POWER ELECTRONICS

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SCR RECTIFIER

- **SCR Rectifier:** the rectifiers that use SCR in the place of diode and in which the output voltage is varied using firing angle, α are called SCR rectifiers.
- These rectifiers are also called controlled rectifiers

- **Firing angle:**

❑ Definition: The firing angle is typically measured in electrical degrees and represents a delay within the AC cycle before the semiconductor device starts conducting.

❑ Control: The firing angle is a crucial parameter in controlling the output voltage or power in AC circuits. By adjusting the firing angle, you can control the amount of power delivered to the load.

❑ Effect on Output: In systems like AC voltage controllers or motor drives, altering the firing angle changes the portion of the AC waveform that is allowed to pass through to the load. This affects the average voltage or power delivered to the load.

❑ Applications: Firing angle control is widely used in applications such as motor speed control, light dimming, and temperature control in heating systems.

❑ Implementation: The firing angle control is often achieved through control circuits that generate a gate signal to trigger the semiconductor device at a desired point in the AC cycle.

SCR RECTIFIER

If we want the SCR to start conducting at a specific point in each half-cycle of the AC waveform, we can specify the firing angle in degrees. For example:

- If we set the firing angle to 30 degrees, it means the SCR will start conducting 30 electrical degrees after the zero crossing of the AC waveform.
- If we set the firing angle to 90 degrees, it means the SCR will start conducting at the midpoint of each half-cycle.

The actual value chosen depends on factors such as the desired output voltage, power requirements, load characteristics, and system constraints.

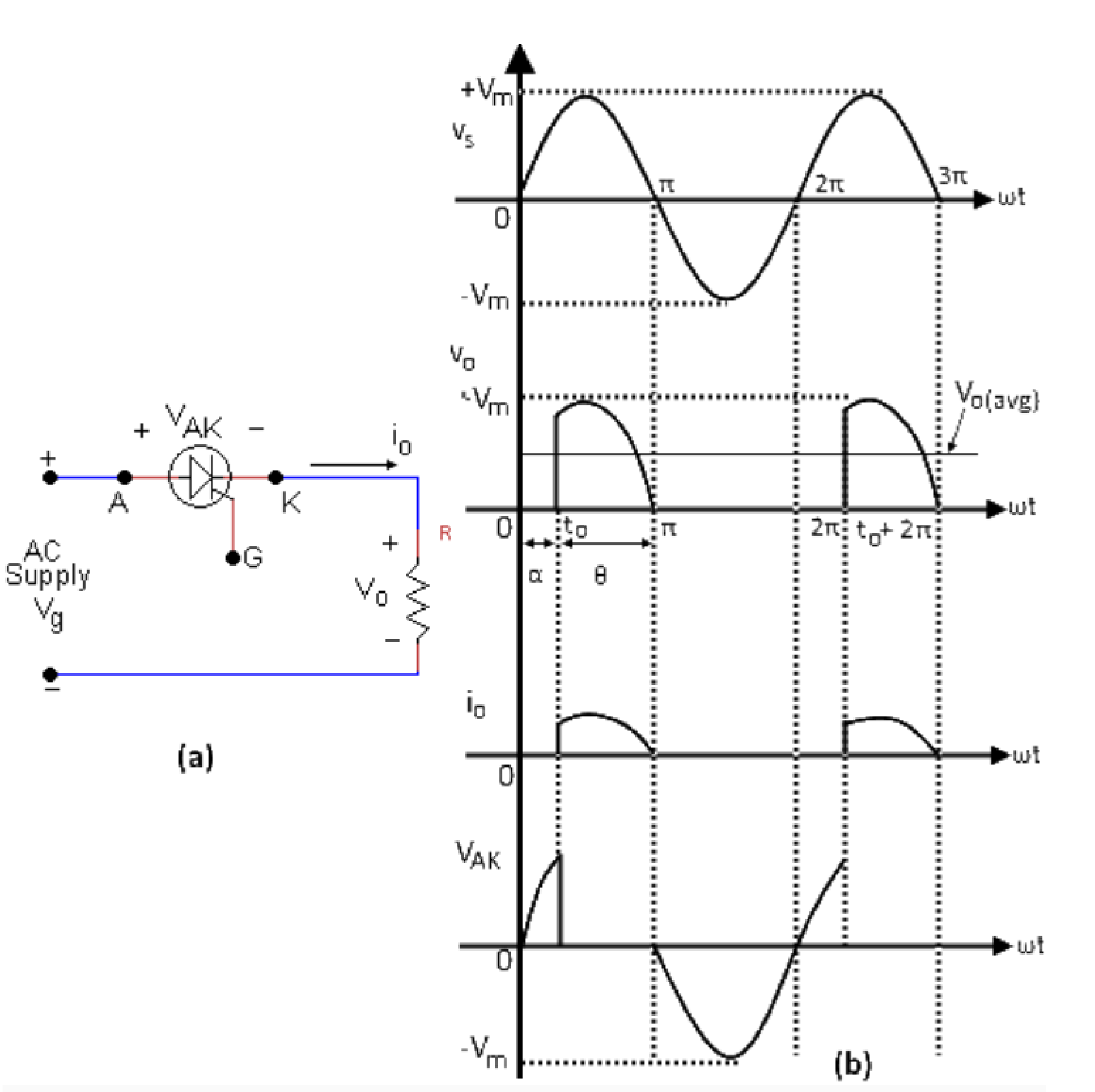
SCR RECTIFIER

The choice of firing angle depends on the specific requirements of the application. Here are some considerations:

1. **Output Voltage Control**: If you need to control the average output voltage, you can adjust the firing angle. A smaller firing angle results in the SCR turning on earlier in the half-cycle, allowing more of the waveform to pass through and thus producing a higher average output voltage. Conversely, a larger firing angle reduces the average output voltage.
2. **Power Control**: The firing angle also affects the amount of power delivered to the load. A smaller firing angle means more power is delivered to the load, while a larger firing angle reduces the delivered power.
3. **Efficiency**: Lower firing angles can result in higher efficiency in terms of power delivery since more of the input waveform is utilized. However, extremely small firing angles may cause excessive distortion or harmonics in the output waveform.
4. **Ripple and Filtering**: The choice of firing angle also affects the ripple in the output waveform. Smaller firing angles tend to result in lower ripple, but this might require additional filtering to achieve the desired output quality.
5. **Load Characteristics**: The type and characteristics of the load also influence the choice of firing angle. Some loads may require specific voltage or power levels, which can be achieved by adjusting the firing angle accordingly.

SINGLE PHASE HALF WAVE CONTROLLED RECTIFIER

Figure 1(a) shows a half-wave controlled rectifier circuit with a resistive load. During the positive half-cycle of the supply voltage, the SCR is forward-biased and will conduct if a trigger is applied to the gate. If the SCR turns on at t_o load current flows and the output voltage V_O will be the same as the input voltage. At time t = π, the current falls natural to zero, since the SCR is reverse-biased. During the negative half-cycle, the SCR blocks the flow of current, and no voltage is applied to the load. The SCR stays off until the gate signal is applied again at $(t_O + 2\pi)$. The period from 0 to t_O in Figure 1(b) represents the time in the positive half-cycle when the SCR is off. This angle (measured in degrees) is called the firing angle or delay angle (α). The SCR conducts from t_O to π; this angle is called the conduction angle(θ).



SINGLE PHASE HALF WAVE CONTROLLED RECTIFIER

A gate signal is applied to the SCR at $\omega t = \alpha$, where α is the delay angle. The average (dc) voltage across the load resistor,

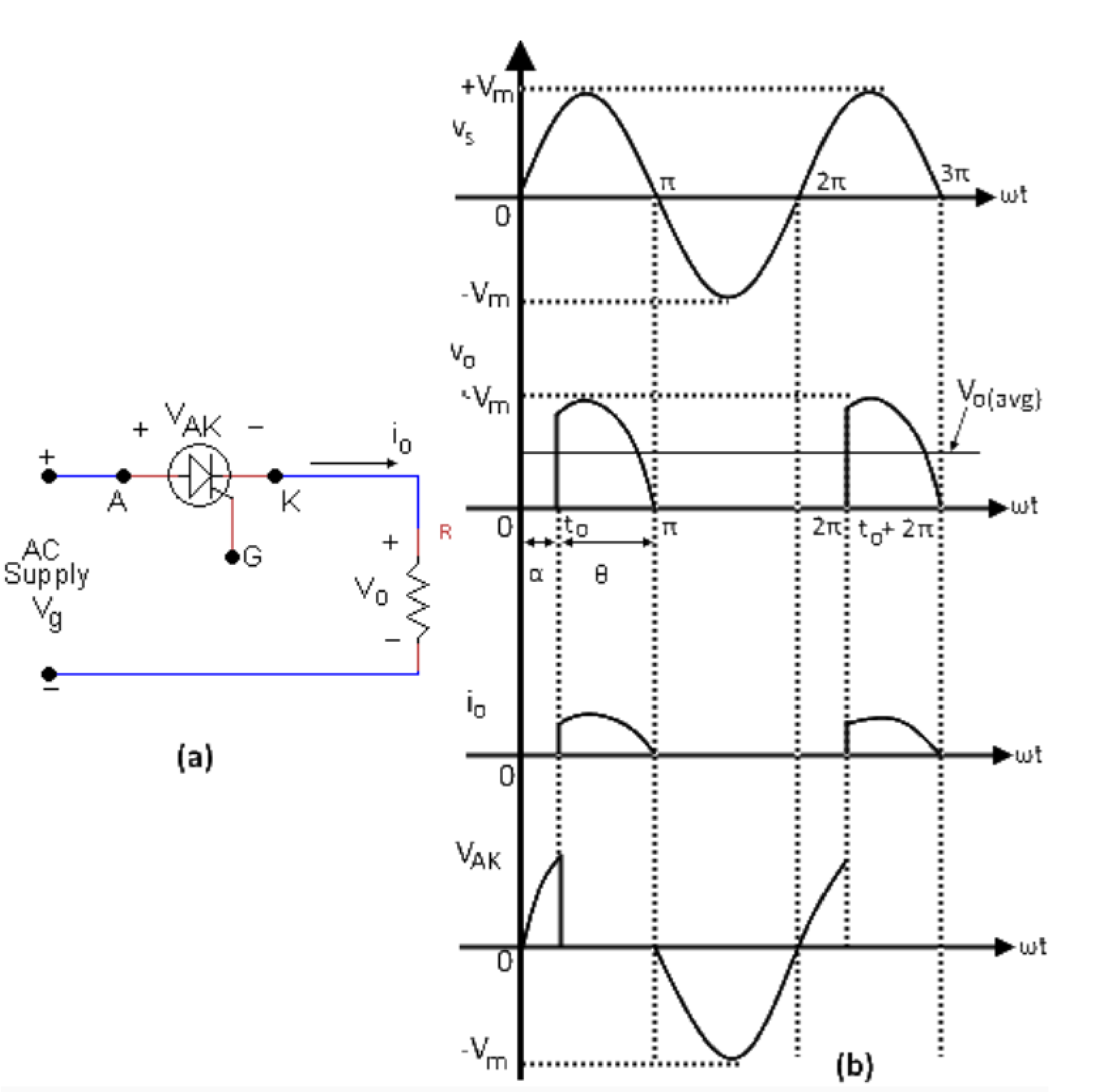
$$V_o = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin(\omega t)\, d(\omega t) = \frac{V_m}{2\pi}(1 + \cos\alpha)$$

The power absorbed by the resistor is V_{rms}^2/R, where the rms voltage across the resistor is computed from

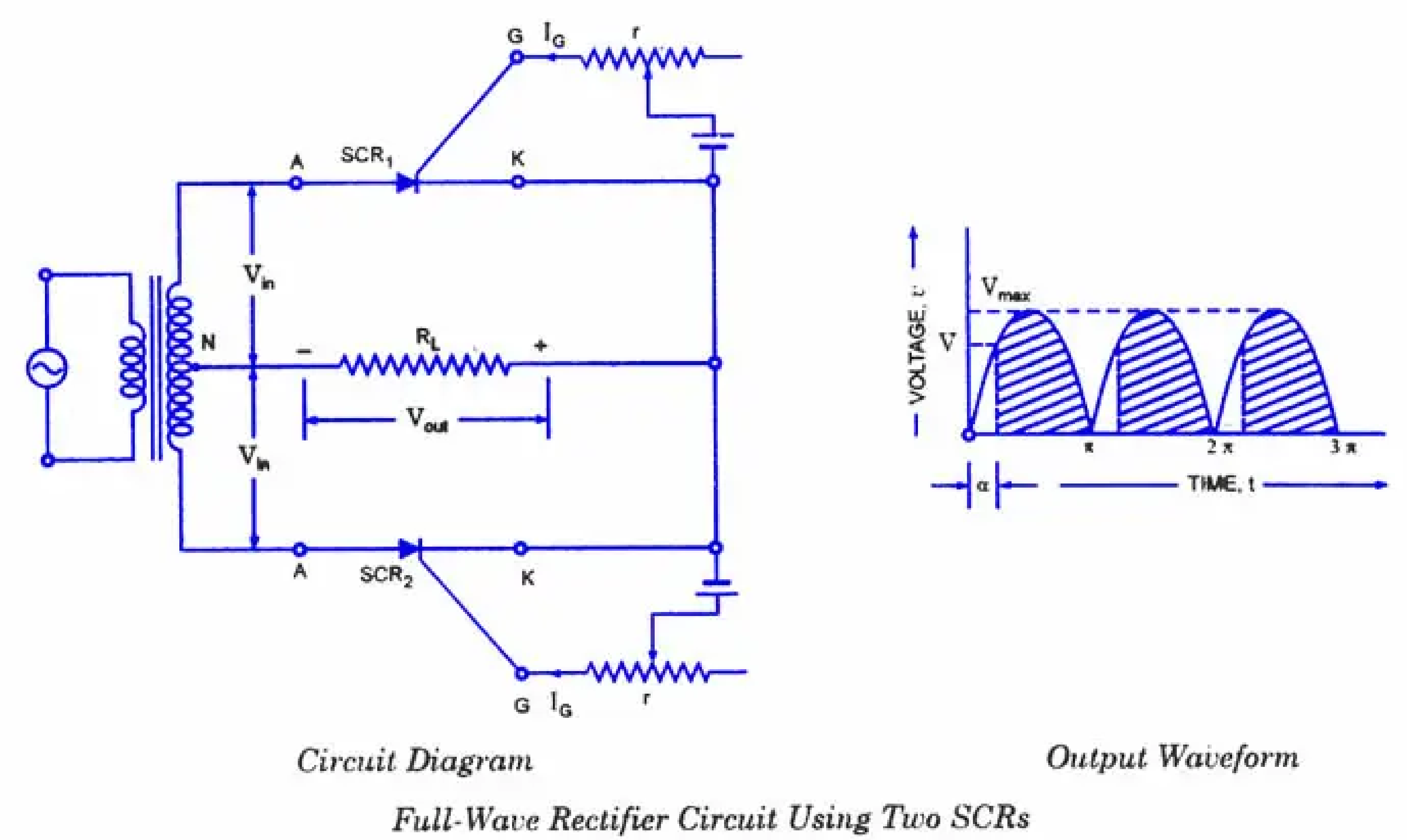
$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_{0}^{2\pi} v_o^2(\omega t)\, d(\omega t)}$$

$$= \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\pi} [V_m \sin(\omega t)]^2\, d(\omega t)}$$

$$= \frac{V_m}{2}\sqrt{1 - \frac{\alpha}{\pi} + \frac{\sin(2\alpha)}{2\pi}}$$



SINGLE PHASE FULL WAVE CONTROLLED RECTIFIER



ASSIGNMENT

Describe the operation of full-wave controlled rectifier with waveshapes and determine the average and r.m.s voltage.

PROBLEMS

1. Let's consider a numerical example of an SCR rectifier circuit. Suppose we have the following specifications:

- Input AC voltage $V_{AC}=230V$(rms)
- Frequency of the AC supply $f=50$
- Load resistance $R_{load}=10$

We'll assume an ideal situation for simplicity and focus on calculating the average output voltage for different firing angles.

Solution:

Calculate Peak Voltage (Vpk): The peak voltage of the AC supply can be calculated using the formula: $V\text{pk}=\sqrt{2}\times V\text{AC}$ $V\text{pk}=\sqrt{2}\times 230\approx 325$ V

Calculate Period (T): The period of the AC waveform is the reciprocal of the frequency: $T=1/f=1/50\approx 0.02$ s

Calculate Output Voltage for Different Firing Angles: We'll calculate the average output voltage for firing angles of 0 degrees, 30 degrees, 60 degrees, and 90 degrees.

The average output voltage (Vavg) for a half-wave rectifier with an SCR can be calculated using the formula: $V\text{avg}=\pi\times \text{Vpk}\times(1+\cos(\alpha))$ where α is the firing angle in radians.

- For a firing angle of 0 degrees (SCR conducts immediately): $V\text{avg}=1/2\pi\times 325\times(1+\cos(2\alpha))$
  $V\text{avg}=1/2\pi\times 325\times(1+\cos(0\circ))=325/\pi\approx 103.3$ V
- For a firing angle of 30 degrees: $V\text{avg}=1/2\pi\times 325\times(1+\cos(30\circ))=325/\pi\times 32\approx 155.0$ V
- For a firing angle of 60 degrees: $V\text{avg}=1/2\pi\times 325\times(1+\cos(60\circ))=325/\pi\times 12\approx 51.7$ V
- For a firing angle of 90 degrees (SCR conducts at the peak): $V\text{avg}=1/\pi\times 325\times(1+\cos(90\circ))=325/\pi\times 1\approx 103.3$ V

PROBLEMS

A half-wave rectifier circuit employing an SCR is adjusted to have a gate current of 1mA. The forward breakdown voltage of SCR is 100 V for Ig = 1mA. If a sinusoidal voltage of 200 V peak is applied,

find : (i) firing angle

(ii) conduction angle

(iii) average current.

Assume load resistance = 100Ω and the holding current to be zero.

Solution. $v = V_m \sin\theta$

Here, $v = 100\text{ V}, \quad V_m = 200\text{ V}$

(i) $\therefore \quad 100 = 200 \sin\theta$

or $\sin\theta = \frac{100}{200} = 0.5$

$\therefore \quad \theta = \sin^{-1}(0.5) = 30°$ *i.e.* Firing angle, $\alpha = \theta = \mathbf{30°}$

(ii) Conduction angle, $\phi = 180° - \alpha = 180° - 30° = \mathbf{150°}$

(iii) Average voltage $= \frac{V_m}{2\pi}(1 + \cos\alpha) = \frac{200}{2\pi}(1 + \cos 30°) = 59.25\text{ V}$

$\therefore$ Average current $= \frac{\text{Average voltage}}{R_L} = \frac{59.25}{100} = \mathbf{0.5925\ A}$

PROBLEMS

An SCR half-wave rectifier has a forward breakdown voltage of 150 V when a gate current of 1 mA flows in the gate circuit. If a sinusoidal voltage of 400 V peak is applied,
find: (i) firing angle
(ii) average output voltage
(iii) average current for a load resistance of 200Ω (iv) power output
Assume that the gate current is 1mA throughout and the forward breakdown voltage is more than 400 V when Ig = 1 mA.

Solution. $V_m = 400\text{ V}, \quad v = 150\text{ V}, \quad R_L = 200\ \Omega$

(i) Now $v = V_m \sin\theta$

or $$\sin\theta = \frac{v}{V_m} = \frac{150}{400} = 0.375$$

i.e. $$\text{firing angle, } \alpha\ (= \theta) = \sin^{-1} 0.375 = \mathbf{22^\circ}$$

(ii) Average output voltage is

$$V_{av} = \frac{V_m}{2\pi}(1 + \cos 22^\circ) = \frac{400}{2\pi}(1 + \cos 22^\circ) = \mathbf{122.6\ V}$$

(iii) Average current, $$I_{av} = \frac{\text{average output voltage}}{R_L} = \frac{122.6}{200} = \mathbf{0.613\ A}$$

(iv) $$\text{Output power} = V_{av} \times I_{av} = 122.6 \times 0.613 = \mathbf{75.15\ W}$$

PROBLEMS

Power (brightness) of a 100W, 110 V tungsten lamp is to be varied by controlling the firing angle of an SCR in a half-wave rectifier circuit supplied with 110 V a.c. What r.m.s. voltage and current are developed in the lamp at firing angle α = 60°?

Solution. The a.c. voltage is given by;

$$v = V_m \sin\theta$$

Let α be the firing angle as shown in Fig. 3. This means that the SCR will fire (i.e. start conducting) at $\theta = \alpha$. Clearly, SCR will conduct from α to 180°.

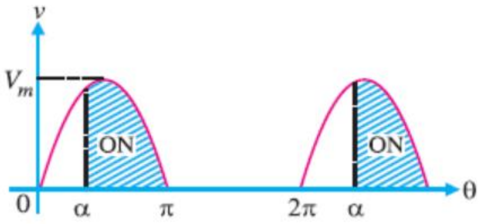


Fig.3

$$E_{r.m.s.}^2 = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\theta \, d\theta$$

$$= V_m^2 \frac{2(\pi-\alpha)+\sin 2\alpha}{8\pi}$$

$$\therefore \quad E_{r.m.s.} = V_m \sqrt{\frac{2(\pi-\alpha)+\sin 2\alpha}{8\pi}}$$

Here, $V_m = \sqrt{2}\times 110 = 156\text{V}; \ \alpha = 60° = \pi/3$

$$\therefore \quad E_{r.m.s.} = 156\sqrt{\frac{2(\pi-\pi/3)+\sin 120°}{8\pi}} = \mathbf{70\ V}$$

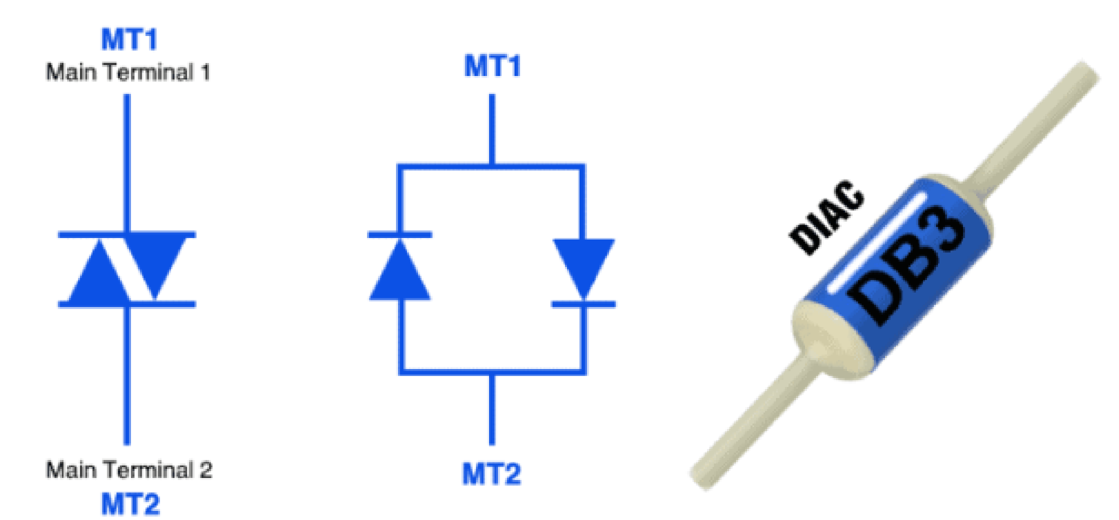
Lamp resistance, $R_L = \frac{V^2}{P} = \frac{(110)^2}{100} = 121\Omega$

$$\therefore \quad I_{r.m.s.} = \frac{E_{r.m.s.}}{R_L} = \frac{70}{121} = \mathbf{0.58\ A}$$

DIAC

- Semiconductor devices such as thyristors play vital role in power regulation in power electronics but since they conduct in only one direction, they not suitable for AC circuits. This is where DIAC and TRIAC comes into play. They regulate power supplied to AC loads such as controlling speed of motors.
- A DIAC is a full-wave or bi-directional semiconductor switch that can be turned on in both forward and reverse polarities.
- The name DIAC comes from the words **DI**ode for **A**lternating **C**urrent. This name gives an insight into its operation and applications within electronic circuit design.

- The symbol of DIAC resembles two diodes in antiparallel DIAC Symbol. It has two terminals named A1 or MT1 and A2 or MT2. MT stands for main terminals. Since it can conduct in both directions, there are no anode and cathode terminal as shown in the figure.
- It does not have gate or controlling terminal. Instead, it turns on and off by increasing or decreasing the terminal voltage above or below its break over voltage.



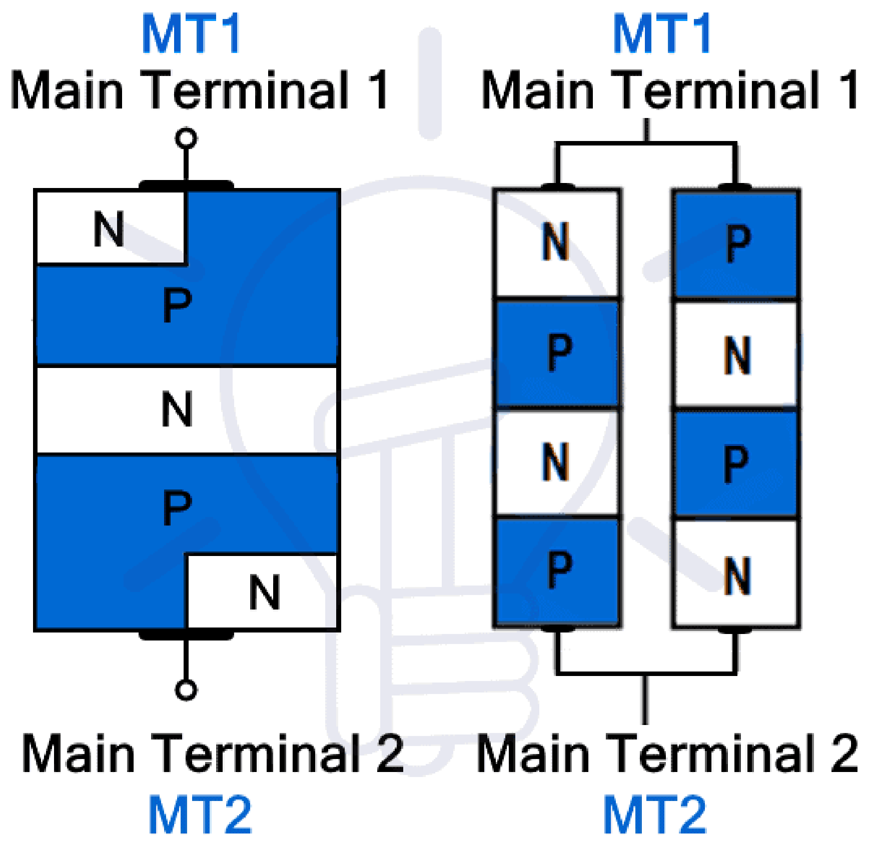
DIAC

Construction of DIAC

DIAC is a five layer device from the combination of two antiparallel SCR without the gate terminals. It has only two terminals MT1 and MT2. It has symmetrical structure from both terminals having equal width of the regions as well as its doping percentage.

DIAC can be constructed in 3-layer and 5-layer symmetrical structure. The 3-layer structure is mostly used which is made by either sandwiching N or P between its alternating layers forming PNP or NPN structure. The break over voltage of such DIAC lies around 30 volts.

The 5-layer DAIC construction resembles the combination of two SCR without the gate terminal. It has a symmetrical structure made of 2 P-layer and 3 N-layers. The terminal’s regions are made of both P and N layer. The doping and width of all layers are equal. The symmetrical structure provides symmetrical switching capabilities in both forward as well as reverse polarity.



DIAC Structure

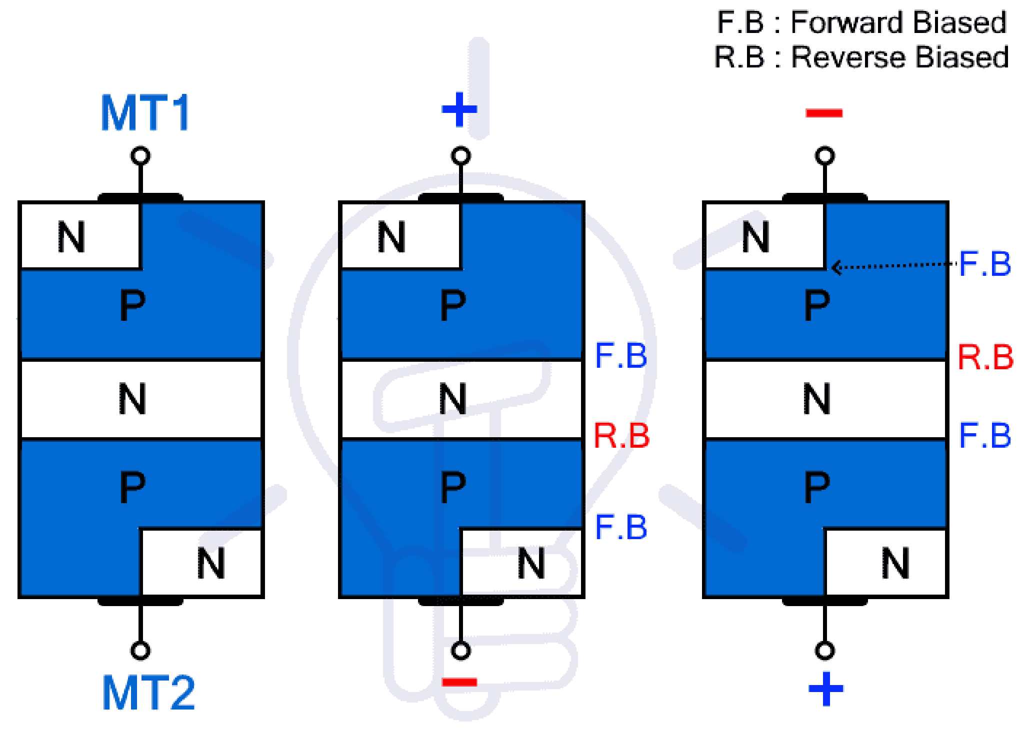
DIAC

Working of DIAC

The DIAC can conduct current in both directions unless the applied voltage falls below the break over voltage.

Suppose the applied voltage at MT1 is positive with respect to MT2, the junctions at the ends become forwards biased and the middle junction becomes reverse biased. At this moment, the applied Voltage $V < V_{BO}$, so the middle junction remains reverse biased and does not allow current flow. The device remains in off-state.

In order to trigger the DIAC into conduction, the applied voltage V must exceed break over voltage V_{BO}. When it happens, avalanche break down occurs at the reverse bias junction and the current starts to flow through it. The DIAC is triggered into conduction and the voltage across it reduces to ON-state voltage drop.

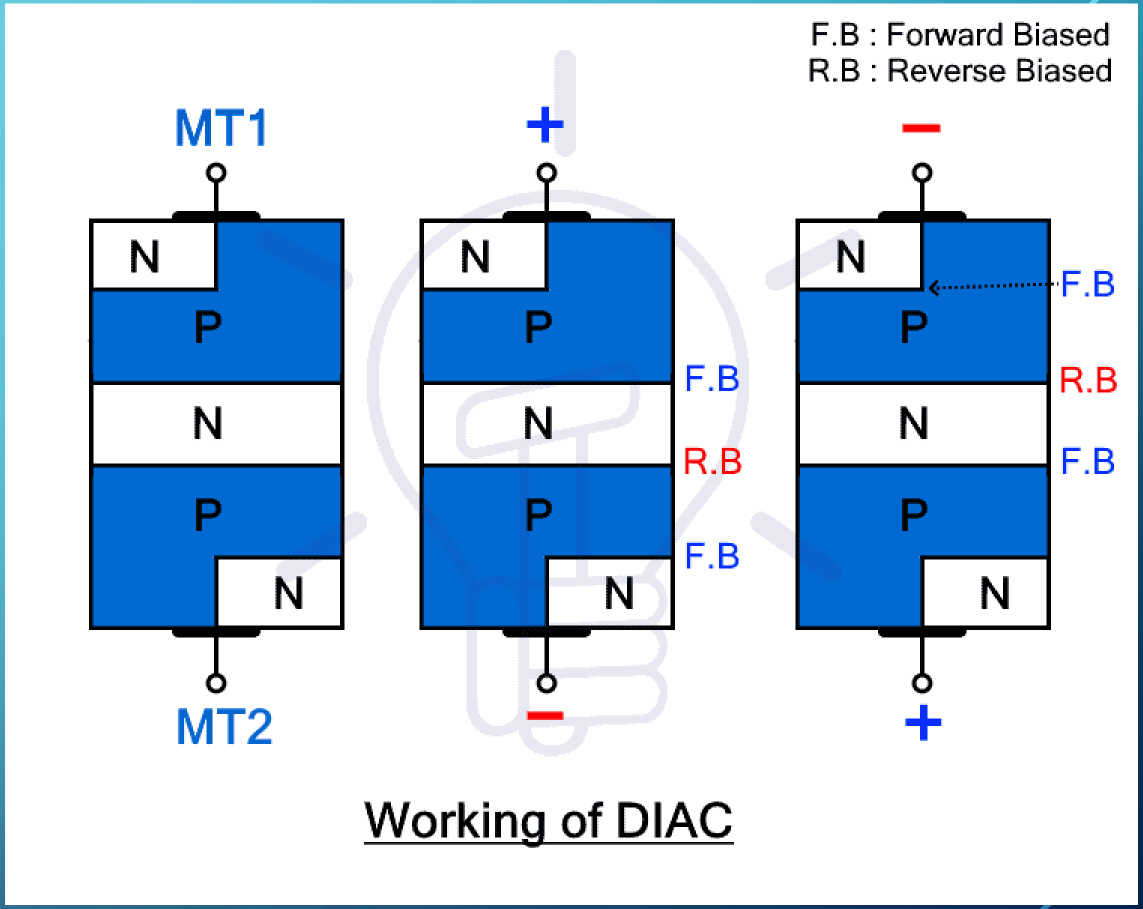


Working of DIAC

DIAC

Similarly, if the voltage polarities are swapped, the same process will repeat except the current will flow in reverse direction. There is no difference in operation whatsoever if the polarities are swapped. It has symmetrical switching characteristics for both voltage polarities i.e. its forward break over voltage is equal to reverse break over voltage.

The DIAC conducts current unless the current falls below the holding current limit. As soon as it falls below the said limit, the device switches into off-state.



DIAC

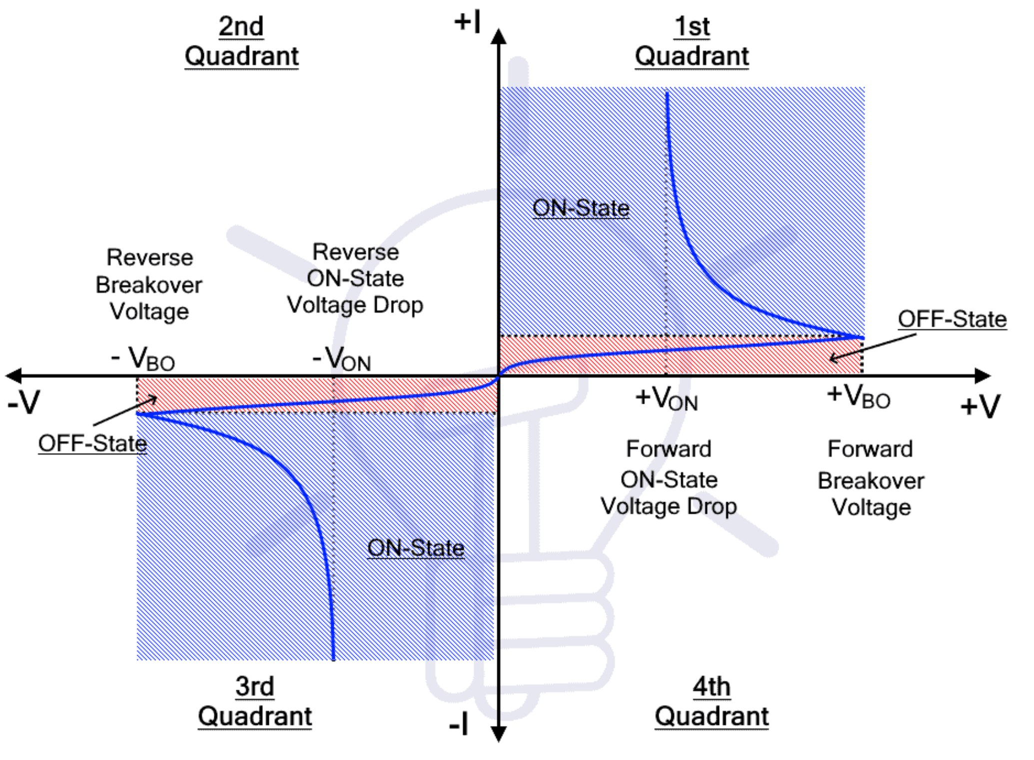
V-I Characteristics of DIAC

The following characteristic curve shows the relation between the main voltage and main current of a DIAC. As you can see, the DIAC only operate in 1st and 3rd quadrant. It is a symmetrical device; therefore, the graph is symmetrical in both quadrants forming the shape of letter “Z”.

In 1st quadrant, the voltage and current are positive. As you can see, when the voltage is below the break over voltage V_{BO}, the DIAC blocks the current except for the leakage current. The device remains in OFF-state. Once the voltage increases, the DIAC triggers into ON-state and the current rises. The voltage across the device starts to reduce to steady ON-state voltage.

The device operates similarly in the 3rd quadrant. The only difference between the 1st and 3rd quadrant is that the voltage and current are reverse. That is it.

Most DIACs have a breakdown voltage of around 30 volts, although the exact specifications will depend upon the particular type of device.



V-I Characteristics of DIAC

BASIC EQUATIONS AND CHARACTERISTICS RELATED TO A DIAC

1. Breakover Voltage (V_{BO}): The breakover voltage is the voltage at which the DIAC starts conducting. It's typically denoted as V_{BO}.
2. Holding Voltage (V_H): The holding voltage is the voltage at which the DIAC stops conducting. It's typically denoted as V_H.
3. Peak Voltage (Vpk): The peak voltage of an AC waveform is the maximum voltage value reached during each cycle. For a sinusoidal waveform, it's $Vpk=\sqrt{2}\times Vrms$, where $Vrms$ is the root mean square voltage.
4. Triggering Condition: The DIAC conducts when the voltage across it exceeds the breakover voltage (V_{BO}). Therefore, for a DIAC to trigger, the peak voltage of the AC waveform must be greater than or equal to the breakover voltage ($Vpk \geq V_{BO}$).
5. Current Conduction: Once the DIAC triggers, it conducts in both directions until the current drops below a certain level. It acts as a bidirectional switch.
6. Application: DIACs are commonly used in conjunction with triacs or SCRs in phase control circuits for dimmers, motor speed controllers, light dimming circuits, etc.

PROBLEM

Suppose we have a DIAC with the following characteristics:

- Breakover voltage (VBO) = 30 V
- Holding voltage (VH) = 5 V

We also have an AC voltage source with a peak voltage (Vpk) of 50 V.

1. Determine if the DIAC will trigger with this AC voltage source.
2. If the DIAC triggers, calculate the effective voltage across the load.

1. Triggering Condition: For the DIAC to trigger, the peak voltage of the AC waveform (Vpk) must be greater than or equal to the breakover voltage (VBO). $Vpk \geq VBO$ 50 V≥30 V

The condition is satisfied, so the DIAC will trigger.

2. Effective Voltage Across Load: When the DIAC triggers, it conducts current through the load. The effective voltage across the load (Vload) is the difference between the peak voltage of the AC waveform and the holding voltage of the DIAC.

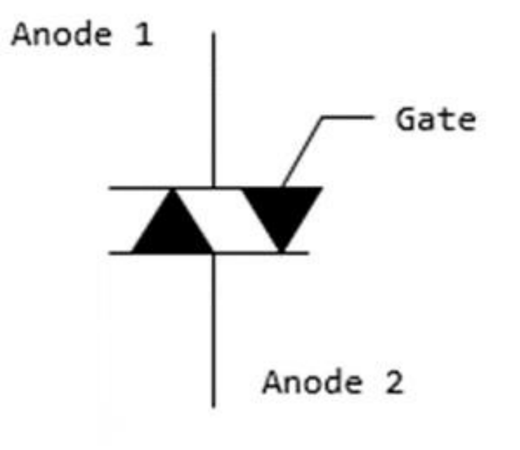
$V\text{load}=Vpk-VH$

$V\text{load}=50\text{ V}-5\text{ V}$

$V\text{load}=45\text{ V}$

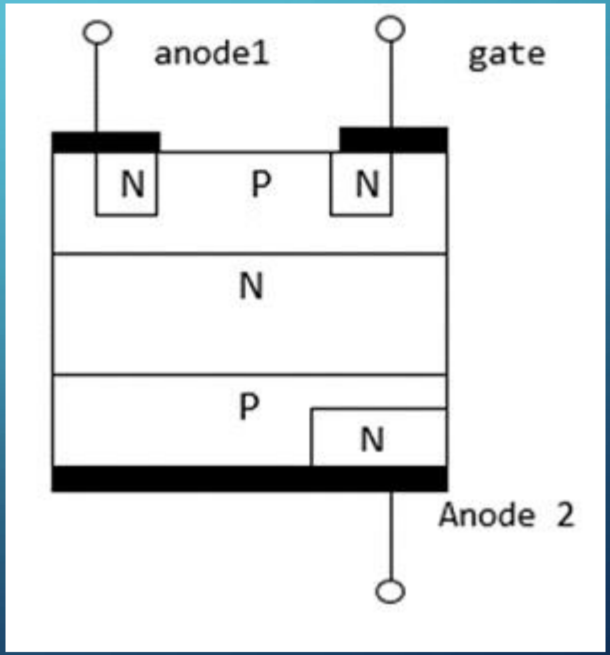
TRIAC

The acronym TRIAC stands for Triode for Alternating Current. A TRIAC is a semiconductor device with three terminals that control the flow of current, thus the name Triac. Unlike SCR, TRIAC is bi-directional while SCR is uni-directional. It is ideal for operation utilizing AC power for switching purposes since it can control current flow for both halves in an alternating current cycle.



TRIAC Structure

The TRIAC Structure is regarded as a DIAC having an extra gate contact incorporated to ensure device control. Similar to other power devices, the TRIAC is manufactured from silicon. Consequently, the process of fabricating the silicon leads to the production of cheaper devices. As indicated below, the TRIAC has a six areas namely; four N-type regions and two P-type regions.



OPERATION OF TRIAC

The triac can be turned on by applying the gate voltage higher than break over voltage. However, without making the voltage high, it can be turned on by applying the gate pulse of 35 micro seconds to turn it on. When the voltage applied is less than the break over voltage, we use gate triggering method to turn it on.

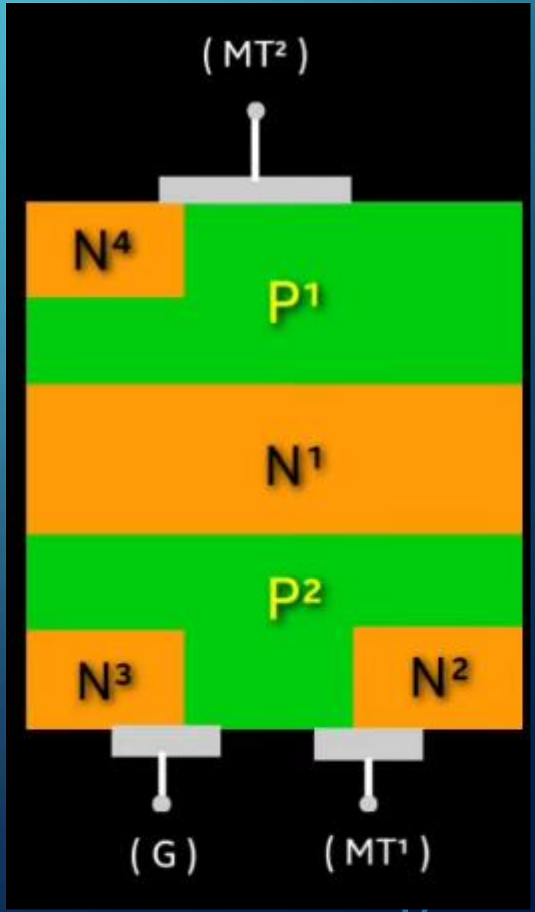
There are four different modes of operations, they are-

1. When MT_2 and Gate being Positive with Respect to MT_1

   When this happens, current flows through the path P_1-N_1-P_2-N_2. Here, P_1-N_1 and P_2-N_2 are forward biased but N_1-P_2 is reverse biased. The triac is said to be operated in positively biased region. Positive gate with respect to MT_1 forward biases P_2-N_2 and breakdown occurs.

2. When MT_2 is Positive but Gate is Negative with Respect to MT_1

   The current flows through the path P_1-N_1-P_2-N_2. But P_2-N_3 is forward biased and current carriers injected into P_2 on the triac.



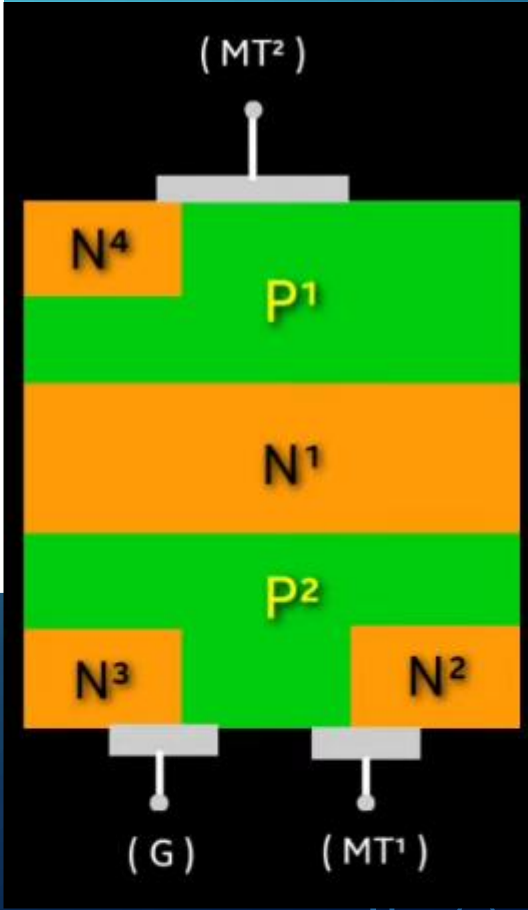
TRIAC

3. When MT_2 and Gate are Negative with Respect to MT_1

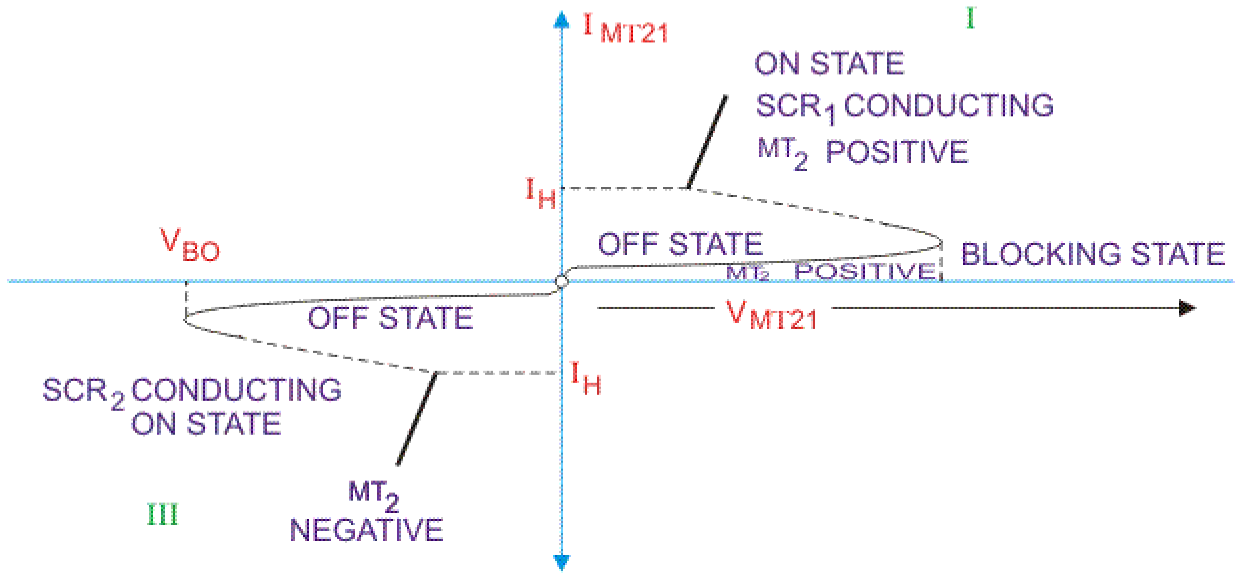
   Current flows through the path P_2-N_1-P_1-N_4. Two junctions P_2-N_1 and P_1-N_4 are forward biased but the junction N1-P1 is reverse biased. The triac is said to be in the negatively biased region.

4. When MT_2 is Negative but Gate is Positive with Respect to MT_1

   P_2-N_2 is forward biased at that condition. Current carriers are injected so the triac turns on. This mode of operation has a disadvantage that it should not be used for high (di/dt) circuits. Sensitivity of triggering in mode 2 and 3 is high and if marginal triggering capability is required, negative gate pulses should be used. Triggering in mode 1 is more sensitive than mode 2 and mode 3.



TRIAC



V-I Characteristic of a Triac

PROBLEM

Suppose we have a TRIAC with the following characteristics:

- Gate trigger voltage (V_{GT}) = 1.5 V
- Gate trigger current (I_{GT}) = 50 mA
- Holding current (I_H) = 10 mA

We also have an AC voltage source with a peak voltage (V_{pk}) of 120 V and a frequency of 60 Hz.

1. Determine if the TRIAC will trigger with this AC voltage source.
2. If the TRIAC triggers, calculate the effective voltage across the load.

- Triggering Condition: For the TRIAC to trigger, both gate trigger voltage and gate trigger current must be exceeded. $V_{gate} \geq V_{GT}$ $I_{gate} \geq I_{GT}$
- Since the TRIAC's gate trigger voltage is 1.5 V and gate trigger current is 50 mA, we need to check if the control circuit can provide these values. If the control circuit ensures that the gate voltage is at least 1.5 V and the control circuit ensures that the gate current is at least 50 mA, then this condition is met.

PROBLEM

- **Effective Voltage Across Load:** To calculate the effective voltage across the load when the TRIAC triggers, we need to consider the voltage drop across the TRIAC during conduction. The TRIAC typically has a small voltage drop when conducting, which we'll denote as VTRIAC. Then, the effective voltage across the load (Vload) is the difference between the peak voltage of the AC waveform and VTRIAC.

We'll assume a typical forward voltage drop for the TRIAC and calculate VTRIAC.
Let's proceed with the calculation:
Calculate VTRIAC: The TRIAC's forward voltage drop is typically small, let's assume it to be around 1 V. $V\text{TRIAC} \approx 1\text{ V}$
Calculate Vload:

$V\text{load} = Vpk - V\text{TRIAC}$

$V\text{load} = 120\text{ V} - 1\text{ V}$

$V\text{load} = 119\text{ V}$

Thank You!