

Power Converter Systems

Graduate Course EE8407

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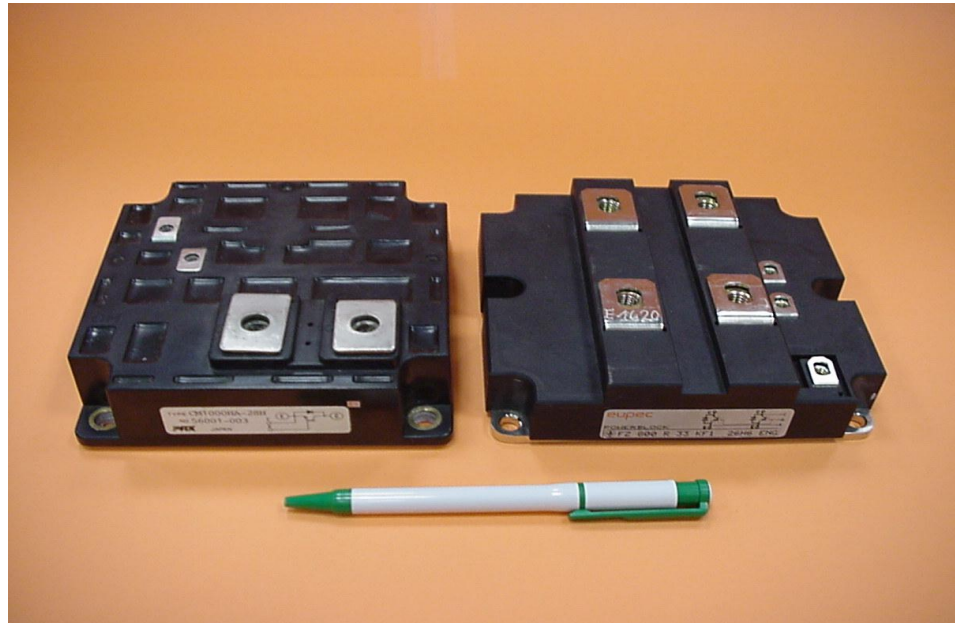
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Ryerson Campus

Topic 2

High-Power Semiconductor Devices



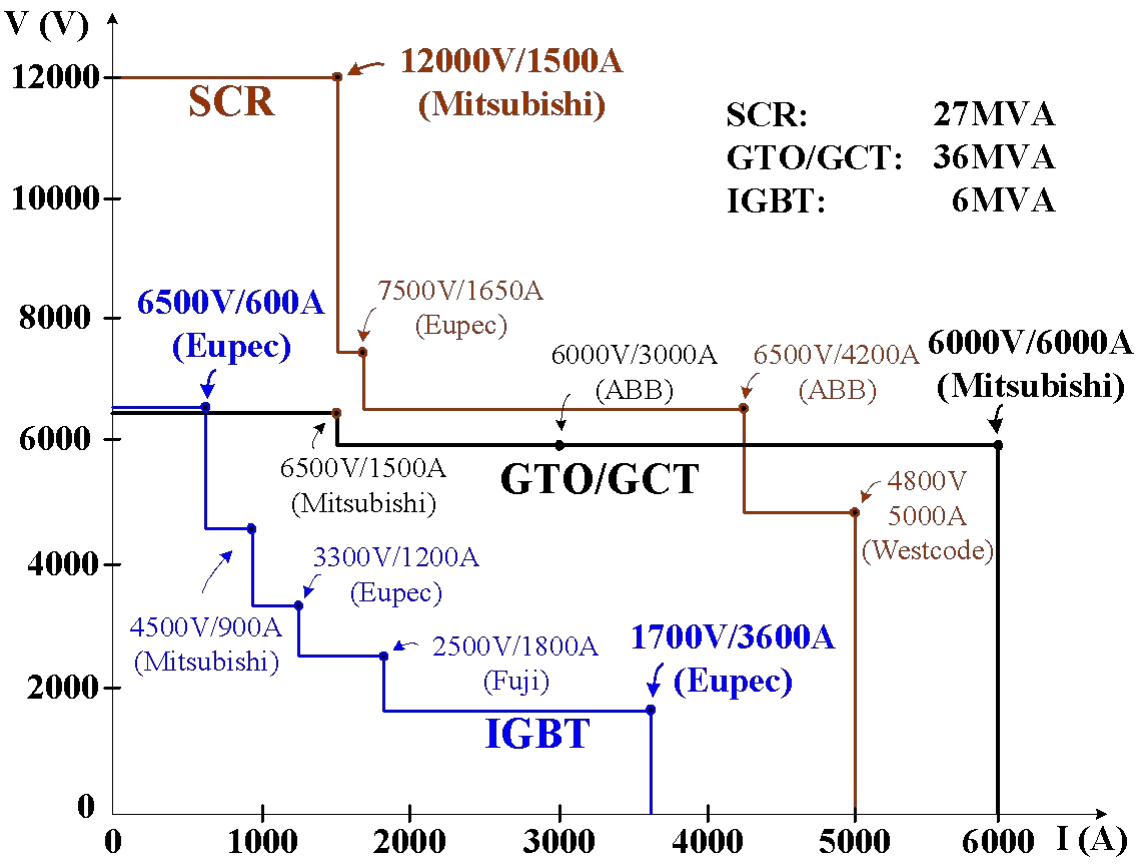
High-Power Semiconductor Devices

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



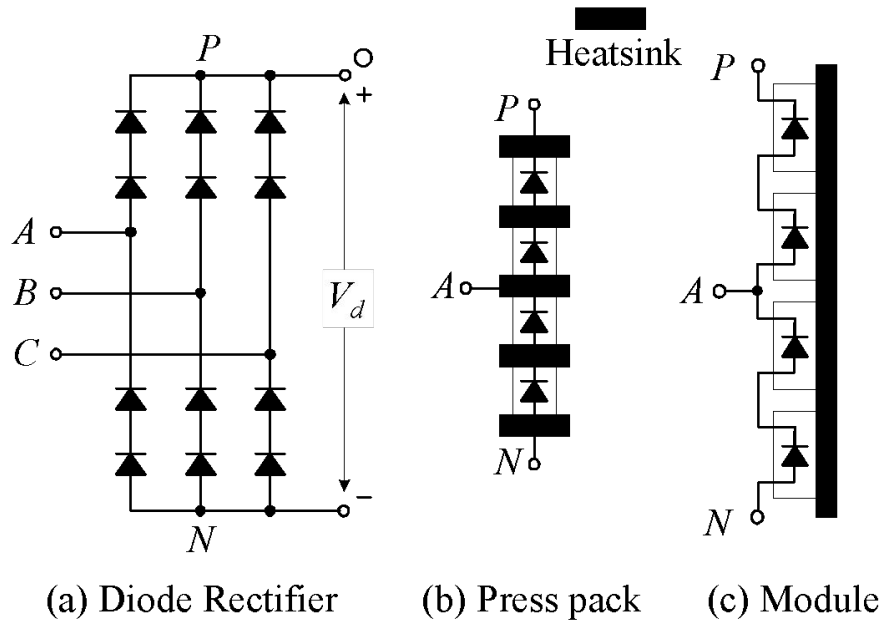
Power Diode



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

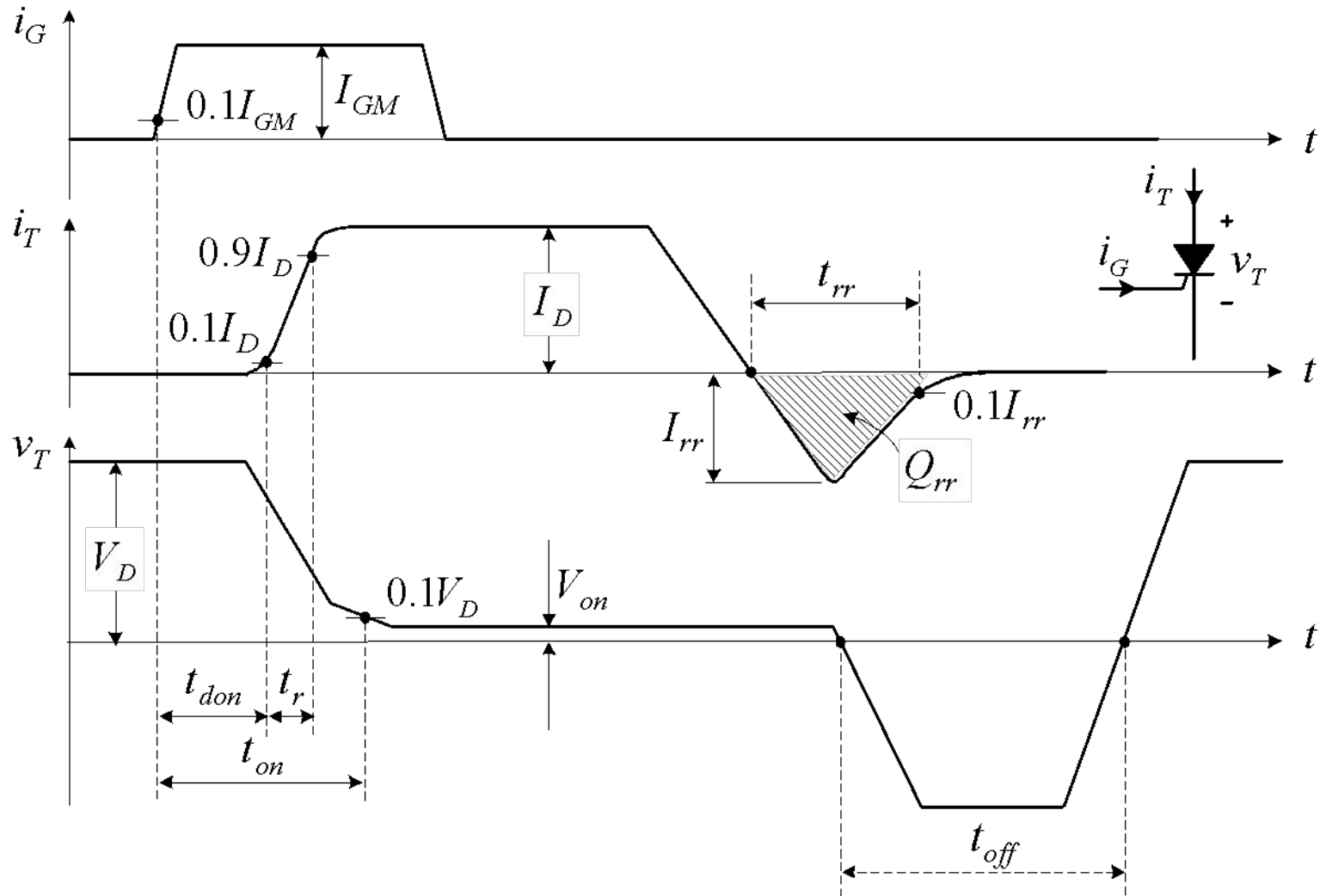
SCR Thyristor



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

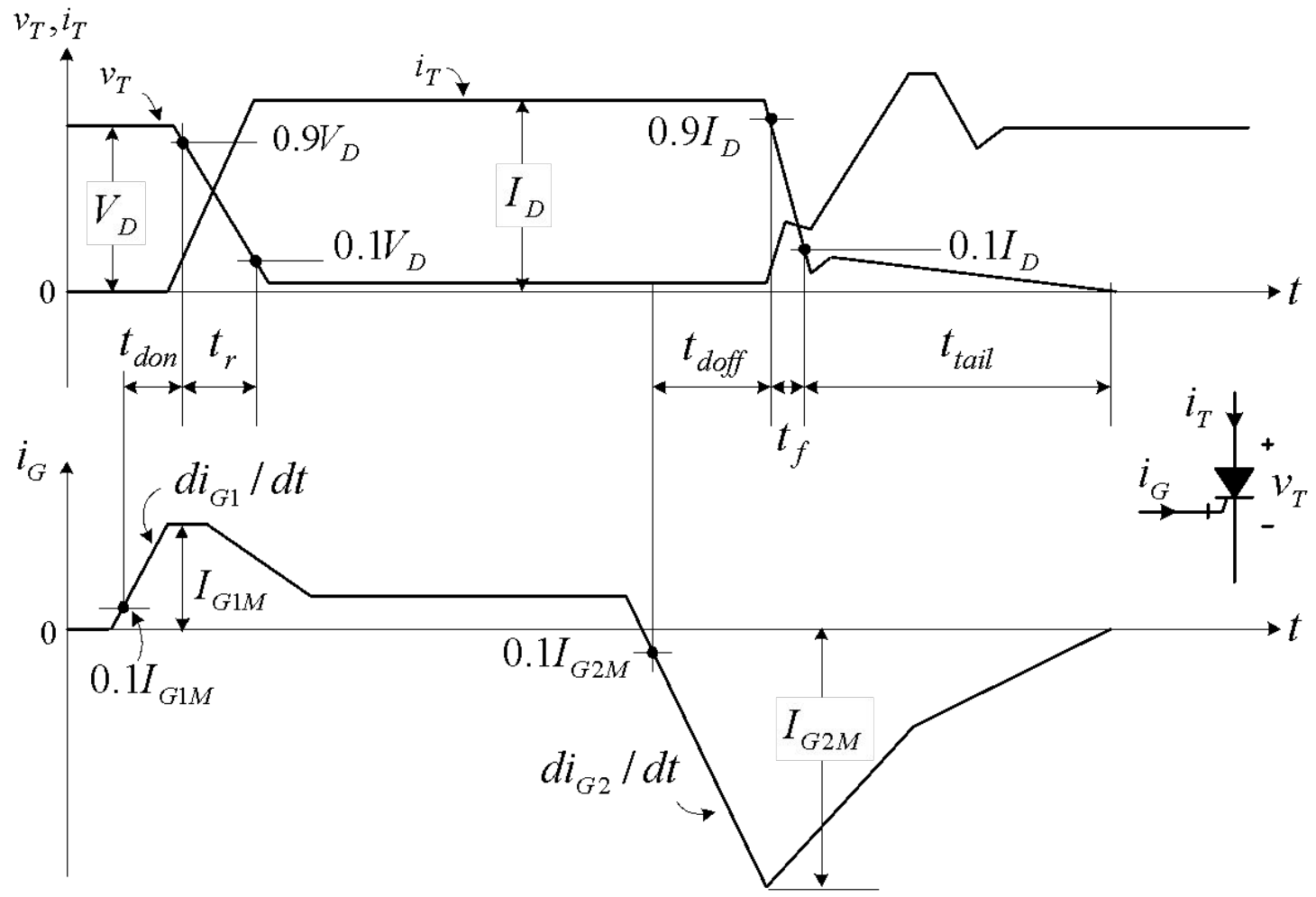
- **Symmetrical versus Asymmetrical GTOs**

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



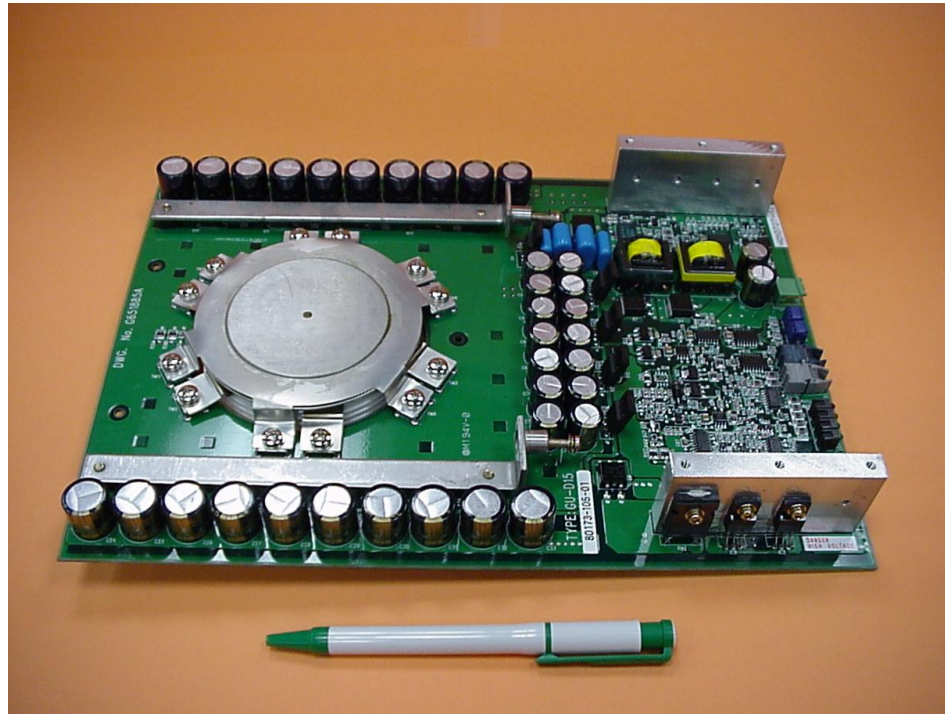
Gate Turn-Off (GTO) Thyristor

• 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)

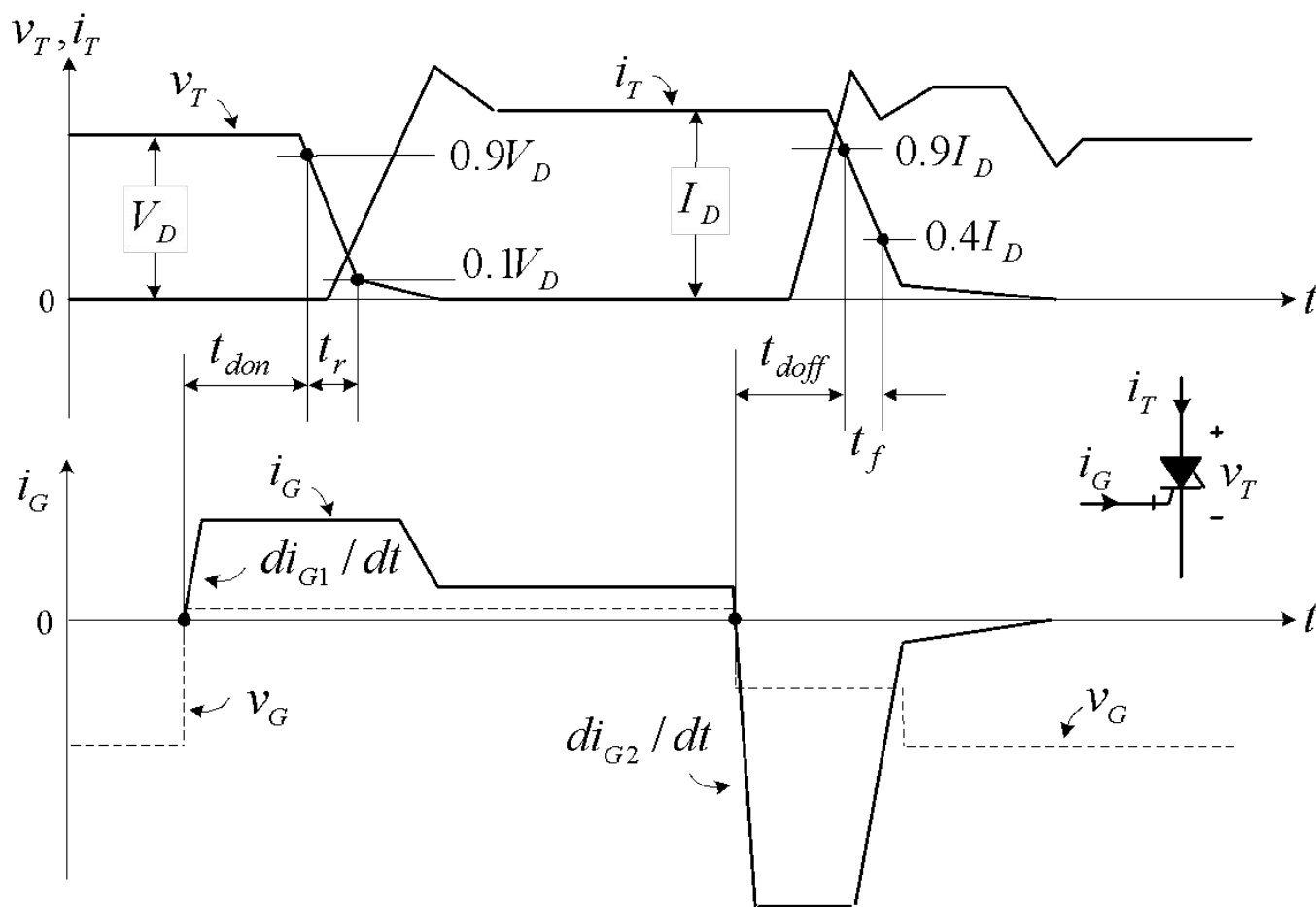
Integrated Gate Commutated Thyristor

• 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



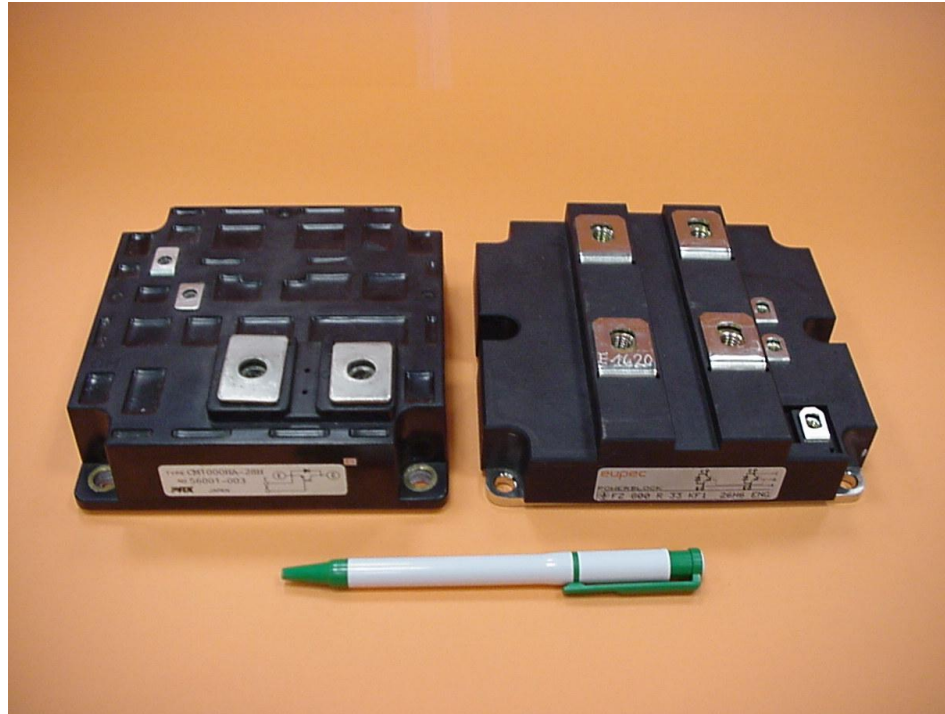
Integrated Gate Commutated Thyristor

• Main Specifications

6000V/6000A Asymmetrical GCT

Maximum Rating	V_{DRM}	V_{RRM}	I_{TORM}	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)			

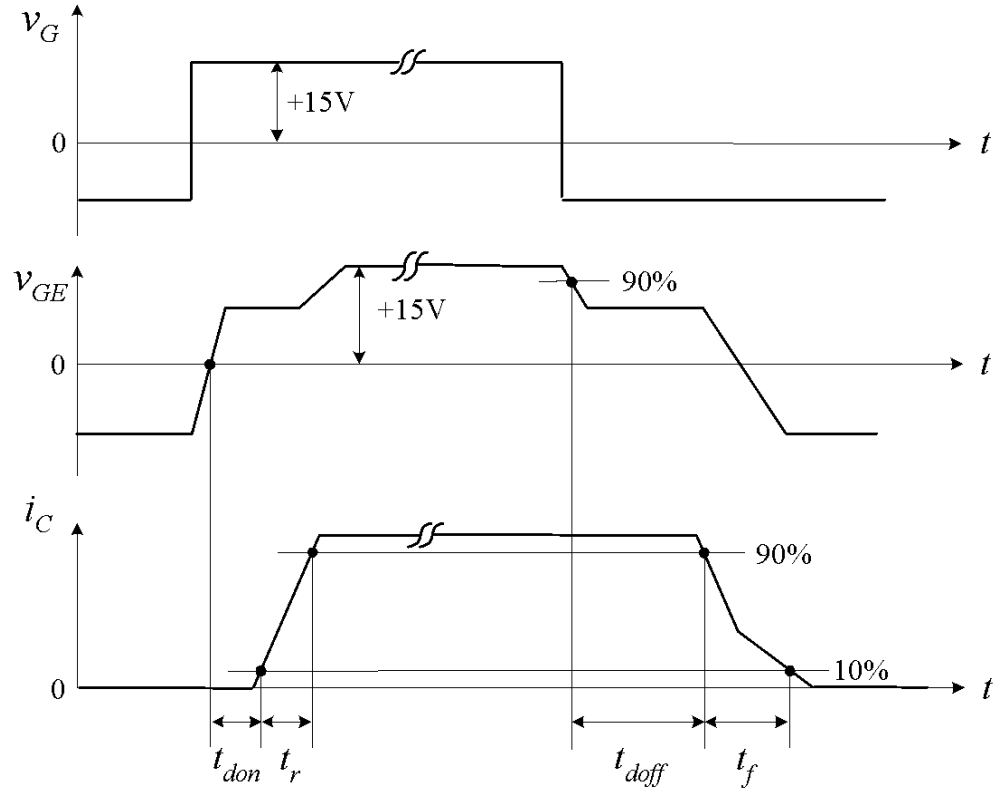
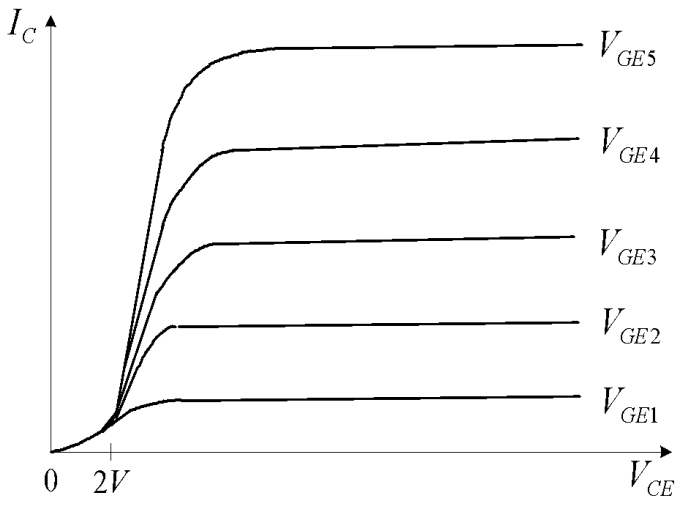
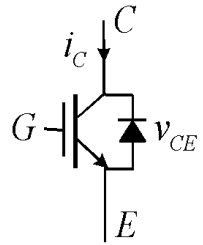
Insulated Gate Bipolar Transistor (IGBT)



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)

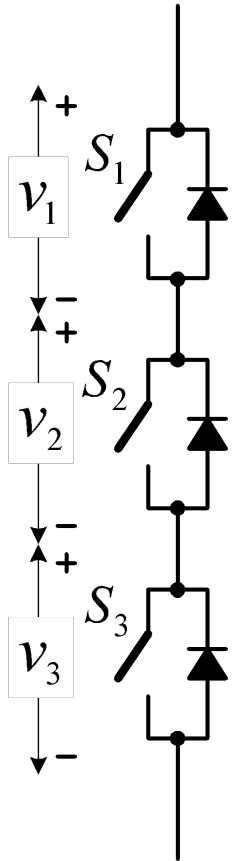
• Main Specifications

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

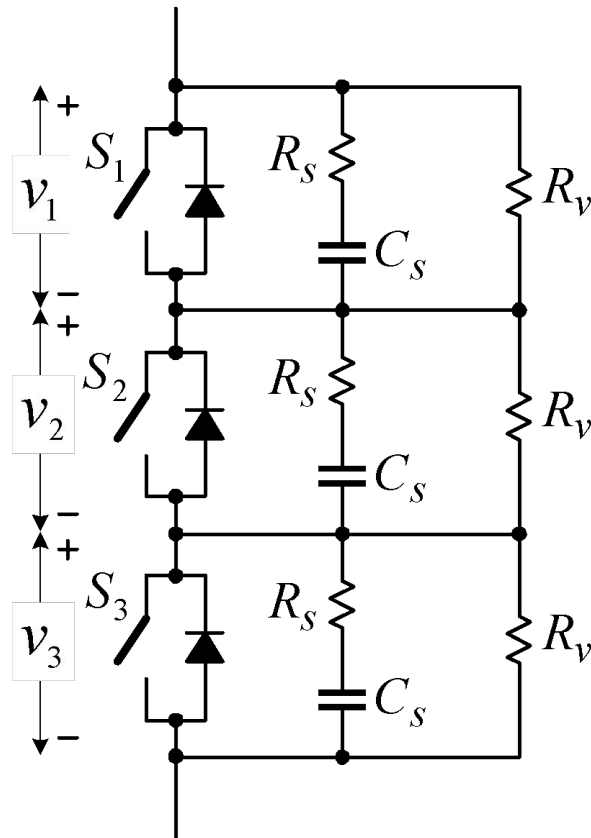
• Cause of Voltage Imbalance



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

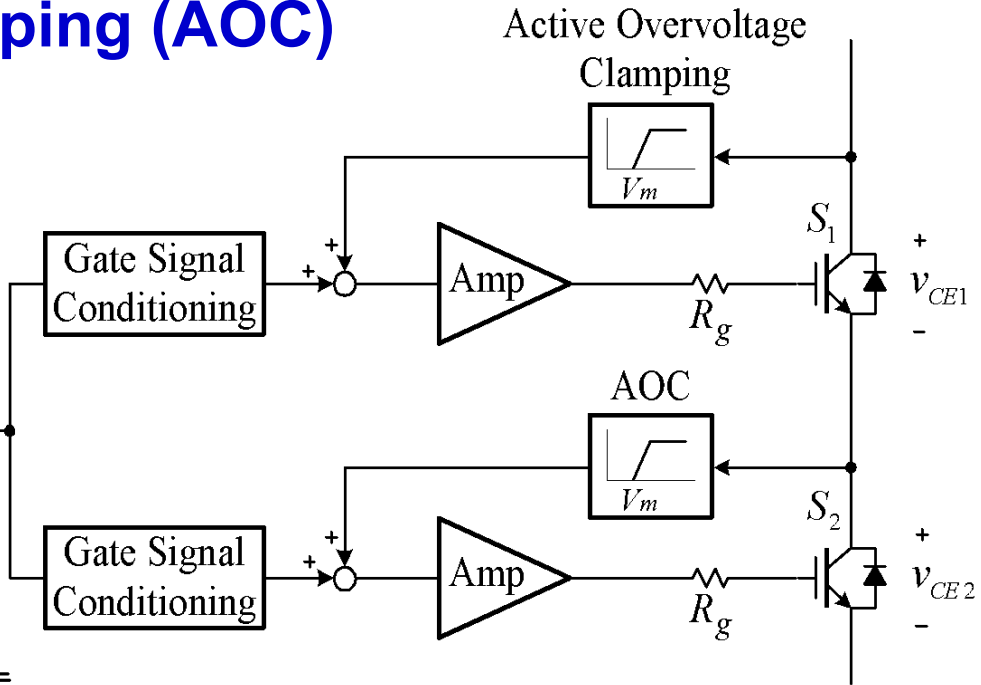
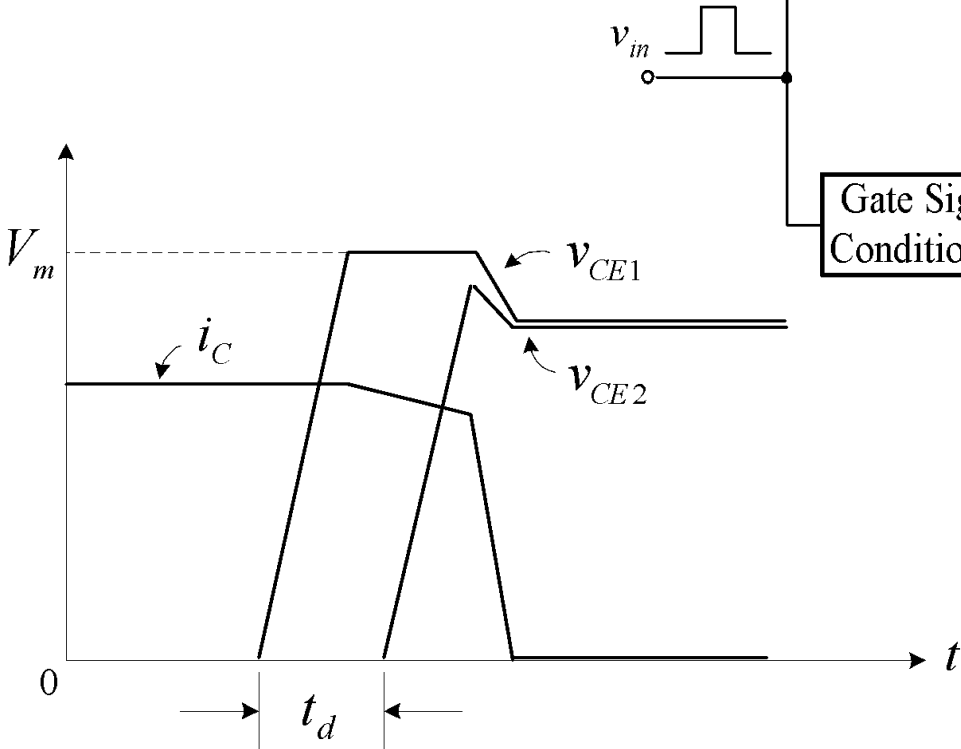


- S_1, S_2, S_3 :
GTO, GCT or IGBT
- Voltage Sharing:
 $V_1 = V_2 = V_3$ in steady state
and transients
- Static Voltage Sharing:
 R_v
- Dynamic Voltage Sharing:
 R_s and C_s

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