Power Converter Systems

Graduate Course EE8407

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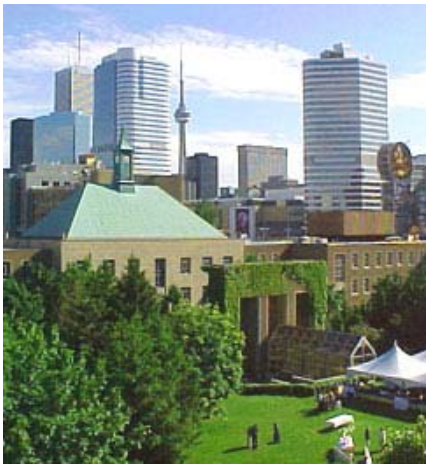

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EE8407

Topic 2

High-Power Semiconductor Devices

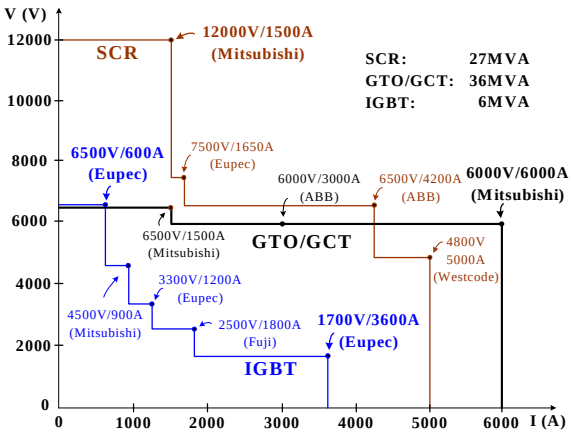
High-Power Semiconductor Devices

Lecture Topics

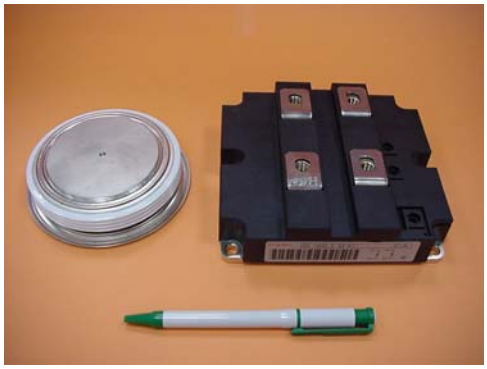
- **Power Diode**
- **SCR Thyristor**
- **Gate Turn-Off Thyristor (GTO)**
- **Integrated Gate Commutated Thyristor (GCT)**
- **Insulated Gate Bipolar Transistor (IGBT)**
- **Switch Series Operation**

High-Power Semiconductor Devices

- **Device Rating**



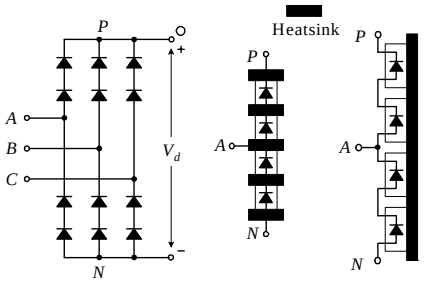
Power Diode



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

Power Diode

- **Heatsink Assembly**



(a) Diode Rectifier (b) Press pack (c) Module

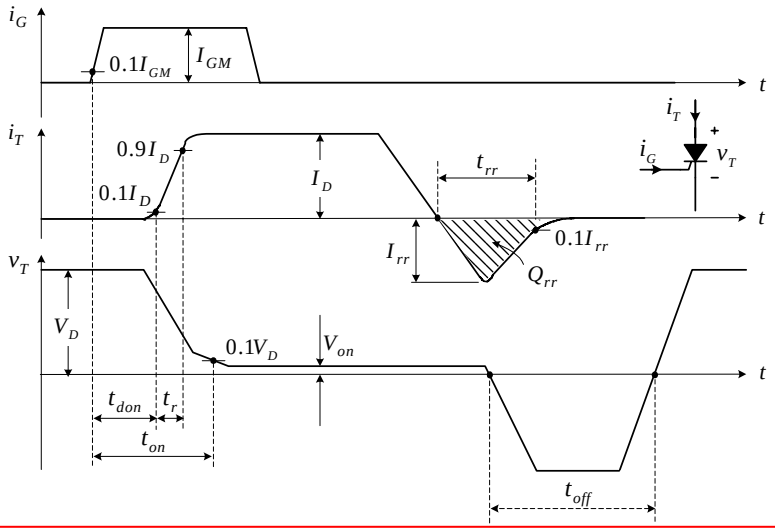
Press pack device:
- **Double sided cooling**
- **Low assembly cost and high power density**
- **Preferred choice for high voltage high power applications**

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}
	$t_{on} = 14\mu s$	$t_{off} = 1200\mu s$	$100A/\mu s$	$2000V/\mu s$	$7000\mu C$

V_{DRM} – Repetitive peak off-state voltage V_{RRM} – Repetitive peak reverse voltage

I_{TAVM} – Maximum average on-state current I_{RRMS} – Maximum rms on-state current

$Q_{rr} = \frac{t_{rr} I_{rr}}{2}$ – Reverse recovery Charge 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**

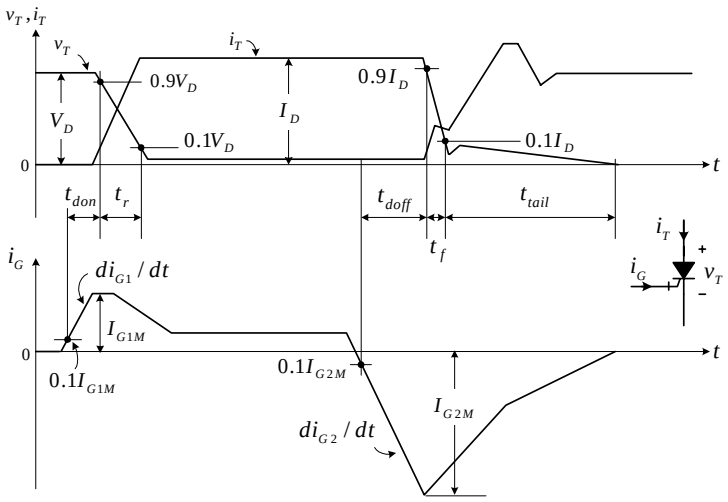
Type	Blocking Voltage	Example (6000V GTOs)	Applications
Asymmetrical GTO	$V_{RRM} << V_{DRM}$	$V_{DRM} = 6000V$ $V_{RRM} = 22V$	For use in voltage source inverters with anti-parallel diodes.
Symmetrical GTO	$V_{RRM} \approx V_{DRM}$	$V_{DRM} = 6000V$ $V_{RRM} = 6500V$	For use in current source inverters.

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)

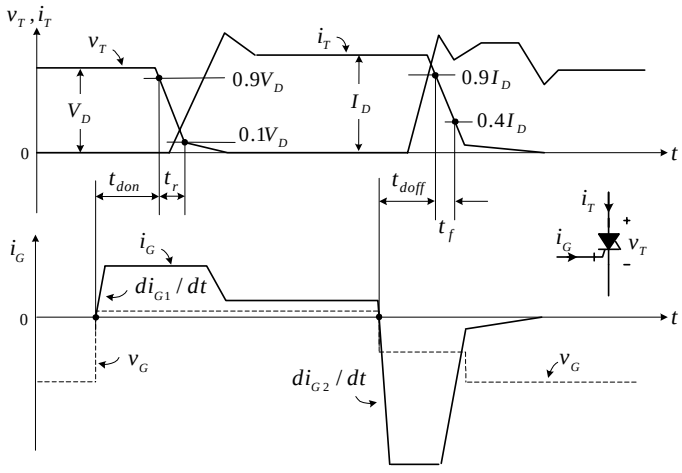
Integrated Gate Commutated Thyristor

• GCT Classifications

Type	Anti-parallel Diode	Blocking Voltage	Example (6000V GCT)	Applications
Asymmetrical GCT	Excluded	$V_{RRM} << V_{DRM}$	$V_{DRM} = 6000V$ $V_{RRM} = 22V$	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_{TQRM}	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	$1000A/\mu s$	$3000V/\mu s$	$200A/\mu s$	10,000 $A/\mu s$
On-state Voltage	$V_{T(on-state)} < 4V$ at $I_T = 6000A$					

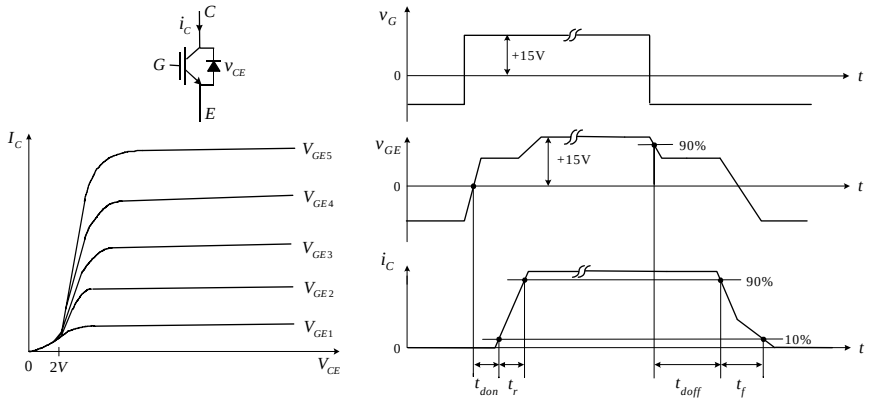
V_{DRM} - Repetitive peak off-state voltage
V_{RRM} - Repetitive peak reverse voltage
I_{TGRM} - Repetitive controllable on-state current
I_{TAVM} - Maximum average on-state current
I_{RRMS} - Maximum rms on-state current
Part number – FGC6000AX120DS (Mitsubishi)

Insulated Bipolar Transistor (IGBT)

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

Insulated Bipolar Transistor (IGBT)

• IGBT Characteristics



Static V-I Characteristics **Switching characteristics**

Insulated 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
	$0.35\mu s$	$0.27\mu s$	$1.7\mu s$	$0.2\mu s$
Saturation Voltage	$I_{CE\,sat} = 4.3V$ at $I_C = 1200A$			

V_{CE} - Rated collector-emitter voltage

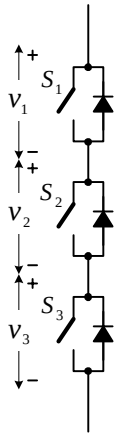
I_C - Rated dc collector current

I_{CM} - Maximum repetitive peak collector current

Part number – FZ1200 R33 KF2 (Eupec)

Device Series Operation

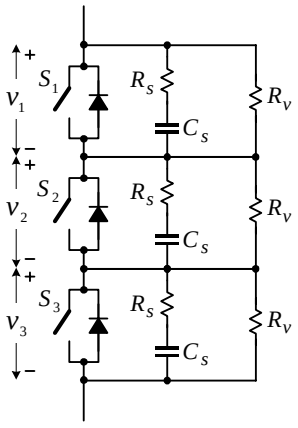
• Cause of Voltage Imbalance



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

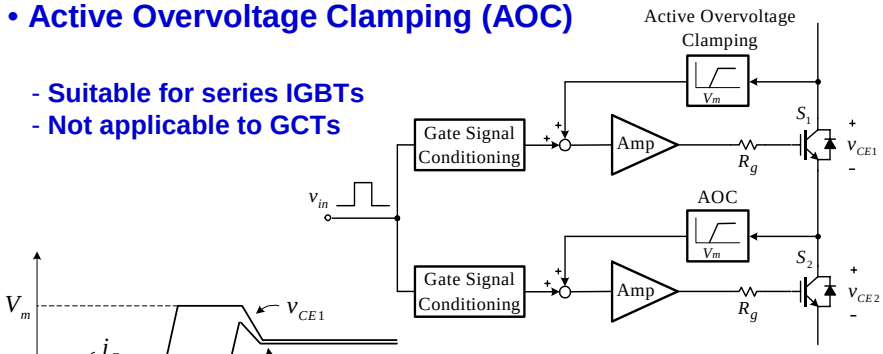


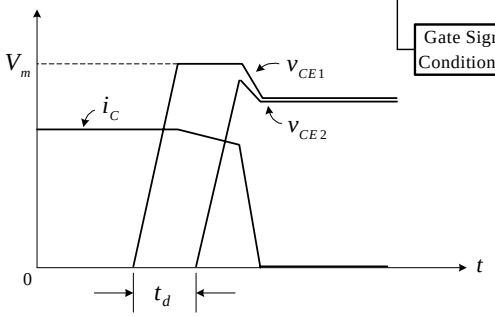
- ***S_1, S_2, S_3:***
  GTO, GCT or IGBT
- **Voltage Sharing:**
  $v_1 = v_2 = v_3$ **in steady state and transients**
- **Static Voltage Sharing:**
  R_v
- **Dynamic Voltage Sharing:**
  R_S **and** ***C_S***

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 clamed 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

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Thanks