Electronic-Circuit II
Chap 3 Power Electronics
Silicon Controlled Rectifier

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Course Homepage
www.courses.esmartdesign.com

Introduction

- Thyristor Family
  - SCR
  - Triac
  - GTO
  - MCT
  - IGCT
- Thyristors have been the traditional workhorses for bulk power conversion and control in industry
- The term "thyristor" came from its gas tube equivalent, thyratron

Silicon Controlled Rectifier (SCR)

- Belongs to a thyristor family of semiconductors
- The Silicon Controlled Rectifier is the most popular of the thyristor family of four layer regenerative devices so it is used synonymously with thyristor
- Compared to transistors
  - Have lower on-state conduction losses & handle higher power
  - Have slower switching speeds and higher switching losses

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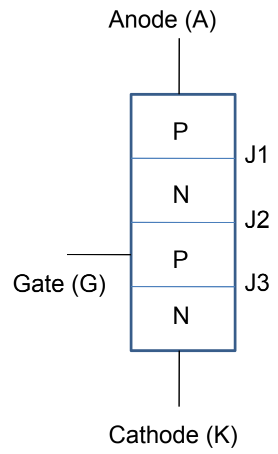
SCR Introduction

- A thyistor is a four layered semiconductor device of p-n-p-n structure with three p-n junction
- It has 3 p-n junctions and 3 terminals
- It is normally turned on by the application of a gate pulse when a forward bias voltage is present at the main terminals.
- However, being regenerative or 'latching', it cannot be turned off via the gate terminals



Structure of SCR

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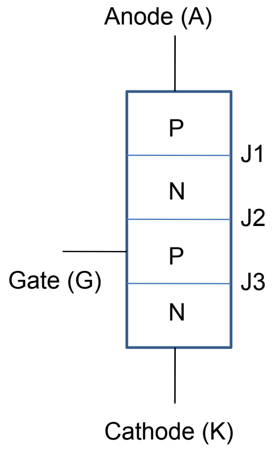
SCR Characteristics

- When V_{AK}=positive (anode made more positive)
  - Junction J_1 and J_3 are forward biased
  - Junction J_2 Is reverse biased
  - Small leakage current flows from anode to cathode (I_D= off-state current)
  - Forward blocking or off-state condition



Structure of SCR

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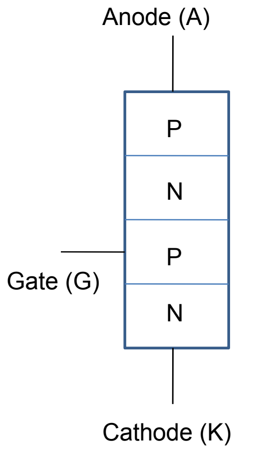
SCR Characteristics contd…

- When V_{AK} is increased sufficiently
  - Such that J2 breaks down (avalanche)
  - VAK= VBO (forward breakdown voltage)
  - Large forward current (Device ON)
  - Typical voltage drop =1V (Ohmic drop)
  - Anode current limited by external resistance
  - Anode current must exceed latching current
  - Works as a normal diode once turned ON



Structure of SCR

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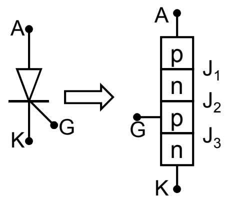
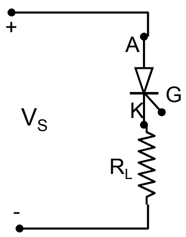
SCR Characteristics contd..

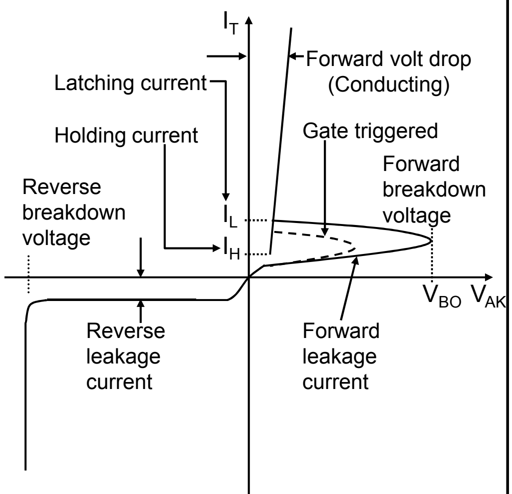
- When V_{AK}=negative
  - Junction J1 and J3 are reverse biased
  - Junction J2 Is forward biased
  - Small leakage current flows from cathode to anode (IR= reverse current)
  - Reverse blocking state





SCR Characteristics contd..

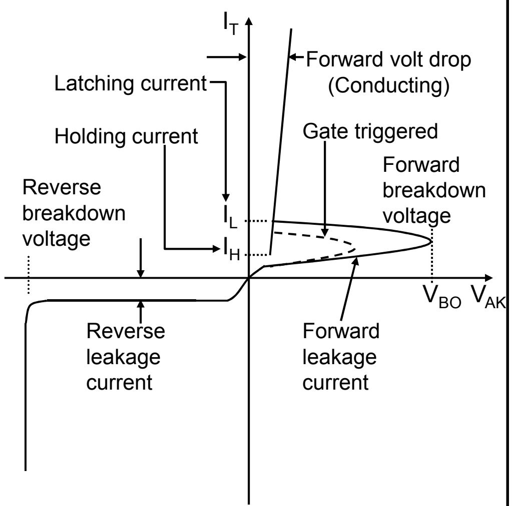
- When V_{AK} is greater than or equal to V_{BO}
  - Device turned ON
  - Anode current > I_L in order to maintain the amount of carrier flow across the junction
  - Otherwise the device reverts back to off-state
- Latching Current
  - Minimum anode current to maintain the thyristor in on-state immediately after it has been turned ON and gating signal has been removed



V-I Characteristics

SCR Characteristics contd..

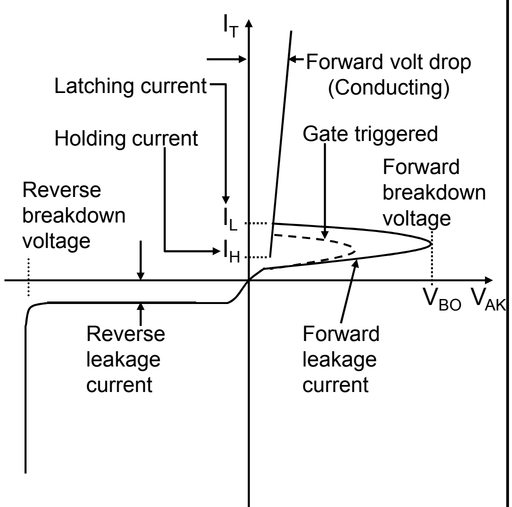
- Once the device is ON it operates a normal diode and there is no control over the device
- The device conducts as if there is an absence of the depletion region
- In ON state if the anode current is lowered below the Holding current, depletion region forms due to reduced no. of carriers and switches to blocking state



V-I Characteristics

SCR Characteristics contd..

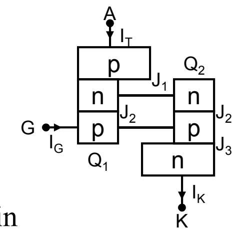
- Holding Current
  - Minimum anode current to maintain the thyristor in ON state
- Switching thyristor by making $V_{AK}>V_{BO}$ leads to destructive turn ON
- Thyristor can be turned ON with $V_{AK}<V_{BO}$ and applying positive gate voltage
- Once conducting the gate signal can be removed if the anode current > holding current

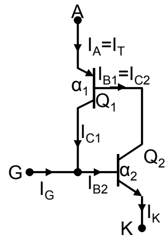


V-I Characteristics

Two Transistor model of thyristor

- Can be separated into pnp (Q1) & npn (Q2)





$$I_C = \alpha I_E + I_{CBO}$$

$$\alpha \approx \frac{I_C}{I_E} = \text{common base current gain}$$

$$I_{C1} = \alpha_1 I_A + I_{CBO1}$$

$$I_{C2} = \alpha_2 I_K + I_{CBO2}$$

$$I_A = I_{C1} + I_{C2} = \alpha_1 I_A + I_{CBO1} + \alpha_2 I_K + I_{CBO2}$$

For a gating current I_G, $I_K = I_A + I_G$

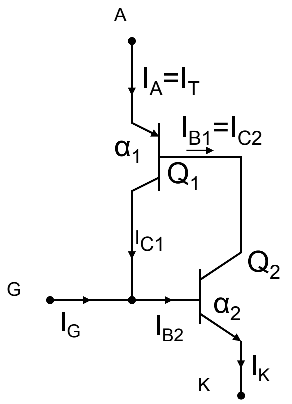
$$I_A = \frac{I_{CBO1} + I_{CBO2} + \alpha_2 I_G}{1 - (\alpha_1 + \alpha_2)}$$

Two transistor model contd…

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

- The device is in off state when $\alpha_1 + \alpha_2 << 1$. This happens for lower value of I_E (or I_A, I_K). In this case I_A is equal to the sum of the leakage currents.
- When $\alpha_1 + \alpha_2$ is nearly equal to 1, the current increases without limit and the device is in the ON state

Regenerative Feedback in SCR

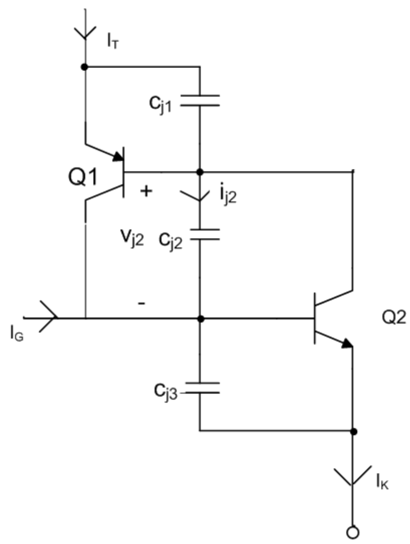


- If I_{C1} increases, I_{B2} increases which increases I_{C2} ($I_{C2}=\beta I_{B2}$). This increases I_{B1} ($I_{B1}= I_{C2}$) which then further increases I_{C1} ($I_{C1}=\beta I_{B1}$)
- IC1↑ IB2↑ IC2↑ IB1↑ IC1↑

Two-transistor transient model

$$i_{j2} = \frac{d(q_{j2})}{dt} = \frac{d(C_{j2}V_{j2})}{dt}$$

$$i_{j2} = V_{j2}\frac{d(C_{j2})}{dt} + C_{j2}\frac{d(V_{j2})}{dt}$$



Numerical

- The capacitance of reverse-biased junction J2 in a thyristor is C_{J2} =20 pF and can be assumed to be independent of the off-state voltage. The limiting value of the charging current to turn on the thyristor is 16 mA. Determine the critical value of dv/dt.

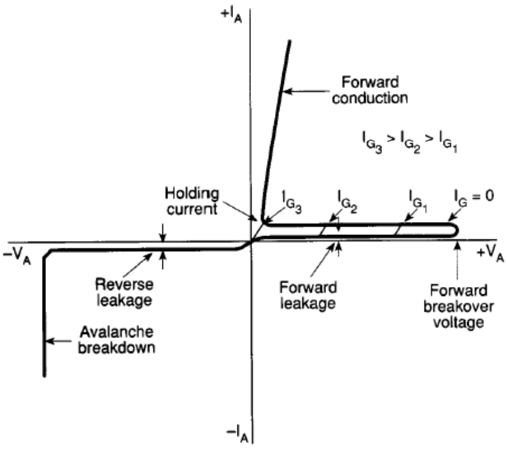
(Ans: 800V/μs)

Methods to turn on the SCR

- Thermal
  - High temperature → increase in electron-hole pairs →increase in leakage current → increase in α_1 and α_2
  - Regenerative action leads to (α_1 + α_2)=unity turning ON the device
  - Thermal runaway must be avoided
- Light
  - Light striking the junction may increase electron hole pairs
- High Voltage
  - When $V_{AK} > V_{BO}$
  - Maybe destructive TURN ON

Thyristor Turn on Methods contd.

- When the thyristor is forward biased
  - Injection of gate curren →applying +ve voltage between gate and cathode
  - Increasing gate current →increases gating voltage →reduces forward blocking voltage
- Gating signal should be removed after turn ON to decrease power loss



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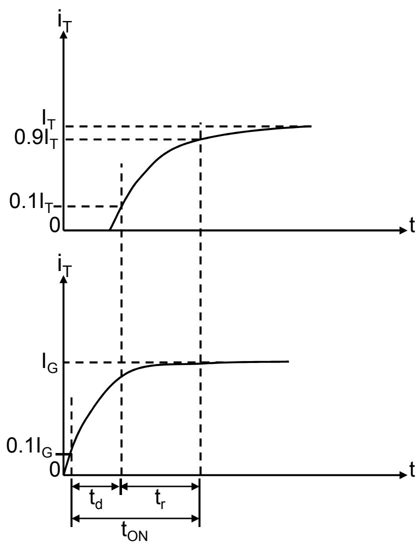
Thyristor turn on Parameters………

- Device turns ON after time delay t_{ON}
- t_{ON}=delay time (t_d) + rise time (t_r)
- t_{ON}→ time interval between 10% gate current to 90% steady state current
- t_d→ time interval between 10% gate current to 10% ON state current
- t_r→ time interval between 10% ON current to 90% ON state current



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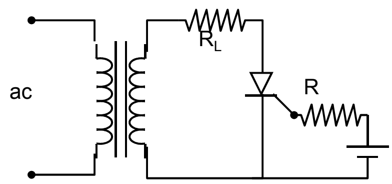
Assignment-1

- Write short notes on Thyristor Commutation Techniques, DIAC and TRIAC
  – Deadline: Tomorrow 2:00 PM

SCR Half Wave Rectifier

- Same a normal diode rectifier
- The average output voltage however differs
- Conduction is defined by the phase of gating signal



If $v = V_m \sin\theta$ is the input signal

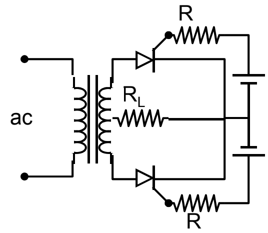
Average output is,

$$V_{av} = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin\theta d\theta = \frac{V_m}{2\pi}[-\cos\theta]_{\alpha}^{\pi}$$

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

SCR Full wave Rectifier

- Same a normal diode rectifier
- The average output voltage however differs
- Conduction is defined by the phase of gating signal



If $v = V_m \sin\theta$ is the input signal

Average output is,

$$V_{av} = \frac{2}{2\pi}\int_{\alpha}^{\pi} V_m \sin\theta d\theta = \frac{V_m}{\pi}[-\cos\theta]_{\alpha}^{\pi}$$

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