is 2KHz and Vgt=0.3V. Also calculate minimum and maximum triggering frequency.

Soln :- Assuming $C = 0.01\,\mu F$ & $V_D = 0.8V$

$$T = \frac{1}{f} = \frac{1}{2 KHz} = 0.5 msec$$

WKT
$$T = RC \ln\left(\frac{1}{1-\eta}\right)$$

$$R = T / C \ln\left(\frac{1}{1-\eta}\right) = 0.5 msec / 0.01\mu F \ln\left(\frac{1}{1-0.6}\right)$$

$$\boxed{R = 54.56\,K\Omega}$$

* $R_2 = \dfrac{10^4}{\eta V_{BB}} = \dfrac{10^4}{0.6 \times 10V}$

$$\boxed{R_2 = 1.66\,K\Omega}$$

* $R_1 = \dfrac{V_{gt}}{I_{leakage}} = \dfrac{0.3V}{4 \times 10^{-3}}$

$$\boxed{R_1 = 75\,\Omega}$$

* Peak Voltage : $V_P = \eta V_{BB} + V_D$

$V_P = 0.6 \times 10\,V + 0.8V$

$$\boxed{V_P = 6.8V}$$

* $R_{(max)} = \dfrac{V_{BB} - V_P}{I_P} = \dfrac{10V - 6.8V}{50\mu A}$

$$\boxed{R_{(max)} = 64\,K\Omega}$$

* $R_{(min)} = \dfrac{V_{BB} - V_V}{I_V} = \dfrac{10V - 2V}{5mA}$

$$\boxed{R_{(min)} = 1.6\,K\Omega}$$

* $T_{max} = R_{max}\, C \ln\left(\dfrac{1}{1-\eta}\right) = 64\,K\Omega \times 0.01\,\mu F \ln\left(\dfrac{1}{1-0.6}\right)$

$T_{max} = 5.86 \times 10^{-4}$ sec

$$f_{max} = \frac{1}{T_{max}} = \frac{1}{5.86 \times 10^{-4} sec}$$

$$\boxed{f_{max} = 1.705 KHz}$$

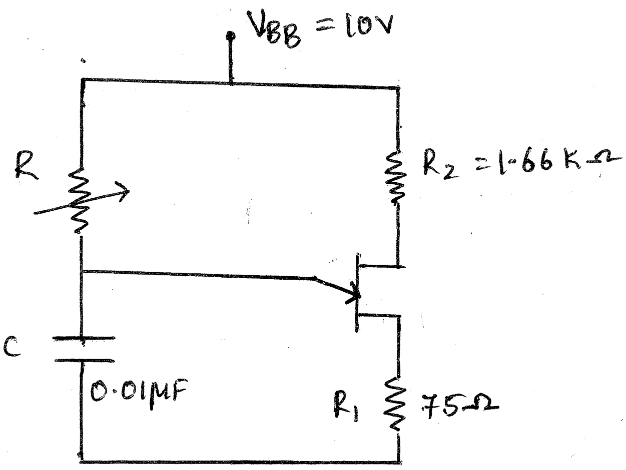
* $T_{min} = R_{min} C \ln\left(\frac{1}{1-\eta}\right)$

$$= 1.6K\Omega \times 0.01\mu F \ln\left(\frac{1}{1-0.6}\right)$$

$$T_{min} = 1.466 \times 10^{-5} \ sec$$

$$f_{min} = \frac{1}{T_{min}} = \frac{1}{1.466 \times 10^{-5}}$$

$$\boxed{f_{min} = 68.21 KHz}$$



❖ **Design UJT relaxation oscillator for triggering of thyristor. The UJT has the following parameters =0.7, I_p=50μA, V_V=2V, I_V=6mA, V_{BB}=20V. R_{BB}=7KΩ, I_{EO}=2mA. Also determine the limits for the output frequency of the oscillator. Assume $V_{g(min)}$=0.2V**

June-11,6M

Given:- $\eta = 0.7$, $I_P = 50\mu A$, $V_V = 2V$, $I_V = 6mA$, $V_{BB} = 20V$, $R_{BB} = 7K\Omega$, $I_{EO} = 2mA$ $V_{g(min)} = 0.2V$.

Soln:- Assume $\boxed{C = 0.1\mu F}$ & $V_D = 0.7V$

* WKT $V_P = \eta V_{BB} + V_D$

$$= 0.7 \times 20V + 0.7V$$

$$\boxed{V_P = 14.7V}$$

* $R_{(max)} = \dfrac{V_{BB} - V_P}{I_P} = \dfrac{20V - 14.7V}{50\mu A}$

$\boxed{R_{max} = 106 K\Omega}$ ⟵ (1M)

* $R_{(min)} = \dfrac{V_{BB} - V_V}{I_V} = \dfrac{20V - 2V}{6 \times 10^{-3}}$

$\boxed{R_{min} = 3K\Omega}$ ⟵ (1M)

* $R_2 = \dfrac{10^4}{\eta V_{BB}} = \dfrac{10^4}{0.7 \times 20V}$

$\boxed{R_2 = 714.28\Omega}$ ⟵ (1M)

* $R_1 = \dfrac{V_{gt}}{I_{leakage}} = \dfrac{V_{g(min)}}{I_{EO}} = \dfrac{0.2V}{2mA}$

$\boxed{R_1 = 100 K\Omega}$ ⟵ (1M)

* $T_{max} = R_{max} \cdot C \cdot \log_e \left(\frac{1}{1-\eta} \right)$

$= 106 K\Omega \times 0.1 \mu F \log_e \left(\frac{1}{1-0.7} \right)$

$\boxed{T_{max} = 12.76 \text{ msec}}$

* $T_{min} = R_{min} \times C \log_e \left(\frac{1}{1-\eta} \right)$

$= 3 K\Omega \times 0.1 \mu F \log_e \left(\frac{1}{1-0.7} \right)$

$\boxed{T_{min} = 0.36 \text{ msec}}$ (1M)

* $f_{max} = \frac{1}{T_{min}} = \frac{1}{0.36 \text{msec}}$

$\boxed{f_{max} = 2.77 \text{ KHz}}$

* $f_{min} = \frac{1}{T_{max}} = \frac{1}{12.76 \text{msec}}$

$\boxed{f_{min} = 78.35 \text{ Hz}}$ (1M)

❖ **dv/dt and di/dt protection :-**

❖ **dv/dt protection :-**

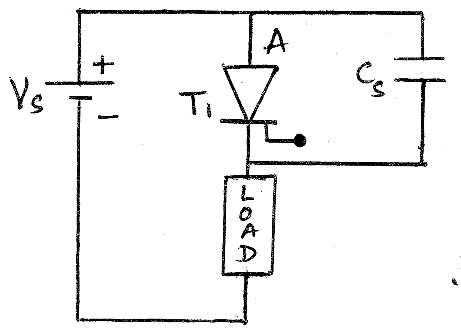
❖ **Discuss the need of protection against di/dt and dv/dt. Explain how it is achieved with suitable circuit diagrams.**

June-11,8M (E&E)

❖ **What is the need of di/dt protection and dv/dt protection? Explain how protection is provided.** **June-10,4M**

❖ **What is the need for protection of thyristors? Explain how thyristors are protected against high di/dt and high dv/dt**

June-08,7M Jan-07,7M



When forward vtg is applied accross anode and cathode of an SCR, Junction J_1 & J_3 are forward biased but Junction J_2 is reverse biased and acts as capacitor. Then the charging current is given by.

$$i = \frac{dq}{dt}$$

Where q is the charge & is given by

$$q = C_j V_s,$$

$$i = \frac{d}{dt}(C_j V_s)$$

$$i = C_j \frac{dV_s}{dt} + V_s \frac{dC_j}{dt}$$

($\because$ Cj is almost constant)

$$\boxed{i = C_j \frac{dV_s}{dt}}$$

* If the rate of rise of forward Vtg increases, the charging current 'i' also increases, this current turns ON the SCR even when the gate current is Zero. This turn ON is called $\frac{dv}{dt}$ turn ON & it leads to false operation of the thyristor. Hence it is necessary to protect SCR from the $\frac{dv}{dt}$ turn ON

❖ di/dt protection :-

WKT, In thyristor at the time of turn-ON, anode current increases rapidly. This rapid variation of anode current doesnot spread accross the junction area of the thyristor. This creates the local hot spots in the junction & increases the junction temperature.

* If the junction temperature exceeds permissible value, then the thyristor is damaged.

The rapid variation of the thyristor current are also called $\frac{di}{dt}$

* The thyristor can be protected from excessive $\frac{di}{dt}$ by using an series inductor Ls as shown in fig①.

* $\frac{di}{dt}$ can be calculated by using the formula

$$\frac{di}{dt} = \frac{V_s}{L_s}$$

$$L_s = \frac{V_s}{di/dt}$$

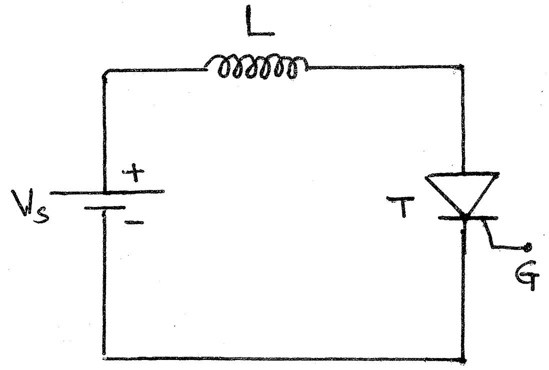


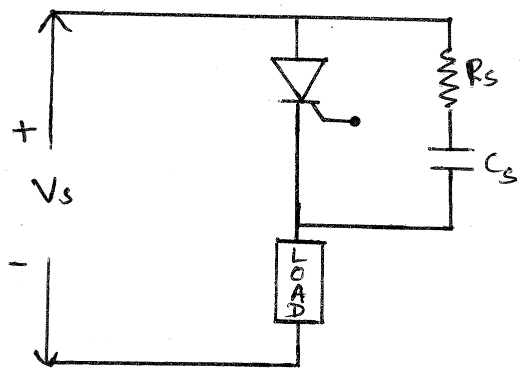
fig ①

❖ Snubber Circuit :-

Snubber ckt is used to protect SCR from $\frac{dv}{dt}$ turn-ON

A Snubber ckt consist of a series combination of resistance R_s & Capacitence C_s in parallel with the thyristor as shown in fig

* When forward vtg is applied across the thyristor capacitor C_s charges slowly & prevents sudden rise of vtg accross the thyristor.



* The purpose of connecting Resistar R_s in series with C_s because, when thyristor turns ON, Capacitor discharges through thyristor & sends a heavy current and may damage the thyristor.

In order to limit the discharge current a resistance R_s is connected in series with C_s.

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❖ Design of SNUBBER circuit :-

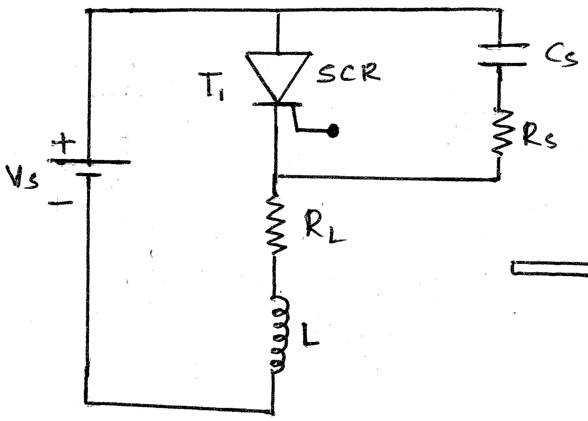


fig ⓐ : Snubber ckt

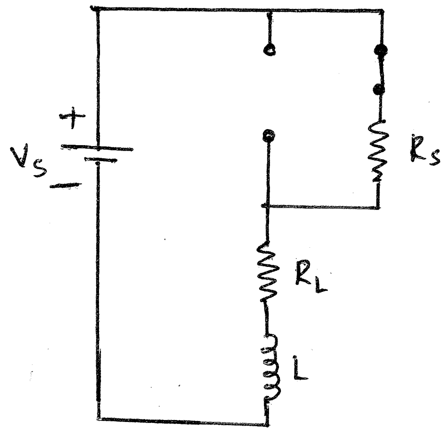


fig ⓑ : Equivalent ckt When SCR is OFF

* Snubber ckt is a series connection of Rs & Cs and is connected parallel to SCR. L is connected in series with load resistor R_L for $\frac{di}{dt}$ protection.

* The Capacitor 'C_s' behaves like a short circuit and SCR is in the forward blocking state offers a very high resistance as shown in fig ⓑ.

* The Voltage equation for fig ⓑ is

$$V_s = i(R_s + R_L) + L\frac{di}{dt} \longrightarrow (1)$$

Apply Laplace & inverse laplace transform & Simplifying, the Solution of eq (1) is.

$$\boxed{i = I(1 - e^{-t/\tau})}$$

Where $I = V_s / R_s + R_L$ & $\tau = L / R_s + R_L$

Differentiating eq ② wrt 't', we get

$$\frac{di}{dt} = I\left[0 - e^{-t/\tau} \cdot -\frac{1}{\tau}\right]$$

$$\because \frac{d}{dt} e^{at} = e^{at} \cdot \frac{1}{a}$$

$$\boxed{\frac{di}{dt} = I e^{-t/\tau} \cdot \frac{1}{\tau}} \longrightarrow ③$$

Substituting I & τ values in eq ③, we get

$$\frac{di}{dt} = \frac{V_s}{R_s + R_L} e^{-t/\tau} \cdot \frac{1}{\frac{L}{R_s+R_L}}$$

$$\frac{di}{dt} = \frac{V_s}{R_s + R_L} e^{-t/\tau} \cdot \frac{R_s+R_L}{L}$$

$$\frac{di}{dt} = \frac{V_s}{L} e^{-t/\tau}$$

The value of $\frac{di}{dt}$ is maximum when $t = 0$.

$$\left(\frac{di}{dt}\right)_{max} = \frac{V_s}{L} e^{-0/\tau}$$

$$\left(\frac{di}{dt}\right)_{max} = \frac{V_s}{L}$$

$$\therefore L = \frac{V_s}{\left(\frac{di}{dt}\right)_{max}}$$

* The Voltage across SCR is given by

$$V_{AK} = i R_s \longrightarrow ④$$

differentiate eqn ④ wrt t

$$\frac{dV_{AK}}{dt} = R_s \frac{di}{dt}$$

$$\left(\frac{dV_{AK}}{dt}\right)_{max} = R_s \cdot \left(\frac{di}{dt}\right)_{max}$$

Substituting $\left(\frac{di}{dt}\right)_{max}$ value in above equation

$$\left(\frac{dV_{AK}}{dt}\right)_{max} = R_s \cdot \frac{V_s}{L}$$

$$\therefore \boxed{R_s = \frac{L}{V_s}\left(\frac{dV_{AK}}{dt}\right)_{max}}$$

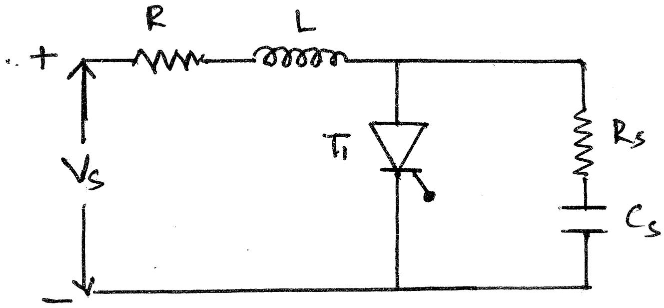
* Capacitor 'C_s' can be calculated by using the formulae

$$\boxed{C_s = \frac{1}{2L}\left[\frac{0.564\,V_m}{\frac{dv}{dt}}\right]^2}$$

Where V_m is the peak input Voltage

SNUBBER circuit Formulae :-

1) $\left(\frac{di}{dt}\right)_{max} = \frac{V_s}{L}$

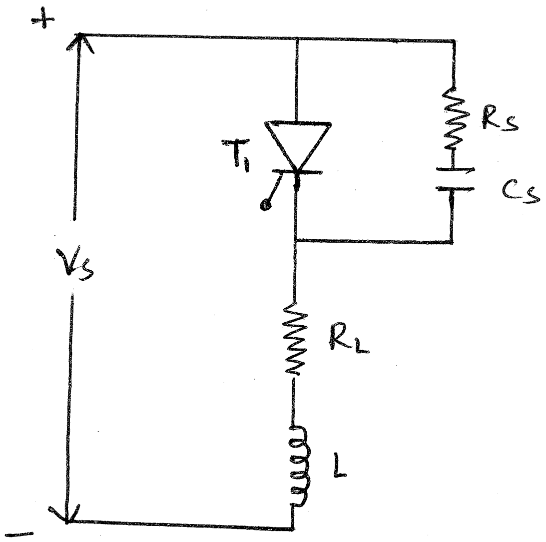


or

2) $L = \frac{V_s}{\left(\frac{di}{dt}\right)_{max}}$

3) $R_s = \frac{L}{V_s}\left(\frac{dV_{AK}}{dt}\right)_{max}$

4) $(R_s + R_L) = 2\sqrt{\frac{L}{C}}$



5) $C_s = \frac{1}{2L}\left[\frac{0.564\, V_m}{dv/dt}\right]^2$

6) $V_s = i\,(R_s + R_L) + L\frac{di}{dt}$

NOTE :-

* $(R_s + R_L) = 2\xi\sqrt{\frac{L}{C}}$

Where ξ is the damping factor & is 0.65 ($\xi = 0.65$)

* $R_s = 2\xi\sqrt{\frac{L}{C}}$

* $R_s = \frac{V_s}{i}$

PROBLEMS

❖ **A SCR has a di/dt = 120 A/μs and a dv/dt of 300 V/μs. It operates on a 250V DC source with a load resistance of 10Ω . Find the suitable values for the components of the snubber circuit.**

Given :-

$\frac{di}{dt} = 120A/\mu s$, $\frac{dv}{dt} = 300V/\mu s$, $V_s = V_m = 250V$, $R_L = 10\Omega$

Soln :-

* $L = \frac{V_s}{\frac{di}{dt}} = \frac{250V}{120A/\mu s}$

$\boxed{L = 2.08\mu H}$

* $C = \frac{1}{2L}\left[\frac{0.564V_m}{dv/dt}\right]^2 = \frac{1}{2\times 2.08\mu H}\left[\frac{0.564\times 250}{300V/\mu s}\right]^2$

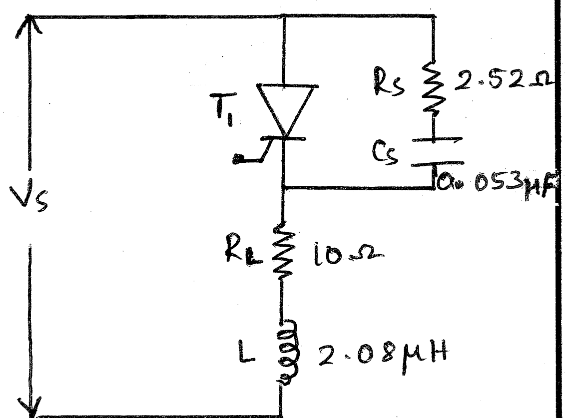
$\boxed{C = 0.053\mu F}$

* $(R_s + R_L) = 2\sqrt{\frac{L}{C}}$

$R_s + 10\Omega = 2\sqrt{\frac{2.08\mu H}{0.053\mu F}}$

$R_s + 10\Omega = 12.529\Omega$

$\boxed{R_s = 2.529\Omega}$



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❖ **Explain the need for dv/dt and di.dt protection for SCR. A SCR circuit has the following data: Supply voltage = 200V, dv/dt rating = 100 V/µs, di/dt rating = 50 A/µs. Calculate the snubber circuit elements using approximate expressions.**

Jan-06,8M

Given :- $V_s = V_m = 200V$, $\frac{dv}{dt} = 100V/\mu s$, $\frac{di}{dt} = 50A/\mu s$

assuming $\boxed{\xi = 0.65}$

Soln :-

* $L = \frac{V_s}{\frac{di}{dt}} = \frac{200V}{50\times10^6}$

$\boxed{L = 4\mu H}$

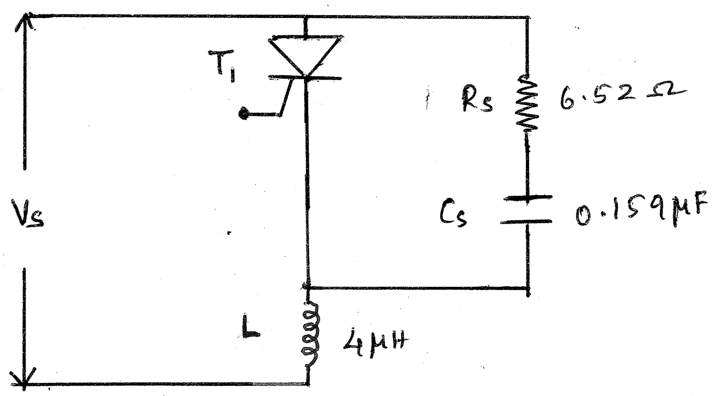
* $C = \frac{1}{2L}\left[\frac{0.564 V_m}{dv/dt}\right]^2 = \frac{1}{4\mu H}\left[\frac{0.564 \times 200}{100\times10^6}\right]^2$

$C = 0.159\mu F$

* $R_s = 2\xi\sqrt{\frac{L}{C}}$

$= 2\times0.65\sqrt{\frac{4\mu H}{0.159\mu F}}$

$\boxed{R_s = 6.52\,\Omega}$



❖ **Calculate the required parameters for snubber circuit to provide dv/dt protection to an SCR used in single phase bridge converter. The SCR has maximum dv/dt capacity of 60 V/µs. The input line to line voltage has a peak value of 425V and the source inductance is 0.2mH. Damping factor = 0.65.**

Jan-09,4M

Given : $\frac{dv}{dt} = 60V/\mu sec$, $L = 0.2mH$, $V_m = 425V$

Soln :

$$C = \frac{1}{2L}\left[\frac{0.564 V_m}{dv/dt}\right]^2$$

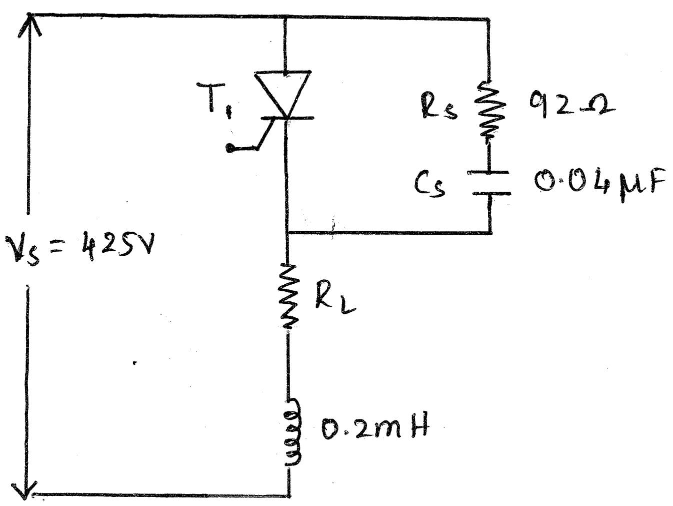
$$= \frac{1}{2 \times 0.2mH}\left[\frac{0.564 \times 425}{60 \times 10^6}\right]^2$$

$$\boxed{C = 0.04\mu F}$$

* The damping factor $\xi = 0.65$

$$R_s = 2\xi\sqrt{\frac{L}{C}} = 2 \times 0.65\sqrt{\frac{0.2mH}{0.04\mu F}}$$

$$\boxed{R_s = 92\Omega}$$



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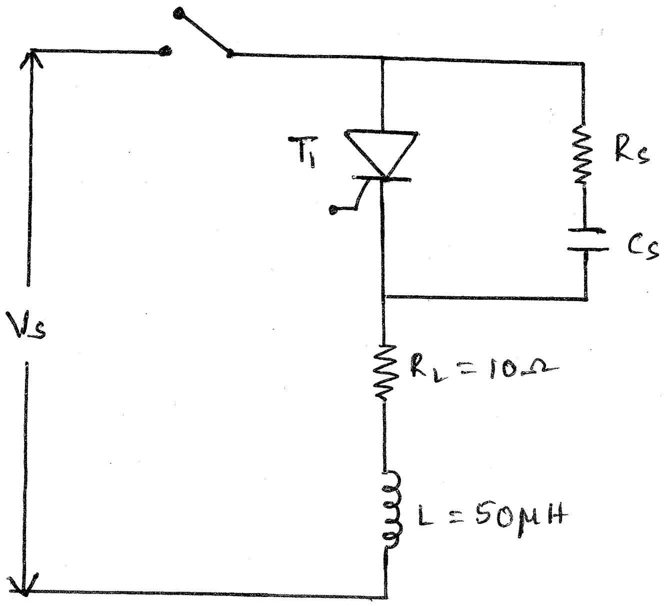
❖ **The input voltage to circuit shown below is Vs=200V with a load resistance of R=10Ω and a load inductance of L=50μH . If the damping ratio is 0.7 and discharging current of capacitor is 5A determine**

i) The values of Rs and Cs

ii) Maximum dv/dt

June-05,6M



Given :- $V_s = 200V$, $\xi = 0.7$, $R_L = 10\Omega$, $L = 50\mu H$, $i = 5A$,

$R_s = ?$, $C_s = ?$ $\left(\frac{dv}{dt}\right)_{max} = ?$ $V_s = V_m = 200V$

soln :-

WKT $\quad L = \dfrac{V_s}{(di/dt)_{max}}$

$$\left(\frac{di}{dt}\right)_{max} = \frac{V_s}{L} = \frac{200}{50\mu H}$$

$$\boxed{\left(\frac{di}{dt}\right)_{max} = 4A/\mu sec}$$

$$R_S = \frac{V_S}{i}$$

$$= \frac{200V}{5A}$$

$$R_S = 40\Omega$$

WKT

$$(R+R_S) = 2\xi\sqrt{\frac{L}{C_S}}$$

$$\sqrt{\frac{L}{C_S}} = \frac{R+R_S}{2\xi}$$

$$= \frac{10\Omega + 40\Omega}{2\times 0.7}$$

$$\sqrt{\frac{L}{C_S}} = 35.714$$

Squaring on both Sides

$$\frac{L}{C_S} = (35.714)^2$$

$$\frac{L}{C_S} = 1275.510$$

$$C_S = \frac{L}{1275.510} = \frac{50\,\mu H}{1275.510}$$

$$C_S = 0.0392\,\mu F$$

WKT

$$C_S = \frac{1}{2L}\left[\frac{0.564 V_m}{dv/dt}\right]^2$$

$$C_S 2L = \left[\frac{0.564 V_m}{dv/dt}\right]^2$$

$$0.0392\,\mu F \times 2 \times 50\,\mu H = \left[\frac{0.564 V_m}{dv/dt}\right]^2$$

$$3.92\times10^{-12} = \left[\frac{0.564 V_m}{dv/dt}\right]^2$$

$$\sqrt{3.92\times10^{-12}} = \frac{0.564 V_m}{dv/dt}$$

$$\frac{dv}{dt} = \frac{0.564 V_m}{\sqrt{3.92\times10^{-12}}}$$

$$\frac{dv}{dt} = \frac{0.564\times200}{1.9798\times10^{-6}}$$

$$\boxed{\frac{dv}{dt} = 56.972 V/\mu sec}$$

❖ **To provide reliable dv/dt protection to an SCR used in a single phase fully controlled bridge, compute the required parameters for a snubber circuit. The SCR has maximum dv/dt capability of 50V/sec. The input line to line voltage has a peak value 380V and the source inductance is 0.1mH.**

Given :- $L = 0.1 mH$, $V_m = 380V$, $(dV/dt)_{max} = 50V/\mu sec$

Soln :-

$$C_s = \frac{1}{2L}\left[\frac{0.564\, V_m}{dV/dt}\right]^2$$

$$= \frac{1}{2\times0.1\times10^{-3}}\left[\frac{0.564\times380}{50V/\mu sec}\right]^2$$

$$\boxed{C_s = 0.092\,\mu F}$$

* Assuming $\xi = 0.65$

WKT

$$R_s = 2\xi\sqrt{\frac{L}{C}} = 2 \times 0.65 \times \sqrt{\frac{0.1\times10^{-3}}{0.092\mu F}}$$

$$R_s = 42.86\,\Omega$$

WKT

$$R + R_s = 2\xi\sqrt{\frac{L}{C_s}}$$

$$\sqrt{\frac{L}{C_s}} = \frac{R+R_s}{2\xi}$$

$$\sqrt{\frac{L}{C_s}} = \frac{10\,\Omega + 40\,\Omega}{2\times0.7}$$

$$\sqrt{\frac{L}{C_s}} = 35.714$$

Squaring on both sides

$$\left(\sqrt{\frac{L}{C_s}}\right)^{\cancel{2}} = (35.714)^2$$

$$\frac{L}{C_s} = 1275.510$$

$$C_s = \frac{L}{1275.510} = \frac{50\mu H}{1275.510}$$

$$\boxed{C_s = 0.0392\mu F}$$

* WKT

$$C_s = \frac{1}{2L}\left[\frac{0.564\,V_m}{dV/dt}\right]^2$$

$$C_s(2L) = \left(\frac{0.564\,V_m}{dV/dt}\right)^2$$

$$0.0392\mu F \times 2 \times 50\mu H = \left(\frac{0.564\,V_m}{dV/dt}\right)^2$$

$$3.92 \times 10^{-12} = \left(\frac{0.564\,V_m}{dV/dt}\right)^2$$

$$\sqrt{3.92 \times 10^{-12}} = \frac{0.564\,V_m}{dV/dt}$$

$$\frac{dv}{dt} = \frac{0.564\,V_m}{\sqrt{3.92 \times 10^{-12}}}$$

$$\frac{dv}{dt} = \frac{0.564 \times 200}{1.9798 \times 10^{-6}}$$

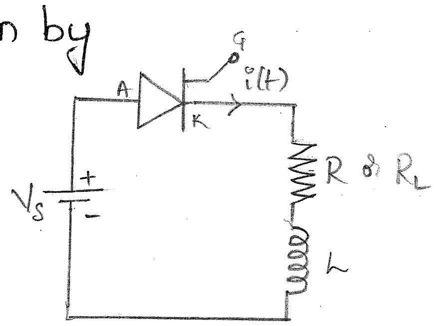
$$\boxed{\frac{dv}{dt} = 56.972\,V/\mu sec}$$

SCR CURRENT PROBLEMS

FORMULAE

1) Current through SCR is given by

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



2) To determine 't' in current equation.

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

$$\frac{i(t) \cdot R}{V_s} = 1 - e^{-tR/L}$$

$$e^{-tR/L} = 1 - \frac{i(t) \cdot R}{V_s}$$

Taking natural log on both sides

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

$$-\frac{tR}{L}\ln(e) = \ln\left[1 - \frac{i(t) \cdot R}{V_s}\right]$$

$$-\frac{tR}{L} = \ln\left[1 - \frac{i(t) \cdot R}{V_s}\right] \qquad \because \ln e = 1$$

$$\boxed{t = -\frac{L}{R}\ln\left[1 - \frac{i(t) \cdot R}{V_s}\right]}$$

3) If $I_L > i(t)$, The SCR will not trigger. It will be in OFF state.

If $I_L < i(t)$, the SCR will trigger.

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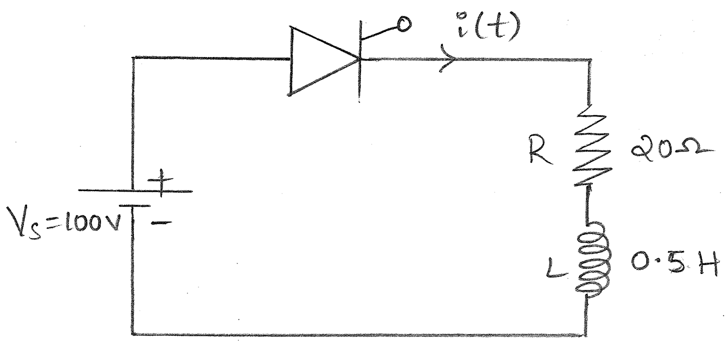
SCR CURRENT PROBLEMS

❖ **The SCR shown in fig1. Has the latching current of 20mA and is fired by the pulse of with 50sec. Determine whether the SCR triggers or not.**



fig(1)

Given: $I_L = 20mA$, $t = 50\mu s$, $R = 20\Omega$, $L = 0.5H$,
$V_S = 100V$.

Soln:

The Current $i(t)$ through the SCR at 50μ Sec

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

$$i(t) = \frac{100}{20}\left[1 - e^{-\frac{50\times10^{-6}\times 20}{0.5}}\right]$$

$$\boxed{i(t) = 10mA}$$

The Current through the SCR is 10mA

The condition to trigger SCR is

$$\boxed{i(t) \geq I_L}$$

The $i(t) < I_L$. Thus SCR will not be triggered.

❖ **A SCR is connected in series with a 0.5H inductor and 20Ω resistance. A 100V DC voltage is applied to this circuit. If the latching current of the SCR is 4mA. Find the minimum width of the gate trigger pulse required to properly turn-ON the SCR.**

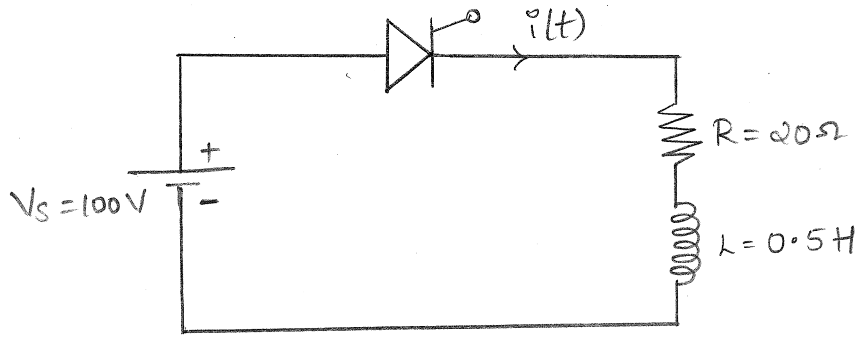


fig (1)

Given : $I_L = 4mA$, $L = 0.5H$, $R = 20\Omega$, $V_s = 100V$

The current through the RL ckt is given by:

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

In fig(1), when $i(t) = I_L$, SCR turns ON.

$$\Rightarrow \quad I_L = \frac{V_s}{R}\left[1 - e^{-tR/L}\right]$$

$$t = -\frac{L}{R}\ln\left[1 - \frac{I(L)\cdot R}{V_s}\right]$$

$$t = -\frac{0.5}{20}\ln\left[1 - \frac{4\times10^{-3}\times 20}{100}\right]$$

$$t = -0.025\ \ln\left[1 - 8\times10^{-4}\right]$$

$$t = -0.025\ \ln\left[0.9992\right]$$

$$t = -0.025 \times -8.0032\times10^{-4}$$

$$\boxed{t = 20\,\mu A}$$

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❖ **The latching current of an SCR used in a phase controlled circuit, comprising an inductive load of R=10Ω and L=0.1h is 15mA. The input voltage is 325sin314t. Obtain the minimum gate pulse width required for reliable triggering of the SCR if gated at π/3 angle in every positive half cycle.**

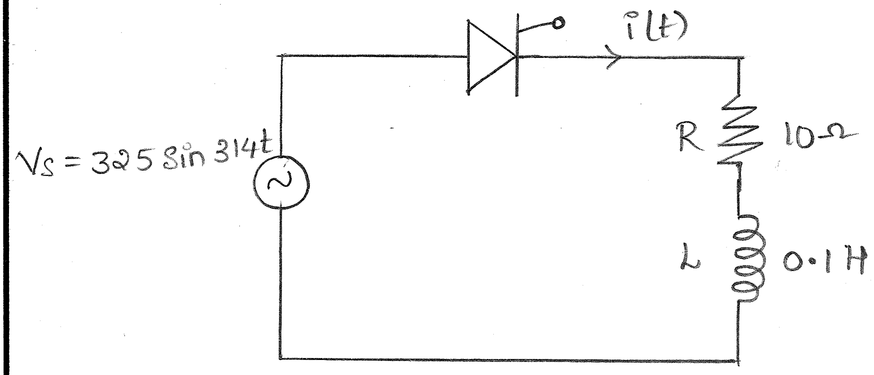


fig (1)

Given : $V_S = 325 \sin(314)t$, $R = 10\Omega$, $L = 0.1H$, $\alpha = \frac{\pi}{3}$

$I_L = 15mA$.

SCR is triggered at $\frac{\pi}{3}$. Hence applied voltage at this angle will be

$$V_S = V_m \sin\alpha$$

$$V_S = 325 \sin(314)t$$

$$V_S = 325 \times 0.866602$$

$$\boxed{V_S = 281.45V}$$

*> The current through Load is given by

$$i(t) = I_L = \frac{V_S}{R}\left[1 - e^{-tR/L}\right]$$

$$t = \frac{-L}{R} \ln\left[1 - \frac{I_L \cdot R}{V_S}\right]$$

$$t = \frac{-0.1}{10\Omega} \ln\left[1 - \frac{15\times10^{-3}\times 10}{281.45}\right]$$

$$t = -0.01 \ln\left[1 - 5.3295\times10^{-4}\right]$$

$$t = -0.01 \ln\left[0.99946\right]$$

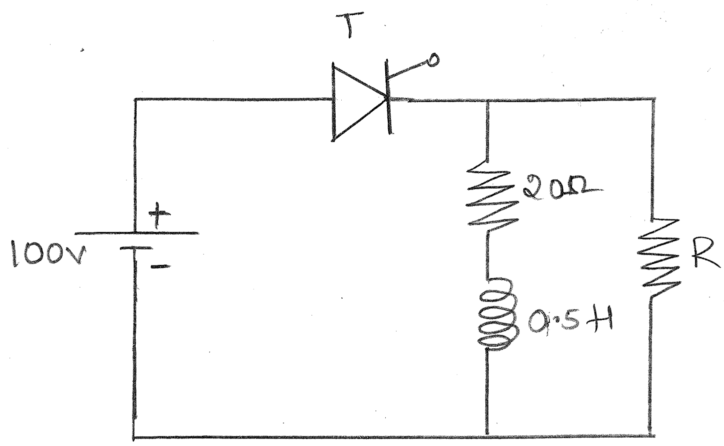
$$t = -0.01 \times -5.33096\times10^{-4}$$

$$\boxed{t = 5.33\mu Sec}$$

∴ The minimum gate pulse should be 5.33 μSec to reliably turn ON the SCR.

❖ **In the thyristor circuit shown in fig1 the thyristor has a latching current of 20mA and is fired by a gate pulse of width 50μs, show that without the resistance R, the thyristor will fail to remain ON. Also find the maximum value of 'R' to ensure firing.**

Jan-10,6M



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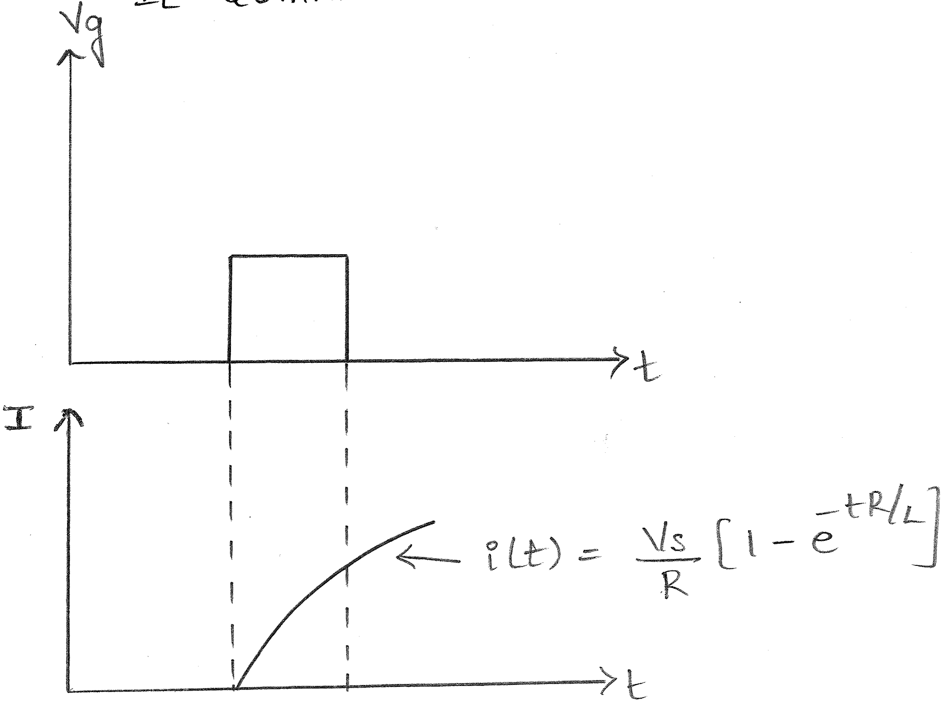
Given : $V_S = 100V$, $R = 20\Omega$, $L = 0.5H$, $t = 50\mu Sec$

$I_L = 20mA$.



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

at $t = 50\mu Sec$.

$$i(t) = \frac{100}{20}\left[1 - e^{-\frac{50\times10^{-6}\times20}{0.5}}\right]$$

$$i(t) = 5\left[1 - e^{-2\times10^{-3}}\right]$$

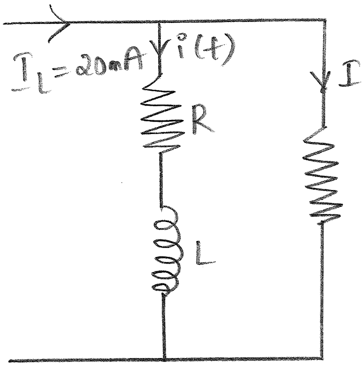
$$i(t) = 5\left[1 - 0.998\right]$$

$$i(t) = 5\left[1.99802\times10^{-3}\right]$$

$$i(t) = 9.99mA$$

$$\boxed{i(t) \simeq 10mA}$$

PTO →



$$I_L = i(t) + I$$

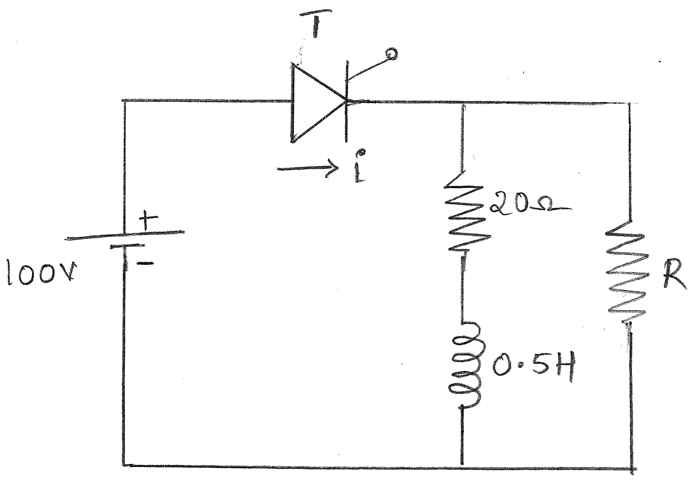
$$20mA = 10mA + I$$

$$\boxed{I = 10mA}$$

$$R = \frac{V_s}{I} = \frac{100V}{10mA}$$

$$\boxed{R = 10K\Omega}$$

❖ **In the thyristor circuit shown in fig1. Below, the SCR has a latching current of 50mA and is fired by a pulse of length 50μsec. Show that without resistance R', the thyristor will fail to remain ON, when the firing pulse ends and then find the maximum value of R to ensure firing.**



fig(1)

Given: $V_s = 100V$, $R = 20\Omega$, $L = 0.5H$, $R = ?$

$I_L = 50mA$, $t = 50\mu Sec$

Soln: WKT

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

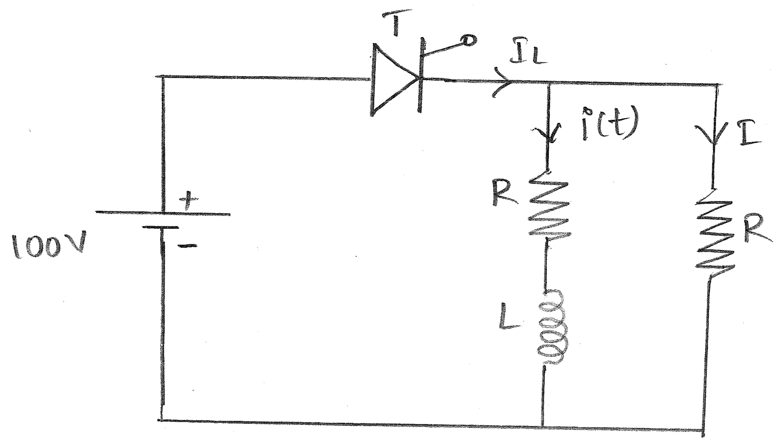
$$i(t) = \frac{100}{20}\left[1 - e^{-50\times10^{-6}\times\frac{20}{0.5}}\right]$$

$$= 5\left[1 - e^{-2\times10^{-3}}\right]$$

$$= 5\left[1 - 0.99800\right]$$

$$i(t) = 9.99mA$$

$$\boxed{i(t) = 10mA}$$



WKT

$$I_L = i(t) + I$$

$$50mA = 10mA + I$$

$$\boxed{I = 40mA}$$

$$R = \frac{V_s}{I}$$

$$R = \frac{100V}{40mA}$$

$$\boxed{R = 2500\Omega}$$

This is the maximum value of R' which ensures proper turn ON of the thyristor.

Proof:

Including of shunting resistance R'

$$I_L = I + i(t)$$

$$= \frac{V}{R} + i(t)$$

$$= \frac{100V}{2.5k\Omega} + 10mA$$

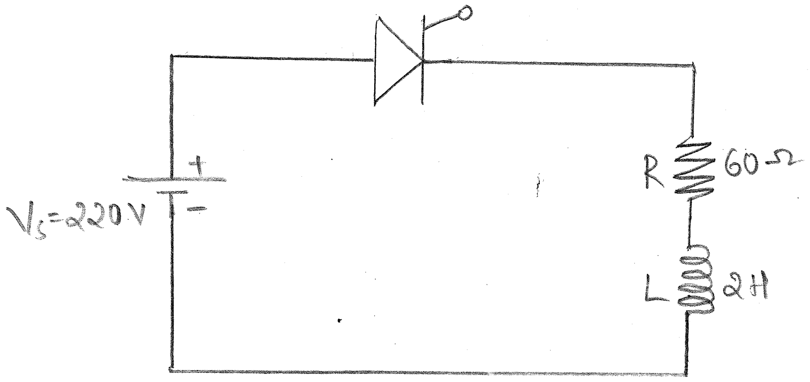
$$I_L = 40mA + 10mA$$

$$I_L = 50mA$$

$$50mA = 50mA$$

Thus by connecting R', thyristor will remain ON when the gate pulse ends.

❖ **The thyristor is gated with a pulse width of 40μsec. The latching current of thyristor is 36mA. For a load of 60Ω and 2H, will the thyristor get turned ON? If not, how it can be overcome for the given load? Find its value.** **June-07,4M**



Given : $V_S = 220V$, $R = 60\Omega$, $L = 2H$, $I_L = 36mA$

$t = 40\mu sec$, $\boxed{I_L = I_H = 36mA}$

Soln :

WKT

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

$$i(t) = \frac{220V}{60}\left[1 - e^{-40\times10^{-6}\times\frac{60}{2}}\right]$$

$$\boxed{i(t) = 4.397mA}$$

Since $i(t) < I_H$ i.e, $4.397mA < 36mA$.

Thus SCR will not turn ON.

SCR can be turned ON by changing t.

* The current through the load is given by

$$i(t) = I_L = \frac{V_S}{R}\left[1 - e^{-tR/L}\right]$$

$$\Rightarrow t = -\frac{L}{R}\ln\left[1 - \frac{I_L \cdot R}{V_S}\right]$$

$$t = -\frac{2}{60}\ln\left[1 - \frac{36\times10^{-3}\times60}{220}\right]$$

$$t = -0.0333\ln\left[1 - 9.8181\times10^{-3}\right]$$

$$t = -0.0333\ln\left[0.99018\right]$$

$$t = -0.0333 \times -0.98666\times10^{-3}$$

$$\boxed{t = 0.3285\ mSec}$$

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Thus if the triggering pulse is 0.328 mSec long, then SCR current will rise to 36mA and it will remain in ON condition.

The current through the load is given by

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

$$100mA = \frac{200}{20}\left[1 - e^{-t\,20/0.2}\right]$$

$$100mA = 10\left[1 - e^{-100t}\right]$$

$$10mA = 1 - e^{-100t}$$

$$e^{-100t} = 0.99$$

taking natural log on both sides we get

$$-100t = \ln(0.99)$$

$$t = \frac{-0.01005}{-100}$$

$$\boxed{t = 0.1\, mSec}$$

❖ **The latching current for SCR inserted in between a dc voltage source of 200V and load is 100mA. Calculate the minimum width gate pulse current required to turn-on this SCR in case the load consist of i) L=0.2H; ii) R=20Ω in series with L=0.2H**

June-10,6M

Given: $V_s = 200V$, $I_L = 100mA$

i) $R = 20\Omega$, $L = 0.2H$, $t = ?$

WKT

$$I_L = \frac{V_s}{R}\left[1 - e^{-tR/L}\right]$$

$$100mA = \frac{200V}{20\Omega}\left[1 - e^{-t\,20/0.2}\right]$$

$$100\,mA = 10\left[1 - e^{-100t}\right]$$

$$10mA = 1 - e^{-100t}$$

$$e^{-100t} = 1 - 10mA$$

$$e^{-100t} = 0.99$$

taking natural log on both side, we get

$$-100t = \ln(0.99)$$

$$\boxed{t = 0.1mSec}$$

ii) $R = 20\Omega$, $L = 2.0H$, $t = ?$

WKT

$$I_L = \frac{V_S}{R}\left[1 - e^{-tR/L}\right]$$

$$100mA = \frac{200V}{20\Omega}\left[1 - e^{-t20/2}\right]$$

$$100mA = 10\left[1 - e^{-10t}\right]$$

$$10mA = 1 - e^{-10t}$$

$$e^{-10t} = 1 - 10mA$$

$$\boxed{e^{-10t} = 0.99}$$

taking natural log on both side, we get

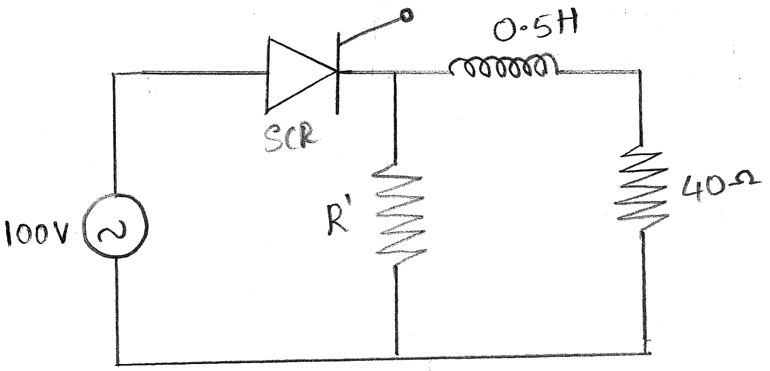
$$-10t = \ln(0.99)$$

$$t = \frac{-0.0100}{-10}$$

$$\boxed{t = 1m\,Sec.}$$

❖ **The SCR in the circuit of fig1 has a latching current of 50mA and if triggered by a gate pulse width of 50μsec. Show that without resistance R, the thyristor will fail to remain ON when the gating pulse ends. Also find the maximum value of R to ensure firing. The ON-state voltage drop of an SCR can be neglected.**

June-09,4M



Given : $V_s = 100V$, $L = 0.5H$, $R = 40\Omega$, $I_L = 50mA$
$t = 50\mu sec$, $R' = ?$

Soln : WKT

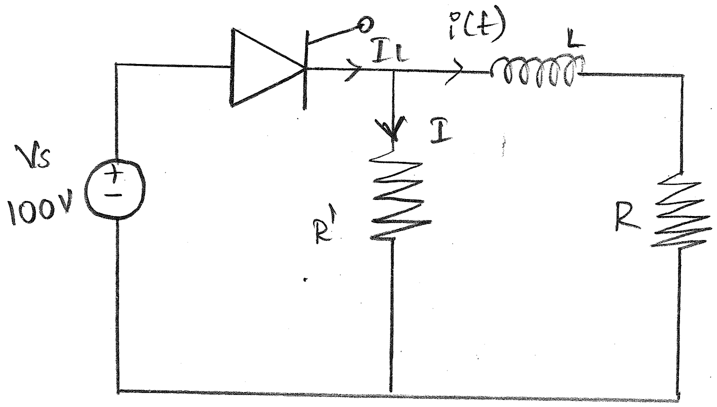
$$i(t) = \frac{V_s}{R}\left[1 - e^{-tR/L}\right]$$

$$i(t) = \frac{100V}{40\Omega}\left[1 - e^{-50\times10^{-6}\times 40/0.5}\right]$$

$$i(t) = 2.5\left[1 - e^{-4\times10^{-3}}\right]$$

$$i(t) = 2.5\left[1 - 0.9960\right]$$

$$\boxed{i(t) = 9.980\,mA}$$



from fig ②

$$I_L = I + i(t)$$

$$50mA = I + 9.98mA$$

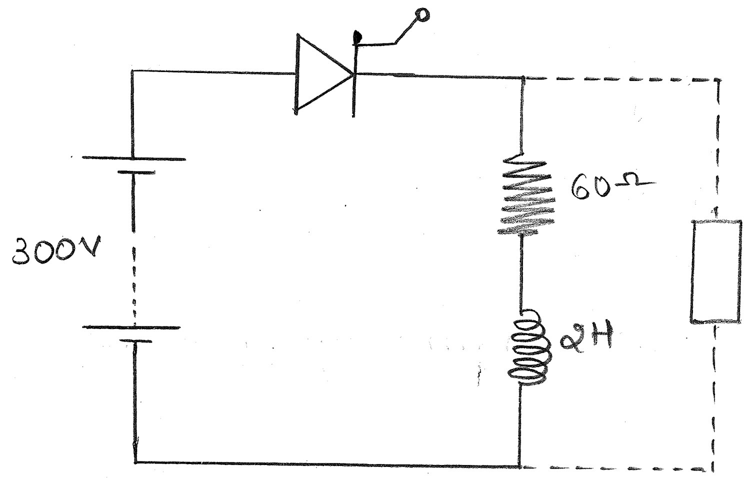
$$I = 50mA - 9.98mA$$

$$I = 40.02mA.$$

$$R = \frac{V_s}{I} = \frac{100V}{40.02mA}$$

$$\boxed{R = 2.498k\Omega}$$

* In the Circuit of fig ①, the thyristor is gated with a pulse width of 40μsec. The latching current of thyristor is 36mA. For a load of 60Ω & 2H, will the the thyristor get turned ON? check. If the answer is negative, how this difficulty can be overcome for the given load. Find the maximum value of the remedial parameter shown dotted



Given: $V_s = 300V$, $R = 60\Omega$, $L = 2H$, $I_L = 36mA$ $t = 40\mu s$.

Soln: WKT

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

$$= \frac{300V}{60\Omega}\left[1 - e^{-40\times10^{-6}\times60/2H}\right]$$

$$\boxed{i(t) = 5.996\,mA}$$

$i(t) < I_L$, thus thyristor will not get turned ON.

* The remedial parameter shown in fig, should be resistance, say R_1, because current can rise in resistance without any time delay.

WKT

$$I_L = I + i(t)$$

$$I = I_L - i(t)$$

$$= 36mA - 5.996mA$$

$$I = 30.004mA$$

$$R_1 = \frac{V_s}{I} = \frac{300V}{30.004mA}$$

$$\boxed{R_1 = 9.9986\,k\Omega}$$

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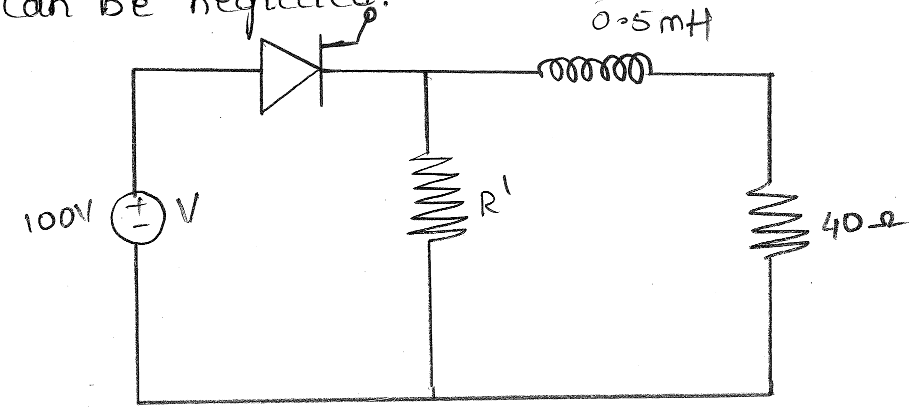
* The thyristor in the circuit of fig ① has a latching current of 50mA and is triggered by a get pulse of width 50μsec. Show that without resistance R' the thyristor will fail to remain ON when the gating pulse ends. Also find the maximum value of R' to ensure →

→ firing . The ON - state voltage drop of the thyristor can be neglected.



Given : $V = 100V$, $L = 0.5mH$, $R = 40\Omega$, $I_L = 50mA$

$t = 50\,\mu sec.$

Soln : WKT

$$i(t) = \frac{V}{R}\left[1 - e^{-tL/R}\right]$$

$$= \frac{100}{40}\left[1 - e^{-50\times10^{-6}\times 0.5mH/40}\right]$$

$$\boxed{i(t) = 10mA}$$

Since $i(t) < I_L$ ie. $\boxed{10mA < 50mA}$

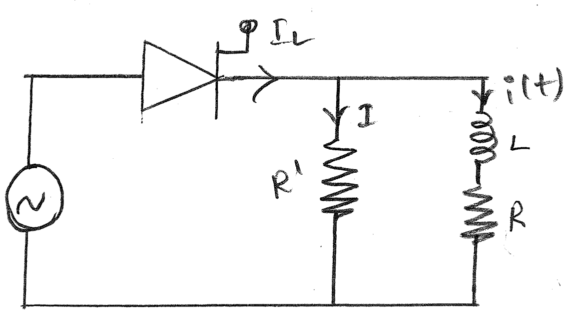
Since the thyristor current fails to reach the latching current value $I_L = 50mA$, when the gate pulse ends. Thus the thyristor fails to remains ON after the gate pulse ends

* By shunting R',

$$I_L = I + i(t)$$

$$\boxed{I = I_L - i(t)} \quad \text{——} (1)$$

$$I = 50mA - 10mA$$



ARUNKUMAR.G M.Tech, Lecturer in E&CE dept. S.T.J.I.T, Ranebennur.

$$\boxed{I = 40mA}$$

$$R' = \frac{V}{I} = \frac{100V}{40mA}$$

$$\boxed{R' = 2.5 K\Omega}$$

This is the maximum value of R' which ensures proper turn ON of the thyristor.

Proof:

Including of shunting resistance R'

$$I_L = I + i(t)$$

$$= \frac{V}{R} + i(t)$$

$$= \frac{100V}{2.5 K\Omega} + 10mA$$

$$I_L = 40mA + 10mA$$

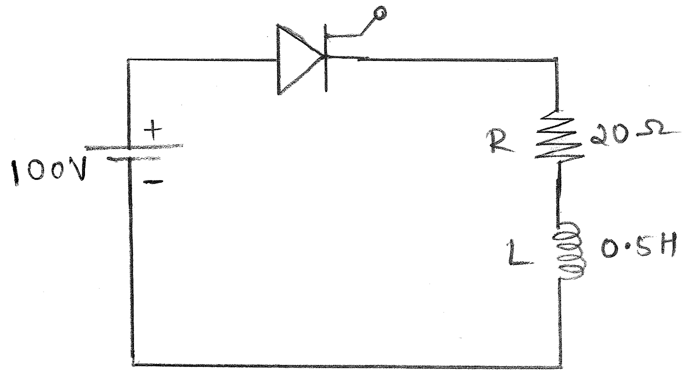
$$I_L = 50mA$$

$$\boxed{50mA = 50mA}$$

Thus by connecting R', thyristor will remain ON when the gate pulse ends.

❖ **The latching current of a thyristor shown in fig is 50mA. The duration of gate pulse is 50 μsec. Will the thyristor get fired?**

June-11, 4M



Given: $V_s = 100V$, $R = 20\Omega$, $L = 0{\cdot}5H$, $I_L = 50mA$, $t = 50\mu sec$

Soln: WKT

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

$$i(t) = \frac{100V}{20\Omega}\left[1 - e^{-\frac{(50\times10^{-6})\times 20\Omega}{0{\cdot}5}}\right]$$

$$i(t) = 9{\cdot}99mA$$

At $t = 50\mu sec$, $i(t) < I_L$ i.e. $9{\cdot}99mA < 50mA$

∴ SCR can't fire.

POWER ELECTRONICS

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Power semiconductor devices

Power electronic circuits or Converters

- **Explain in brief the different types of power electronic converter circuit and mention the type of input supply and its related output in each case. Also indicate two application in each case**

  Jan-10,10M

- **Mention and explain the different ypes of power electronic circuits and draw their input/output characteristics.** **June-10,8M**

- **List the major type of power electronic circuits and mention in each case the type of input supply given and the output obtained**

  June-08,8M

- **Mention and explain the different types of power electronic circuit and draw their input/output characteristics.Mention and explain the different types of power electronic converter system. Draw their output/input characteristics.** **June-07,8M**

- **Explain briefly the different types of thyristor power converters and mention two applications of each.** **Jan-09,9M**

- **Give a list of power electronic circuits for different input/output requirements** **Jan-07,5M**

- **Mention at least four power electronic circuits; indicate their inputs and outputs with one applications ofeach type.**

  June-06,6M

- **What is power converter? List the different types of power converters and mention their conversion functions.** **Jan-06,7M**
- **List the different types of power electronic circuits.** **June-05,4M**
- **List the major types of power electronic circuits and mention in each case, the type of input supply given and the output we get** **June-04,6M**
- **Explain briefly the different types of thyristor power converters and mention two applications of each** **Jan-09,9M**
- **List the different types of power electronic circuits and converter circuit and their pplications.** **June-08,6M**

Control characteristics of power semiconductor devices

- **Explain the control characteristics of SCR and GTO with circuit diagrams and waveforms of control signal and output voltage.** **Jan-10,8M**
- **With neat circuit and waveforms of control signal and output voltage, explain the control characteristics of IGBT and SCR.** **Jan-09,8M**
- **Explain control characteristics of GTO, MCT, SITH with the help of waveforms and circuit diagrams.** **June-08,M**
- **With circuit diagram and waveforms of control signal and output voltage, explain the control characteristics of SCR and MOSFET.** **June-04,8M**

Input/Output Characteristics of power semiconductor devices

❖ **Write the characteristics features of following power devices.**

i) SCR ii) TRIAC iii) LASCR iv) MCT v) SITH

June-10,10M

❖ **List out and explain the different types of power electronic converters. Show their output input characteristics.** **June-09,8M**

❖ **Plot the input and output characteristics of any four power semiconductor devices.** **June-08,8M**

❖ **Draw the input and output characteristics of four of the following devices:**

i)BJT ii) MOSFET iii) IGBT iv) UJT v) SCR

June-06,8M

❖ **Give the characteristics features of the following devices:**

i) MOSFET ii) TRIAC iii) GTO iv) RCT

Jan-08,8M

PERIPHERALS EFFECTS

❖ **What are the peripherals effects of power electronic circuit? What are the remedies for them?** **Jan-06,5M**

❖ **What are the advantages of static power converters? Mention the peripheral (terminal) effects of such staticpower converters.**

June-10,10M

❖ **Discuss the peripheral effects of power electronics equipments**

Jan-07,5M

- **What are the peripheral effects of power converter system.**

  June-07,4M

- **Explain the peripheral effects caused by power electronic converters.** Jan-08,6M

- **What are peripheral effects of a power converter system?**

  June-10,4M(IT) June-09,4M

- **What are the peripheral effects of power electronic circuits on load and source?** Jan-09,3M

- **What are the advantages of static power converters? Mention the peripheral effects of such static power converters.** June-08,6M

- **What are the peripheral effects of power electronic components and equipments? How to eliminate them?** June-08,6M

APPLICATIONS, ADVANTAGES & DISADVANTAGES

- **List out some applications of power controller.** June-10,6M

Chapter-2

POWER TRANSISTORS

MOSFET :-

- Discuss steady state characteristics power MOSFETs compare this with characteristics of power BJT. **June-10,10M**
- Sketch the structure of n-channel enhancement type MOSFET and explain its working principle. Also daw its transfer characteristics. **Jan-09,8M**
- With the help of switching waveforms explain the switching times of a power MOSFET. **June-08,7M**
- Draw the switching model and switching waveforms of a power MOSFET. Define the different switching times. **June-06,6M**
- With the help of switching waveforms explain the switching times of power MOSFET **Jan-06,7M**
- Sketch the output characteristics of enhancement type MOSFET. What are the differences in control of BJT and MOSFET? **June-04,6M**

BJT

- **Explain the switching characteristics of BJT, with the neat wavefirm.** **June-10,8M(IT)**
- **With necessay waveforms, explain the switching performance of power BJT.** **June-09,7M**
- **Name and explain various switching limits in case of power BJY's. With a circuit diagram, explain anisaturation control ofBJT. Mention the improvement and drawback of this arrangement**

  June-08,8M
- **Sketch and explain the switching characteristics of power BJT. The sketch should have the waveforms of i) V_{BE} ii) I_B iii) I_C**

  Jan-08,6M
- **With the necessary waveforms explain the switching characterstics of a power transistor.** **June-07,7M**
- **With model and waveforms, explain how the internal capacitances of the transistor influence the switching characteristics of the transistor.**

  Jan-07,10M
- **Explain the important characteristicss features of power transistors. With the aid of output and transfer characteristics discuss the different operating regions of a power BJT**

  Jan-05,10M
- **Explain the terms over drive factor (ODF) and forced beta (β_f) for a power transistor in switching applications** **June-08,4M**
- **What is secondary breakdown?** **Jan-10,2M**

TRANSISTOR SWITCHING PROBLEMS.

- **The beta(β) bipolar transistor shown in fig1 below varies from 12 to 75. The load resistance R_C=1.5Ω . The dc supply voltage is V_{CC}=40V and input voltage to the base circuit V_B=6V, if $V_{CE(sat)}$=1.6v, R_B=0.7Ω. Determine :**
  - **i) Overide factor (ODF)**
  - **ii) The forced β and**
  - **iii) The power loss in the transistor P_T.** **June-10,10M**

Circuit

- **For the switching circuit shown in fig1 calculate :**
- **I) the forced β of transistor**
- **The minimum ODF if the manufacturer specified β is 10**
- **The power loss P_T of the transistor.** **Jan-10,6M**

Circuit

- **In the circuit of fig1, the BJT has β in the ange 10 to 25. If V_{CC}=230V, R_C=12, V_{BB}=15v, $V_{CE(sat)}$=1.2v and $V_{BE(sat)}$=1.8v, calculate :**
  - **i) the value of R_B required to move the transistor into saturation with an ODF of 6Ω**
  - **ii) forced beta β_f**
  - **iii) total power dissipation** **June-09,6M**

Circuit

- **A transistor switch of fig1 has β in the range of 8 to 40. Calculate**
  i)The value of R_B that results in saturation with a overide factor of 5.
  ii) The forced β_f and
  i) The power loss in the BJT.

June-04,6M June-08,7M Jan-07,8M

Circuit

- **A power BJT is connected as a switch as in fig1 with the following data calculate :**
  i) The value of RB that will result in saturaton with an over drive factor of 20.
  ii) Power loss in the transistor **June-06,8M**

circuit

IGBT :-

- **Give the construction, static characteristics and applications of IGBT** **Jan-08,6M**

- **With the necessay sketches, explain the switching characteristics of an IGBT** **June-07,7M**

ANTISATURATION

- **What is the necessity of base drive control in high power transistor? Explain proportional base and anti-saturation control.**

  June-09,8M

- **Explain how antisaturation base control improves the switching performance of a BJT.** **June-08,6M**

- **What is the need of a base drive control in a power transistor? Explain proportional and antisaturation control.** **June-07,8M**

- **Explain the antisaturation control techniques used to improve the switching speed of a power BJT.** **Jan-07,6M**

- **Explain how antisaturation base control techniques used to improve the performance of BJT.** **Jan-06,6M**

- **Describe briefly the various base drive control methods used in junction transistors** **June-05,10M**

- **With a circuit diagram, explain antisaturation control of BJT. Mention the improvement and drawback of this arrangement.**

  June-04,6M

Antisaturation PROBLEMS-

- The collector clamping circuit of fig1 has V_{CC}=100v, R_C=1.5Ω, V_{d1}=2.1v, V_{d2}=0.9v, V_{BE}=0.7v, V_B=15vv and R_B=2.5Ω and β=16. Calculate

  i) the collector current without clamping

  i) the collector-emitter clamping voltage, V_{CE} and

  ii) the collector current with clamping. **Jan-08,6M**

Circuit

ISOLATION

- What is the need for isolation of gate drive circuits? Discuss the different methods of providing isolation of gate drive circuits from power circuit. **Jan-108M**

- With relevant diagrams, discuss the method for providing isolation of gate/base drive control in power circuits and what are its limitation? **June-09,7M**

- Explain different methods of providing gate and base drive isolation. **June-08,8M**

- What is the need of a base drive control in a power transistor? Explain proportional and antisaturation control. **June-07,8M**

- Discuss methods of providing isolation of gate/base circuits from power circuits. **Jan-07,6M**

❖ **Discuss methods for providing isolation of gate/base circuits from power circuits, with circuit diagrams.** **June-04,8M**

COMPARISIONS

❖ **Compare the characteristic of power MOSFET ang IGBT**

June-10,4M

❖ **Compare an SCR with BJT** **Jan-10,6M**

❖ **Compare BJT, MOSFET and SCR with reference to power switching applications.** **June-06,6M**

❖ **Give the comparison between SCR, MOSFET and IGBT**

June-07,6M

THYRISTORS

- **Define the following term with respect to SCR:**

  i) Latching current **iii) Turn-on time**

  ii) Holding current **iv) Turn-off time** June-10,8M

- **With neat sketch, explain the static V-I characteristics of an SCR? What are the significance of Latching current, Holding current and Break over voltage.** Jan-09,8M Jan-05,8M

- **Sketch the static V-I characteristics of an SCR and explain :**

  i) Latching current **iii) Break over voltage**

  ii) Holding current

  June-10,8M(IT) June-08,7M June-07M

- **Distinguish between :** Jan-08,6M

  i) Latching current and Holding current

  ii) Converter grade thyristor and Inverter grade thyristor.

  iii) Thyristor turn-off time and circuit turn-off time

- **Distinguish between :** Jan-06,4M

  i) Latching current and Holding current

  ii) Converter grade thyristor and Inverter grade thyristor.

TWO TRANSISTOR ANALOGY (SCR)

- **Explain the turn-on mechanism of a thyristor using two transistor analogy and derive an expression for the anode current in terms of transistor parameters.** **Jan-10,8M**
- **Usingthe Two transistor model, explain how a small gate current can turn on an SCR** **June-10,6M June-08,6M June-04,6M**
- **With help of two transistor model of an SCR, derive the expression for anode current. There from explain the switching action and significance of Gate control.** **June-09,8M**
- **Using two transistor analogy, derive an expression for anode current of SCR.** **Jan-09,8M**
- **Explain the principle of an SCR using two transistor model.** **Jan-07,6M June-08,6M**
- **Using two transistor model, explain the switching action of a thyistor and significance of gate control. Also derive an expression for the anode current.** **Jan-08,8M**
- **Using two transistor model, explain the the turn-ON mechanism of a SCR. Derive an expression for anode current in terms of transistor parameters.** **June-06,8M**
- **Explain the different types pf turn-ON methods(triggering mechanisms) used to switch-ON a thyristor device. Use the two transistor model of a thyristor as the basis to explain the switching behaviour of the thyristor.** **Jan-05,10M**

SCR Turn-ON and Turn-OFF Characteristics

- **Explain the turn-ON nd turn-OFF characteristics of the SCR**
  June-05,8M
- **Define turn-OFF time of thyristor and mention any two factors that affect it.** **Jan-06,3M**

Methods of SCR Turn-ON :

- **Explain the various methods of turn-ON of our SCR**
  June-10,6M(IT)
- **Mention the different turn-ON methods employed to switch-ON SCR. Explain with waveforms, the resistancetriggering circuit to Turn-ON the SCR in the phase control circuit.** **June-09,10M**
- **Explain the various methodsof Turn-ON of an SCR and mention the advantages of gate triggering.** **June-07,8M**

dv/dt and di/dt protection :

- **What is the need of di/dt protection and dv/dt protection? Explain how protection is provided.** **June-10,4M**
- **What is the need for protection of thyristors? Explain how thyristors are protected against high di/dt and high dv/dt**
  June-08,7M Jan-07,7M

dv/dt and di/dt PROBLEMS

SCR FIRING or TRIGGERING circuits

- With the help of neat circuit diagram and waveforms, explain RC firing circuit used with half controlled rectifier

June-10,6M

- Mention the different turn-ON methods employed to switch ON SCR. Explain with waveforms, the resistance triggering circuits to turn-ON SCR in the phase control circuit. **Jan-09,10M**
- With a circuit diagram and waveforms explain RC-triggering circuit. **June-06,4M**
- With circuit diagrams and waveforms, discuss the operation of RC firing circuit for a half wave SCR controlled rectifier.

June-04,8M

- With relevant circuit diagram and waveforms, explain the UJT relaxation oscillator. **Jan-10,6M**
- Brief the working principle of a UJT relaxation oscillator with the help of a circuit diagram and show period of oscillation $T= RC \log_e(1/1-n)$. **June-08,6M**

SCR CURRENT PROBLEMS

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

June-10,6M

- In the thyristor circuit shown in fig1 the thyristor has a latching current of 20mA and is fired by a gate pulse of width 50μs, show that without the resistance R, the thyristor will fail to remain ON. Also find the maximum value of 'R' to ensure firing. **Jan-10,6M**

Circuit

- The SCR in the circuit of fig1 has a latching current of 50mA and if triggered by a gate pulse width 50μsec. Show that without resistance R^{I} the thyristor will fail to remain ON when the gating pulse ends. Also find the maximum value of R^{I} to ensure firing. The ON-state voltage drop of an SCR can be neglected.

June-09,4M

Circuit

- Latching current of a SCR, with a dc voltage source of 200V, is 100mA. Compute the minimum width of gate pulse current required to turn-on this SCR, in case the load consists of i)L=0.2H ii)R=20Ω in series with L=0.2H and iii) R=20Ω in series with L=2.0H. **Jan-08,6M**
- The thyristor is gated with a pulse width of 40μsec. The latching current of thyristor is 36mA. For a load of 60Ω and 2H, will the thyristor get turned ON? If not, how it can be overcome for the given load? Find its value. **June-07,4M**

Chapter-6

AC VOLTAGE REGULATORS

ON-OFF Control

- Draw the circuit diagram of a single phase AC voltage controller and explain the principle of ON-OFF control, with the help of relevant waveforms. Derive the expression for rms output voltage interms of rms supply voltage and duty cycle of the operation of the controller.

  June-10,6M Jan-04,10M

- What is an ac voltage regulator(controller)? With the help of waveforms, explain ON-OFF control and phase control.

  June-09,6M

- With a circuit diagram and waveforms of gating pulses and output voltage, explain the operation of 1-phase ON-OFF type ac voltage controller. Derive an expression for Vo(rms).

  June-08,10M

- Derive an expression for the rms value of the output voltage f a bi-directional ac voltage controller, employing ON-OFF control.

  Jan-08,6M

- Draw the circuit of a single phase ac voltage controller and explain the principle of ON-OFF control, with the help of relevant waveforms. Derive the expression for the RMS output voltage in terms of the RMS supply voltage and the duty cycle of operation of the controller.

  Jan-05,8M

- Distinguish between ON-OFF control and phase control of ac voltage controller. Jan-10,4M

- **What are advantages and disadvantages of ON-OFF control and phase control of ac voltage controller?** **June-10,8M**
- **Compare and contrast ON-OFF control with phase control as applied to ac voltage controllers.**
  June-05,6M June-10,6M(IT)
- **Mention the advantages and disadvantages of ON-OFF control method of ac voltage control.** **Jan-06,3M**

ON-OFF Control PROBLEMS :

- **An AC voltage controller has a resistive load of 10Ω and rms input voltage 230V, 50Hz. The thyristor switch is ON for 25 cycles & OFF for 75 cycles.**
  Determine : i) rms output voltage ii) input power factor
  Jan-10,6M June-10,6M(IT) June-08,6M
- **An ON-OFF controller with an input of 230V, 50Hz is connected to a resistive load of 20Ω, the circuit is operating with the switch ON for 30 cycles and OFF for 30 cycles.**
  Determine : i) rms output current ii) input power factor
  Jan-09,10M June-04,4M

PHASE CONTROL (With R-Load)

- **With neat circuit diagram and waveforms, explain the working principle of 1-phase ac voltage ontroller with R-load (resistive load).** **June-10,8M(IT)**
- **Explain the operation of a single phase directional controller with resistive load. Obtain the equation forrms and output voltage. Show the waveforms.** **June-09,8M**

- **What is a free wheeling diode? What are the advantages of free wheeling diode in rectifier circuits feeding inductive load?**

  June-10,10M June-06,4M

- **What is the use of free wheeling diode in a converter circuit?**

  Jan-10,3M

- **What are the advantages of freewheeling diode? Explain the principle of operation of a single phase HWR feeding an RL-load. Draw the necessary sketches.** **June-07,8M**

PHASE CONTROL (With RL-Load)

- **With neat circuit diagram and waveforms derive an expression for the RMS valueof output voltage of single phase converter with RL load.(Assume discontinuous load current).**

  Jan-09,6M

- **With necessary waveforms explain the operation of 1-phase full wave controller with inductive load. Derive expressions for rms output voltage and rms output current.** **June-08,10M**
- **Explain the operation of a single-phase phase control type of voltage controller with RL load. Give an illustration to show that for firing angle 'α' less than load angle , output voltage of the ac voltage controller cannot be regulated.**

  Jan-08,8M

- **With necessary circuit and waveforms, explain the operation and fullwave ac voltage controller feeding an RL load.**

  June-07,8M

- **Explain the various methods of gating an SCR. State why short duration pulses are insufficient for an ac voltage controller feeding an RL load.** **June-07,6M**

- **With necessary waveforms, explain the operation of a 1-phase full wave controller with inductive load. Derive the expression for rms output voltage and rms output current.** **Jan-07,10M**
- **Why short duration gate pulses are not suitable for bi-directional ac voltage controller with inductive loads.** **Jan-07,5M**
- **Explain why short duration single gate pulses are not suitable for triggering thyristors in a full wave ac voltage contoller with inductive loads.** **Jan-06,6M**
- **What is the use of freewheeling diode in converter. Explain the principle operation of single phase FWR feeding with RL load. Draw the relevant sketch and waveforms.** **June-09,6M**
- **Explain the working of a single phase full converter feeding highly inductive load. Derivean expression for average output voltage.**

June-06,8M

PROBLEMS :

- **For the ac voltage controller shown in the following fig 1, the delay angles of thyristor are equal and $\alpha_1 = \alpha_2 = 2\pi/3$. Determine the:**

  i) RMS O/P voltage

  ii) Input power factor

  iii) Average and RMS current of the thyristors.

June-10,12M

CIRCUIT

❖ **The single phase full wave ACVC in fig1, operates on a single phase supply voltage of 230V rms at 50Hz. If the triac is triggered at a delay angle of α(Alpha)= 45° during both the half cycles of the input supply, calculate**

i) rms value of the putput voltage

ii) IO(rms) through the heater element

iii) Average value of the triac current

iv) rms value of triac current

June-09,6M

Circuit

❖ **A 1-phase full wave ac voltage controller in fig 1 has a resistive load of R=10Ω and the input voltage is Vs=120V(rms), 60Hz. The delay angles of thyristors T_1, T_2 are equal : $\alpha_1 = \alpha_2 = \pi/2$.**

Determine :

i) the rms output voltage 'V_o'

ii) the input power factor PF,

iii) the average current of thyristors I_A, and

iv) the rms current of thyristor 'I_R' **June-08,6M**

❖ **A single phase full wave voltage controller has an input voltage of 230v and a load having R=4Ω and L=22mH. The frequency is 50Hz. The firing angles are 600 for both thyristors.**

Find i) Conduction angle of thyristors and

ii) rms output voltgage.

Jan-08,6M

- **A 1-phase full wave ac voltage controller supplies a resistive load of R=10Ω from an input voltage Vs=200v, 60Hz. The delay angles of the thyristors are equal,**

  Determine :

  i) the rms output voltage

  ii) the input p.f. and

  iii) Average current of thyristors

  iv) RMS current of thyristors Jan-07,5M

- **A singlephase full wave ac voltage controller using two thyristors in antiparallel has a resistive load of R=1.5Ω and the input voltage is 120V(rms), 50Hz. If the desired output power is P_o=4.53kW, determine :**

  i) The delay angles of the thyristors T_1 and T_2

  ii) The rms output voltage and output currentthe input power factor, PF and

  iii) The rms current of each thyristor. Jan-06,11M

- **A single phase half wave ac voltage controller shown in the following figure feeds power to a resistive load of 6Ω from 230V, 50Hz source. The firing angle of SCR is $\alpha = \pi/2$.**

  Calculate :

  i) RMS value of output voltage

  ii) Input power factor

  iii) Average input current.

  Derive any formulae for atleast two sub division

  June-05,10M

- **The single phase full wave ac voltage controller operates on a single phase voltage of 230V RMS, at 50Hz. If the triac is triggered at a delay angle of 45°, driving both the half cycles of input supply. Calculate**

  i) RMS value of output voltage

  ii) RMS value of current through the heater

  iii) Average value of triac current

  iv) RMS value of triac current

  v) Input PF.

  Derive any expression used. **Jan-05,12M**

Chapter-7

DC CHOPPERS

STEP-UP CHOPPERS

- **What is chopper? Explain the principle of step-up chopper with relevant equations.** June-10,10M
- **Explain the principle of operation of a step up chopper with suitable circuit diagram and waveforms. Derive the expression for average output voltage to step up chopper.** Jan-10,10M
- **Obtain an expression for the output voltage for a step up chopper. Explain how duty cycle is controlled.** June-10,10M(IT)
- **Obtain expression for the output voltage for a step up chopper. Explain how duty cycle is controlled.** June-07,8M
- **Explain the principle of operation of a step up chopper.** Jan-07,6M

STEP-DOWN CHOPPERS

- **Describe the operation of step-down chopper with RL load. Derive an expression for maximum ripple of continous current.** June-08,10M
- **With the help of a circuit diagram and waveforms explain the working of a DC chopper. Derive an expression for**
  i) Output voltage ii) Output power June-06,12M
- **With the help of a neat circuit diagram explain the principle of a step down chopper.** Jan-06,6M

- **With the aid of a basic circuit and waveform explain the basic principles of operation of a step-down chopper with resistive load. Obtain the expressions for**
  iii) DC O/P voltage ii) O/P power iii) Chopper efficiency

  Jan-05,10M

- **With circuit diagram, equivalent circuit and waveforms of load voltage and load current, discuss the operation of a step doewn dc chopper with R-L load. Distinguish between continuous and discontinuous current modes of operation.** **June-04,10M**

- **Explain how the principle of a step-up chopper can be used to transfer energy from a low voltage dc source to a high voltage dc source.** **Jan-06,7M**

THYRISTOR IMPULSE COMMUTATOR

- **Explain the working principle of IMPULSE commutated thyristor chopper with necessary circuit diagrams and waveforms**

  June-10,10M(IT)

- **With neat circuit, explain the working principle of impulse commutated thristor chopper.** **Jan-09,8M**
- **With the help of necessary mode equivalent circuits and waveforms, explain the operation of an impulse commutated chopper.** **Jan-07,14M**

CLASSIFICATION OF CHOPPERS

- ❖ Give the classification of chopper. Explain briefly each one of them. **June-10,10M**
- ❖ Explain how the choppers are classified with reference to load voltage and load current. **Jan-106M June-06,8M**
- ❖ What is chopper? Classify and explain the different types of chopper with each circuit diagrams. **June-09,6M**
- ❖ Explain brefly how choppers are classified. **Jan-09,4M**
- ❖ Explain in detail how choppers are classified. **June-08,10M June-05,10M**
- ❖ Classify the choppers and explain the different types of chopper circuits. **Jan-08,10M**
- ❖ Explain how the DC choppers are classified, with reference to load voltage and load current, write the circuit of class-B,class-C and class-D choppers and briefly explain to show the type of load voltage and load current waveform they give. **Jan-05,10M**

CLASS-E CHOPPER

- ❖ Explain the working principle of a four quadrant chopper with the necessary circuit diagram. **June-10,10M(IT)**
- ❖ With the help of a ciruit and quadrantal diagrams, explain the working of a class-E chopper. Mention the devices that gives path for the current in each quadrant. **June-09,8M**
- ❖ With the help of circuit and quadrantal diagrams, explain the working of a class-E chopper. Mention the devices that provide path for the current in each quadrant. **Jan-08,10M**
- ❖ Draw the schematic circuit of a class-E four quadrant dc chopper and mention the devices that provide the path for current in the first and third quadrants of operation. **June-04,6M**

CHOPPERS PROBLEMS

- A dc chopper has a resistive load of 20Ω and input voltage 220V. When the chopper is ON its voltage drop is 1.5V and chopping frequency is 10KHz. If the duty cycle is 80% determinethe average output voltage and rms output voltage. **Jan-10,4M**

- For the step down chopper circuits, the duty cycle K=0.5, chopping frequency f=5KHz, Vs=220v, R=10Ω, L=15.5mH and F=20v. Determine
  - i) Minimum instantaneous load current
  - ii) Peak instantaneous load current
  - iii) Maximum peak to peak current in the load
  - iv) Average load current
  - v) RMS load current. **June-10,10M(IT)**

- In the chopper circuit of fig1, the averageoutput voltage is 110v. The voltage drop across the chopper switch when it is ON i.e. Vs=2V. If the load resistance R=10Ω, f=1.5KHz and duty cycle ∂=50%, calculate :
  - i) The dc input voltage to the chopper
  - ii) The rms output voltage
  - iii) The chopper efficiency
  - iv) Input resistance of chopper **June-09,6M**

Circuit

❖ **A DC chopper shown in figure1 has a resistive load of 10Ω and the input voltage Vs=200V. When the chopper switch is ON, its voltage drop is 2V and the chopping frequency is 1KHz. If the duty cycle is 50%, determine**

i) Average output voltage

ii) RMS output voltage

iii) The chopper frequency,

iv) The effective input resistance of the chopper. **Jan-09,8M**

Circuit

❖ **A chopper is feeding an R-L load as shown in the figure1, Vs=220v, R=5Ω, L=7.5mH, f=1KHz, ∂=0.5, and E=0volts. Calculate**

i) Minimum instantaneous load current I_{Min}

ii) Peak instantaneous load current I_{Max}

iii) Maximum peak to peak load ripple current

iv) Average value of load current

v) rms load current $I_{o(rms)}$ **June-08,10M**

Circuit

- **The chopper in fig1 has a load resistance R=0.25Ω, input voltage Vs=550V, and battery voltage E=0V. The average load current Ia=200A, and chopping frequency f=250Hz. Use the average output voltage to calculate the load inductance 'L' which would limit the maximum load ripple current to 10% of Ia.**

June-08,10M

Circuit

- **A chopper is feeding an RL load as shown in figure1. The chopper frequency is 1KHz and duty cycle K=0.5. Calculate**
  - **i) the minimum instantaneous load current**
  - **ii) the peak instantaneous load current**
  - **iii) the average value of load current**
  - **iv) the rms load current**
  - **v) the rms chopper input current**

Jan-08,10M

Circuit

- **In a step down chopper, the source voltage is 220V DC. The load circuit parameters are R=10Ω and L=5mH. If the chopper is operating at a frequency of 200Hz and the ON/OFF ratio of the chopper is 2:1, calculate**
  - **i) The average load current**
  - **ii) The maximum and minimum values of instantaneous load current under steady state conditions.**

Jan-06,7M

- **For a type A chopper circuit, Edc=220v, f=500Hz, duty cycle K=0.3 and load R=1Ω, L=3mH and E=23volts. Compare the following quantities**
  - **i) Check whether the conversion is continuous or not**
  - **ii) Average output current**
  - **iii) I_{Max} and I_{Min}** **June-05,6M**

- **For an ideal type class A chopper circuit Vs=220volts, R=5Ω, L=7.5mH, f=1KHz and E=0. Duty cycle K=0.5, calculate**
  - **i) Imin and Imax**
  - **ii) Average and rms value of load current**
  - **iii) Effective input resistance of chopper**
  - **iv) Rms chopper current**

June-05,10M

Circuit

- **Consider the switch, to be ideal in the circuit of fig1, determine :**
  - **ii) The duty cycle, k for whichthe output average dc voltage and rms voltage are equal**
  - **iii) The chopper efficiency** **June-04,4M**

Circuit

POWER ELECTRONICS

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Power semiconductor devices

Power electronic circuits or Converters

- **Explain in brief the different types of power electronic converter circuit and mention the type of input supply and its related output in each case. Also indicate two application in each case**

  Jan-10,10M

- **Mention and explain the different ypes of power electronic circuits and draw their input/output characteristics.** **June-10,8M**

- **List the major type of power electronic circuits and mention in each case the type of input supply given and the output obtained**

  June-08,8M

- **Mention and explain the different types of power electronic circuit and draw their input/output characteristics.Mention and explain the different types of power electronic converter system. Draw their output/input characteristics.** **June-07,8M**

- **Explain briefly the different types of thyristor power converters and mention two applications of each.** **Jan-09,9M**

- **Give a list of power electronic circuits for different input/output requirements** **Jan-07,5M**

- **Mention at least four power electronic circuits; indicate their inputs and outputs with one applications ofeach type.**

  June-06,6M

- What is power converter? List the different types of power converters and mention their conversion functions. **Jan-06,7M**
- List the different types of power electronic circuits. **June-05,4M**
- List the major types of power electronic circuits and mention in each case, the type of input supply given and the output we get **June-04,6M**
- Explain briefly the different types of thyristor power converters and mention two applications of each **Jan-09,9M**
- List the different types of power electronic circuits and converter circuit and their pplications. **June-08,6M**

Control characteristics of power semiconductor devices

- Explain the control characteristics of SCR and GTO with circuit diagrams and waveforms of control signal and output voltage. **Jan-10,8M**
- With neat circuit and waveforms of control signal and output voltage, explain the control characteristics of IGBT and SCR. **Jan-09,8M**
- Explain control characteristics of GTO, MCT, SITH with the help of waveforms and circuit diagrams. **June-08,M**
- With circuit diagram and waveforms of control signal and output voltage, explain the control characteristics of SCR and MOSFET. **June-04,8M**

Input/Output Characteristics of power semiconductor devices

- **Write the characteristics features of following power devices.**

  i) SCR ii) TRIAC iii) LASCR iv) MCT v) SITH

  June-10,10M

- **List out and explain the different types of power electronic converters. Show their output input characteristics.** **June-09,8M**

- **Plot the input and output characteristics of any four power semiconductor devices.** **June-08,8M**

- **Draw the input and output characteristics of four of the following devices:**

  i)BJT ii) MOSFET iii) IGBT iv) UJT v) SCR

  June-06,8M

- **Give the characteristics features of the following devices:**

  i) MOSFET ii) TRIAC iii) GTO iv) RCT

  Jan-08,8M

PERIPHERALS EFFECTS

- **What are the peripherals effects of power electronic circuit? What are the remedies for them?** **Jan-06,5M**

- **What are the advantages of static power converters? Mention the peripheral (terminal) effects of such staticpower converters.**

  June-10,10M

- **Discuss the peripheral effects of power electronics equipments**

  Jan-07,5M

- **What are the peripheral effects of power converter system.**

June-07,4M

- **Explain the peripheral effects caused by power electronic converters.** Jan-08,6M

- **What are peripheral effects of a power converter system?**

June-10,4M(IT) June-09,4M

- **What are the peripheral effects of power electronic circuits on load and source?** Jan-09,3M

- **What are the advantages of static power converters? Mention the peripheral effects of such static power converters.** June-08,6M

- **What are the peripheral effects of power electronic components and equipments? How to eliminate them?** June-08,6M

APPLICATIONS, ADVANTAGES & DISADVANTAGES

- **List out some applications of power controller.** June-10,6M

POWER TRANSISTORS

MOSFET :-

- Discuss steady state characteristics power MOSFETs compare this with characteristics of power BJT. June-10,10M
- Sketch the structure of n-channel enhancement type MOSFET and explain its working principle. Also daw its transfer characteristics. Jan-09,8M
- With the help of switching waveforms explain the switching times of a power MOSFET. June-08,7M
- Draw the switching model and switching waveforms of a power MOSFET. Define the different switching times. June-06,6M
- With the help of switching waveforms explain the switching times of power MOSFET Jan-06,7M
- Sketch the output characteristics of enhancement type MOSFET. What are the differences in control of BJT and MOSFET? June-04,6M

BJT

- **Explain the switching characteristics of BJT, with the neat wavefirm.** **June-10,8M(IT)**

- **With necessay waveforms, explain the switching performance of power BJT.** **June-09,7M**

- **Name and explain various switching limits in case of power BJY's. With a circuit diagram, explain anisaturation control ofBJT. Mention the improvement and drawback of this arrangement**

  June-08,8M

- **Sketch and explain the switching characteristics of power BJT. The sketch should have the waveforms of i) V_{BE} ii) I_B iii) I_C**

  Jan-08,6M

- **With the necessary waveforms explain the switching characterstics of a power transistor.** **June-07,7M**

- **With model and waveforms, explain how the internal capacitances of the transistor influence the switching characteristics of the transistor.**

  Jan-07,10M

- **Explain the important characteristicss features of power transistors. With the aid of output and transfer characteristics discuss the different operating regions of a power BJT**

  Jan-05,10M

- **Explain the terms over drive factor (ODF) and forced beta (β_f) for a power transistor in switching applications** **June-08,4M**

- **What is secondary breakdown?** **Jan-10,2M**

TRANSISTOR SWITCHING PROBLEMS.

- **The beta(β) bipolar transistor shown in fig1 below varies from 12 to 75. The load resistance R_C=1.5Ω . The dc supply voltage is V_{CC}=40V and input voltage to the base circuit V_B=6V, if $V_{CE(sat)=}$1.6v, R_B=0.7Ω. Determine :**
  - **i) Overide factor (ODF)**
  - **ii) The forced β and**
  - **iii) The power loss in the transistor P_T.** **June-10,10M**

Circuit

- **For the switching circuit shown in fig1 calculate :**
- **I) the forced β of transistor**
- **The minimum ODF if the manufacturer specified β is 10**
- **The power loss P_T of the transistor.** **Jan-10,6M**

Circuit

- **In the circuit of fig1, the BJT has β in the ange 10 to 25. If V_{CC}=230V, R_C=12, V_{BB}=15v, $_{VCE(sat)}$=1.2v and $V_{BE(sat)}$=1.8v, calculate :**
  - **i) the value of R_B required to move the transistor into saturation with an ODF of 6Ω**
  - **ii) forced beta β_f**
  - **iii) total power dissipation** **June-09,6M**

Circuit

- **A transistor switch of fig1 has β in the range of 8 to 40. Calculate**

  i)The value of R_B that results in saturation with a overide factor of 5.

  ii) The forced β_f and

  i) The power loss in the BJT.

June-04,6M June-08,7M Jan-07,8M

Circuit

- **A power BJT is connected as a switch as in fig1 with the following data calculate :**

  i) The value of RB that will result in saturaton with an over drive factor of 20.

  ii) Power loss in the transistor **June-06,8M**

circuit

IGBT :-

- **Give the construction, static characteristics and applications of IGBT** **Jan-08,6M**
- **With the necessay sketches, explain the switching characteristics of an IGBT** **June-07,7M**

ANTISATURATION

- **What is the necessity of base drive control in high power transistor? Explain proportional base and anti-saturation control.** **June-09,8M**
- **Explain how antisaturation base control improves the switching performance of a BJT.** **June-08,6M**
- **What is the need of a base drive control in a power transistor? Explain proportional and antisaturation control.** **June-07,8M**
- **Explain the antisaturation control techniques used to improve the switching speed of a power BJT.** **Jan-07,6M**
- **Explain how antisaturation base control techniques used to improve the performance of BJT.** **Jan-06,6M**
- **Describe briefly the various base drive control methods used in junction transistors** **June-05,10M**
- **With a circuit diagram, explain antisaturation control of BJT. Mention the improvement and drawback of this arrangement.** **June-04,6M**

Antisaturation PROBLEMS-

- The collector clamping circuit of fig1 has V_{CC}=100v, R_C=1.5Ω, V_{d1}=2.1v, V_{d2}=0.9v, V_{BE}=0.7v, V_B=15vv and R_B=2.5Ω and β=16. Calculate

  i) the collector current without clamping

  i) the collector-emitter clamping voltage, V_{CE} and

  ii) the collector current with clamping. **Jan-08,6M**

Circuit

ISOLATION

- What is the need for isolation of gate drive circuits? Discuss the different methods of providing isolation of gate drive circuits from power circuit. **Jan-108M**

- With relevant diagrams, discuss the method for providing isolation of gate/base drive control in power circuits and what are its limitation? **June-09,7M**

- Explain different methods of providing gate and base drive isolation. **June-08,8M**

- What is the need of a base drive control in a power transistor? Explain proportional and antisaturation control. **June-07,8M**

- Discuss methods of providing isolation of gate/base circuits from power circuits. **Jan-07,6M**

❖ **Discuss methods for providing isolation of gate/base circuits from power circuits, with circuit diagrams.** **June-04,8M**

COMPARISIONS

❖ **Compare the characteristic of power MOSFET ang IGBT**

June-10,4M

❖ **Compare an SCR with BJT** **Jan-10,6M**

❖ **Compare BJT, MOSFET and SCR with reference to power switching applications.** **June-06,6M**

❖ **Give the comparison between SCR, MOSFET and IGBT**

June-07,6M

THYRISTORS

- **Define the following term with respect to SCR:**

  i) Latching current   iii) Turn-on time

  ii) Holding current   iv) Turn-off time   **June-10,8M**

- **With neat sketch, explain the static V-I characteristics of an SCR? What are the significance of Latching current, Holding current and Break over voltage.**   **Jan-09,8M   Jan-05,8M**

- **Sketch the static V-I characteristics of an SCR and explain :**

  i) Latching current   iii) Break over voltage

  ii) Holding current

  June-10,8M(IT)   June-08,7M   June-07M

- **Distinguish between :**   **Jan-08,6M**

  i) Latching current and Holding current

  ii) Converter grade thyristor and Inverter grade thyristor.

  iii) Thyristor turn-off time and circuit turn-off time

- **Distinguish between :**   **Jan-06,4M**

  i) Latching current and Holding current

  ii) Converter grade thyristor and Inverter grade thyristor.

TWO TRANSISTOR ANALOGY (SCR)

- **Explain the turn-on mechanism of a thyristor using two transistor analogy and derive an expression for the anode current in terms of transistor parameters.** **Jan-10,8M**
- **Usingthe Two transistor model, explain how a small gate current can turn on an SCR**
  June-10,6M June-08,6M June-04,6M
- **With help of two transistor model of an SCR, derive the expression for anode current. There from explain the switching action and significance of Gate control.** **June-09,8M**
- **Using two transistor analogy, derive an expression for anode current of SCR.** **Jan-09,8M**
- **Explain the principle of an SCR using two transistor model.**
  Jan-07,6M June-08,6M
- **Using two transistor model, explain the switching action of a thyistor and significance of gate control. Also derive an expression for the anode current.** **Jan-08,8M**
- **Using two transistor model, explain the the turn-ON mechanism of a SCR. Derive an expression for anode current in terms of transistor parameters.** **June-06,8M**
- **Explain the different types pf turn-ON methods(triggering mechanisms) used to switch-ON a thyristor device. Use the two transistor model of a thyristor as the basis to explain the switching behaviour of the thyristor.** **Jan-05,10M**

SCR Turn-ON and Turn-OFF Characteristics

- **Explain the turn-ON nd turn-OFF characteristics of the SCR**
  June-05,8M
- **Define turn-OFF time of thyristor and mention any two factors that affect it.** **Jan-06,3M**

Methods of SCR Turn-ON :

- **Explain the various methods of turn-ON of our SCR**
  June-10,6M(IT)
- **Mention the different turn-ON methods employed to switch-ON SCR. Explain with waveforms, the resistancetriggering circuit to Turn-ON the SCR in the phase control circuit.** **June-09,10M**
- **Explain the various methodsof Turn-ON of an SCR and mention the advantages of gate triggering.** **June-07,8M**

dv/dt and di/dt protection :

- **What is the need of di/dt protection and dv/dt protection? Explain how protection is provided.** **June-10,4M**
- **What is the need for protection of thyristors? Explain how thyristors are protected against high di/dt and high dv/dt**
  June-08,7M Jan-07,7M

dv/dt and di/dt PROBLEMS

SCR FIRING or TRIGGERING circuits

- **With the help of neat circuit diagram and waveforms, explain RC firing circuit used with half controlled rectifier**
  June-10,6M
- **Mention the different turn-ON methods employed to switch ON SCR. Explain with waveforms, the resistance triggering circuits to turn-ON SCR in the phase control circuit.** **Jan-09,10M**
- **With a circuit diagram and waveforms explain RC-triggering circuit.** **June-06,4M**
- **With circuit diagrams and waveforms, discuss the operation of RC firing circuit for a half wave SCR controlled rectifier.**
  June-04,8M
- **With relevant circuit diagram and waveforms, explain the UJT relaxation oscillator.** **Jan-10,6M**
- **Brief the working principle of a UJT relaxation oscillator with the help of a circuit diagram and show period of oscillation T= RC $\log_e(1/1-n)$.** **June-08,6M**

SCR CURRENT PROBLEMS

- **The latching current for SCR inserted in between a dc voltage source of 200V and load is 100mA. Calculate the minimum width gate pulse current required to turn-on this SCR in case the load consist of i) L=0.2H; ii) R=20Ω in series with L=0.2H**
  June-10,6M

- In the thyristor circuit shown in fig1 the thyristor has a latching current of 20mA and is fired by a gate pulse of width 50μs, show that without the resistance R, the thyristor will fail to remain ON. Also find the maximum value of 'R' to ensure firing. **Jan-10,6M**

Circuit

- The SCR in the circuit of fig1 has a latching current of 50mA and if triggered by a gate pulse width 50μsec. Show that without resistance R^{I} the thyristor will fail to remain ON when the gating pulse ends. Also find the maximum value of R^{I} to ensure firing. The ON-state voltage drop of an SCR can be neglected.

June-09,4M

Circuit

- Latching current of a SCR, with a dc voltage source of 200V, is 100mA. Compute the minimum width of gate pulse current required to turn-on this SCR, in case the load consists of i)L=0.2H ii)R=20Ω in series with L=0.2H and iii) R=20Ω in series with L=2.0H. **Jan-08,6M**
- The thyristor is gated with a pulse width of 40μsec. The latching current of thyristor is 36mA. For a load of 60Ω and 2H, will the thyristor get turned ON? If not, how it can be overcome for the given load? Find its value. **June-07,4M**

Chapter-6

AC VOLTAGE REGULATORS

ON-OFF Control

- Draw the circuit diagram of a single phase AC voltage controller and explain the principle of ON-OFF control, with the help of relevant waveforms. Derive the expression for rms output voltage interms of rms supply voltage and duty cycle of the operation of the controller.

  June-10,6M Jan-04,10M

- What is an ac voltage regulator(controller)? With the help of waveforms, explain ON-OFF control and phase control.

  June-09,6M

- With a circuit diagram and waveforms of gating pulses and output voltage, explain the operation of 1-phase ON-OFF type ac voltage controller. Derive an expression for Vo(rms).

  June-08,10M

- Derive an expression for the rms value of the output voltage f a bi-directional ac voltage controller, employing ON-OFF control.

  Jan-08,6M

- Draw the circuit of a single phase ac voltage controller and explain the principle of ON-OFF control, with the help of relevant waveforms. Derive the expression for the RMS output voltage in terms of the RMS supply voltage and the duty cycle of operation of the controller.

  Jan-05,8M

- Distinguish between ON-OFF control and phase control of ac voltage controller. Jan-10,4M

- **What are advantages and disadvantages of ON-OFF control and phase control of ac voltage controller?** June-10,8M

- **Compare and contrast ON-OFF control with phase control as applied to ac voltage controllers.**

  June-05,6M June-10,6M(IT)

- **Mention the advantages and disadvantages of ON-OFF control method of ac voltage control.** Jan-06,3M

ON-OFF Control PROBLEMS :

- **An AC voltage controller has a resistive load of 10Ω and rms input voltage 230V, 50Hz. The thyristor switch is ON for 25 cycles & OFF for 75 cycles.**

  Determine : i) rms output voltage ii) input power factor

  Jan-10,6M June-10,6M(IT) June-08,6M

- **An ON-OFF controller with an input of 230V, 50Hz is connected to a resistive load of 20Ω, the circuit is operating with the switch ON for 30 cycles and OFF for 30 cycles.**

  Determine : i) rms output current ii) input power factor

  Jan-09,10M June-04,4M

PHASE CONTROL (With R-Load)

- **With neat circuit diagram and waveforms, explain the working principle of 1-phase ac voltage ontroller with R-load (resistive load).** June-10,8M(IT)

- **Explain the operation of a single phase directional controller with resistive load. Obtain the equation forrms and output voltage. Show the waveforms.** June-09,8M

- **What is a free wheeling diode? What are the advantages of free wheeling diode in rectifier circuits feeding inductive load?**

  June-10,10M June-06,4M

- **What is the use of free wheeling diode in a converter circuit?**

  Jan-10,3M

- **What are the advantages of freewheeling diode? Explain the principle of operation of a single phase HWR feeding an RL-load. Draw the necessary sketches.** **June-07,8M**

PHASE CONTROL (With RL-Load)

- **With neat circuit diagram and waveforms derive an expression for the RMS valueof output voltage of single phase converter with RL load.(Assume discontinuous load current).**

  Jan-09,6M

- **With necessary waveforms explain the operation of 1-phase full wave controller with inductive load. Derive expressions for rms output voltage and rms output current.** **June-08,10M**

- **Explain the operation of a single-phase phase control type of voltage controller with RL load. Give an illustration to show that for firing angle 'α' less than load angle , output voltage of the ac voltage controller cannot be regulated.**

  Jan-08,8M

- **With necessary circuit and waveforms, explain the operation and fullwave ac voltage controller feeding an RL load.**

  June-07,8M

- **Explain the various methods of gating an SCR. State why short duration pulses are insufficient for an ac voltage controller feeding an RL load.** **June-07,6M**

- **With necessary waveforms, explain the operation of a 1-phase full wave controller with inductive load. Derive the expression for rms output voltage and rms output current.** **Jan-07,10M**
- **Why short duration gate pulses are not suitable for bi-directional ac voltage controller with inductive loads.** **Jan-07,5M**
- **Explain why short duration single gate pulses are not suitable for triggering thyristors in a full wave ac voltage contoller with inductive loads.** **Jan-06,6M**
- **What is the use of freewheeling diode in converter. Explain the principle operation of single phase FWR feeding with RL load. Draw the relevant sketch and waveforms.** **June-09,6M**
- **Explain the working of a single phase full converter feeding highly inductive load. Derivean expression for average output voltage.** **June-06,8M**

PROBLEMS :

- **For the ac voltage controller shown in the following fig 1, the delay angles of thyristor are equal and $\alpha_1 = \alpha_2 = 2\pi/3$. Determine the:**

  i) RMS O/P voltage

  ii) Input power factor

  iii) Average and RMS current of the thyristors.

  June-10,12M

CIRCUIT

❖ **The single phase full wave ACVC in fig1, operates on a single phase supply voltage of 230V rms at 50Hz. If the triac is triggered at a delay angle of α(Alpha)= 45° during both the half cycles of the input supply, calculate**

i) rms value of the putput voltage

ii) IO(rms) through the heater element

iii) Average value of the triac current

iv) rms value of triac current

June-09,6M

Circuit

❖ **A 1-phase full wave ac voltage controller in fig 1 has a resistive load of R=10Ω and the input voltage is Vs=120V(rms), 60Hz. The delay angles of thyristors T_1, T_2 are equal : $\alpha_1 = \alpha_2 = \pi/2$.**

Determine :

i) the rms output voltage 'V_o'

ii) the input power factor PF,

iii) the average current of thyristors I_A, and

iv) the rms current of thyristor 'I_R' **June-08,6M**

❖ **A single phase full wave voltage controller has an input voltage of 230v and a load having R=4Ω and L=22mH. The frequency is 50Hz. The firing angles are 600 for both thyristors.**

Find i) Conduction angle of thyristors and

ii) rms output voltgage.

Jan-08,6M

- A 1-phase full wave ac voltage controller supplies a resistive load of R=10Ω from an input voltage Vs=200v, 60Hz. The delay angles of the thyristors are equal,

  Determine :

  i) the rms output voltage

  ii) the input p.f. and

  iii) Average current of thyristors

  iv) RMS current of thyristors **Jan-07,5M**

- A singlephase full wave ac voltage controller using two thyristors in antiparallel has a resistive load of R=1.5Ω and the input voltage is 120V(rms), 50Hz. If the desired output power is P_o=4.53kW, determine :

  i) The delay angles of the thyristors T_1 and T_2

  ii) The rms output voltage and output currentthe input power factor, PF and

  iii) The rms current of each thyristor. **Jan-06,11M**

- A single phase half wave ac voltage controller shown in the following figure feeds power to a resistive load of 6Ω from 230V, 50Hz source. The firing angle of SCR is $\alpha = \pi/2$.

  Calculate :

  i) RMS value of output voltage

  ii) Input power factor

  iii) Average input current.

  Derive any formulae for atleast two sub division

  June-05,10M

- **The single phase full wave ac voltage controller operates on a single phase voltage of 230V RMS, at 50Hz. If the triac is triggered at a delay angle of 45°, driving both the half cycles of input supply. Calculate**

  i) RMS value of output voltage

  ii) RMS value of current through the heater

  iii) Average value of triac current

  iv) RMS value of triac current

  v) Input PF.

  Derive any expression used. **Jan-05,12M**

Chapter-7

DC CHOPPERS

STEP-UP CHOPPERS

- What is chopper? Explain the principle of step-up chopper with relevant equations. **June-10,10M**
- Explain the principle of operation of a step up chopper with suitable circuit diagram and waveforms. Derive the expression for average output voltage to step up chopper. **Jan-10,10M**
- Obtain an expression for the output voltage for a step up chopper. Explain how duty cycle is controlled. **June-10,10M(IT)**
- Obtain expression for the output voltage for a step up chopper. Explain how duty cycle is controlled. **June-07,8M**
- Explain the principle of operation of a step up chopper. **Jan-07,6M**

STEP-DOWN CHOPPERS

- Describe the operation of step-down chopper with RL load. Derive an expression for maximum ripple of continous current. **June-08,10M**
- With the help of a circuit diagram and waveforms explain the working of a DC chopper. Derive an expression for
  i) Output voltage ii) Output power **June-06,12M**
- With the help of a neat circuit diagram explain the principle of a step down chopper. **Jan-06,6M**

- **With the aid of a basic circuit and waveform explain the basic principles of operation of a step-down chopper with resistive load. Obtain the expressions for**

  iii) DC O/P voltage ii) O/P power iii) Chopper efficiency

  Jan-05,10M

- **With circuit diagram, equivalent circuit and waveforms of load voltage and load current, discuss the operation of a step doewn dc chopper with R-L load. Distinguish between continuous and discontinuous current modes of operation.** **June-04,10M**

- **Explain how the principle of a step-up chopper can be used to transfer energy from a low voltage dc source to a high voltage dc source.** **Jan-06,7M**

THYRISTOR IMPULSE COMMUTATOR

- **Explain the working principle of IMPULSE commutated thyristor chopper with necessary circuit diagrams and waveforms**

  June-10,10M(IT)

- **With neat circuit, explain the working principle of impulse commutated thristor chopper.** **Jan-09,8M**

- **With the help of necessary mode equivalent circuits and waveforms, explain the operation of an impulse commutated chopper.** **Jan-07,14M**

CLASSIFICATION OF CHOPPERS

- **Give the classification of chopper. Explain briefly each one of them.** June-10,10M
- **Explain how the choppers are classified with reference to load voltage and load current.** Jan-106M June-06,8M
- **What is chopper? Classify and explain the different types of chopper with each circuit diagrams.** June-09,6M
- **Explain brefly how choppers are classified.** Jan-09,4M
- **Explain in detail how choppers are classified.** June-08,10M June-05,10M
- **Classify the choppers and explain the different types of chopper circuits.** Jan-08,10M
- **Explain how the DC choppers are classified, with reference to load voltage and load current, write the circuit of class-B,class-C and class-D choppers and briefly explain to show the type of load voltage and load current waveform they give.** Jan-05,10M

CLASS-E CHOPPER

- **Explain the working principle of a four quadrant chopper with the necessary circuit diagram.** June-10,10M(IT)
- **With the help of a ciruit and quadrantal diagrams, explain the working of a class-E chopper. Mention the devices that gives path for the current in each quadrant.** June-09,8M
- **With the help of circuit and quadrantal diagrams, explain the working of a class-E chopper. Mention the devices that provide path for the current in each quadrant.** Jan-08,10M
- **Draw the schematic circuit of a class-E four quadrant dc chopper and mention the devices that provide the path for current in the first and third quadrants of operation.** June-04,6M

CHOPPERS PROBLEMS

- A dc chopper has a resistive load of 20Ω and input voltage 220V. When the chopper is ON its voltage drop is 1.5V and chopping frequency is 10KHz. If the duty cycle is 80% determinethe average output voltage and rms output voltage. **Jan-10,4M**
- For the step down chopper circuits, the duty cycle K=0.5, chopping frequency f=5KHz, Vs=220v, R=10Ω, L=15.5mH and F=20v. Determine
  - i) Minimum instantaneous load current
  - ii) Peak instantaneous load current
  - iii) Maximum peak to peak current in the load
  - iv) Average load current
  - v) RMS load current. **June-10,10M(IT)**
- In the chopper circuit of fig1, the averageoutput voltage is 110v. The voltage drop across the chopper switch when it is ON i.e. Vs=2V. If the load resistance R=10Ω, f=1.5KHz and duty cycle ∂=50%, calculate :
  - i) The dc input voltage to the chopper
  - ii) The rms output voltage
  - iii) The chopper efficiency
  - iv) Input resistance of chopper **June-09,6M**

Circuit

- **A DC chopper shown in figure1 has a resistive load of 10Ω and the input voltage Vs=200V. When the chopper switch is ON, its voltage drop is 2V and the chopping frequency is 1KHz. If the duty cycle is 50%, determine**

  i) Average output voltage

  ii) RMS output voltage

  iii) The chopper frequency,

  iv) The effective input resistance of the chopper. **Jan-09,8M**

Circuit

- **A chopper is feeding an R-L load as shown in the figure1, Vs=220v, R=5Ω, L=7.5mH, f=1KHz, ∂=0.5, and E=0volts. Calculate**

  i) Minimum instantaneous load current I_{Min}

  ii) Peak instantaneous load current I_{Max}

  iii) Maximum peak to peak load ripple current

  iv) Average value of load current

  v) rms load current $I_{o(rms)}$ **June-08,10M**

Circuit

- The chopper in fig1 has a load resistance R=0.25Ω, input voltage Vs=550V, and battery voltage E=0V. The average load current Ia=200A, and chopping frequency f=250Hz. Use the average output voltage to calculate the load inductance 'L' which would limit the maximum load ripple current to 10% of Ia.

June-08,10M

Circuit

- A chopper is feeding an RL load as shown in figure1. The chopper frequency is 1KHz and duty cycle K=0.5. Calculate
  - i) the minimum instantaneous load current
  - ii) the peak instantaneous load current
  - iii) the average value of load current
  - iv) the rms load current
  - v) the rms chopper input current

Jan-08,10M

Circuit

- In a step down chopper, the source voltage is 220V DC. The load circuit parameters are R=10Ω and L=5mH. If the chopper is operating at a frequency of 200Hz and the ON/OFF ratio of the chopper is 2:1, calculate
  - i) The average load current
  - ii) The maximum and minimum values of instantaneous load current under steady state conditions.

Jan-06,7M

- **For a type A chopper circuit, Edc=220v, f=500Hz, duty cycle K=0.3 and load R=1Ω, L=3mH and E=23volts. Compare the following quantities**
  - **i) Check whether the conversion is continuous or not**
  - **ii) Average output current**
  - **iii) I_{Max} and I_{Min}** **June-05,6M**

- **For an ideal type class A chopper circuit Vs=220volts, R=5Ω, L=7.5mH, f=1KHz and E=0. Duty cycle K=0.5, calculate**
  - **i) Imin and Imax**
  - **ii) Average and rms value of load current**
  - **iii) Effective input resistance of chopper**
  - **iv) Rms chopper current**

June-05,10M

Circuit

- **Consider the switch, to be ideal in the circuit of fig1, determine :**
  - **ii) The duty cycle, k for whichthe output average dc voltage and rms voltage are equal**
  - **iii) The chopper efficiency** **June-04,4M**

Circuit