Lecture Notes

Gate Turn-off Thyristors (GTOS)

William P. Robbins
Professor, Dept. of Electrical and Computer Engineering
University of Minnesota

OUTLINE

• GTO construction and I-V characteristics.
• Physical operation of GTOs.
• Switching behavior of GTOS
GTO (Gate Turn-off Thyristor) Construction

- Unique features of the GTO.
  - Highly interdigitated gate-cathode structure (faster switching)
  - Etched cathode islands (simplify electrical contacts)
  - Anode shorts (speed up turn-off)
  - GTO has no reverse blocking capability because of anode shorts
  - Otherwise i-v characteristic the same as for standard SCR

GTO circuit symbol
GTO Turn-off Gain

- Turn off GTO by pulling one or both of the BJTs out of saturation and into active region.

- Force Q2 active by using negative base current $I_G'$
  
  $\frac{I_{C2}}{\beta_2}$

  $I_{B2} = \alpha_1 I_A - I_G'$
  $I_{C2} = (1 - \alpha_1) I_A$

- $\alpha_1 I_A - I_G' < \frac{(1 - \alpha_1) I_A}{\beta_2} = \frac{(1 - \alpha_1)(1 - \alpha_2) I_A}{\alpha_2}$

- $I_G' > \frac{I_A}{\beta_{off}}$
  $\beta_{off} = \frac{\alpha_2}{(1 - \alpha_1 - \alpha_2)}$ = turn-off gain

- Large turn-off gain requires $\alpha_2 \approx 1, \alpha_1 << 1$

- Make $\alpha_1$ small by
  1. Wide $n_1$ region (base of Q1) - also needed for large blocking voltage
  2. Short lifetime in $n_1$ region to remove excess carriers rapidly so Q1 can turn off

- Short lifetime causes higher on-state losses

- Anode shorts helps resolve lifetime dilemma
  1. Reduce lifetime only moderately to keep on-state losses reasonable
  2. $N^+$ anode regions provide a sink for excess holes - reduces turn-off time

- Make $\alpha_2 \approx$ unity by making $p_2$ layer relatively thin and doping in $n_2$ region heavily (same basic steps used in making beta large in BJTs).

- Use highly interdigitated gate-cathode geometry to minimize cathode current crowding and di/dt limitations.

GTOs - 3

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Maximum Controllable Anode Current

- Large negative gate current creates lateral voltage drops which must be kept smaller than breakdown voltage of $J_3$.

- If $J_3$ breaks down, it will happen at gate-cathode periphery and all gate current will flow there and not sweep out any excess carriers as required to turn-off GTO.

- Thus keep gate current less than $I_{G,max}$ and so anode current restricted by $I_A < I_{G,max} \beta_{off}$.
GTO Step-down Converter

• GTO used in medium-to-high power applications where electrical stresses are large and where other solid state devices used with GTOs are slow e.g. free-wheeling diode $D_F$.

• GTO almost always used with turn-on and turn-off snubbers.

  1. Turn-on snubber to limit overcurrent from $D_F$ reverse recovery.

  2. Turn-off snubber to limit rate-of-rise of voltage to avoid retriggering the GTO into the on-state.

• Hence should describe transient behavior of GTO in circuit with snubbers.
GTOs - 6
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GTO Turn-on Waveforms

- GTO turn on essentially the same as for a standard thyristor
- Large $I_{GM}$ and large rate-of-rise insure all cathode islands turn on together and have good current sharing.
- Backporch current $I_{GT}$ needed to insure all cathode islands stay in conduction during entire on-time interval.
- Anode current overshoot caused by free-wheeling diode reverse recovery current.
- Anode-cathode voltage drops precipitously because of turn-on snubber
GTO Turn-off Waveforms

• $t_s$ interval
  Time required to remove sufficient stored charge to bring BJTs into active region and break latch condition

• $t_{fi}$ interval
  1. Anode current falls rapidly as load current commutates to turn-off snubber capacitor
  2. Rapid rise in anode-cathode voltage due to stray inductance in turn-off snubber circuit

• $t_{w2}$ interval
  1. Junction J3 goes into avalanche breakdown because of inductance in trigger circuit. Permits negative gate current to continuing flowing and sweeping out charge from $p_2$ layer.
  2. Reduction in gate current with time means rate of anode current commutation to snubber capacitor slows. Start of anode current tail.

• $t_{tail}$ interval
  1. Junction J3 blocking, so anode current = negative gate current. Long tailing time required to remove remaining stored charge.
  2. Anode-cathode voltage growth governed by turn-off snubber.
  3. Most power dissipation occurs during tailing time.