

Power Converter Systems

Graduate Course EE8407

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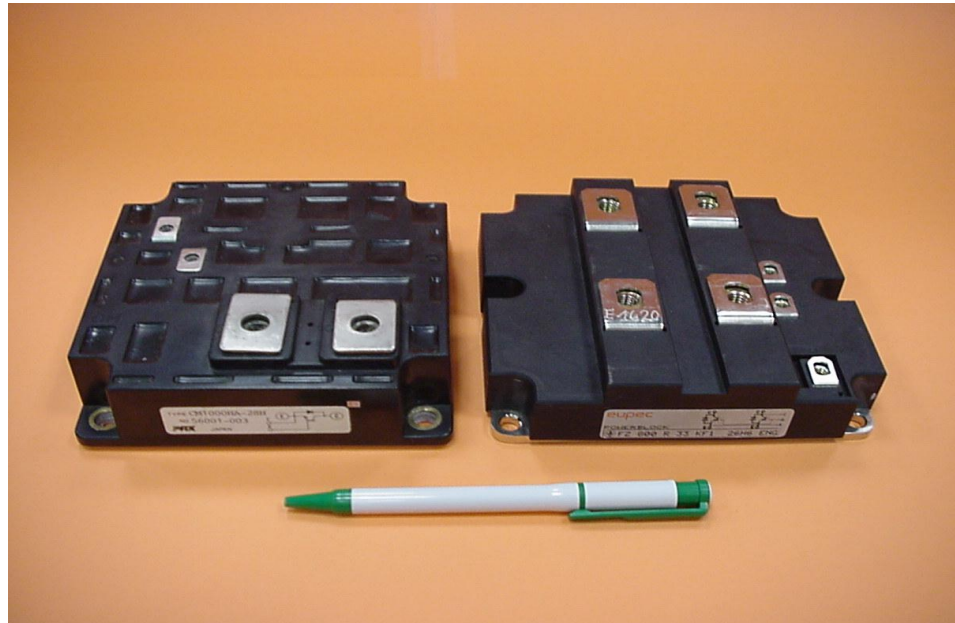
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Ryerson Campus

Topic 2

High-Power Semiconductor Devices



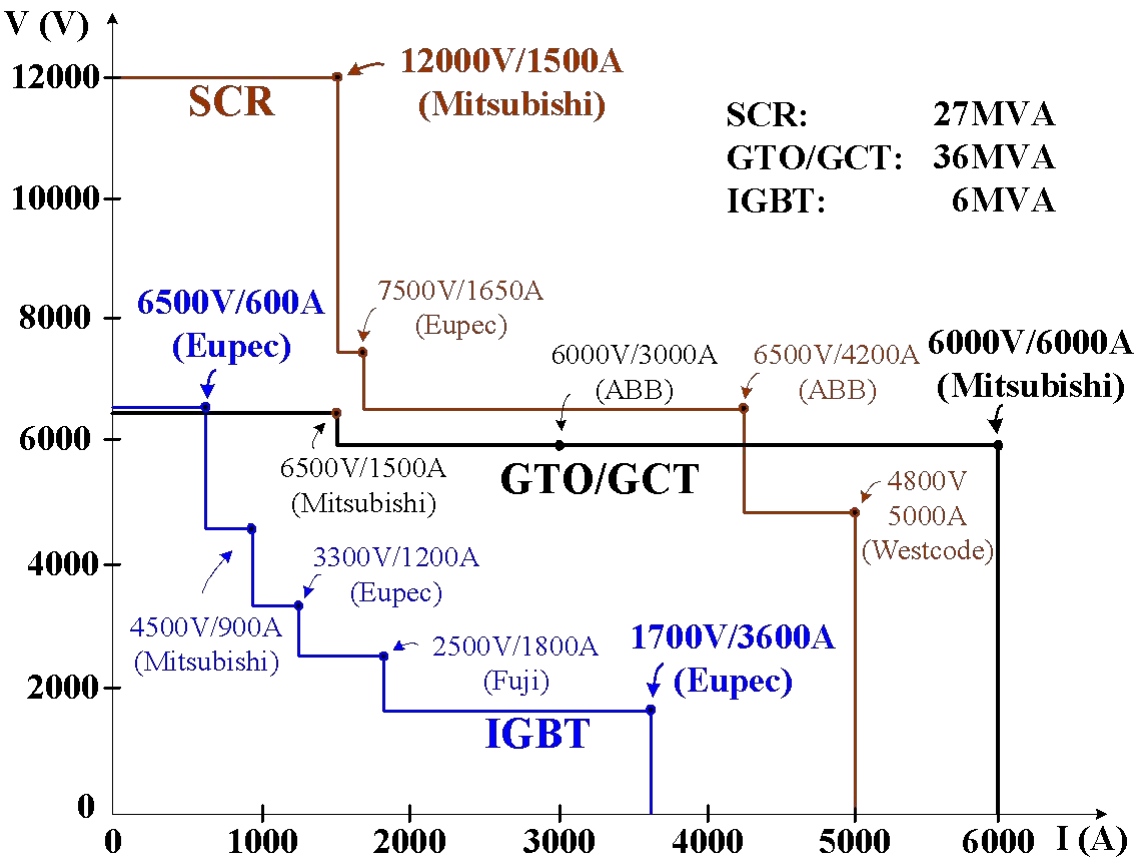
High-Power Semiconductor Devices

Lecture Topics

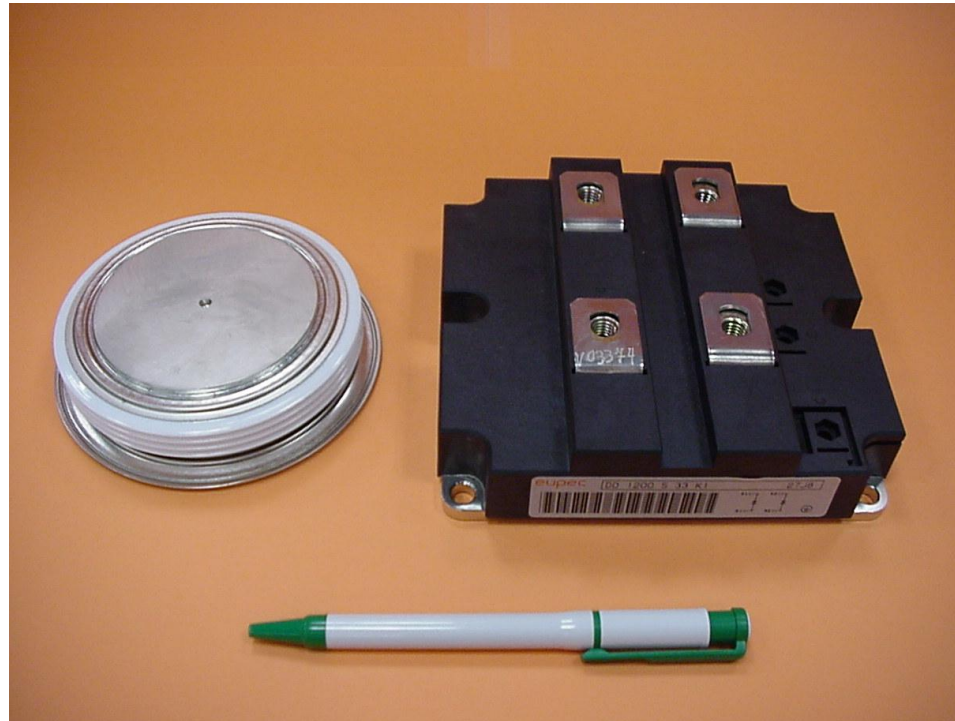
- Power Diode
- SCR Thyristor
- Gate Turn-Off Thyristor (GTO)
- Integrated Gate Commutated Thyristor (GCT)
- Insulated Gate Bipolar Transistor (IGBT)
- Switch Series Operation

High-Power Semiconductor Devices

• Device Rating



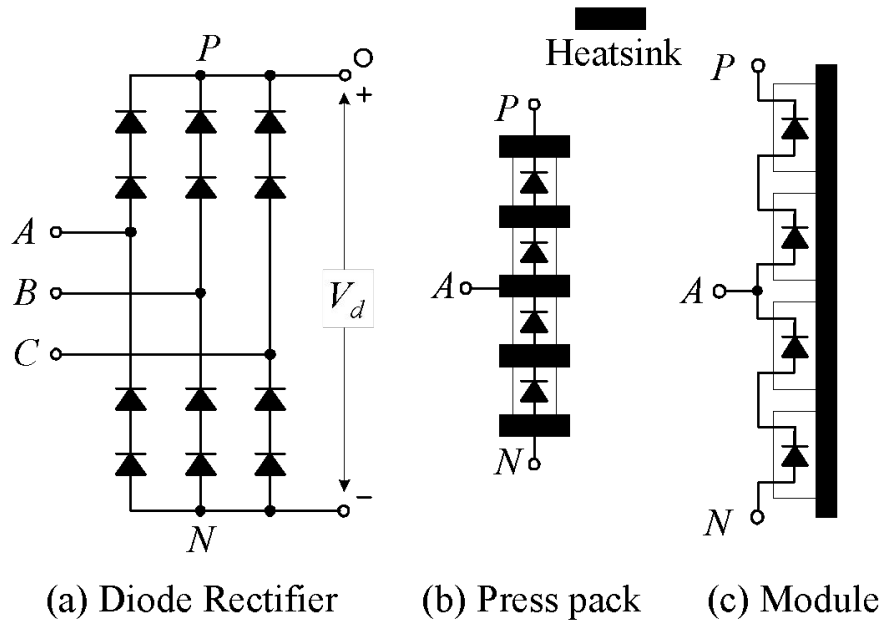
Power Diode



4500V/800A press pack and 1700V/1200A module diodes

Power Diode

• Heatsink Assembly



(a) Diode Rectifier

(b) Press pack

(c) Module

Press pack device:

- Double sided cooling
- Low assembly cost and high power density
- Preferred choice for high voltage high power applications

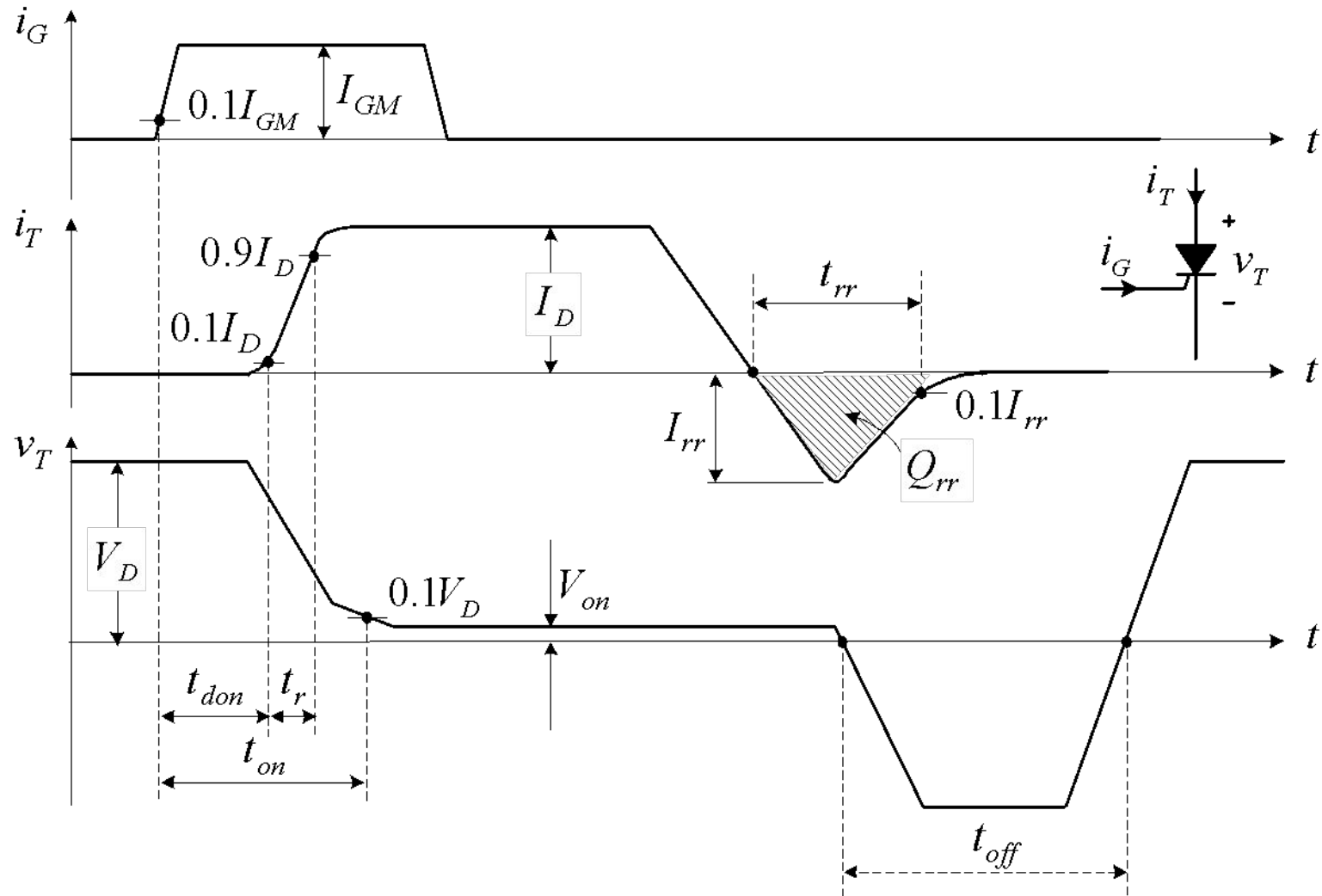
SCR Thyristor



4500V/800A and 4500V/1500A SCRs

SCR Thyristor

• Switching Characteristics



SCR Thyristor

• Main Specifications

12000V/1500A SCR Thyristor

| | | | | | |
|--|--------------------|-----------------------|---|----------------|--------------|
| Maximum Rating | V_{DRM} | V_{RRM} | I_{TAVM} | I_{TRMS} | - |
| | 12000V | 12000V | 1500A | 2360A | - |
| Switching Characteristics | Turn-on Time | Turn-off Time | di_T/dt | dv_T/dt | Q_{rr} |
| | $t_{on} = 14\mu s$ | $t_{off} = 1200\mu s$ | 100A/ μs | 2000V/ μs | 7000 μC |
| V_{DRM} – Repetitive peak off-state voltage I_{TAVM} – Maximum average on-state current $Q_{rr} = \frac{t_{rr} I_{rr}}{2}$ – Reverse recovery Charge | | | V_{RRM} – Repetitive peak reverse voltage I_{RRMS} – Maximum rms on-state current Part number – FT1500AU-240 (Mitsubishi) | | |

Gate Turn-Off (GTO) Thyristor



4500V/800A and 4500V/1500A GTOs

Gate Turn-Off (GTO) Thyristor

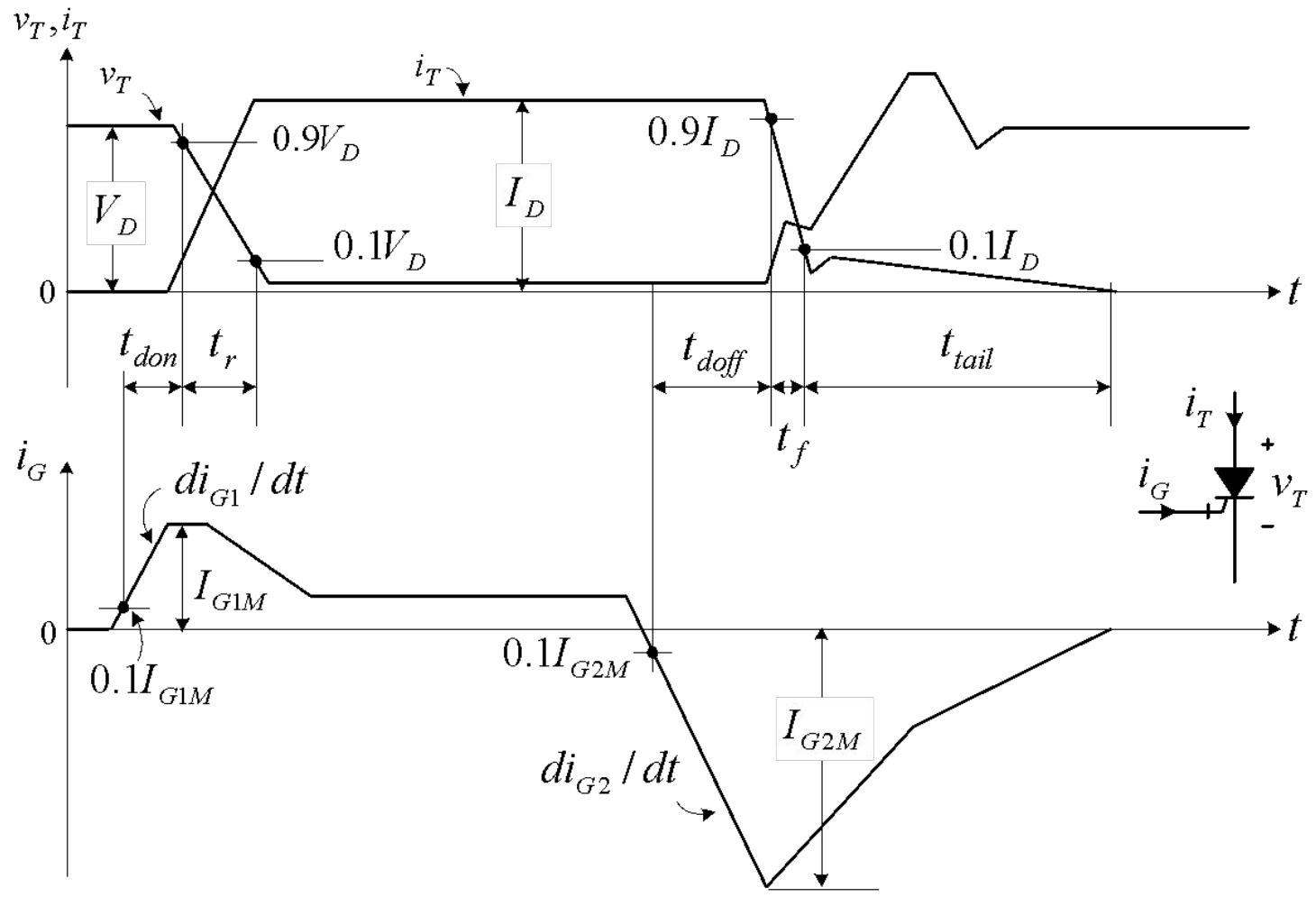
- Symmetrical versus Asymmetrical GTOs

| Type | Blocking Voltage | Example (6000V GTOs) | Applications |
|-------------------------|---------------------------|--|--|
| Asymmetrical GTO | $V_{RRM} \ll V_{DRM}$ | $V_{DRM} = 6000V$ $V_{RRM} = 22V$ | For use in voltage source inverters with anti-parallel diodes. |
| Symmetrical GTO | $V_{RRM} \approx V_{DRM}$ | $V_{DRM} = 6000V$ $V_{RRM} = 6500V$ | For use in current source inverters. |

V_{DRM} - Maximum repetitive peak (forward) off-state voltage
 V_{RRM} - Maximum repetitive peak reverse voltage

Gate Turn-Off (GTO) Thyristor

• Switching Characteristics



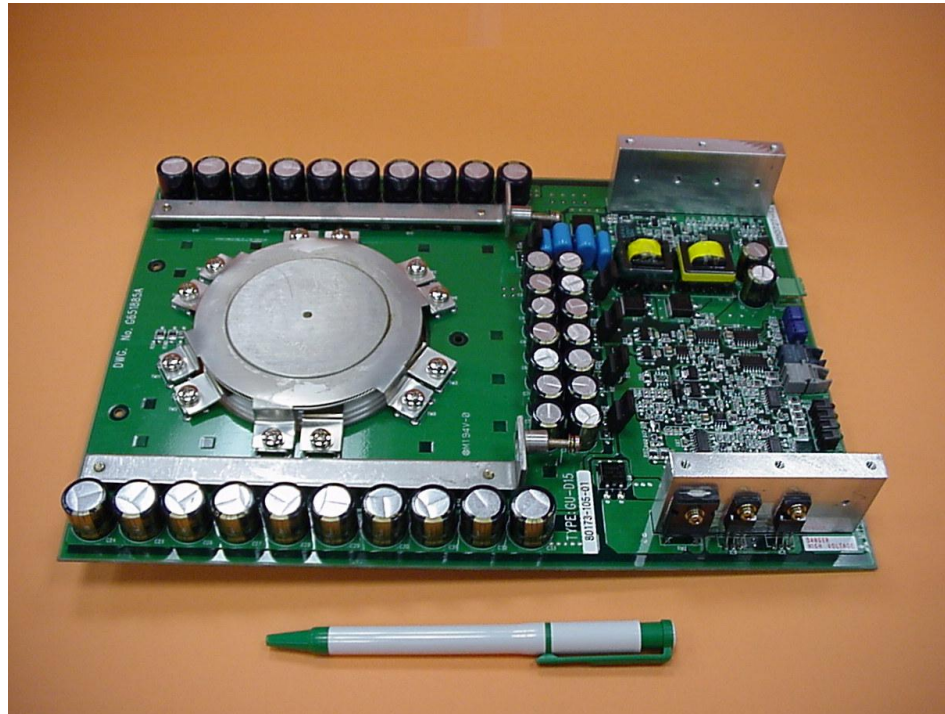
Gate Turn-Off (GTO) Thyristor

• Main Specifications

4500V/4000A Asymmetrical GTO Thyristor

| | | | | | | |
|---|---|--|---|---------------|--------------|--------------|
| Maximum Rating | V_{DRM} | V_{RRM} | I_{TGQM} | I_{TAVM} | I_{TRMS} | - |
| | 4500V | 17V | 4000A | 1000A | 1570A | - |
| Switching Characteristics | Turn-on Switching | Turn-off Switching | di_T/dt | dv_T/dt | di_{G1}/dt | di_{G2}/dt |
| | $t_{don} = 2.5\mu s$ $t_r = 5.0\mu s$ | $t_{doff} = 25.0\mu s$ $t_f = 3.0\mu s$ | $500A/\mu s$ | $1000V/\mu s$ | $40A/\mu s$ | $40A/\mu s$ |
| On-state Voltage | $V_{T(on-state)} = 4.4V$ at $I_T = 4000A$ | | | | | |
| V_{DRM} - Repetitive peak off-state voltage | | | V_{RRM} - Repetitive peak reverse voltage | | | |
| I_{TGQM} - Repetitive controllable on-state current | | | I_{TAVM} - Maximum average on-state current | | | |
| I_{RRMS} - Maximum rms on-state current | | | Part number - 5SGA 40L4501 (ABB) | | | |

Integrated Gate Commutated Thyristor (GCT)



6500V/1500A Symmetrical GCT

GCT = Improved GTO + Integrated Gate + Anti-parallel Diode (optional)

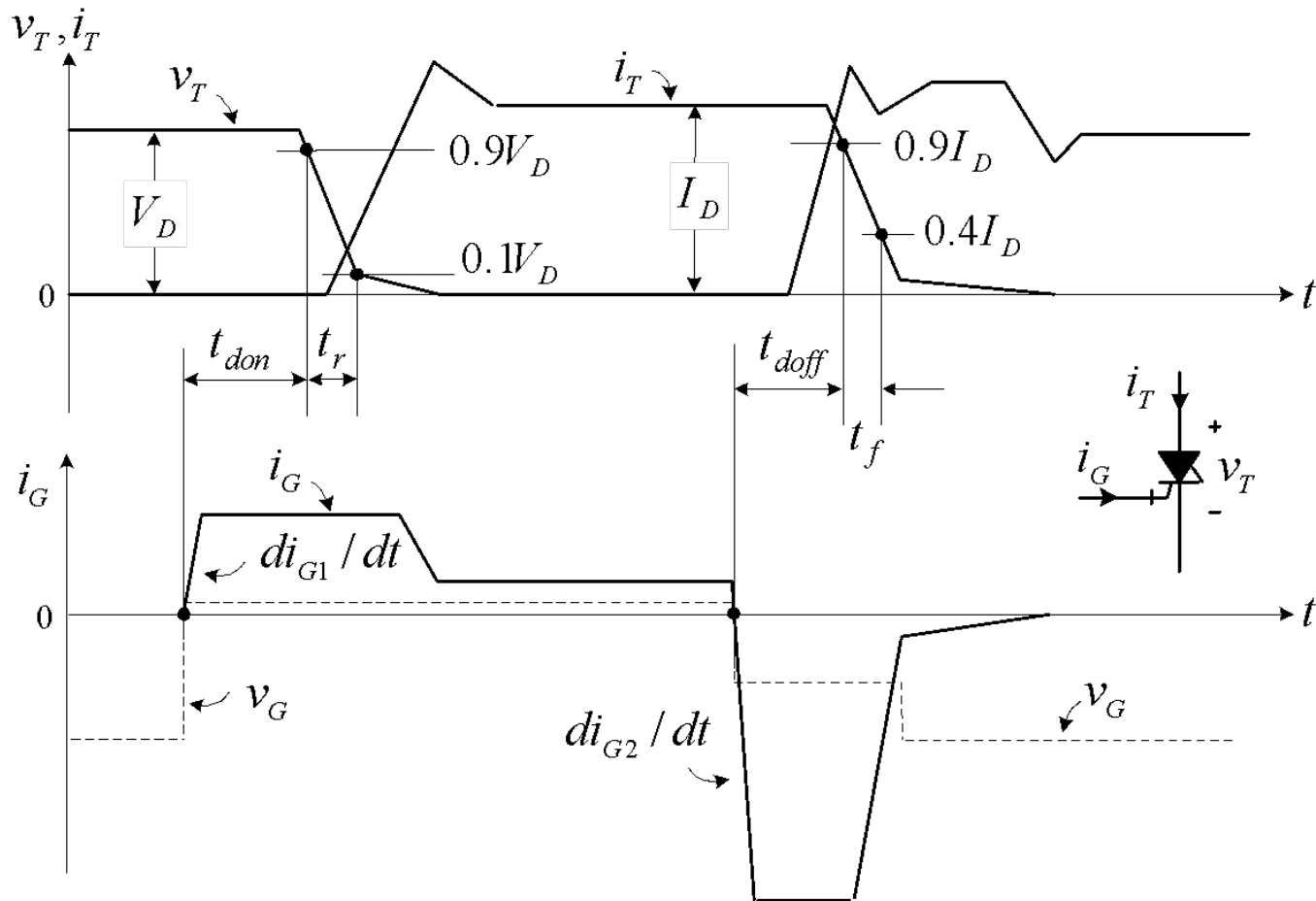
Integrated Gate Commutated Thyristor

• GCT Classifications

| Type | Anti-parallel Diode | Blocking Voltage | Example (6000V GCT) | Applications |
|--|---------------------|---------------------------|--|--|
| Asymmetrical GCT | Excluded | $V_{RRM} \ll V_{DRM}$ | $V_{DRM} = 6000V$ $V_{RRM} = 22V$ | For use in voltage source inverters with anti-parallel diodes. |
| Reverse Conducting GCT | Included | $V_{RRM} \approx 0$ | $V_{DRM} = 6000V$ | For use in voltage source inverters. |
| Symmetrical GCT (Reverse Blocking) | Not required | $V_{RRM} \approx V_{DRM}$ | $V_{DRM} = 6000V$ $V_{RRM} = 6500V$ | For use in current source Inverters. |
| V_{DRM} - Maximum repetitive peak forward off-state voltage V_{RRM} - Maximum repetitive peak reverse voltage | | | | |

Integrated Gate Commutated Thyristor

• Switching Characteristics



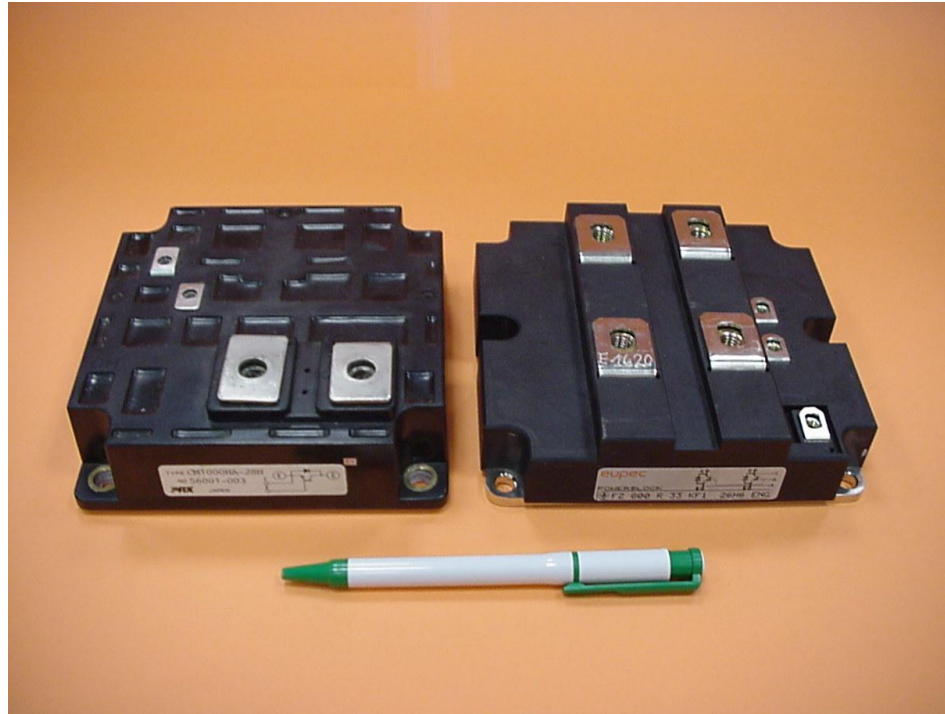
Integrated Gate Commutated Thyristor

• Main Specifications

6000V/6000A Asymmetrical GCT

| | | | | | | |
|---|--|--------------------------------------|---|----------------|---------------|----------------------|
| Maximum Rating | V_{DRM} | V_{RRM} | I_{TGRM} | I_{TAVM} | I_{TRMS} | - |
| | 6000V | 22V | 6000A | 2000A | 3100A | - |
| Switching Characteristics | Turn-on Switching | Turn-off Switching | di_T/dt | dv_T/dt | di_{G1}/dt | di_{G2}/dt |
| | $t_{don} < 1.0\mu s$ $t_r < 2.0\mu s$ | $t_{doff} < 3.0\mu s$ $t_f - N/A$ | 1000A/ μs | 3000V/ μs | 200A/ μs | 10,000 A/ μs |
| On-state Voltage | $V_{T(on-state)} < 4V$ at $I_T = 6000A$ | | | | | |
| V_{DRM} - Repetitive peak off-state voltage | | | V_{RRM} - Repetitive peak reverse voltage | | | |
| I_{TGRM} - Repetitive controllable on-state current | | | I_{TAVM} - Maximum average on-state current | | | |
| I_{RRMS} - Maximum rms on-state current | | | Part number – FGC6000AX120DS (Mitsubishi) | | | |

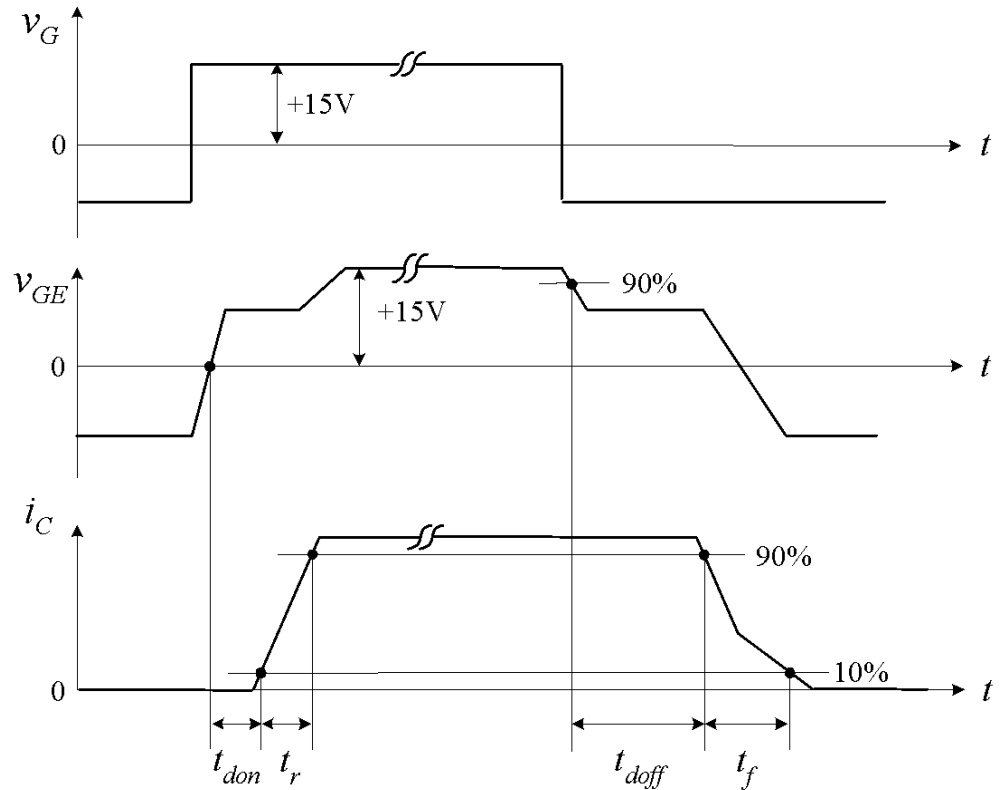
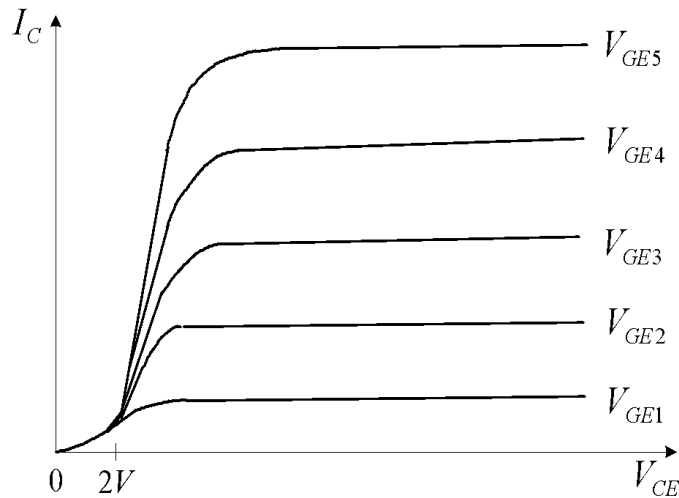
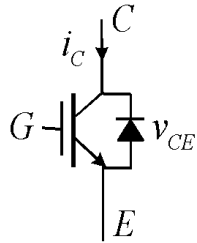
Insulated Gate Bipolar Transistor (IGBT)



1700V/1200A and 3300V/1200A IGBT modules

Insulated Gate Bipolar Transistor (IGBT)

• IGBT Characteristics



Static V-I Characteristics

Switching characteristics

Insulated Gate Bipolar Transistor (IGBT)

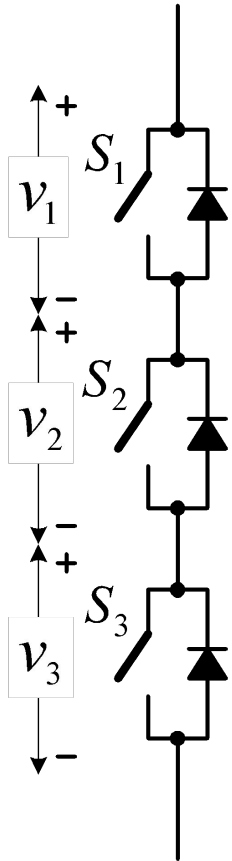
• Main Specifications

3300V/1200A IGBT

| | | | | |
|--|--------------------------------------|--------------|-------------|-------------|
| Maximum Rating | V_{CE} | I_C | I_{CM} | - |
| | 3300V | 1200A | 2400A | - |
| Switching Characteristics | t_{don} | t_r | t_{doff} | t_f |
| | 0.35 μs | 0.27 μs | 1.7 μs | 0.2 μs |
| Saturation Voltage | $I_{CE sat} = 4.3V$ at $I_C = 1200A$ | | | |
| <p>V_{CE} - Rated collector-emitter voltage</p> <p>I_C - Rated dc collector current</p> <p>I_{CM} - Maximum repetitive peak collector current</p> <p>Part number – FZ1200 R33 KF2 (Eupec)</p> | | | | |

Device Series Operation

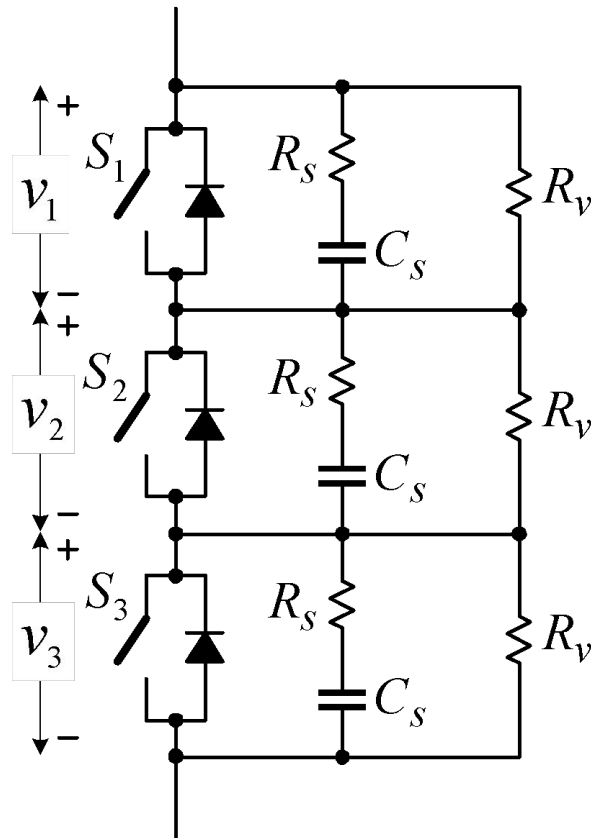
• Cause of Voltage Imbalance



| Type | Causes of Voltage Imbalance | |
|-------------------------|---|---|
| Static Voltage Sharing | ΔI_{lk} – Device off-state leakage current ΔT_j – Junction temperature | |
| Dynamic Voltage Sharing | Device | Δt_{don} – Turn-on delay time Δt_{doff} – Turn-off delay time ΔQ_{rr} – Reverse recovery charge of anti-parallel diode ΔT_j – Junction temperature |
| | Gate Driver | Δt_{GDon} – Gate driver turn-on delay time Δt_{GDoff} – Gate driver turn-off delay time ΔL_{wire} – Wiring inductance between the gate driver and the device gate |
| | Δ – Differences between series connected devices. | |

Device Series Operation

• Equal Voltage Sharing

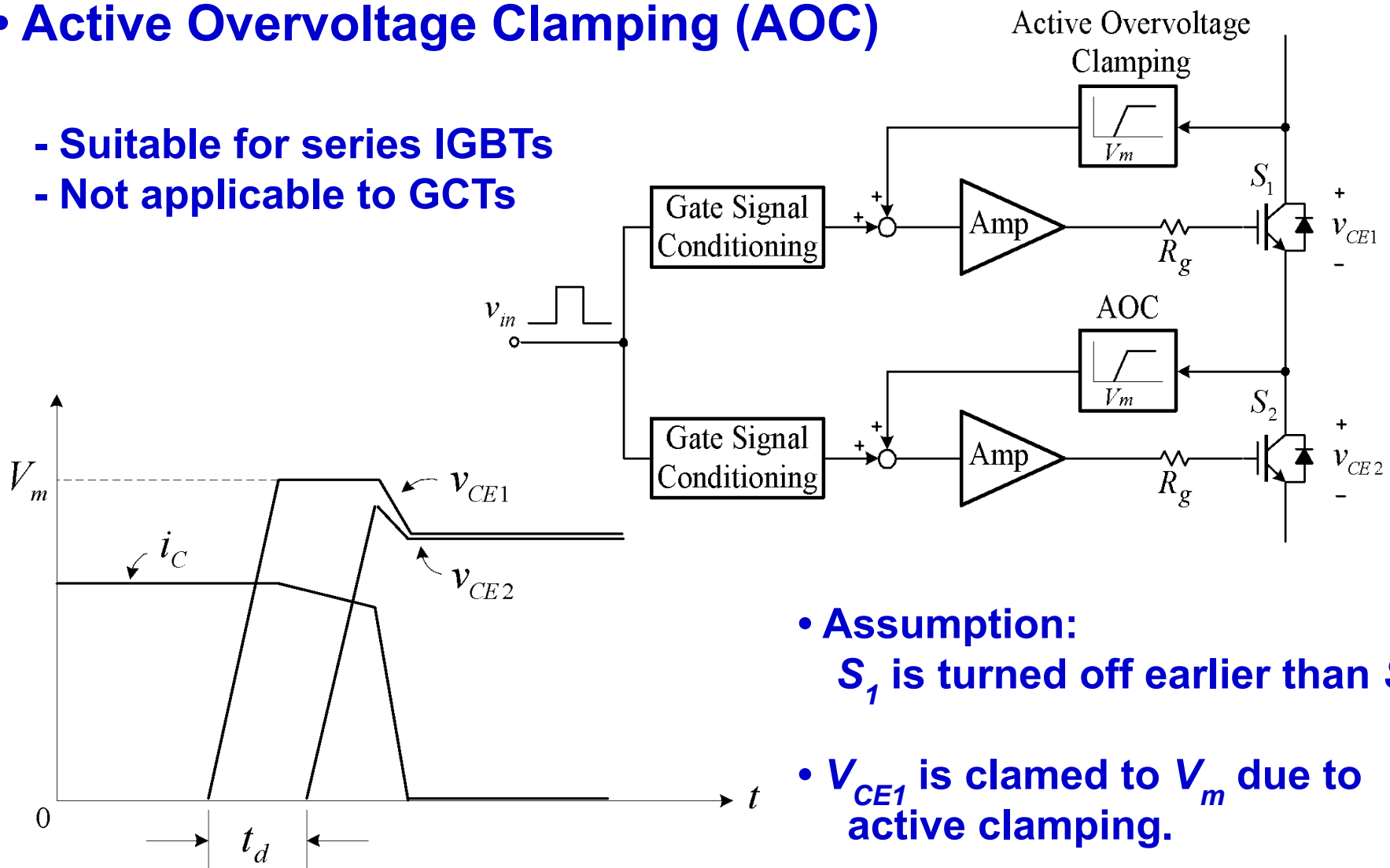


- S_1, S_2, S_3 :
GTO, GCT or IGBT
- Voltage Sharing:
 $V_1 = V_2 = V_3$ in steady state
and transients
- Static Voltage Sharing:
 R_v
- Dynamic Voltage Sharing:
 R_s and C_s

Device Series Operation

• Active Overvoltage Clamping (AOC)

- Suitable for series IGBTs
- Not applicable to GCTs



- Assumption:
 S_1 is turned off earlier than S_2
- V_{CE1} is clamped to V_m due to active clamping.

Summary

| Item | GTO | IGCT | IGBT |
|--|----------------------|------------------------|-----------------------|
| Maximum switch power (Device $V \times I$) | 36MVA | 36MVA | 6MVA |
| Active di/dt and dv/dt control | No | No | Yes |
| Active short circuit protection | No | No | Yes |
| Turn-off (dv/dt) snubber | Required | Not required | No required |
| Turn-on (di/dt) snubber | Required | Required | No required |
| Parallel connection | No | No | Yes |
| Switching speed | Slow | Moderate | Fast |
| Behavior after destruction | Shorted | Shorted | Open in most cases |
| On-state losses | Low | Low | High |
| Switching losses | High | Low | Low |
| Gate Driver | Complex, separate | Complex, integrated | Simple, compact |
| Gate Driver Power Consumption | High | High | Low |



Thanks