IGCT Semiconductors for Reliable, High Power Applications such as Off-Shore Wind, Rail-Intertie or Medium Voltage Drives

Thomas Stiasny - Senior Principal Engineer Bipolar Technology
Christian Winter - Global Product Manager, BiPolar Semiconductor devices

POWERING GOOD FOR SUSTAINABLE ENERGY

2020-07-06

HITACHI ABB POWER GRIDS

Content

- How does an IGCT work
- Different types of IGCTs
- IGCT design – reliability / power handling capability

The IGCT principle

HITACHI ABB

IGCT phase: Thyristor

Conduction

Conducting state of IGCT

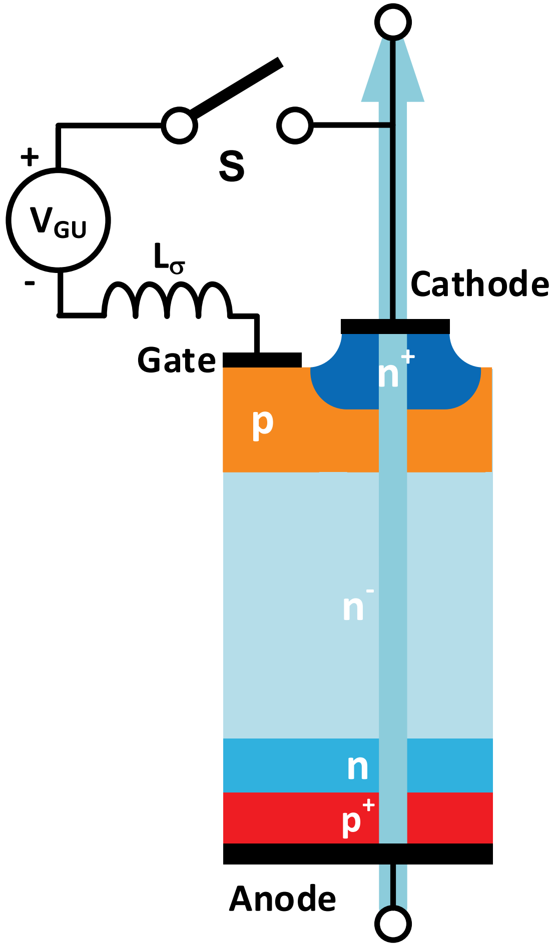
Thyristor mode active

Electron emission from cathode

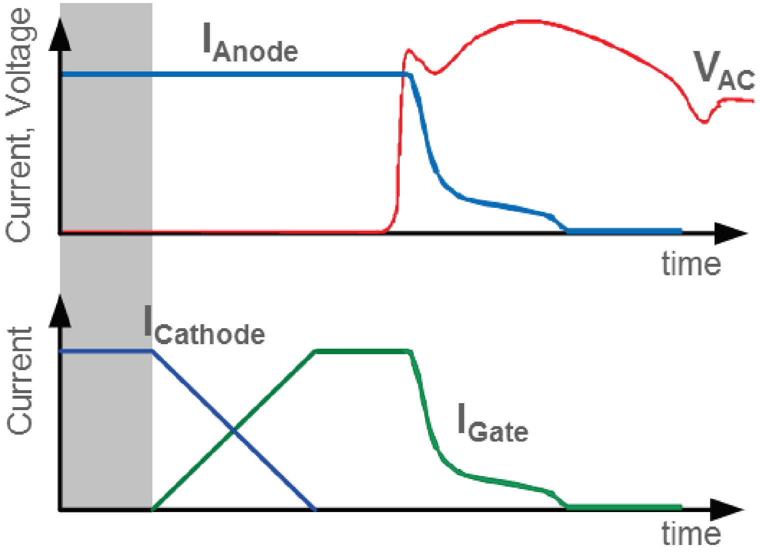
Hole emission from anode

Very low on-state voltage drop

Structure



Current / voltage wave form



The IGCT principle

IGCT phase: Thyristor

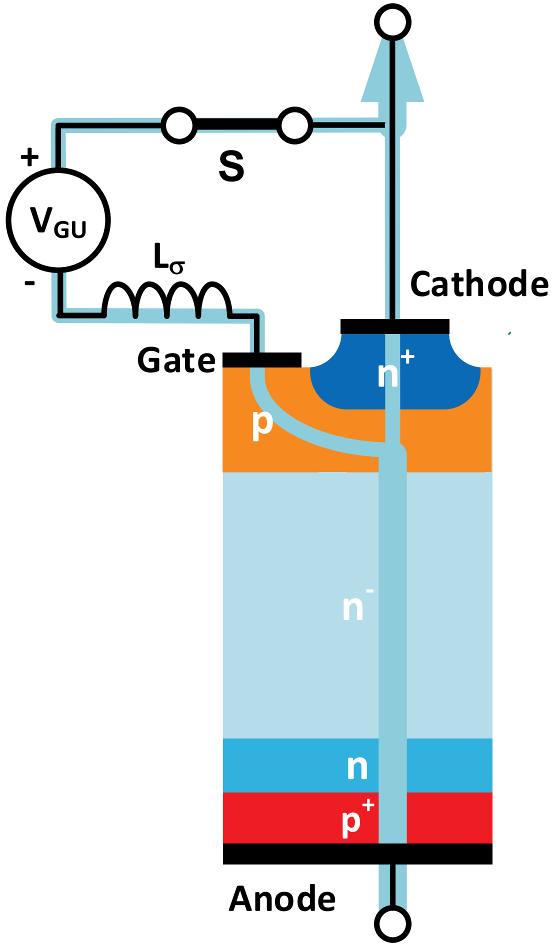
Current commutation

Anode current commutates from Cathode to Gate

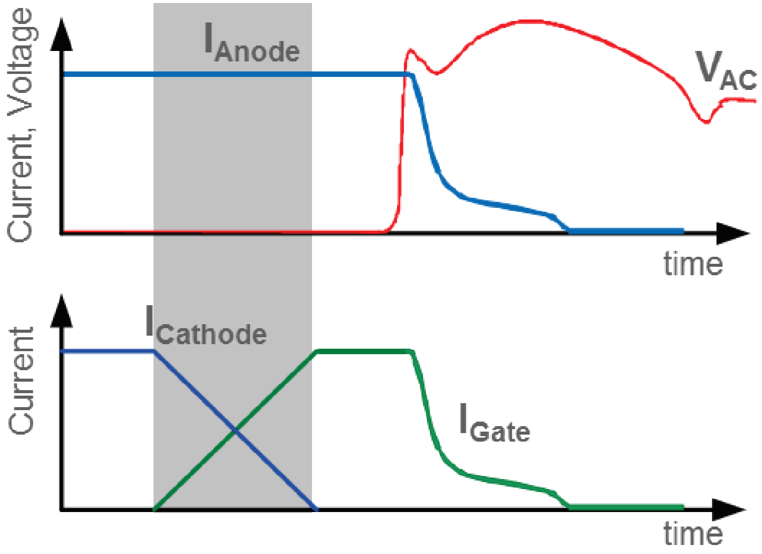
Commutation $dI_{Gate}/dt = V_{GU}/L_{\sigma}$

Low inductive Gate circuit necessary

Structure



Current / voltage wave form



The IGCT principle

IGCT phase: Transitor

Anode current commutated to Gate

Transistor mode activated

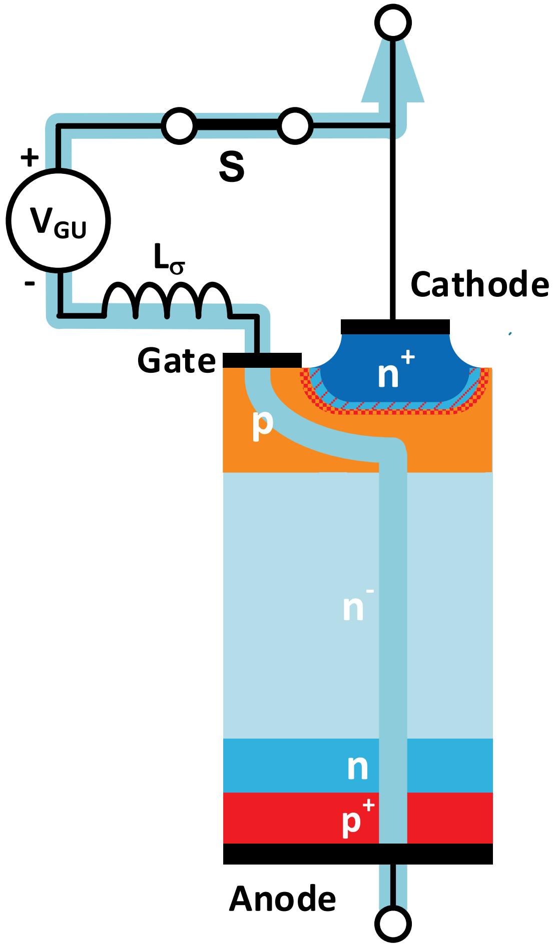
Cathode fully bypassed though Gate Unit

Thyristor converted to open base pnp Transistor

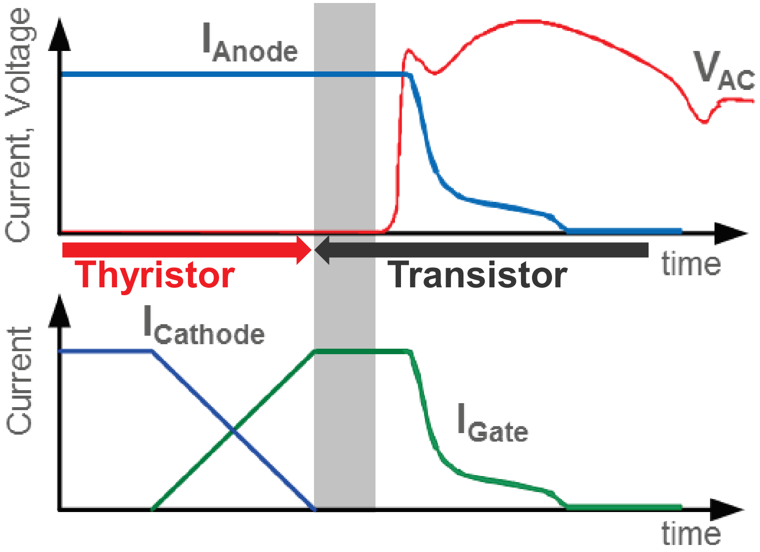
Hard drive condition: commutation before V_{AK} rises

Commutation time ~ $I_T \cdot L_\sigma / V_{GU}$

Structure



Current / voltage wave form



The IGCT principle

HITACHI ABB

IGCT phase: Transitor

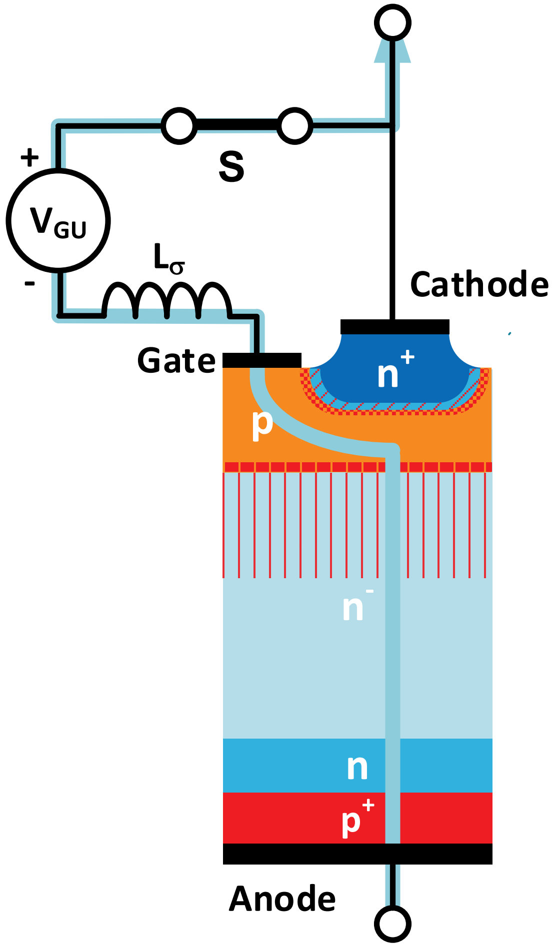
Turn-off as Transistor

Extraction of Charge carriers though Anode and Gate

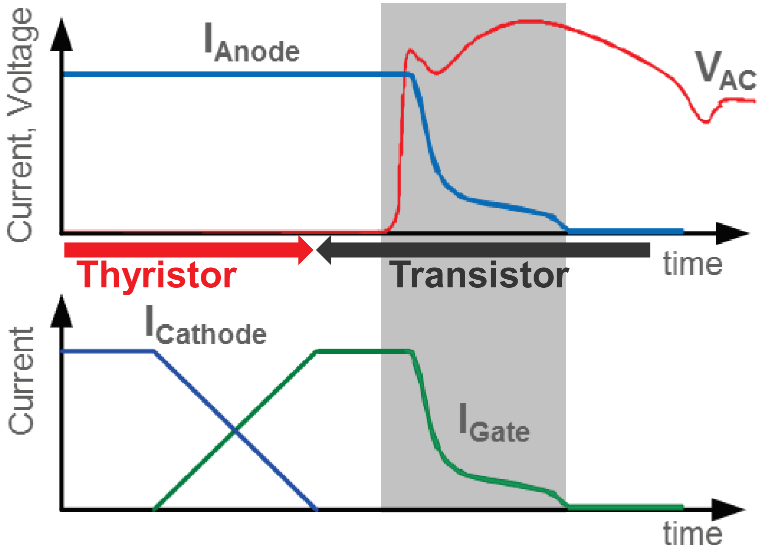
Turn-off dI/dt defined by device

Tail current participates to dynamic losses

Structure



Current / voltage wave form



The IGCT principle

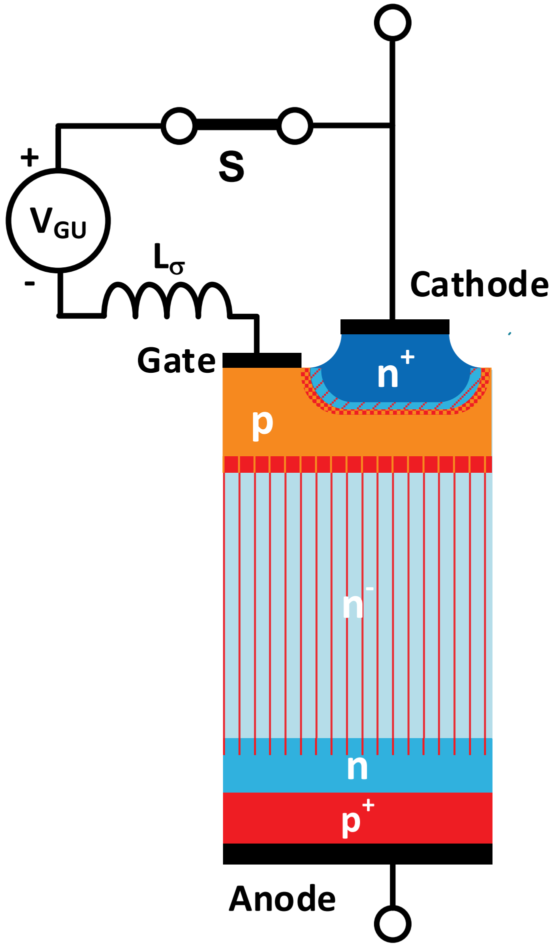
IGCT phase: Transitor

Blocking device

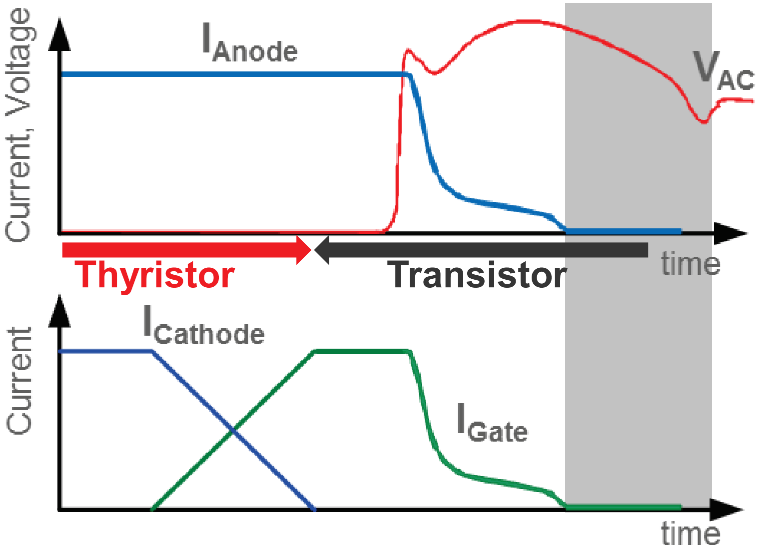
Transistor mode active

High dV/dt immunity through low inductive Gate – Cathode coupling (for powered Gate unit)

Structure



Current / voltage wave form



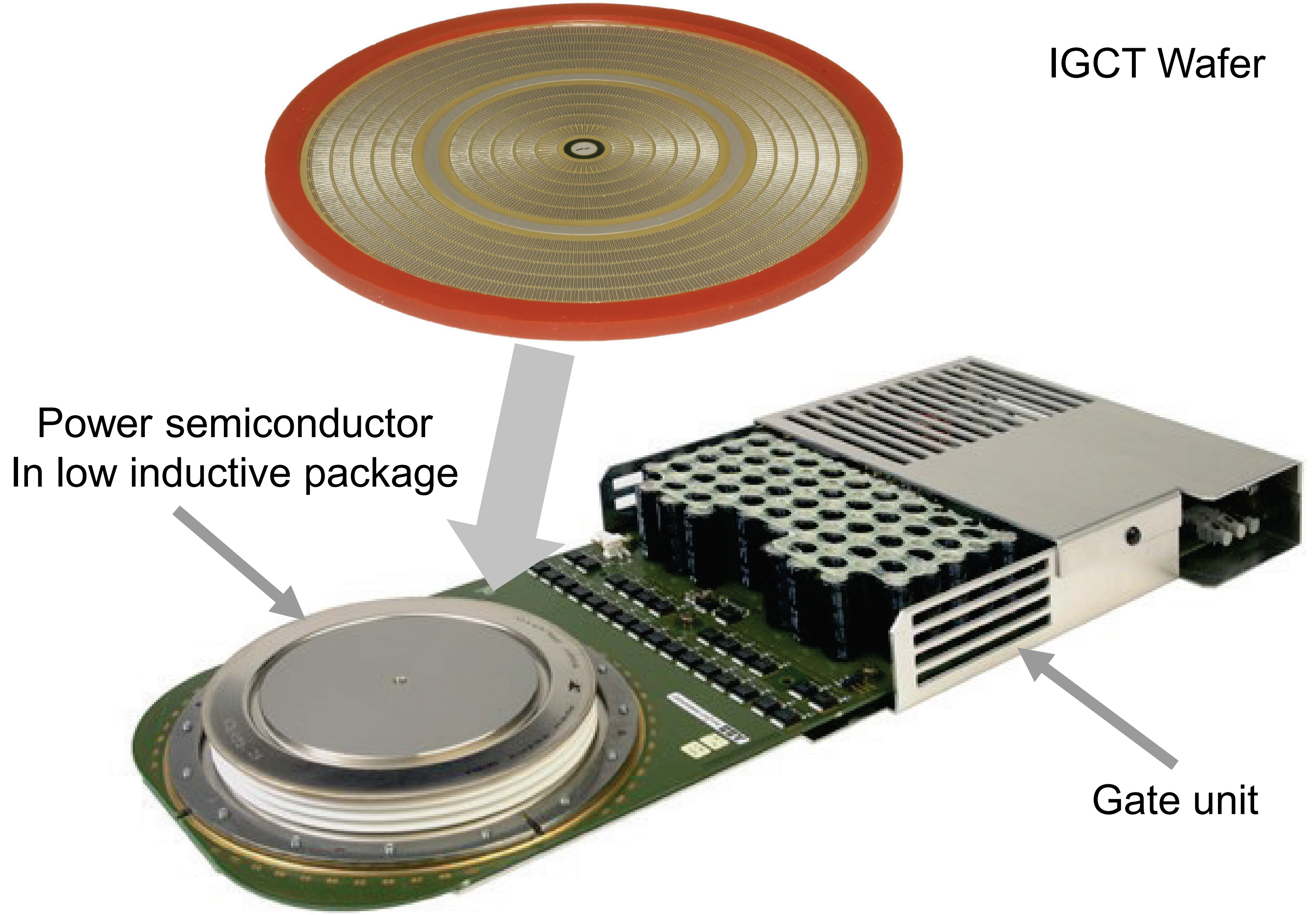
IGCT - Integration of Gate unit and power semiconductor

IGCT Gate circuit requirements

The Thyristor is a current driven device

IGCT operation requires low inductive coupling of gate unit and power semiconductor

- Distributed gate on silicon wafer
- Low inductive package for power semiconductor
- Integration of power semiconductor and gate unit
- Low inductive gate unit



Different types of IGCTs

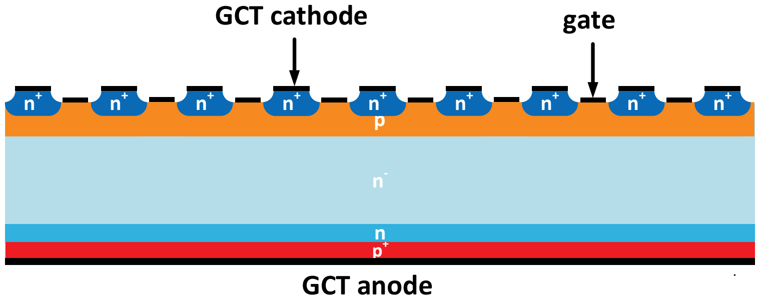
Asymmetric IGCT

Full forward blocking capability

Reverse blocking capability ~ 20V

Typically used with antiparallel diode

Used in voltage source inverters

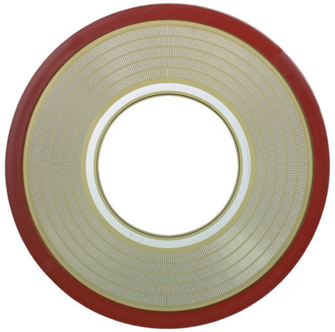


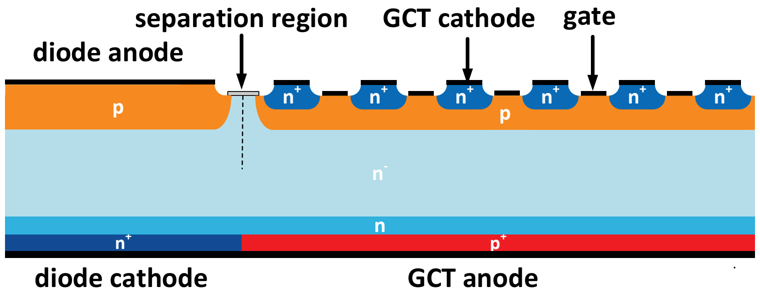
Reverse conducting IGCT

Full forward blocking capability

Integrated antiparallel diode

Used in voltage source inverters



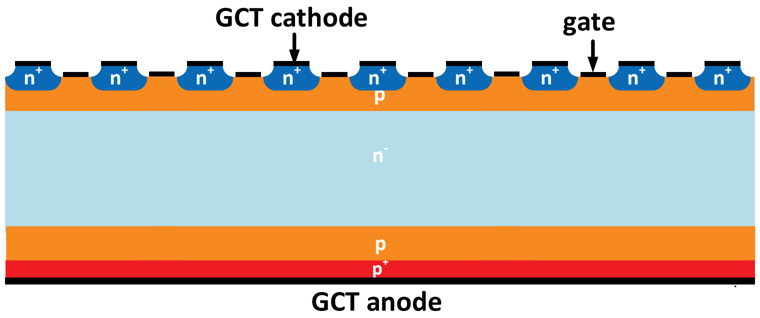


Reverse blocking IGCT

Full forward blocking capability

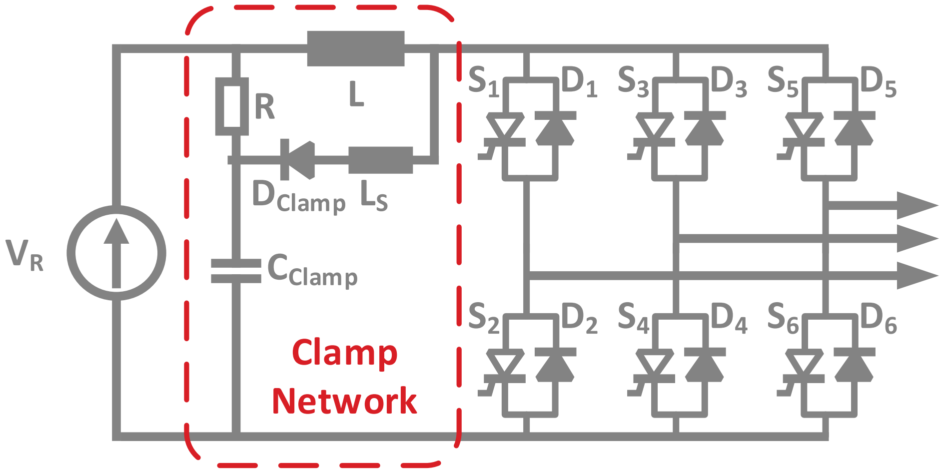
Full reverse blocking capability

Typically used in current source inverters, breakers



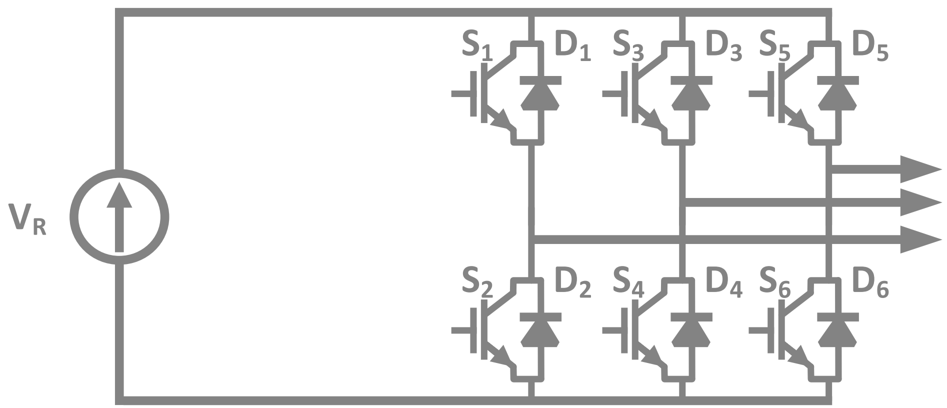
IGCT – IGBT – circuit design

Typical IGCT circuit



- No dI/dt control by switch possible
- extra components (Clamp Network)
- no significant turn-on losses in devices
- immitted fault current
- circuit is **mandatory for IGCTs** (optional for transistors)

Typical IGBT circuit

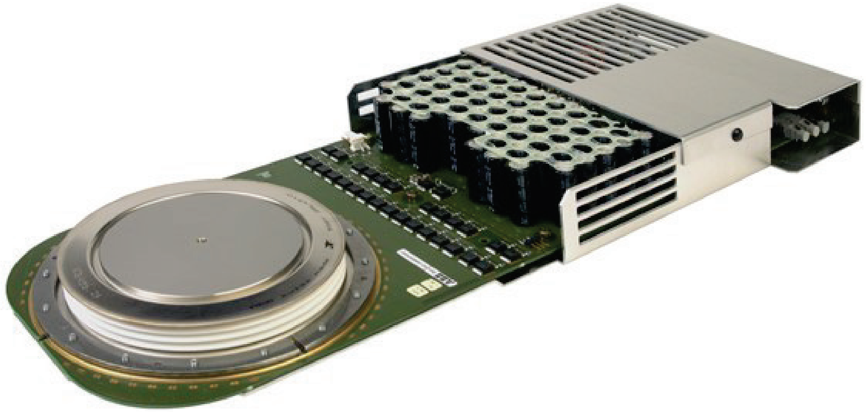


- Turn-on dI/dt limited by switch
- no passive components
- turn-on losses in S1-6
- no fault current limitation
- circuit is suitable for ***Transistors only***

IGCT design – reliability / power handling capability

HITACHI ABB

Design	Reliability – Power handling
Thyristor structure Monolithic silicon design	Lowest On-state losses possible Optimal ratio active area to edge termination Low part count of power semiconductor
Pressure contact design (no bond wire or solder layer)	High ruggedness against load cycling aging Double side cooling for superior thermal management Failure mode: Short circuit, optimal for applications with redundancy
Hermetic ceramic housing	Power semiconductor well protected against environmental influences (e.g. humidity)
Gate unit with redundancy in turn-off circuit	High field reliability of gate unit

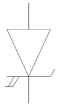


Content

HITACHI ABB

- New 4.5 kV Reverse Conducting (RC) IGCT
- IGCT reliability
- New 4.5 kV Asymmetric IGCT
- 10 kV IGCT
- 2.5 kV Revers Blocking (RB) IGCT
- Fast recovery diode (FRD) platform

IGCT overview

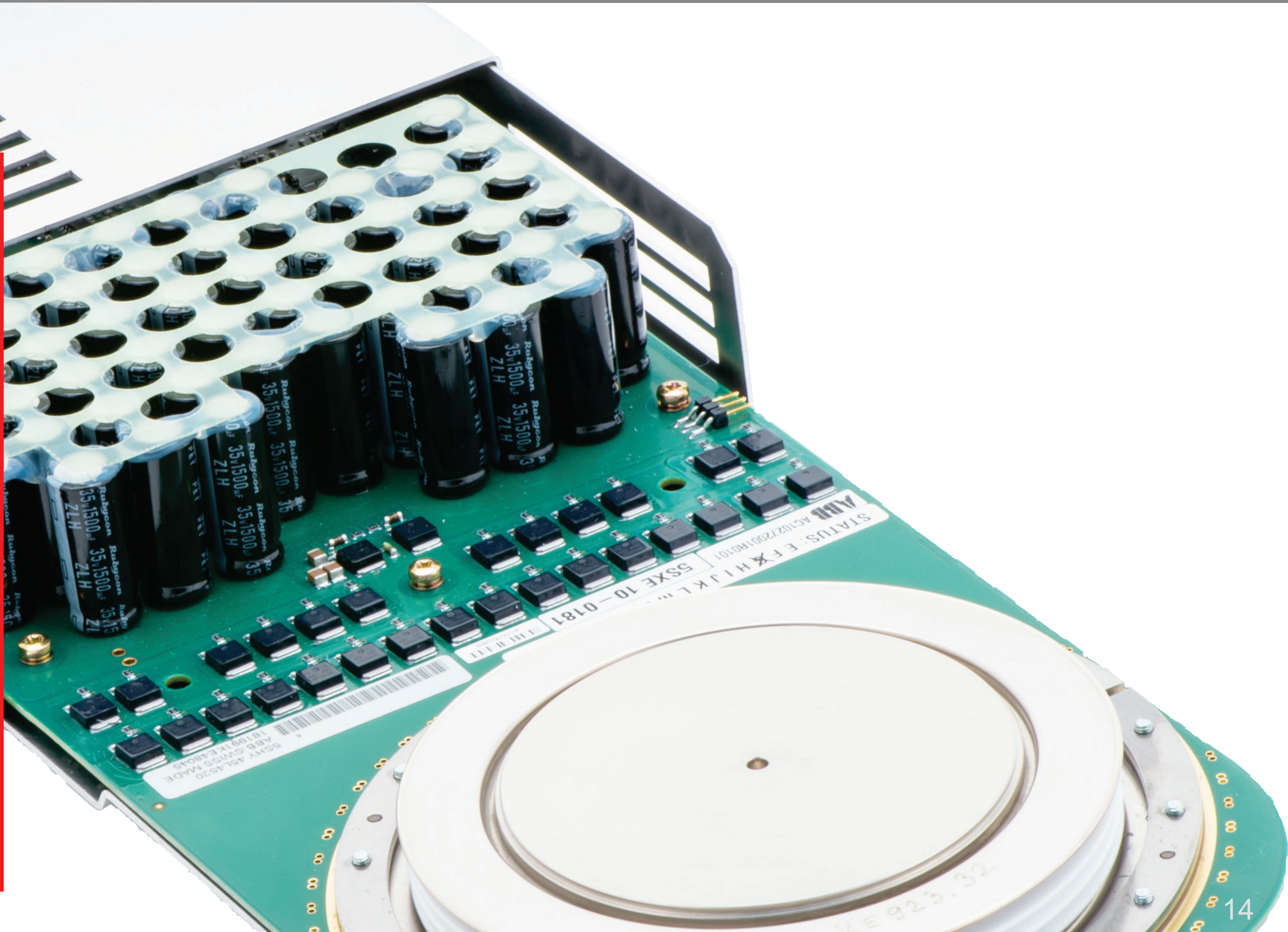


Voltage classes, V	Reverse Conducting (RC)			Asymmetric	Reverse Blocking (RB)	
10000						
6500						
5500						
4500						
2500						
	F / H	L	Y	L	H	L
	47/63	85	138	85	63	85
	Housing / Pole-piece diameter (mm)					

Product
Sample

- Introduced >20 years ago by Hitachi ABB PG.
- Various sizes and voltage classes.
- Three device variants.
- Used in wide application range.

New 4.5 kV 3600 A reverse conducting IGCT



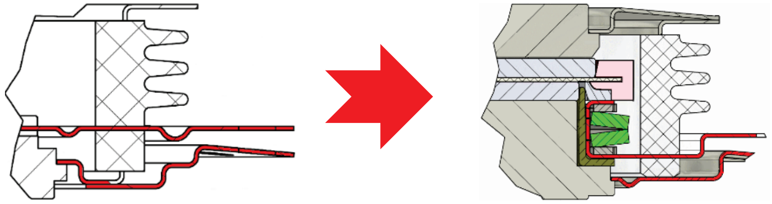
- New Gen3 4.5 kV reverse-conducting IGCT platform in L housing (85 mm).
- Device is available in two variants, one optimized for medium switching frequency application, such as MVD and wind power converter, the second optimized for low switching frequency intended for use in multi-Level modular converter (MMC) for e.g. static synchronous compensators (STATCOMs) or pumped hydro plants.
- The turn-off current of 3600 A is a record value in its class. For the converter manufacturer it means a significantly compact design than previously.

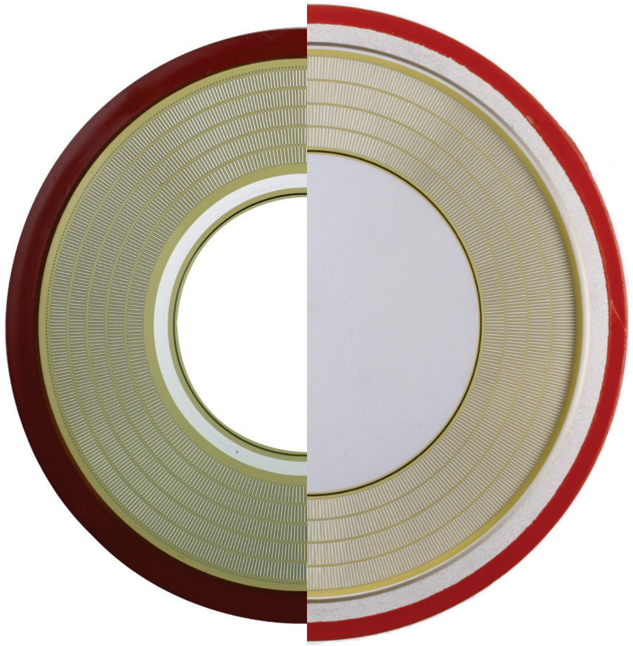
New 4.5 kV 3600 A reverse conducting IGCT

HITACHI ABB

Gen3 design features

- Retain the current outer dimensions for compatibility with the application and integrated gate unit.
- Gen 3 optimization focus: turn-off and thermal performance:
  - Increased device diameter through efficient use of raw silicon wafer.
  - Minimal gate-circuit impedance – achieved by using a gate contact infrastructure at the device's periphery and by optimized routing of the gate contact through the housing.
  - Turn-off current increased by adjusting doping profile.



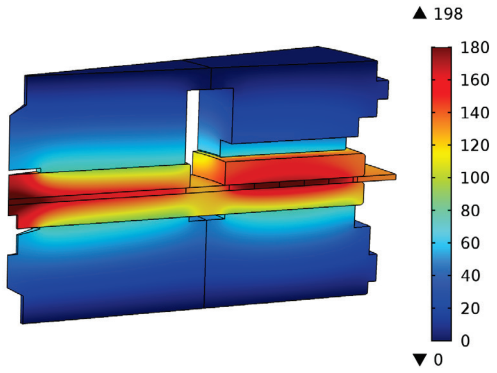


New 4.5 kV 3600 A reverse conducting IGCT

HITACHI ABB

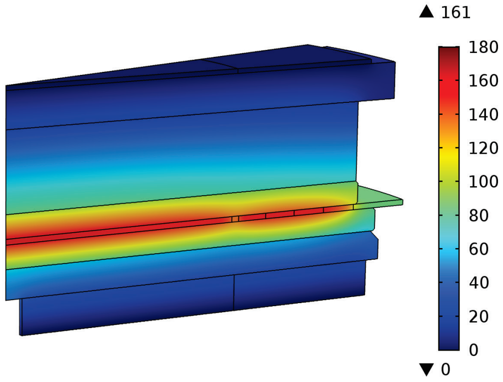
Previous

- Ring gate
- Two part cathode side Molybdenum disk
- Symmetric anode and cathode side pole- piece thickness



New

- Outer ring gate
- Monolithic Molybdenum disk
- Asymmetric anode and cathode side pole- piece thickness



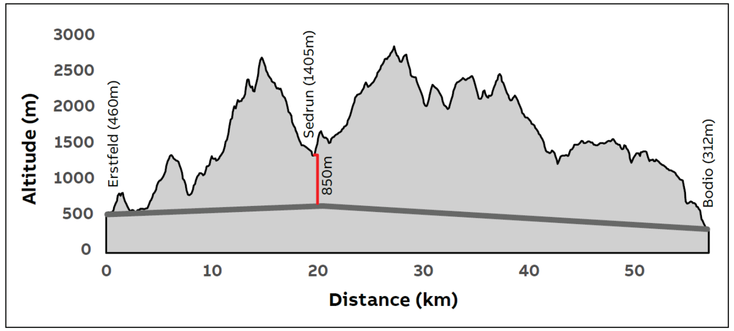
Improved thermal design for more performance and improved reliability

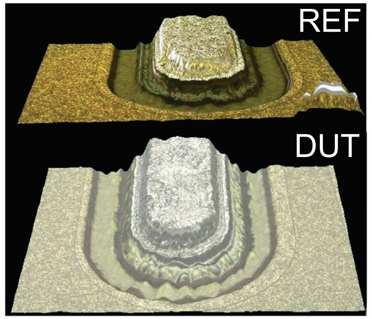
IGCT reliability

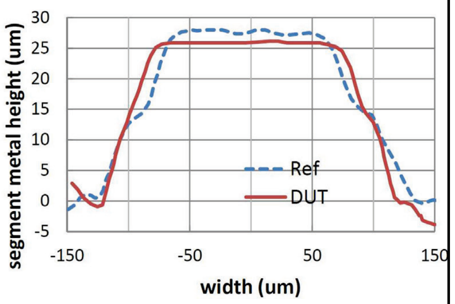
HITACHI ABB

Field reliability “Gotthard lift”

- Devices removed from Sedrun, Gotthard lift application.
- 15 years heavy duty operation in lift drive. Known load profile and number of cycles.
- 28,200,000 tons excavated gravel with lift.
- Traces of wear-out were found but degradation was low. Example shows the minimal degradation of the cathode metallization.







Field Failure Rate (FIT) of GCT and gate unit [1]

Field reliability of IGCTs is state-of-the art and constantly improving over time.

[1] Th. Stiasny, O. Quittard, Ch. Waltisberg, U. Meier. Reliability evaluation of IGCT from accelerated testing, quality monitoring and field return analysis. Proc. ESREF, Denmark, 2018.
Field failure rate FIT: Device field failure of specific customers are monitored. r: reported field failures per reporting year.
Device failures are analyzed: Number N of devices in this application known. Uptime per year estimated to T = 6000h/year.
Field failure rate is calculated in FIT (device failure in 10^9 device hours). Field failure rate = $(r \cdot 10^9)/(N \cdot T)$

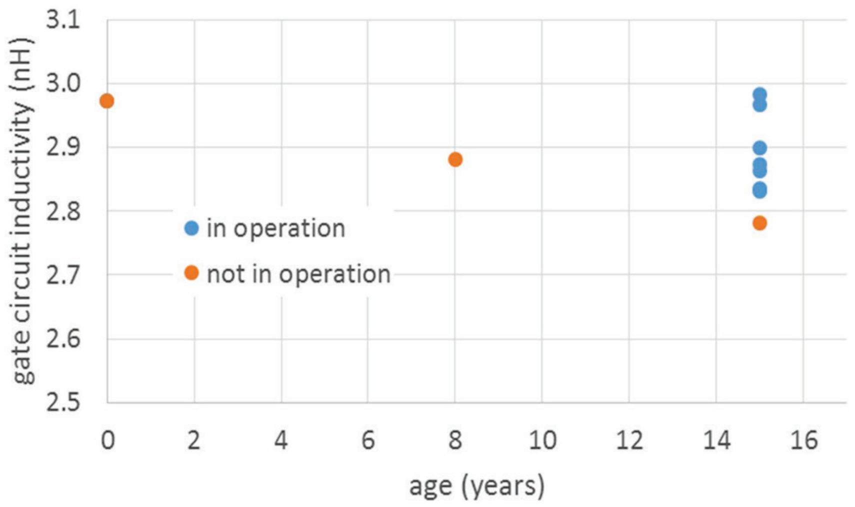
IGCT reliability

HITACHI ABB

Gate unit reliability

- The turn-off circuit of the IGCT gate unit consist of parallel connected electrolytic capacitors (voltage source) and parallel operated MOSFETs to connect gate – cathode to the capacitor.
- The well-known aging of electrolytic capacitors (increased impedance due to dry-out of electrolytes) is considered in the design by redundancy.
- Analyzed IGCTs after 15years of field operation did no show any degradation of the gate circuit impedance.
- Field returns never showed a device failure due to break-down of a electrolytic capacitor of a MOSFET in the turn-off circuit.

Gate circuit aging [1]

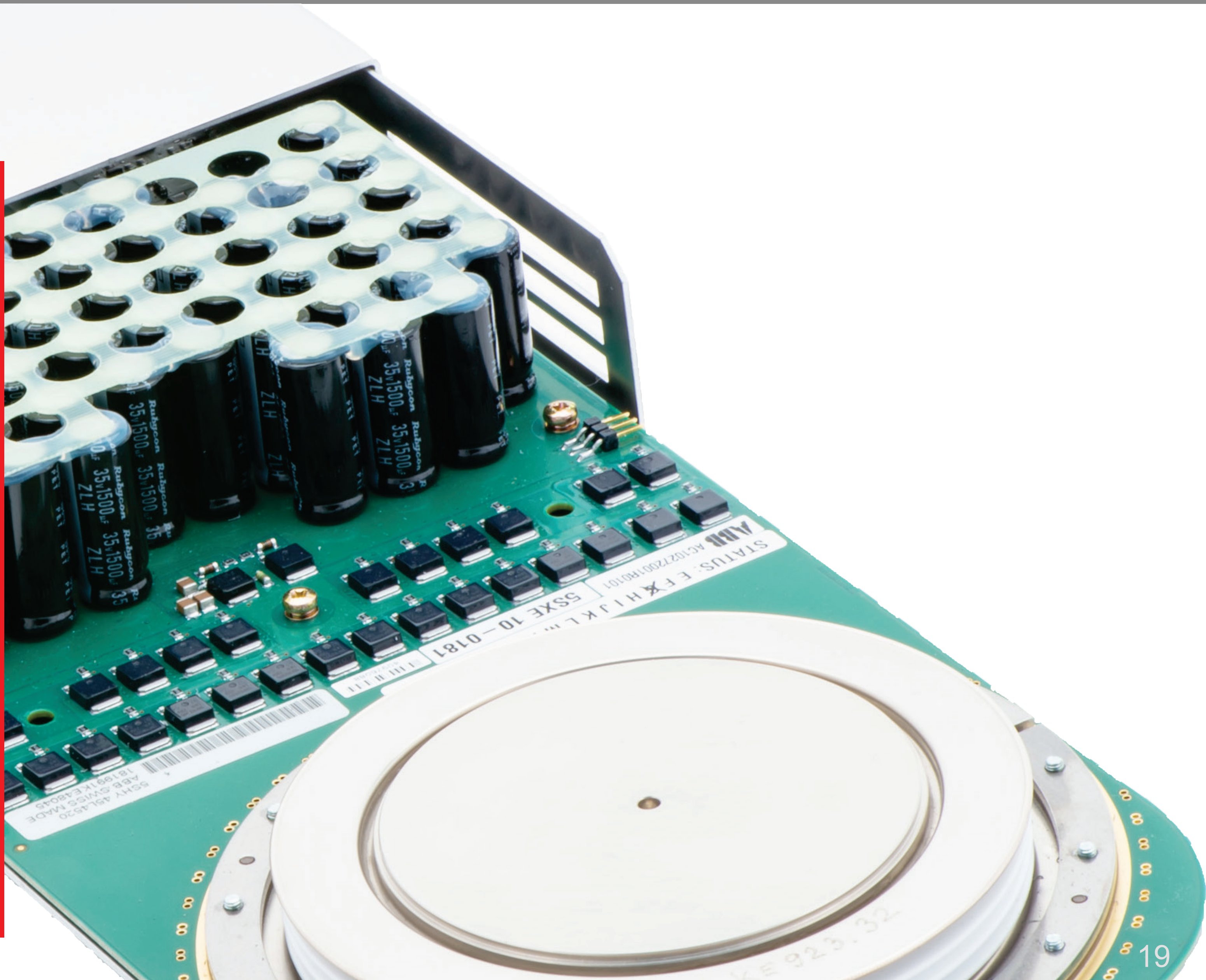


Field experience proves good gate unit reliability (23 years of field experience)

[1] Th. Stiasny, O. Quittard, Ch. Waltisberg, U. Meier. Reliability evaluation of IGCT from accelerated testing, quality monitoring and field return analysis. Proc. ESREF, Denmark, 2018.

New 4.5 kV asymmetric IGCT

- New Gen 3 4.5 kV asymmetric IGCT platform in L housing (85 mm) is in final product development stage. Samples available now. Volume production Q1 2021.
- Based on gen3 technology platform for 4.5 kV, RC-IGCT allows for cost optimization due to streamlining process and supply chain.
- Device will be available in two variants, one optimized for medium switching frequency a second for low switching application.
- The outstanding performance makes the device ideal for off-shore wind application in the range of 10-15 MW+.
- Additional applications are STATCOMs, rail-intertie, pumped hydro or medium voltage drives to mention a few.
- The turn-off current target is 6500 A, a significant step ahead compared to previous generation devices.



Gen3, Asymmetric 4.5kV IGCT (85mm pole piece, L-package)

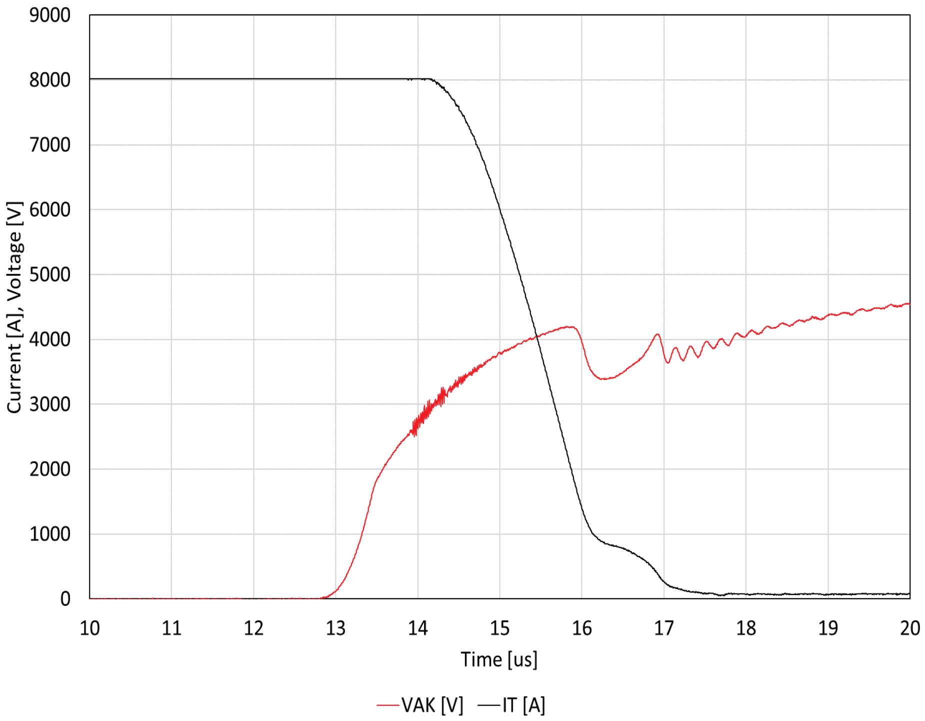
HITACHI ABB

Key device parameters

	Generation 1	Generation 2	Generation 3
Parameter	**5SHY 35L4520**	**5SHY 55L4520**	**5SHY 65L4521**
Status	**Product**	**Product**	**Under development Samples Q4/2020**
Tjmax (°C)	**125**	**125**	**140**
ITGQM (kA)	**4 kA (@2.8kV)**	**5 kA (@2.8kV)**	**6.5 kA (@2.8kV)**
Rthjc (K/kW)	**8.5**	**8.5**	**6.8**

SOA - Example for turn-off capability

- VDC = 2.8 kV
- Tj = 140 °C
- IT = 8 kA

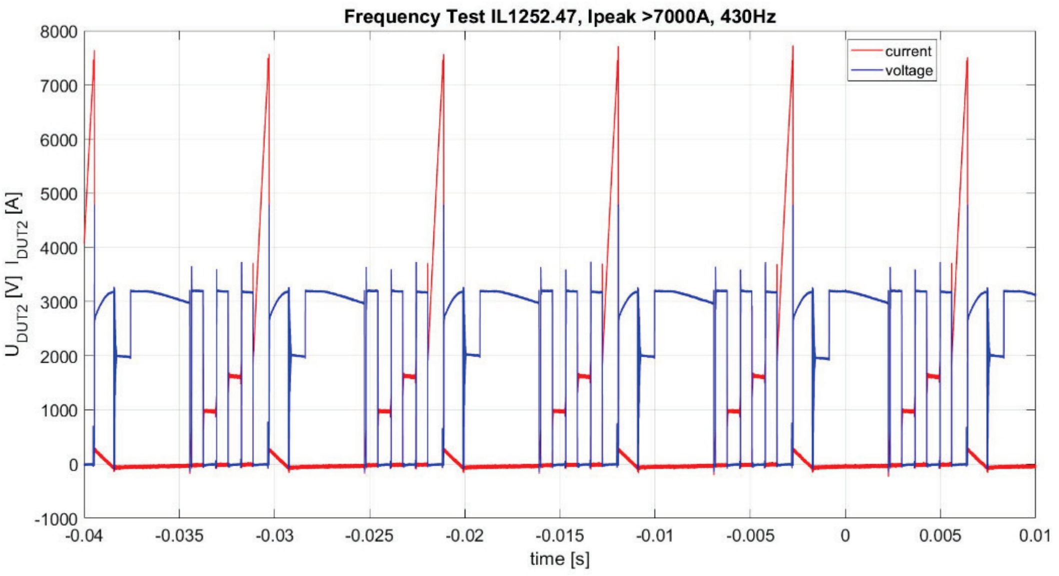


Gen3 device offers significant thermal and turn-off current increase. Device footprint identical to previous generations.

Gen3, Asymmetric 4.5kV IGCT (85mm pole piece, L-package)

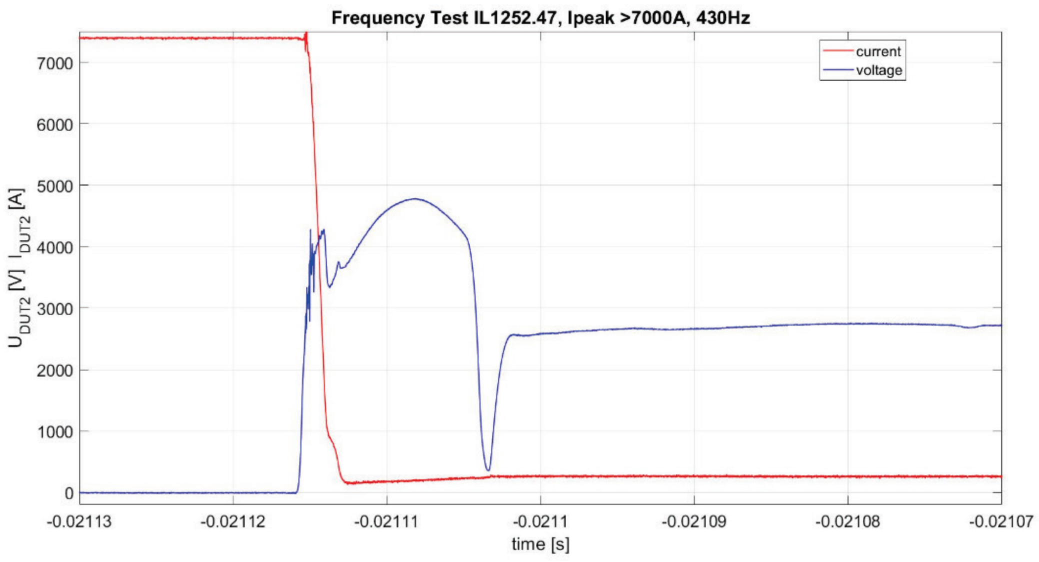
HITACHI ABB

Frequency test



Turn off capability in frequency

VDC = 2.8 kV IT=7.3kA F=430Hz



Benchmark in turn-off capability in frequency

10kV devices: IGCTs & FRD (85mm pole piece, L-package)

Goal

Develop high voltage IGCTs & companion Fast Recovery Diode (FRD) for high power applications (10-15 MW+)

Targeted applications: Offshore-wind, pulse power

10kV devices

RC-IGCT (L-housing)

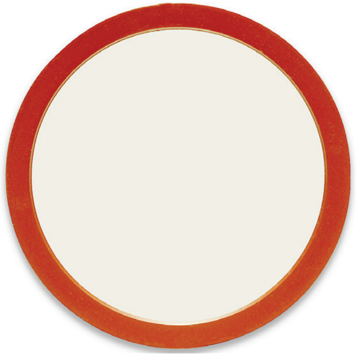
RC-IGCT (**for >10MW**)

SOA : 5.3kV, 2kA, 125°C

Soft reverse recovery

Eng. samples available

FRD (L-housing)



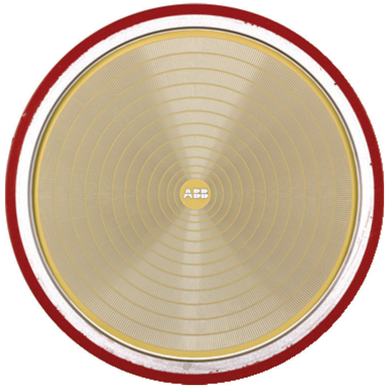
FRD (as NPC, clamp, FWD)

SOA : 6.0kV, 4.1kA, 600-800A/us

Soft reverse recovery

Eng. samples available

A-IGCT (L-housing)

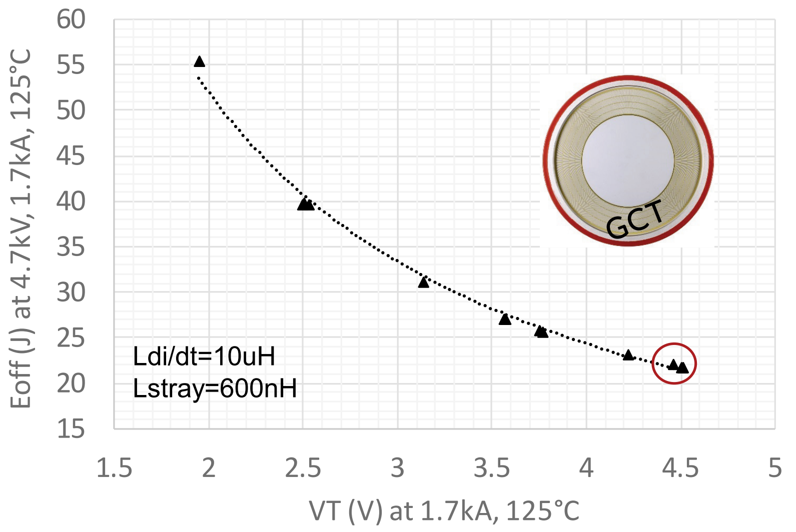


A-IGCT (**for >15MW**)

10kV devices: RC-IGCT & FRD (85mm pole piece, L-package)

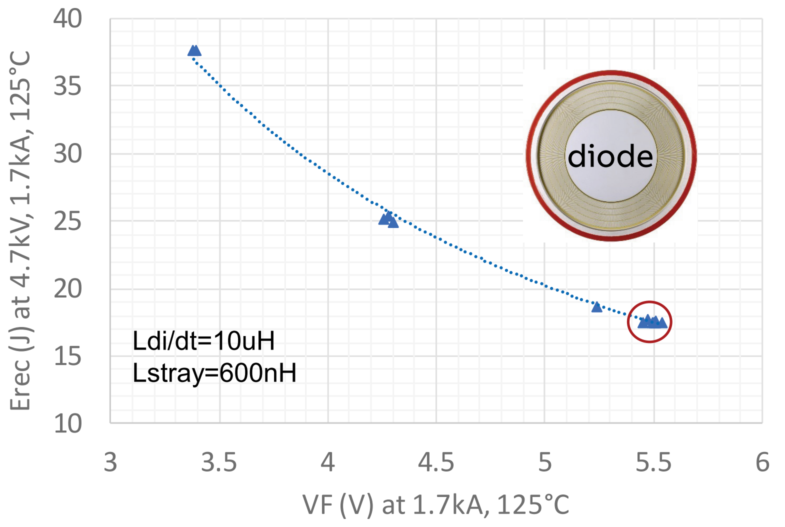
HITACHI ABB

GCT mode: TC at 4.7kV, 1.7kA, 125°C



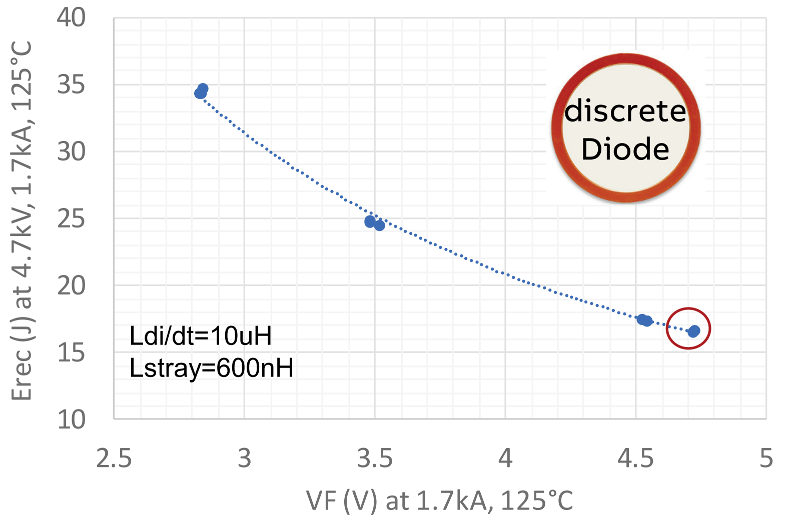
Targeted: V_T=4.5V & E_{off}= 22 J

Diode-mode: TC at 4.7kV, 1.7kA, 125°C



Targeted: V_F=5.5V & E_{rec}= 18 J

discrete FRD: TC at 4.7kV, 1.7kA, 125°C



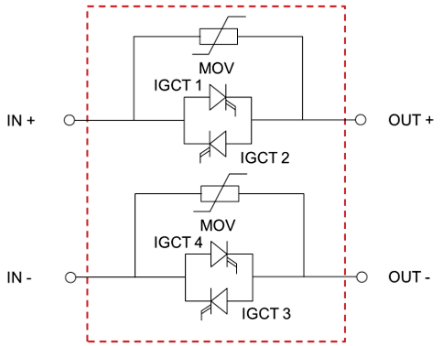
Targeted: V_F=4.7V & E_{rec}= 17 J

2.5kV RB-IGCT and 4.5kV FRD platform

HITACHI ABB

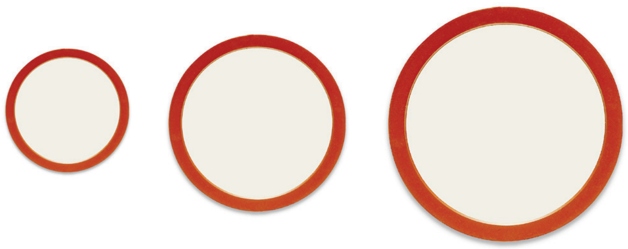
2.5 kV Reverse blocking IGCT

- Designed and optimized for extreme low conduction losses and highest turn-off current capability (up to 6kA).
- Record low on-state losses of below 1 kW at 1 kA, enables customer to design applications with highest efficiency ratings.
- Optimized for DC Solid State Circuit Breaker (SSCB) application. SSCB allows to interrupt fault currents faster than ever before, 100 times compared to traditional electro-mechanical breakers.
- Samples available now



Fast recovery diode (FRD) platform

- Improvement program for our existing and leading FRD platform. Adding large size product.
- New generation of companion L size (85 mm pole-piece) diode for next gen3 asymmetric IGCT allows fully utilization of IGCT.
- New large size FRD used in HVDC / DC breaker as free-wheeling diode.
- Samples available Q2/2021



SSCB: schematic and reference used from https://new.abb.com/news/detail/26578/ultra-fast-high-current-dc-breaker-innovates-marine-applications-and-beyond

HITACHI ABB