Sheikh Hasina University, Netrokona

Department of Computer Science and Engineering

CSE-2205: Introduction to Mechatronics

Lec-16: Electrical Actuation System

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Contents

Electrical System

1. **Switching Devices:**

    - **Mechanical Switches (e.g., Relays):** These are devices that use physical contacts to open or close an electrical circuit. In the case of relays, an electromagnetic coil is used to control the opening and closing of contacts, allowing or interrupting the flow of current.
    - **Solid-State Switches:**
        - **Diodes:** Semiconductor devices that allow current to flow in one direction only. They are often used to rectify AC (alternating current) to DC (direct current).
        - **Thyristors:** Semiconductor devices with three layers of alternating N and P-type material. They are used as rectifiers or switches in power control circuits.
        - **Transistors:** Semiconductor devices that can amplify or switch electronic signals. In the context of control systems, transistors are often used for amplification or as electronic switches.

2. **Solenoid-Type Devices:**

    - **Solenoid:** A coil of wire wound in a helix shape. When an electric current flows through the coil, it produces a magnetic field that can actuate a mechanism. Solenoids are commonly used in hydraulic/pneumatic valves where the control current through the solenoid moves a plunger, allowing or blocking the fluid flow.

3. **Drive Systems:**

    - **DC Motors:** Motors that run on direct current. They convert electrical energy into mechanical energy, producing rotational motion. DC motors are often used in applications where variable speed control is required.
    - **AC Motors:** Motors that run on alternating current. They include various types such as induction motors and synchronous motors. AC motors are widely used for different applications, and their speed is often controlled by adjusting the frequency of the AC power supply.

Mechanical Switches

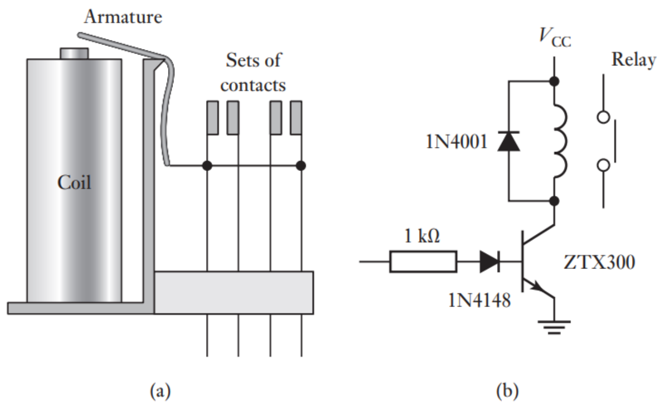
Mechanical switches are devices that use physical movement or displacement to make or break an electrical connection. They can be broadly categorized into different types based on their construction and application. Examples include toggle switches, push-button switches, and rotary switches.

Relays as Mechanical Switches

A relay is a specific type of mechanical switch that utilizes an electromagnetic mechanism to control the opening and closing of electrical contacts. Here are the key components and functions of a relay:

1. **Electromagnetic Coil:** The relay consists of a coil made of wire that is wound around an iron core. When an electric current flows through this coil, it generates a magnetic field around the core.

2. **Armature:** The relay's armature is a movable part typically connected to one or more switches. It is attracted to the core when the coil is energized, and this movement is used to open or close the electrical contacts.



(a) A relay and (b) a driver circuit.

3. **Contacts:** These are the actual switch elements within the relay. When the coil is energized, the contacts are pulled together, completing an electrical circuit. When the coil is de-energized, the contacts are separated, breaking the circuit.

Functionality:

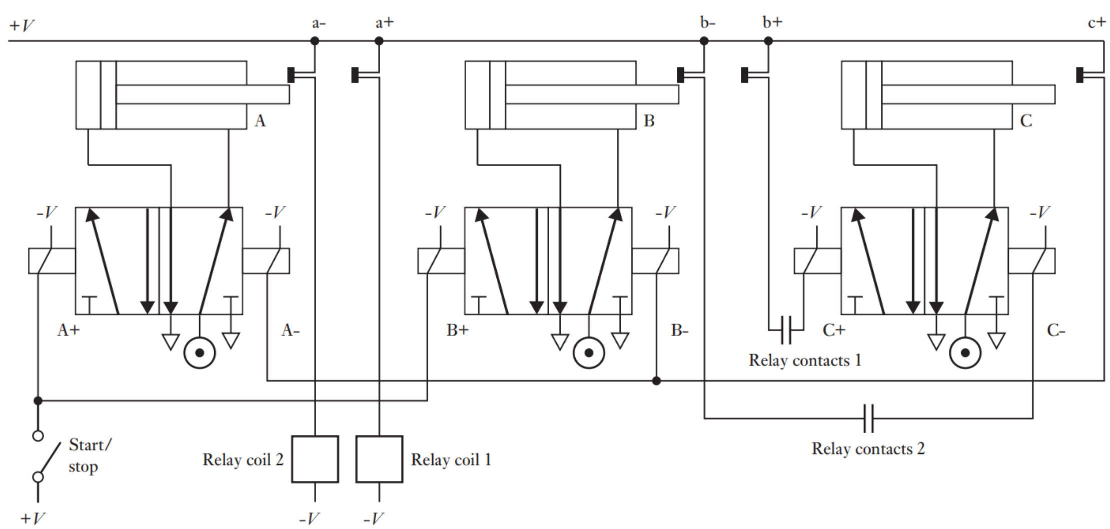
- **Normally Open (NO) and Normally Closed (NC):** Relays can have normally open or normally closed contacts. In the "rest" state (when the coil is not energized), a relay with normally open contacts has an open circuit, while a relay with normally closed contacts has a closed circuit.
- **Activation:** When an electrical current is applied to the coil, the magnetic field it produces attracts the armature, causing the contacts to change their state. For example, normally open contacts may close, and normally closed contacts may open.

Let's break down the sequence of operation outlined in the provided description, which involves the use of two relays to control the operation of pneumatic valves and the movement of pistons in three cylinders (A, B, and C). The sequence is as follows:

1. **Start Switch Closure:**
    - When the start switch is closed, current is applied to the solenoids of cylinders A and B.
    - As a result, both cylinders A and B extend, denoted as A+ and B+.
2. **Limit Switch Closure (a+ and b+):**
    - The extension of cylinders A and B causes the limit switches a+ and b+ to close.
    - When limit switch a+ closes, it allows a current to flow through relay coil 1.
3. **Relay Coil 1 Activation:**
    - Relay coil 1, upon receiving current from limit switch a+, is energized.

- The contacts of relay coil 1 close, supplying current to the solenoid of cylinder C.
- Cylinder C extends, denoted as C+.

4. **Limit Switch Closure (a-):**
    - The extension of cylinder C causes limit switch a- to close.
    - The closing of limit switch a- allows a current to flow through the control valves of cylinders A and B.
5. **Retraction of Cylinders A and B (A- and B-):**
    - The current flowing through the control valves of cylinders A and B results in the retraction of both cylinders A and B simultaneously.
    - This is denoted as A- and B- concurrently.
6. **Limit Switch Closure (a-) and Relay Coil 2 Activation:**
    - The retraction of cylinders A and B causes limit switch a- to close.
    - The closing of limit switch a- passes a current through relay coil 2.
7. **Relay Coil 2 Activation and Retraction of Cylinder C (C-):**
    - Relay coil 2, upon receiving current from limit switch a-, is energized.
    - The contacts of relay coil 2 close, allowing current to flow to the control valve of cylinder C.
    - Cylinder C retracts, denoted as C-.



In summary, the sequence of operation is as follows:

1. A+ and B+ (extension of cylinders A and B concurrently).

2. C+ (extension of cylinder C).
3. A- and B- (simultaneous retraction of cylinders A and B).
4. C- (retraction of cylinder C).

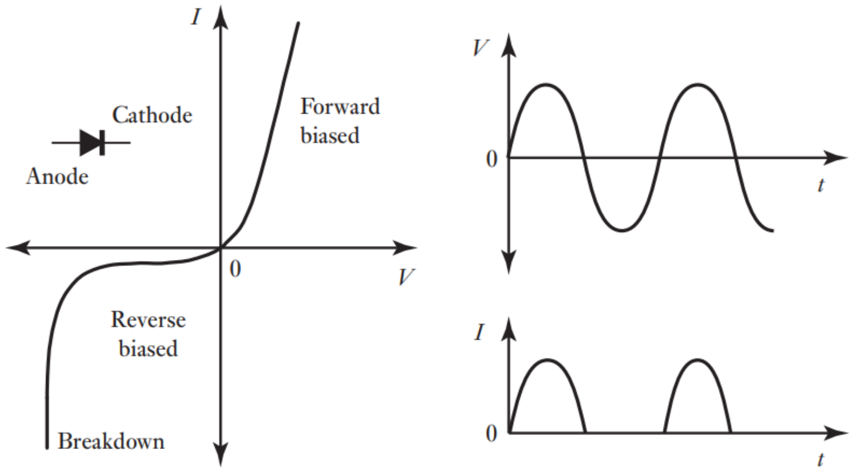
This sequence is controlled by the activation and deactivation of relays, limit switches, and the opening and closing of various pneumatic valves, creating a coordinated and controlled movement of the three cylinders.

Solid-state switches

1. **Diodes:**
   - **Function:** Diodes are semiconductor devices that allow current to flow in one direction only. They exhibit low resistance in one direction (forward-biased) and high resistance in the opposite direction (reverse-biased).
   - **Application:** Diodes are often used for rectification, converting AC to DC, and preventing reverse current flow in circuits.
2. **Thyristors and Triacs:**
   - **Thyristors:** Thyristors are semiconductor devices with three layers of alternating N and P-type material. They act as bistable switches and are used in power control applications.
   - **Triacs:** Triacs are similar to thyristors but are bidirectional, allowing current to flow in both directions. They are commonly used for AC power control.
   - **Application:** Thyristors and triacs are used in phase control circuits for dimmers, motor speed control, and other applications where controlled power delivery is needed.
3. **Bipolar Transistors:**
   - **Function:** Bipolar transistors are three-layer semiconductor devices (NPN or PNP) that can be used as amplifiers or switches. In switching applications, they control the flow of current between two terminals based on the input to the third terminal (base).
   - **Application:** Bipolar transistors are widely used in electronic circuits for amplification and as electronic switches in various applications.
4. **Power MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistors):**
   - **Function:** MOSFETs are semiconductor devices that operate based on the voltage applied to a metal gate, controlling the flow of current between the source and drain terminals.
   - **Application:** Power MOSFETs are often used as electronic switches in power amplifiers, motor control, and other applications where high-speed switching and low power dissipation are essential.

Diode

The characteristic of a diode, as shown in Figure (a), indicates that it primarily allows current to flow when it is forward-biased (anode positive with respect to cathode). When reverse-biased with a sufficiently high voltage, the diode can break down.



(a) (b)

Now, let's consider the application of a diode in the context of half-wave rectification, as described in Figure (b).

Half-Wave Rectification using a Diode:

1. **Diode Behavior:**
    - In the presence of an alternating voltage (AC), the diode effectively "switches on" or conducts current only during the positive half-cycle.
    - During the negative half-cycle, when the voltage is in the reverse direction, the diode blocks the flow of current.
2. **Result of Half-Wave Rectification:**
    - The consequence of this behavior is that only the positive halves of the input voltage are allowed to pass through the diode.
    - The output, therefore, becomes a waveform that only represents the positive half-cycles of the input voltage.
3. **Example of Half-Wave Rectification:**
    - Consider an AC voltage source with both positive and negative half-cycles.
    - When this AC voltage is applied across a diode, the diode conducts only during the positive half-cycle.
    - As a result, the current flows through the load (such as a resistor or a capacitor) only during the positive half-cycles.

4. **Output Waveform:**

    - The output waveform, as illustrated in Figure 9.3(b), is a half-wave rectified waveform.
    - It only represents the positive portions of the input AC waveform.

Significance and Application:

- Half-wave rectification is a simple form of rectification where only one half of the input AC waveform is used.
- While it is not as efficient as full-wave rectification, it finds applications in scenarios where a rudimentary rectification is sufficient, such as in some low-power applications, signal demodulation, or when a simple DC signal is required.

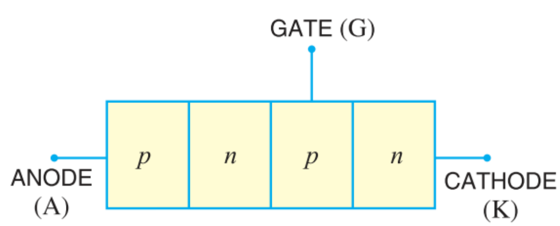
Note: The term "rectification" refers to the process of converting AC to DC. In half-wave rectification, only one half of the AC waveform is utilized, resulting in a pulsating DC output.

Thyristors

The silicon-controlled rectifier (SCR) is a semiconductor device that serves as a true electronic switch, capable of converting alternating current (AC) into direct current (DC) while allowing control over the amount of power delivered to the load. This gives the SCR the combined functionalities of a rectifier and a transistor.

Constructional Details:

1. **Basic Structure:** The SCR is constructed by adding a pn junction to a junction transistor, resulting in a three pn junction device.
2. **Combination of Elements:** Fig. below illustrates the construction, showing that it essentially combines an ordinary rectifier (pn) and a junction transistor (npn) in one unit to create a pnpn device.



3. **Terminals:**

    - **Anode (A):** Taken from the outer p-type material.
    - **Cathode (K):** Taken from the outer n-type material.
    - **Gate (G):** Taken from the base of the transistor section.

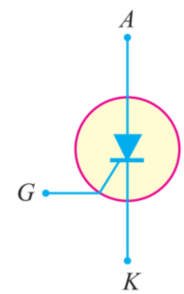
Operating Conditions:

- In normal operating conditions of the SCR:

- The anode is held at a high positive potential with respect to the cathode.
- The gate is at a small positive potential with respect to the cathode.

Symbol and Equivalent of Thyratron:

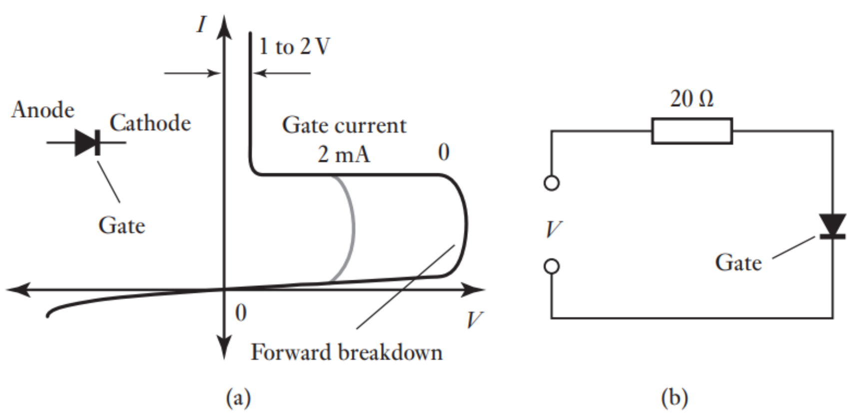
- Fig. shows the symbol of the SCR.



- The SCR is considered a solid-state equivalent of the thyratron, where the gate, anode, and cathode of the SCR correspond to the grid, plate, and cathode of the thyratron.
- Due to this similarity, the SCR is sometimes referred to as a thyristor.

Functionality:

- The SCR can act as an electronic switch, controlling the flow of current from the anode to the cathode.
- It is particularly useful for converting AC to DC and regulating the power delivered to a load.
- The SCR remains in a non-conductive state until triggered, typically by applying a small gate current.



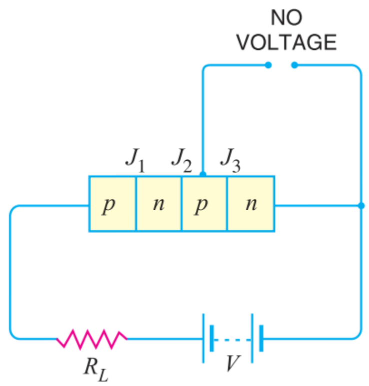
(a) Thyristor characteristic, (b) thyristor circuit.

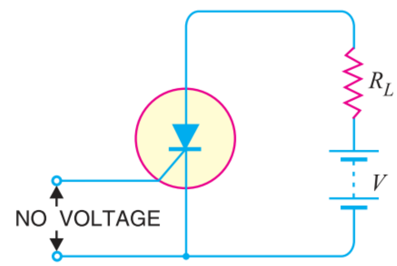
Working Principle of SCR

The working of a Silicon-Controlled Rectifier (SCR) can be understood in two scenarios: when the gate is open (no voltage applied to the gate) and when the gate is positive with respect to the cathode.

1. When the Gate is Open:

- **Circuit Configuration:** In this scenario, the load is connected in series with the anode, and the anode is always kept at a positive potential with respect to the cathode.

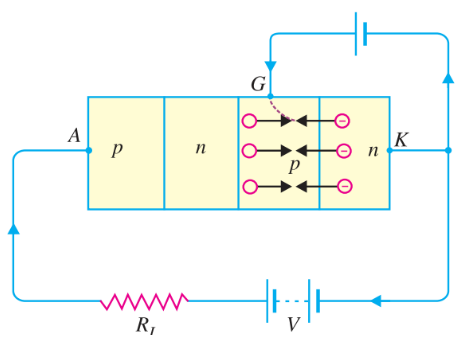


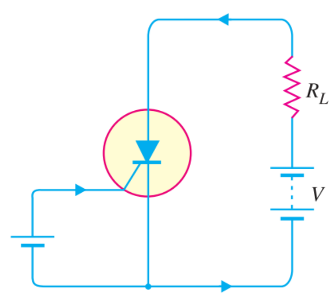


- **Junction Biasing:**
  - Junction J2 is reverse-biased, while junctions J1 and J3 are forward-biased.
  - The situation in junctions J1 and J3 is similar to an npn transistor with the base open.
- **No Conduction (Cut-off State):**
  - No current flows through the load RL, and the SCR is in a cut-off state.
  - As the applied voltage is gradually increased, a stage is reached when the reverse-biased junction J2 breaks down.
  - The SCR now conducts heavily and is in the ON state.
  - The applied voltage at which the SCR conducts heavily without gate voltage is called the Breakover voltage.

2. When the Gate is Positive with Respect to Cathode:

- **Circuit Configuration:** A small positive potential is applied to the gate.



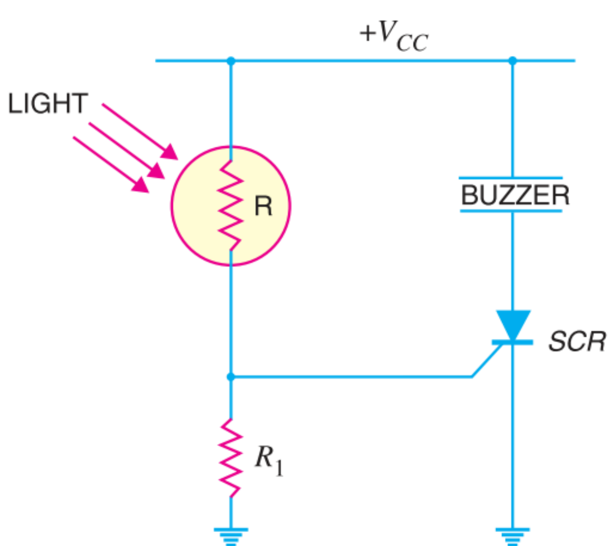


- **Junction Biasing:**
    - Junction J3 is forward-biased, and junction J2 is reverse-biased.
    - Electrons from the n-type material move across junction J3 towards the left, and holes from the p-type material move towards the right.
    - Electrons from junction J3 are attracted across junction J2, and gate current starts flowing.
- **SCR Turns On:**
    - As the gate current flows, the anode current increases.
    - The increased anode current makes more electrons available at junction J2.
    - This process continues, and in an extremely small time, junction J2 breaks down, and the SCR starts conducting heavily.
- **Loss of Gate Control:**
    - Once the SCR starts conducting, the gate loses control.
    - Even if the gate voltage is removed, the anode current does not decrease.
- **Turning Off the SCR:**
    - The only way to stop conduction (bring SCR into the off condition) is to reduce the applied voltage to zero.

Applications of SCR

Overlight Detector

The overlight detector circuit shown in Fig. uses a Silicon-Controlled Rectifier (SCR) to detect excessive light. Let's break down the operation of this circuit:



Components:

1. **Photo-resistor (R):** A photo-resistor is used, and its resistance decreases with an increase in light intensity.
2. **Resistor (R1):** Connected in series with the photo-resistor.
3. **SCR:** The Silicon-Controlled Rectifier is a key component that acts as a switch in response to the light intensity.

Circuit Operation:

1. **Normal Light Conditions:**
    - Under normal light conditions, when the light falling on the photo-resistor (R) has normal intensity, the resistance of R is high.
    - The voltage drop across resistor R1 is insufficient to trigger the SCR.
    - The SCR remains in a non-conductive state, and the buzzer is silent.
2. **Excessive Light Conditions:**
    - When the light intensity increases, the resistance of the photo-resistor (R) decreases.
    - The decreased resistance of R causes an increase in the voltage drop across resistor R1.
    - The increased voltage drop across R1 becomes high enough to trigger the SCR.
    - Once triggered, the SCR enters a conductive state, allowing current to flow through the buzzer, activating the alarm.
    - The buzzer sounds the alarm, indicating the presence of excessive light.
3. **Continuous Alarm:**
    - Importantly, even if the strong light disappears and the resistance of R increases again, the buzzer continues to sound the alarm.
    - This is because once the SCR is fired (triggered), the gate loses all control. The SCR remains in the conductive state until the applied voltage is reduced to zero.
    - The alarm persists until external action is taken to reset the circuit.

SCR crowbar circuit

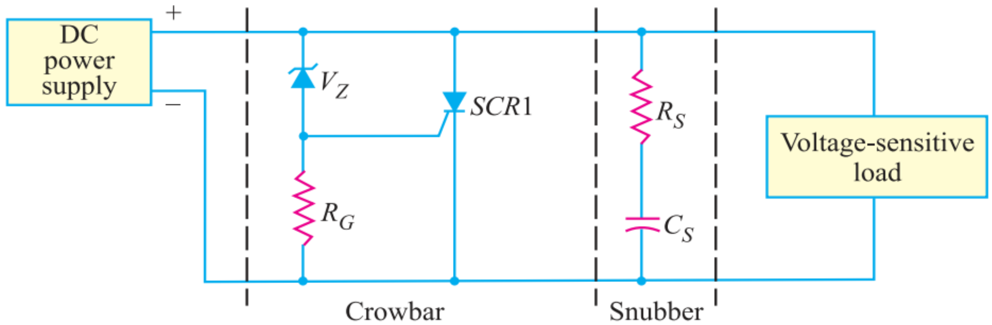
The SCR crowbar circuit shown in Fig. is designed to protect a voltage-sensitive load from excessive DC power supply output voltages. Let's understand the operation of this circuit:

Components:

1. **Zener Diode:** The zener diode is used as a voltage reference. It breaks down and conducts current when the output voltage exceeds a certain threshold.
2. **Gate Resistor (RG):** The gate resistor is connected to the SCR's gate terminal.

3. **SCR:** The Silicon-Controlled Rectifier (SCR) is the key switching element in this circuit.

4. **Snubber:** The snubber is included to prevent false triggering and ensure stable operation.



Circuit Operation:

1. **Normal Conditions:**

    - Under normal conditions, the zener diode and the SCR are in the OFF state.
    - The zener diode is in cutoff, resulting in no current flow through the gate resistor (RG), and there is no voltage drop across RG.
    - The gate of the SCR is at 0V, keeping the SCR in the OFF state.
    - In this state, the SCR behaves as an open circuit, having no effect on the DC power supply or the load.

2. **Excessive Output Voltage:**

    - If the output voltage from the DC power supply suddenly increases beyond the zener diode's breakdown voltage, the zener diode starts to conduct.
    - As the zener diode conducts, a voltage is developed across the gate resistor (RG).
    - The voltage across RG causes the SCR to conduct current.
    - When the SCR conducts, it effectively shorts the voltage source, causing a large current to flow through the SCR.

3. **Protection Action:**

    - The shorting action of the SCR essentially bypasses the excessive voltage, preventing it from reaching the load.
    - The sudden current surge through the SCR triggers the supply voltage fuse, disconnecting the power supply.
    - The load is thus protected from overvoltage conditions.

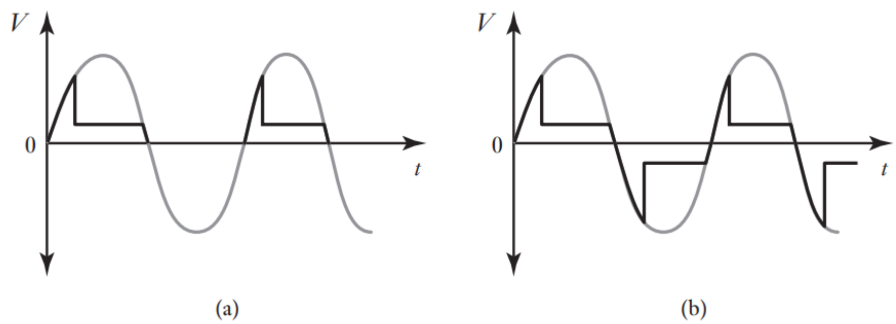
Snubber:

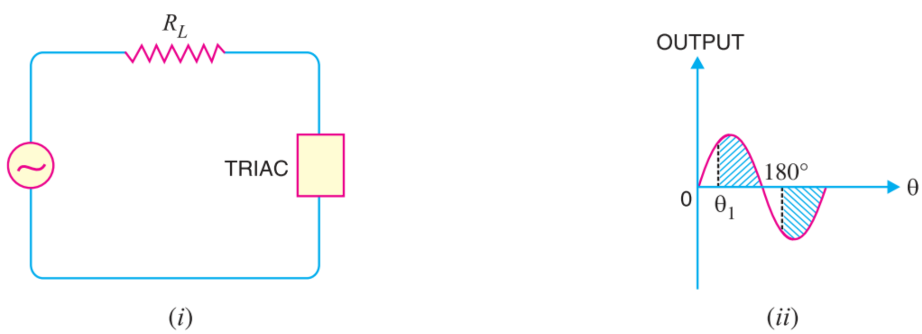
- The snubber is included to prevent false triggering. It helps in stabilizing the SCR's operation and avoiding unintended activation due to noise or transients.

TRIAC

The Triac (short for triode for alternating current) is a three-terminal semiconductor device used for controlling alternating current (AC) in a load. Its name reflects its tri-terminal structure and its ability to control AC, including both positive and negative half-cycles. Unlike the Silicon-Controlled Rectifier (SCR), which can only control current in one direction, the Triac is bidirectional.

Figure shows the type of effect that occurs when a sinusoidal alternating voltage is applied across (a) a thyristor and (b) a triac. Forward breakdown occurs when the voltage reaches the breakdown value and then the voltage across the device remains low.





Key Features of a Triac:

1. **Three Terminals:** A triac has three terminals - Main Terminal 1 (MT1), Main Terminal 2 (MT2), and Gate (G).
2. **Bidirectional Conduction:** The triac can conduct current in both directions, allowing it to control both positive and negative half-cycles of AC.

Operation of a Triac:

1. **Control Circuit Adjustment:**
    - The control circuit of the triac can be adjusted to pass desired portions of both positive and negative half-cycles of the AC supply through the load (RL).

2. **Positive Half-Cycle:**

    - Referring to Fig. (ii), the triac can be adjusted to pass the desired portion of the positive half-cycle of the AC supply from θ1 to 180° (shaded portion).

    - During this interval, the triac conducts, allowing the positive half-cycle to flow through the load.

3. **Negative Half-Cycle:**

    - Similarly, the control circuit can be adjusted to pass the desired portion of the negative half-cycle of the AC supply (shaded portion).

    - The triac conducts during this interval, allowing the negative half-cycle to flow through the load.

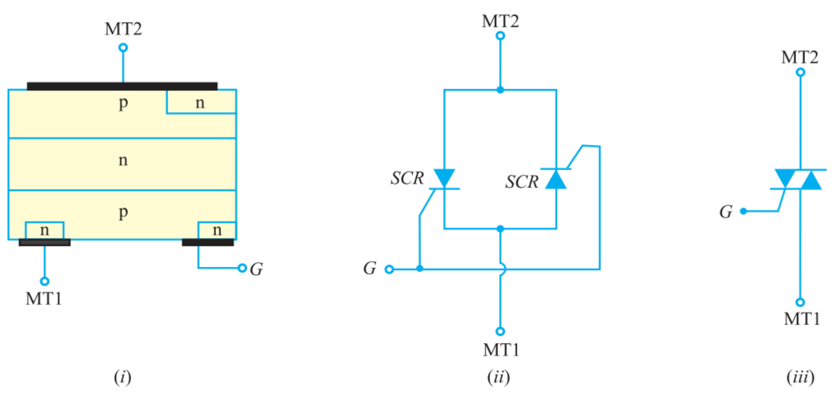
Control of AC Power:

- By adjusting the control circuit of the triac, the portion of the AC waveform that is allowed to pass through the load can be controlled.

- This capability enables the control of AC power flowing through the load.

Construction of TRIAC

The construction of a Triac involves a three-terminal, five-layer semiconductor device structure. The Triac's forward and reverse characteristics are identical to the forward characteristics of the Silicon-Controlled Rectifier (SCR). The three terminals are designated as Main Terminal 1 (MT1), Main Terminal 2 (MT2), and Gate (G).



Triac Construction:

1. **Basic Structure:** Fig. (i) illustrates the basic structure of a Triac. It is a three-terminal device with five layers. The layers are arranged in such a way that the Triac's forward and reverse characteristics are similar to an SCR.

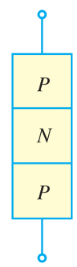
2. **Equivalent to Two SCRs in Inverse Parallel:** Fig. (ii) shows that a Triac is equivalent to two separate SCRs connected in inverse parallel. This means that the anode of one SCR is connected to the cathode of the other, and vice versa. The gates of these SCRs are commoned.

3. **Bidirectional Switching:** The arrangement of two SCRs in inverse parallel allows the Triac to act as a bidirectional switch. It can conduct current in either direction.

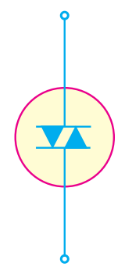
4. **Symbol:** Fig. (iii) depicts the schematic symbol of a Triac. The symbol consists of two parallel diodes connected in opposite directions with a single gate lead. This symbol visually represents the bidirectional nature of the Triac.

DIAC

A Diac is a two-terminal, three-layer bidirectional semiconductor device that can be switched from its OFF state to ON state for either polarity of applied voltage. It is a symmetrical device and can be constructed in either npn or pnp form. The basic structure of a Diac in pnp form is shown in Fig. (i), and its symbol is depicted in Fig. (ii).



DIAC BASIC CONSTRUCTION
(i)



DIAC SYMBOL
(ii)

Diac Construction:

1. **Structure:** The Diac has three layers - two p-regions connected to the two leads and an n-region separating them.

2. **Symmetry:** Unlike a bipolar transistor, the three regions are nearly identical in size, and the doping concentrations are identical, providing symmetrical properties to the device.

3. **No Base Terminal:** There is no terminal attached to the base layer, distinguishing it from a bipolar transistor.

Diac Operation:

1. **Leakage Current (IBO):**

    - When a positive or negative voltage is applied across the terminals, a small leakage current (IBO) flows through the device.

    - As the applied voltage is increased, the leakage current continues until the voltage reaches the breakover voltage (VBO).

2. **Breakover and Negative Resistance:**

    - At the breakover voltage (VBO), avalanche breakdown of the reverse-biased junction occurs.

- The device exhibits negative resistance, meaning that the current through the device increases with decreasing values of applied voltage.
- The voltage across the device then drops to the "breakback" voltage (VW).

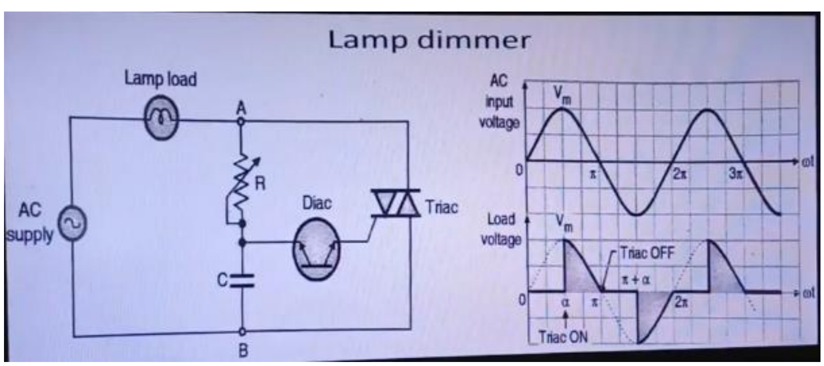
3. **V-I Characteristics:**
    - Fig. 21.18 shows the voltage-current (V-I) characteristics of a Diac.
    - For applied positive or negative voltage less than ±VBO, a small leakage current flows, and the Diac effectively behaves as an open circuit.
    - When the applied voltage is equal to or greater than the breakdown voltage (VBO), the Diac begins to conduct, and the voltage drop across it becomes a few volts.
    - Conduction continues until the device current drops below its holding current.

Breakover Voltage and Holding Current:

- The breakover voltage (VBO) and holding current values are identical for both the forward and reverse regions of operation.
- Breakover voltage and holding current usually have a range of 30 to 50 volts.

<u>Applications of TRIAC and DIAC</u>

A light dimmer circuit that uses a triac (Triode for Alternating Current) and a diac (Diode for Alternating Current) is commonly known as a phase control circuit. It allows you to control the brightness of a light bulb or the speed of a motor by adjusting the amount of power delivered to the load.



Power Supply: The circuit is typically connected to an AC power supply. Let's assume a standard 120V AC supply for this example.

Triac: The triac is a three-terminal semiconductor device that can conduct current in either direction when triggered. It consists of two thyristors connected in reverse-parallel, allowing it to control the flow of current in both positive and negative half-cycles of the AC waveform. The main terminals of the triac are called MT1 (main terminal 1) and MT2 (main terminal 2).

Diac: The diac is a two-terminal device that is used to trigger the triac. It is a bidirectional trigger device that conducts current when the voltage across it exceeds its breakdown voltage. The diac is connected in series with a resistor between the gate (G) terminal of the triac and one of the main terminals (MT1 or MT2).

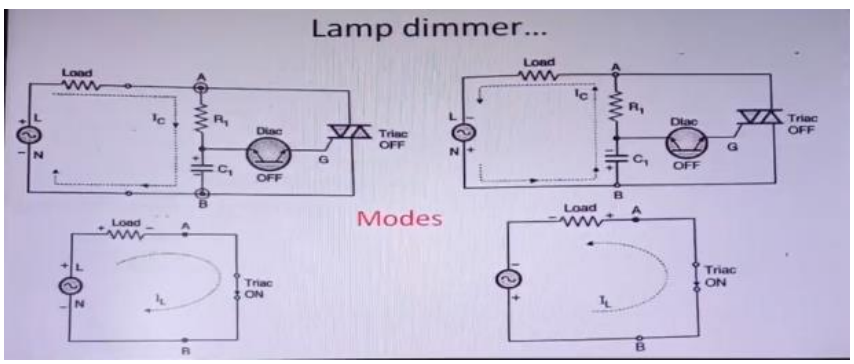
Variable Resistor: A variable resistor, such as a potentiometer, is connected in series with the diac-resistor combination. This variable resistor allows you to adjust the firing angle of the triac, which determines the portion of the AC waveform that is allowed to pass through to the load.

Load: The load in this case is typically a light bulb or a motor. It is connected in series with the triac and supplied with the controlled AC voltage.

Operation: When the AC supply is applied, the voltage waveform alternates between positive and negative half-cycles. Initially, the variable resistor is set to its maximum resistance, which delays the firing of the triac.

Working Principle

During the positive half-cycle, as the voltage across the diac reaches its breakdown voltage, it triggers and allows current to flow through the resistor connected to the gate of the triac. This causes the triac to turn on and conduct current. The current continues to flow until the end of the positive half-cycle, at which point the triac turns off because the current drops below its holding current.



The firing angle, or the point in the AC waveform where the triac turns on, is determined by the resistance set by the variable resistor. By adjusting the resistance, you can control the portion of the AC waveform that is allowed to pass through to the load. This, in turn, controls the amount of power delivered to the load and therefore the brightness of the light or the speed of the motor.

By repeating this process for each half-cycle, the circuit effectively controls the average power delivered to the load, allowing you to dim the light or adjust the motor speed.