The Shirpur Education Society's
R. C. Patel College of Engineering and Polytechnic, Shirpur
Department of Electrical Engineering

NOTES

Programme Code: Electrical Engineering	**Year/Scheme:** EE3K	**Semester:** 3rd
Course Title: Fundamentals of Power Electronics	**Course Abbr.:** FPE	**Course Code:** 313335
	Subject Teacher :- Ms. H.A.Badgujar	

UNIT-02 – (18 MARKS)

PROTECTION AND FIRING CIRCUIT OF THYRISTOR

CO Coverage: - Test the switching performance of a thyristor.

Unit -02 Content (Syllabus)

2.1 Di/dt protection: need, snubber circuit.

2.2 Dv/dt protection: need, snubber circuit.

2.3 Overvoltage protection: need, internal & external overvoltage, voltage clamping device.

2.4 Overcurrent protection: need, electronic crowbar circuit.

2.5 Thermal Protection of SCR: Need, thermal resistance, and heat sink specification.

2.6 Firing circuit: Features and general layout of firing scheme.

2.7 SCR turn-on methods: forward voltage triggering, gate triggering, dv/dt triggering, temperature triggering, and light triggering.

2.8 SCR Firing circuit: resistance firing circuit (no derivation), RC firing circuit (no derivation), and pulse transformer based triggering.

2.9 SCR commutation techniques: load commutation (Class A), line commutation (Class F).

2.1 di/dt Protection :- Need, snubber Circuit

* Need of di/dt protection :-

→ $\frac{di}{dt}$ is rate of change of current in device is called as $\frac{di}{dt}$ protection.

→ 1) Preventing junction damage
→ 2) Avoiding local hotspots.
3) Improving Reliability
4) Protection During switching
5) Reduces stress on components.

* Snubber Circuit :-

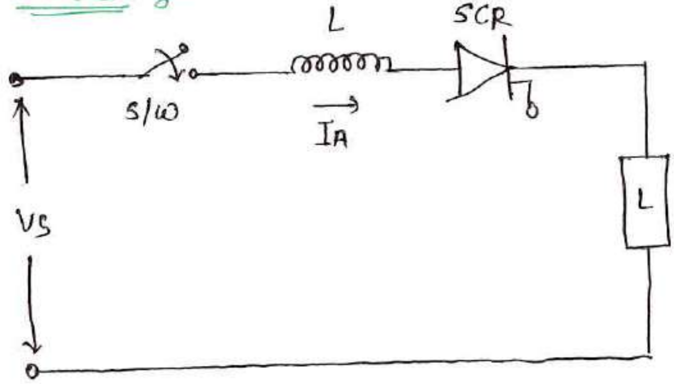


Fig. Snubber Circuit.

→ fig. shows snubber Circuit for di/dt protection.
→ when SCR is in forward biased, and it is ON by gate signal then, there will be flow of anode current.
→ The anode current requires some time to spread inside device.
→ If di/dt spread velocity of charge, it creates hotspot and that may damage SCR.
→ so, to maintain di/dt through SCR, we connect inductor in series with SCR.
→ The rate of change of anode current should not be allowed to exceed the di/dt rating specified by the manufacturer
→ To avoid SCR damage, decrease SCR current by using snubber circuit.
→ Voltage across inductor can be calculated by

$$V_S = L\frac{di}{dt} \quad \therefore \; L = \frac{V}{di/dt}$$

$$\Rightarrow L > \frac{V_S}{di/dt}.$$

→ In snubber Circuit, inductance does not allow the anode current to increase fast, thus achieving the di/dt protection.

2.2 dv/dt Protection :- Need, Snubber Circuit

The SCR should not be triggered only because the dv/dt (max rate of rise of anode voltage) increases. If the forward voltage across the device increases rapidly and exceeds the specified maximum value, the SCR may turn ON even without a gate signal.

* Need of dv/dt protection :→

1) Rapid voltage change across SCR terminals may cause unwanted current flow and turn the SCR ON unintentionally, even without a gate signal. dv/dt protection limits the rate of change of voltage and reduces this risk.
2) Fast voltage changes, switching operations, or noise can cause false triggering of the SCR. This may lead to improper operation or damage to the device. dv/dt protection ensures that the SCR turns ON only when a proper trigger signal is applied.
3) Using dv/dt protection improves the reliability and life of the SCR and the overall circuit.
4) ~~Red.~~ Uncontrolled switching & Rapid voltage changes can create electromagnetic interfeerence (EMI), affecting nearby electronic equipment. dv/dt controls voltage transision and helps reduce EMI.)
5) many industries and applications follow strict safety standards related to voltage transitions and switching protection. dv/dt protection helps the circuit meet these requirements and ensures safe operation.

Summary :-

1) Preventing unintended Turn-ON.
2) Avoiding false triggering.
3) Enhancing Circuit Reliability.
4) Reducing Electromagnetic Interference.
5) meeting safety standards.

* Snubber Circuit :→

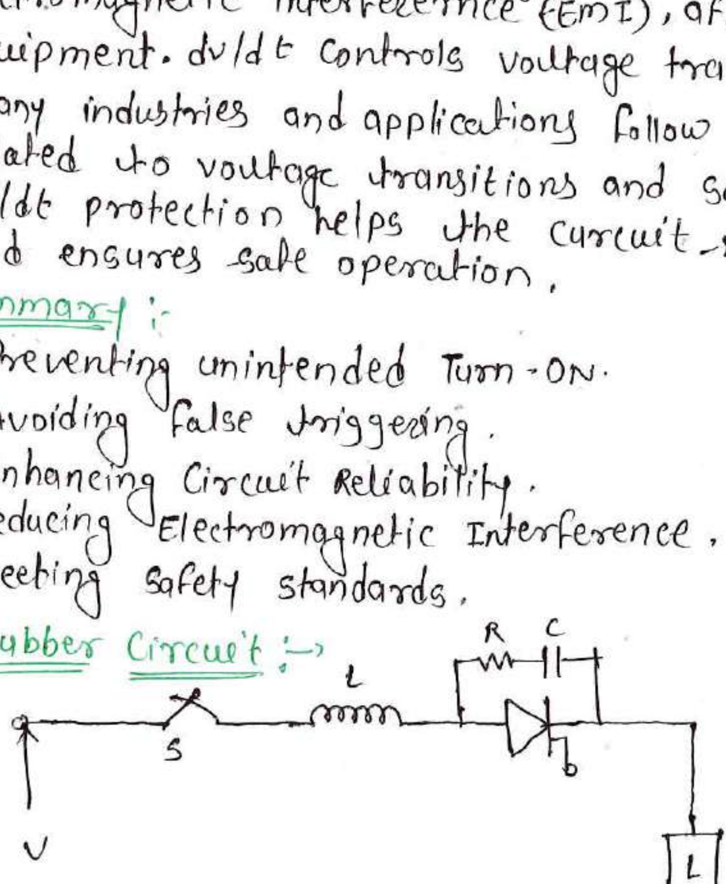


Fig. Turn off Snubber Circuit.

→ To provide dv/dt protection we connect snubber circuit.
→ Capacitor is connected to bypass high dv/dt through SCR.
→ Resistor is connected to decrease discharge current of capacitor through SCR.
→ Thus R-C series circuit across SCR is called as snubber circuit.
→ In some cases inductor (L) is also connected in series with the SCR for di/dt protection.
→ when switch is closed, a sudden voltage appears across the SCR. At that time, the RC Network slows down the rapid rise of voltage. Because of this SCR does not experience a sudden voltage increase.
→ As time passes, the capacitor starts charging and develops voltage across it. Since the dv/dt across the capacitor is very small, the overall dv/dt across the SCR and capacitor combination also remains below the maximum dv/dt of the SCR.

2.3 - Overvoltage protection :- Need, Internal and external overvoltage, Voltage Clamping device.

* Need of overvoltage protection :-

1) overvoltage can cause immediate damage to sensitive components within electronic devices, leading to malfunctions or complete failure.
2) Damage from overvoltage can result in costly downtime and repairs.
3) In extreme cases, overvoltage can pose safety risks, potentially leading to fires or electrical shocks.

* Overvoltages mainly divided into two types
  i) Internal overvoltages.
  ii) External overvoltages.

* **Internal over voltages** :- These originate within the system itself due to switching operations of inductive load, motor startups or short circuits. Internal over voltages are generated while the SCR is operating.

* **External overvoltages** :-

These are caused by events outside the device or system, such as lightning strikes, power surges from grid or electromagnetic interference.

* Voltage Clamping devices :-

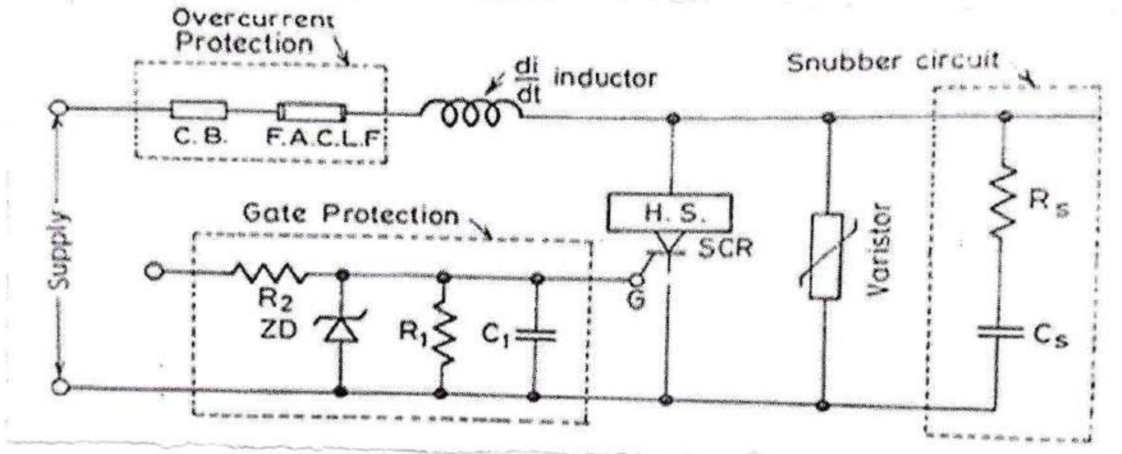


Fig. Voltage clamping device.

→ Voltage clamping device is a non-linear resistor connected across the SCR is as shown in fig.

→ The v.c. device has a falling resistance characteristics, meaning it's resistance decreases as voltage increases.

→ under normal operating conditions, the device has very high resistance and only a small leakage current flows through it.

→ when the voltages increases suddenly, the v-c. device starts operating in the low resistance region and creates a short circuit path across the SCR.

→ As a result, the sudden voltage drop across the source and line impedance limits the voltage across the SCR to a safe value.

→ The surge energy is absorbed and dissipated by the nonlinear resistor.

→ Voltage clamping devices operate in high resistance region under normal conditions.

→ Commonly used non-linear devices for overvoltage protection are-
  i) metal oxide variastor
  ii) Avalanche diode.

→ Since Avalanche diodes have lower current carrying capability compared to varistors are more commonly used.

→ For SCR overvoltage protection, an RC snubber circuit alone is not sufficient.

2.4 * Overcurrent Protection :- need, electronic crowbar circuit.

* Need of overcurrent protection :-

overcurrent ~~protection~~ fault condition is the operating condition of power electronic circuit in which the load current or source current or device current execeeds a safe predefined value.

1) Due to excess current flowing through a circuit, there is a possibility of damage to the load as well as power switching devices.

2) In severe cases over current can lead to fires due to melting components & wiring.

3) We need to use an overcurrent protection circuit to avoid such damage.

* Crowbar Circuit (Overcurrent / Overvoltage protection) :->

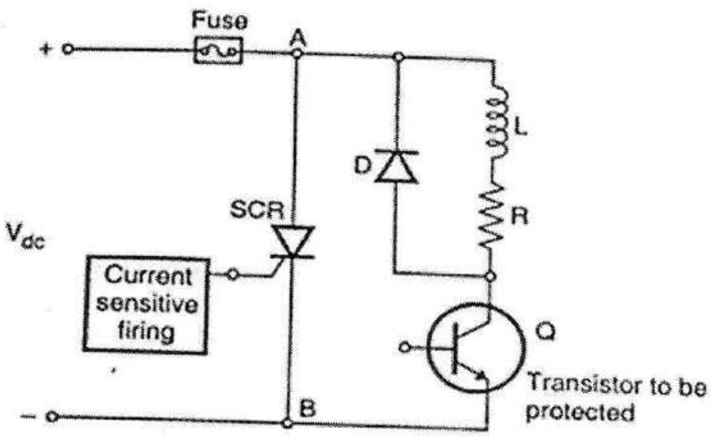


fig - Crowbar Circuit.

→ fig. shows the crowbar circuit. This circuit is used in equipment where a very large amount of energy is involved and where protection circuits cannot be used.

→ The SCR used in the crowbar circuit is normally kept in the off state. It is a voltage sensitive or current sensitive firing circuit. With voltage sensitive firing, the crowbar circuit can be used for protection Against overvoltage.

→ If the transistor Q (sensor device) current execeeds the predetermined value, then the current sensitive firing circuit will turn ON the SCR.

→ The SCR will act like a closed switch & short circuit ~~points A and B as shown in the equivalent circuit of~~

→ Therefor, under fault conditions, the SCR turns ON and creates a virtual short circuit, due to which the fuse link blows & the transistor gets protected.

→ The crowbar circuit can be placed in any converter circuit that needs protection.

2.5 Thermal Protection of SCR :- Need, thermal resistance, and heat sink specification :-

→ Due to the temperature sensitivity of (SCR's), thermal protection is very important for their reliable operation. The concept of thermal resistance and the heat sink specifications required to ensure proper SCR performance are given below.

* Need for Thermal ~~Resistance~~ Protection :-

1) Performance & reliability :-
SCR used for power control. Execessive heat can reduce their performance and may cause failure. Protection from thermal stress increases the life of the SCR and ensures consistent operation.

2) Preventing thermal runaway :-

3) maintaining Electrical characteristics :-
Electrical properties of an SCR, such as current handling capacity and voltage thresholds, can change with temperature variations. keeping the temperature within specified limits helps maintain these characteristics.

* Thermal Resistance :-

→ Thermal resistance is an important concept in thermal management, especially for electronic components such as SCR. It measures the ability of a material or component to resist the flow of heat.

→ Thermal resistance is also defined as the temperature difference produced per unit heat power dissipation in a material or component.

→ It is measured in degrees celcius/watt. (°C/ω).

* Heat Sink specification :-

1) material :- select aluminium for a balance of cost, weight and thermal efficiency.

2) Size and surface area :- Choose a heat sink with adequate surface area by considering the available space and form factor. fins or extrusions can be used to increase the surface area.

3) Cooling mechanism :- for passive cooling, ensure the design allows natural convection. for active cooling, ensure compatibility with fans or liquid cooling systems.

4) mounting and contact :- Use high quality thermal Interface material to improve thermal contact between the SCR's and the heat sink.

→ Ensure proper mounting to avoid air gaps.

2.6 - Firing Circuits :- Features and general layout of firing scheme.

* Features of firing Circuits :→

1) Phase angle Control :- Allows control of power delivered to the load by adjusting firing angle.
2) Provide sharp Reliable gate pulses to ensure proper SCR conduction.
3) It synchronizes the triggering circuit with AC mains.
4) It provides isolation between the gate triggering circuit & SCR.
5) It allows the firing angle change as per requirement.

* General layout of firing scheme :→

The general block diagram of a thyristor gate trigger circuit is as shown in fig.

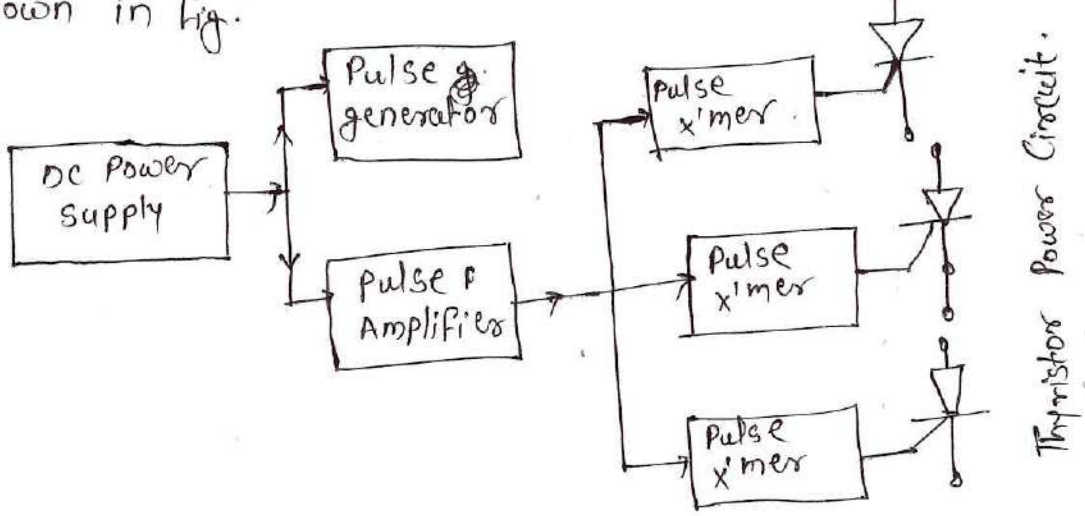


Fig. Basic Triggering Circuit of SCR.

→ The 1Φ ac supply voltage is applied to the primary of an input transformer.
→ It is stepdown transformer.
→ The rectifier & filter combination is used for a producing the dc voltage required for a producing the dc voltage required for the operations of various blocks in the gate triggering circuit.
→ The same secondary voltage is used as a synchronizing input voltage for the gate triggering circuit.

→ The zero Crossing Detector (ZCD) produces short rectangular pulses corresponding to the zero crossing instants of ac supply.

2.7 - SCR turn on methods : forward voltage triggering, gate triggering, dv/dt triggering, temperature triggering, light triggering.

1) Forward voltage triggering :-

→ when the forward anode to cathode voltage V_{AK} execeeds the forward breakover voltage V_{BO}, leakage current starts flowing.
→ In reverse bias, the energy of leakage current carriers is sufficient to dislodge additional carriers.
→ These carriers displace more carriers and due to regenerative action, carrier multiplication occurs, causing avalanch breakdown of junction.
→ Since a large current flows in the device during this condition, the PNPN structure may be damaged.
→ Therefore, this method is generally not used for turning ON an SCR. However, it is used in four layer diode switching.

2) Gate triggering :-

→ DC voltage of sufficient amount and proper magnitude is applied between the gate and cathode terminals.

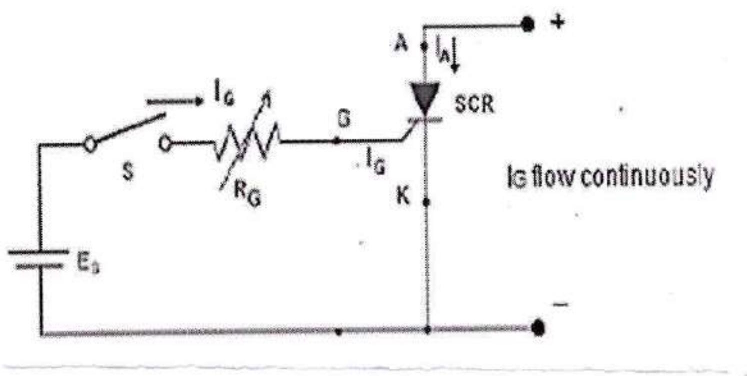


Fig - Gate triggering

→ Therefore, the gate to cathode junction remains continuously forward biased and continuous gate current is allowed to flow.
→ By changing the value of 'R', the magnitude of gate current can be controlled. If the gate current is sufficiently high, the SCR will turn ON.

→ Even after the SCR is triggered ON, the gate current continues to flow. The disadvantage of this technique is that continues gate current causes large gate power loss.

→ Another disadvantage is that there is no isolation between the gate circuit and the anode circuit.

* dv/dt triggering :-

→ when gate current $I_G = 0$ & suddenly high forward +ve voltage is applied SCR will on.
→ Then it is said that the rate of change of voltage dv/dt of of forward voltage is very high.
→ Such situation is called transient operating condition.
→ High dv/dt may result in the accidental turn on of a thyristor. It may even damage the thyristor.
→ Thyristor should be protected against high dv/dt. Care should be taken to limit the applied dv/dt below the value specified by the manufacturer.

* Temperature Triggering :-

→ If temperature of a thyristor increases, there is an increase in the no of electron hole pairs.
→ This will increase the leakage current, therefore value of α_1 and α_2 will increase, then thyristor may get turn ON. This is called thermal triggering of SCR.
→ The breakover voltage goes ~~to~~ decreasing with increase in temperature.
→ In short due to increase in temperature the thermally generated leakage current increases.
→ This current gets multiplied internally & the thyristor is turned ON.

Note :- The thyristor turn ON due to increased temperature should be avoided because it may cause 'thermal run away.

* Light (Illumination) triggering :-

→ If light of appropriate frequency and intensity is allowed to strike the thyristor junction, then the photons will strike the electrons & increase the no. of electrons holes pairs.

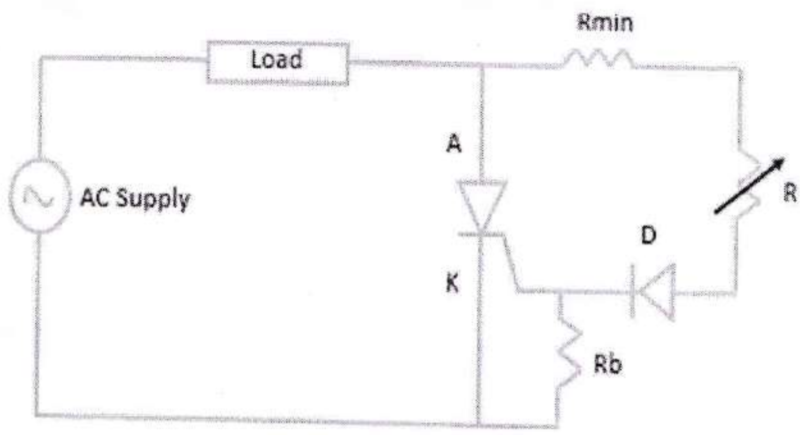
→ Thyristor may turn on due to the increased leakage current

→ This method (Principle) is used to turn on the light activated thyristor (LASCR)

2.8 SCR Firing Circuits :- Resistance Firing Circuit, RC Firing Circuit, Pulse transformer based triggering.

1) Resistance firing Circuits :-

→ R Triggering of SCR is one of the method to turn ON SCR through resistive element.



Fig①: Circuit diagram of R triggering of SCR.

→ The resistance Rmin is used to limit the gate current to it's maximum value. The value of Rmin is decided by the formula,

$$R_{min} \geq \frac{V_m}{I_{g\,max}}.$$

→ The resistance R_b is the stabilizing resistance. This resistance ensures that minimum gate voltage is applied to the SCR.

→ The variable resistor R is used to trigger the thyristor T_1. When the value of R ~~increases~~ zero, the firing angle is minimum.

→ The firing angle increases as the value of R increases.

→ Fig. 2 shows the waveform of this circuit.

→ In the waveforms, it can be observed that at point A and B the supply voltage is same.

→ Therefore it is desired to trigger SCR at point B, the SCR will trigger at point A.

→ In other words, triggering of SCR can be controlled only for 90 degree.

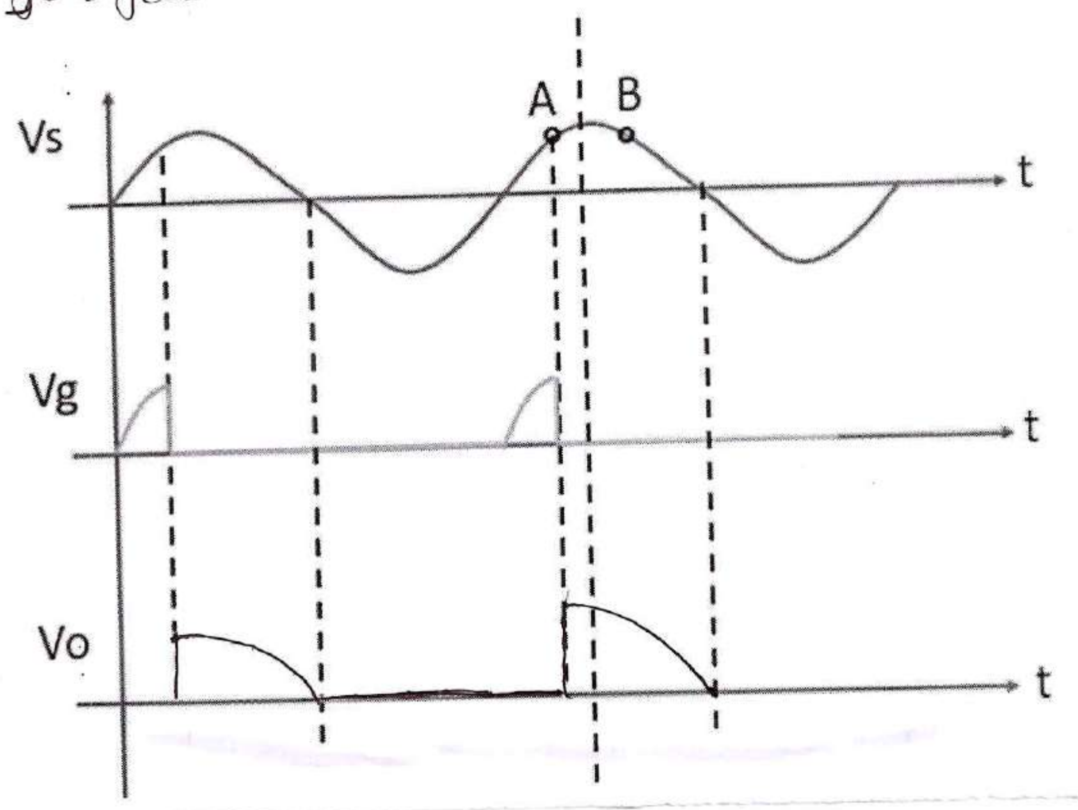


Fig (2) Waveforms of R triggering circuit of SCR.

→ Hence maximum triggering angle that can be achieved is 90°. This is the one of the major drawbacks for this circuit.

* R.C. SCR triggering :-

→ Fig (1) shows the circuit diagram of RC Half wave triggering of SCR.

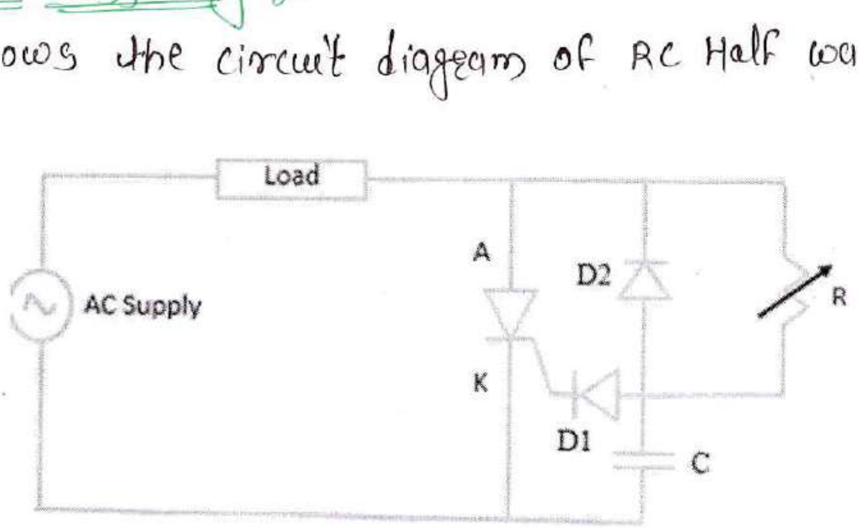


Fig. (1) RC triggering of SCR.

→ During the negative half cycle the capacitor charges to negative polarity through the diode D2 as shown in fig.

→ During positive half cycle, the capacitor discharges through.

the resistor R as shown in fig. once the energy is discharged, the capacitor, the capacitor starts discharging to positive voltage.

→ Once the capacitor charges to the gate voltage, the gate current is provided through the diode D1.

→ Diode D1 also prevents negative capacitor voltage to appear across the gate terminal of SCR.

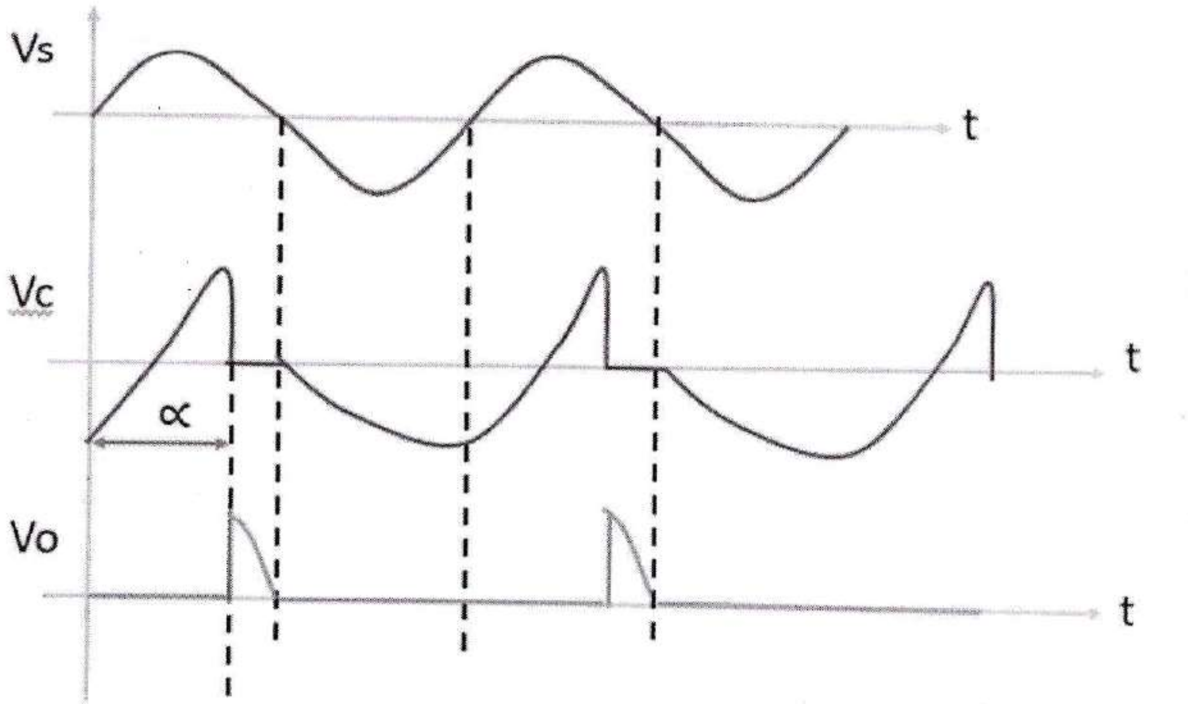


Fig ② - Waveform of RC half wave triggering of SCR.

→ Fig. ② shows waveform of RC triggering of SCR. It can be observed that the SCR can be triggered for 180° range.

→ Hence it is having much better control over the conventional R-triggering circuit of SCR.

→ Since the SCR can be controlled ~~by~~ for only one half cycle range, it is called as Half wave RC triggering circuit of SCR.

→ For zero output (i.e. RC half wave triggering of SCR maximum Firing angle), the following relation holds good:

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

* Pulse transformer based triggering :- (UJT based triggering)

→ fig. ① shows the circuit diagram of UJT triggering circuit for SCR.

→ During positive half cycle, the supply voltage is positive and diode D1 & D2 are forward biased.

→ The rectified voltage is clamped to zener diode V_Z through the zener diode.

→ The capacitor starts charging to positive voltage through the resistor R.

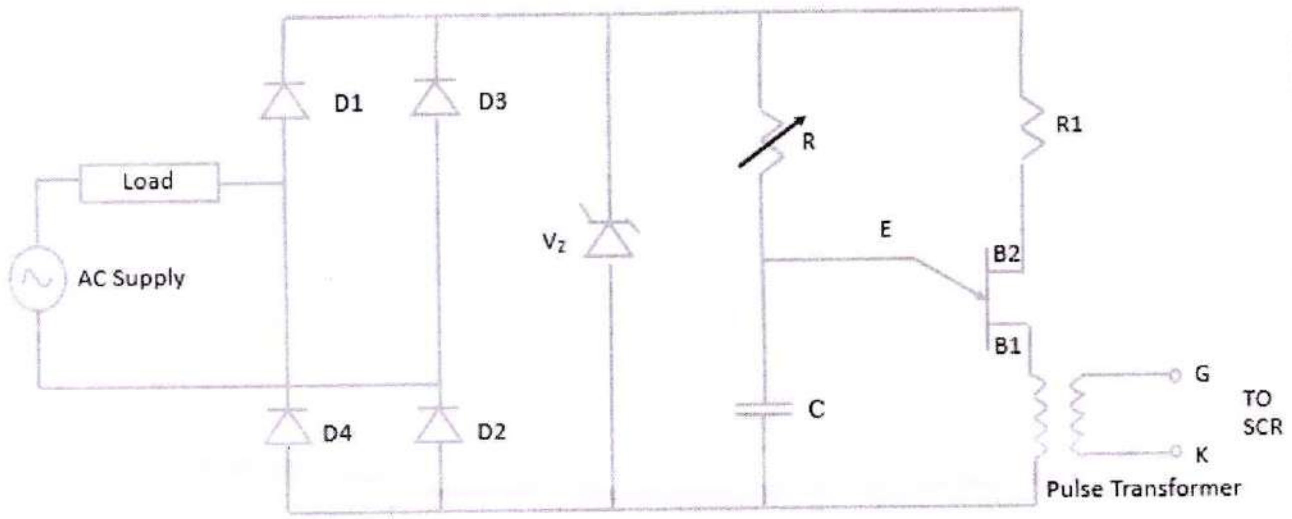
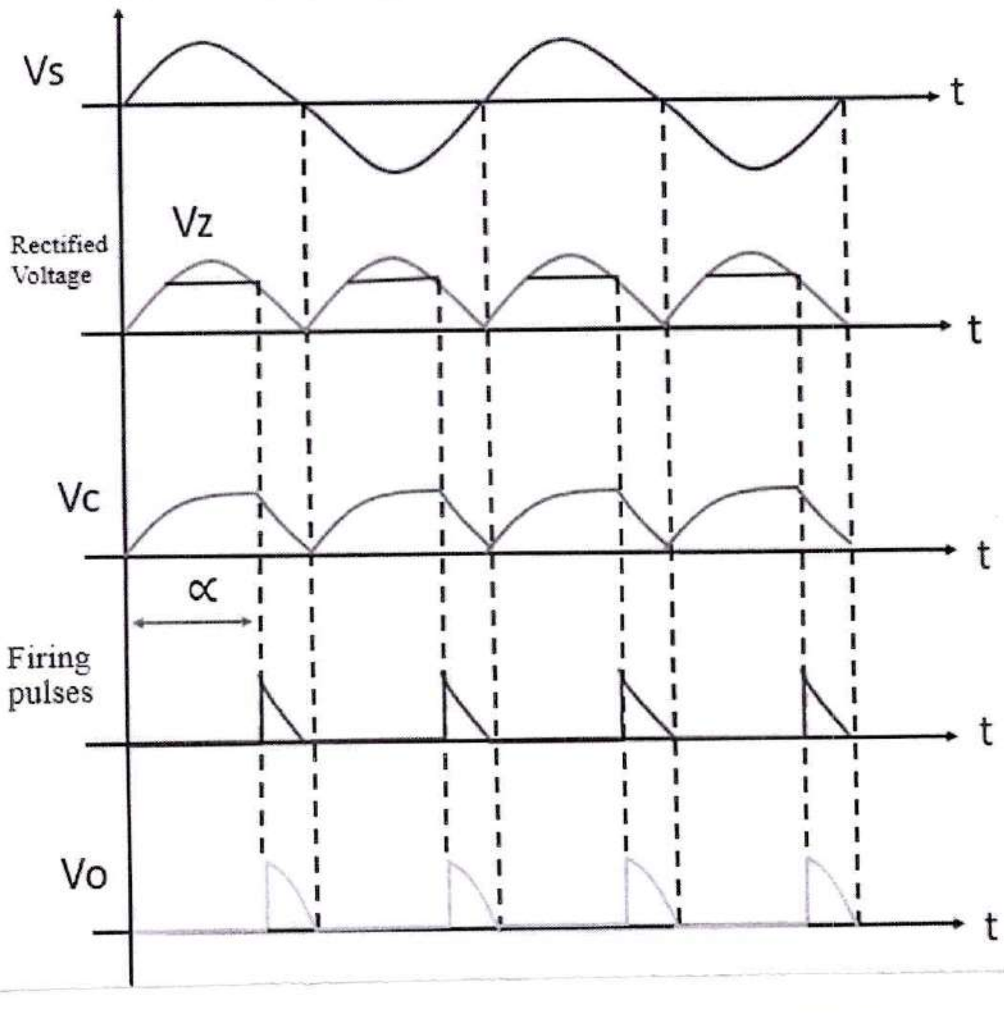


Fig-(a) - UJT Triggering circuit diagram

→ Once the capacitor charges to a peak voltage say V_{AK}, it triggers the UJT and starts discharging. The UJT is turned ON and it supplies excitation to the pulse transfer. The pulse transformer provides the pulse to the gate to cathode terminal of the SCR.



→ This mode of working of UJT is called as relaxation oscillator.
→ Fig ② shows waveforms of UJT triggering circuit of SCR.
→ The firing angle α can be controlled by designing suitable values of R and C elements
→ The UJT triggering circuit has the firing angle range from 0 to 180°.
→ One of the major advantage of this circuit is that the pulse transformer provides electrical isolation with the source and the load terminals.
→ This adds up an additional layer of protection for gate terminals.

2.9 - SCR Commutation Techniques:-

2.9.1 - Load Commutation (Class A) :-

→ The commutating components L and C are used in order to turn off the SCR. When the load resistance of very small value is used, the inductor L and capacitor C are connected in series with load.

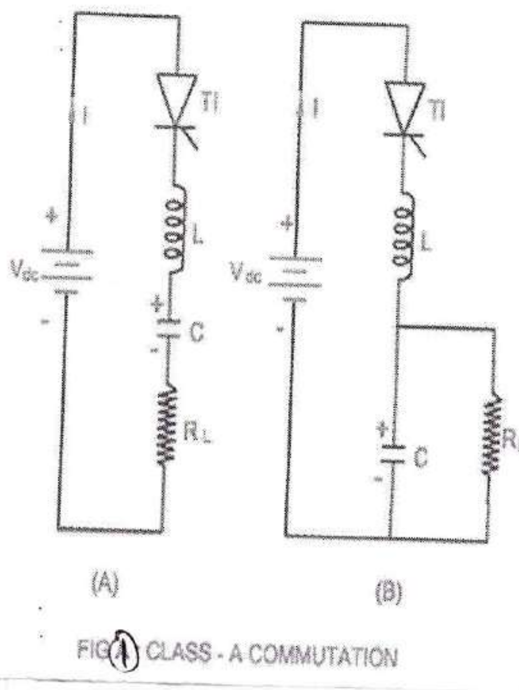


FIG ① CLASS - A COMMUTATION

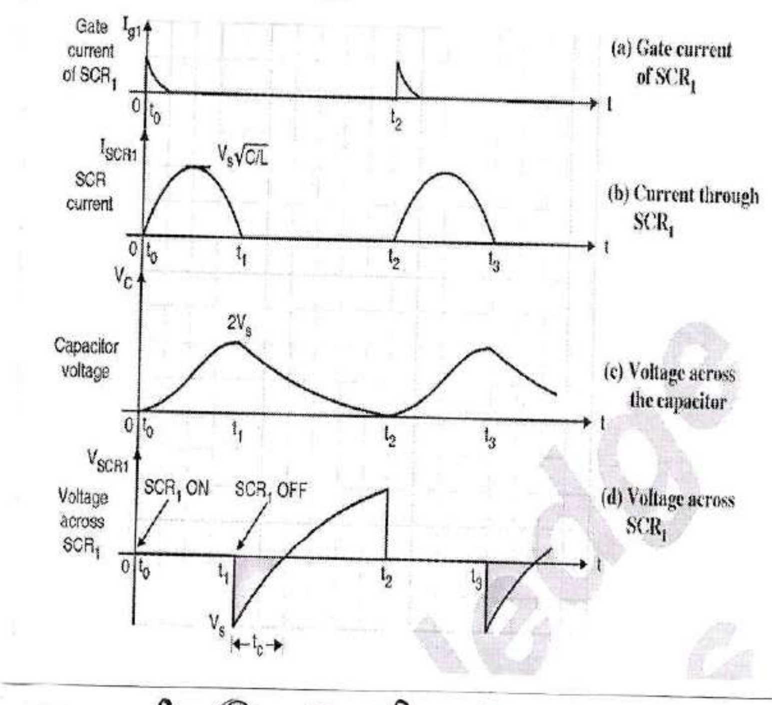


Fig ② Waveforms.

→ Similarly, the load resistance of high value is used; the load resistance is connected across capacitor. The value of L and C are selected so that the circuit becomes under-damped.
→ The current attains zero value at point A as shown in Fig. (B)

→ The polarity of the capacitor is shown in figure. When a capacitor charges upto V_{dc} voltage, the current passing through inductor L reverses.

→ As the inductor current becomes less than the holding current of SCR T_1, the SCR T_1 is turned off.

→ The turned off time of SCR depends upon resonance frequency of the circuit which depends upon commutating components L and C

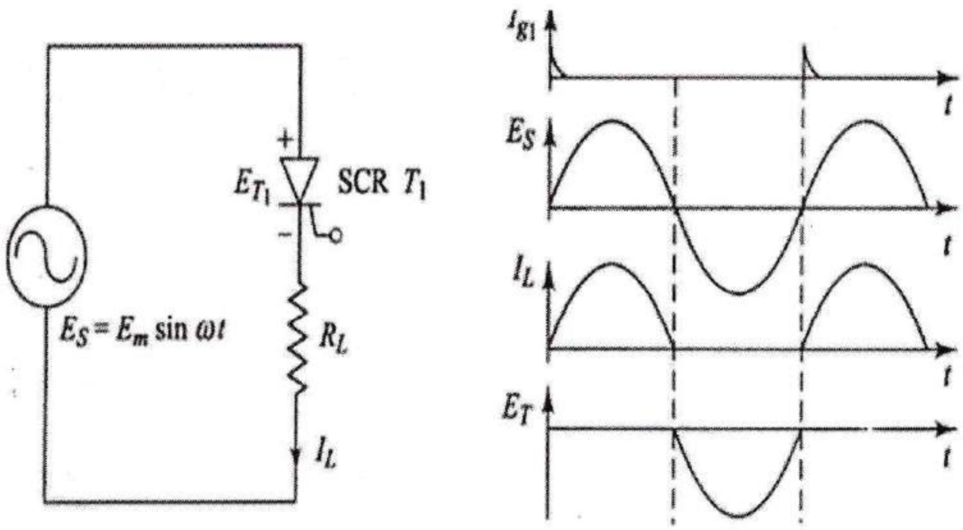
→ The class A Commutation is ~~used for~~ also called as self commutation and it is used in the series inverter.

→ The class A commutation is used for upto 1khz frequency because the cost of circuit increases due to higher rating of inductor L and capacitor C at low frequency.

* Class F Commutation :- (AC or Natural or phase commutation)

→ The class F commutation is also called as line or Natural commutation because SCR is turned off automatically during a negative cycle of alternating supply.

→ There are no commutating components used in this model, therefore it is not called as a forced commutation method.



→ The time duration for the negative half cycle must be greater than the SCR specified turned off time as per data sheet.

→ Fig. ⑨ shows the circuit for the class F Commutation. This method is applicable only alternating supply.

→ This method is used in the line commutator rectifiers, inverters and cycloconverters.

* References :-

1) Google Images.
2) Youtube educational channels.
3) MSBTE e-content.

Shirpur Education Soceity's

R. C. Patel College of Engineering and Polytechnic, Shirpur

Department of Electrical Engineering

QUESTION BANK/ASSIGNMENT -02

Course & Code: EE-3K **Semester:** Third

Name of Subject: Fundamentals of Power Electronics **Subject Code:** 313325

Que. No.	Unit 2 Protection and Firing Circuit of Thyristor (18 Marks)	Exam	Marks
1	State the types of protection circuits (any four).	S-22	2
2	Give the types of SCR turn on methods.	S-22 W-24	2
3	Define firing angle and conduction angle.	S-22, S-23, W-24, S-24	2
4	Explain the operation of RC triggering circuit with neat sketch.	S-22, S-23 W-25	4
5	Describe overcurrent protection with suitable circuit arrangement.	S-22	4
6	Explain the operation of synchronized UJT triggering circuit with a neat sketch. **OR** Draw synchronized UJT triggering circuit and explain its operation. Also draw waveforms.	S-22, S-23, W-22, S-24	4/6
7	Explain the operation of R triggering circuit with a diagram.	S-24	4
8	Define triggering. List the types of Gate triggering methods.	S-23 W-24	2
9	Explain Dv/ dt triggering of SCR	S-23	4
10	Explain in detail over voltage protection.	S-23	4
11	Explain with sketch the operation of an auxiliary voltage commutation.	S-23	4
12	State difference between R and RC triggering circuit.	W-22	2
13	Describe with neat diagram of complementary commutation.	W-22	4
14	Draw and describe Class A commutation.	W-22 W-24	4
15	State triggering circuits and describe any one of them.	W-22, S-24	4
16	Explain the operation of crowbar circuit for overvoltage protection with neat diagram.	W-24	4
17	Explain dv/dt protection circuit for SCR.	W-24	2