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Scalable and Reliable IGCT Power Semiconductor Platform for Offshore Wind Turbines

Christian Winter, Hitachi Energy, Switzerland

Personal Introduction

Speaker:	Christian Winter
Company:	Hitachi Energy Semiconductors, Switzerland, joined 2014.
Position:	Global Product Manager
Job Experience:	More than 25 years in Power Electronics Application and Semiconductors.

Agenda

- The importance of reliability and scalability in Offshore Wind turbine application
- IGCT application exemplified via ABB/Hitachi Energy solutions
- The Integrated Gate Commutated Thyristor (IGCT)
- Power Scaling: Increasing the Power Handling Capability: Gen 3 vs. Gen 2 devices – Features and Parameters
- Gen 3 Platform – scaling to larger size and higher voltage
    - 8.5 kV asym. IGCT with pole piece diam 85 mm (L-size)
    - 8.5 kV RC IGCT with pole piece diam 138mm (Y-size)
- IGCT Reliability –Field Experience and design for reliability
- Conclusion

The importance of reliability and scalability in Offshore Wind turbine application

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Demand for more powerful wind turbines
- Currently global offshore wind turbine manufactures offer ratings of 14 to 15 MW *).
- Larger power ratings support the goal of reducing Levelized Cost of Energy (LCoE).
- Trend is expected to persist potentially leading to turbine power ratings of 20 MW+.
- Offshore wind turbine converter require higher power handling capability.
- Applying devices with higher power handling capability allow to keep the low number of devices.

Reliability
- Reliability is of particular importance for offshore wind turbine application due to remote location.
- Low number of component and high reliability of the device will ensure inherent high converter reliability.

Voltage scaling
- Higher voltage ratings allow for lower currents at same power handling capability.
- Enabling compact converter designs due to smaller requirements for cross-section of bus bars and cabling.

New IGCT platform is ideal for Offshore wind application with high reliability demands and increasing demand in power handling capability

*) - GE Renewable Energy, "Haliade-X offshore wind turbine," GE, [Online]. Available: https://www.ge.com/renewableenergy/wind-energy/offshore-wind/haliade-x-offshore-turbine. [Accessed 18.06.2024].
- Vestas, "V236-15.0 MW™," Vestas, [Online]. Available: https://www.vestas.com/en/products/offshore/V236-15MW. [Accessed 18.06.2024].
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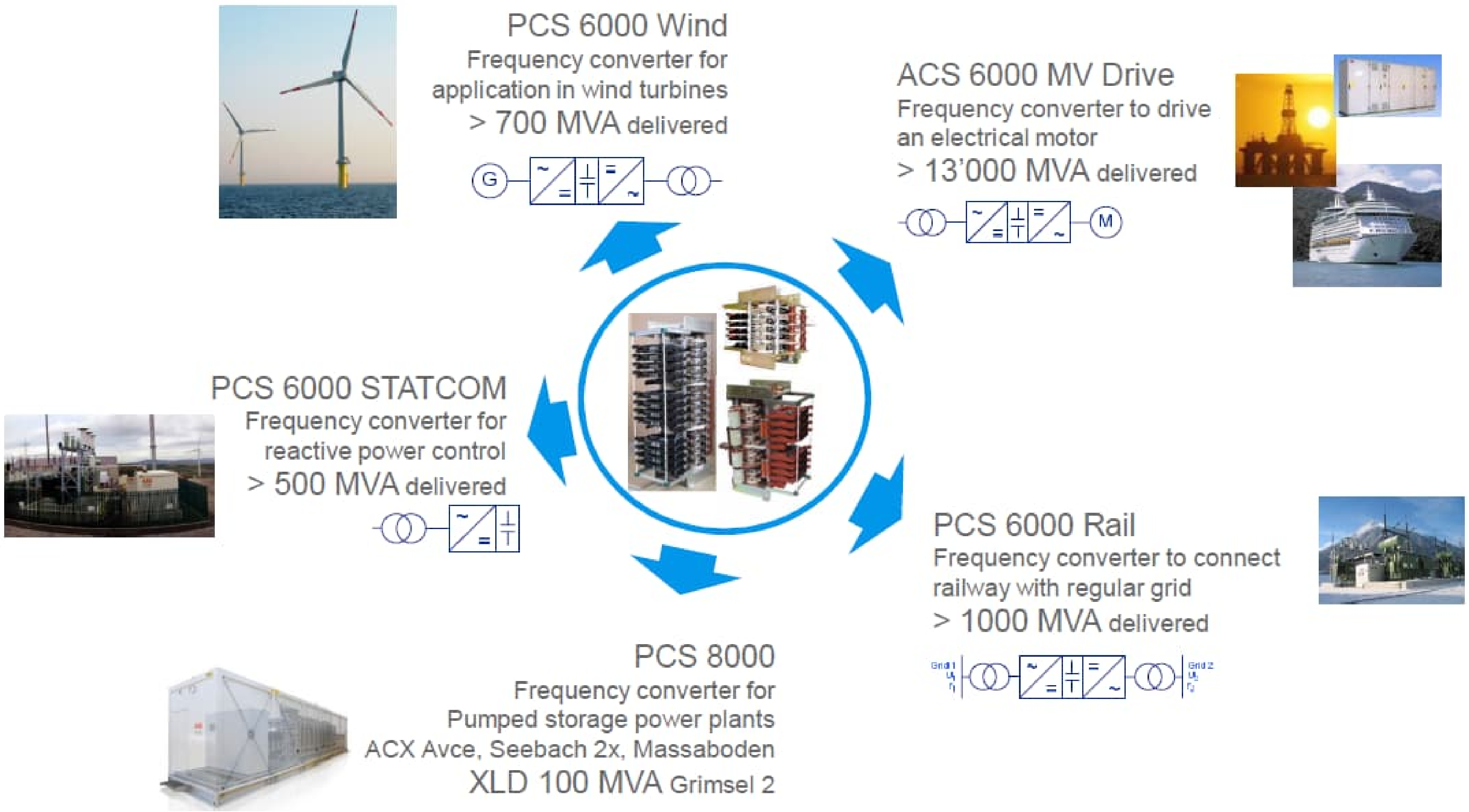
IGCT application exemplified via ABB/Hitachi Energy solutions

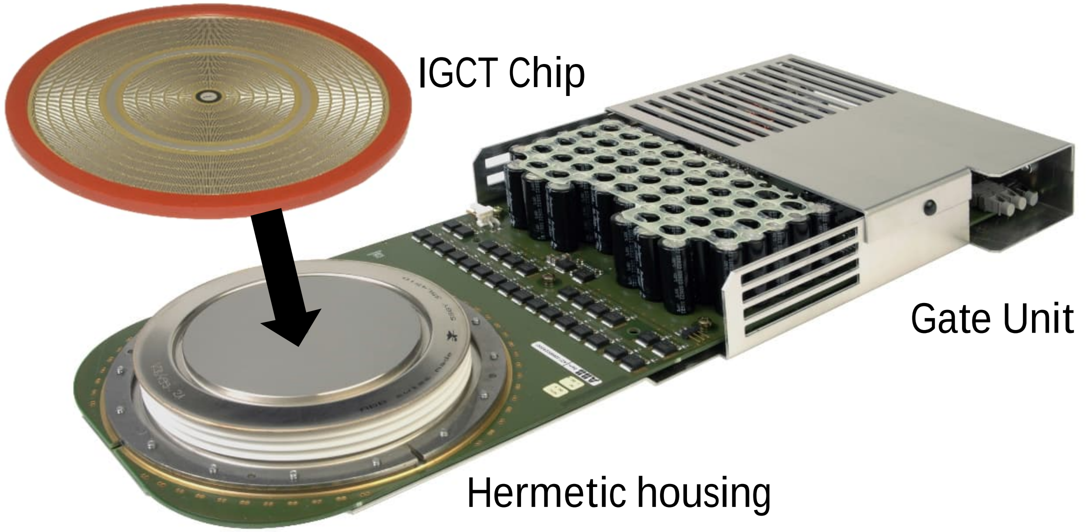
Growing markets: Rail Intertie (PCS 6000), STATCOM (PCS 8000 & PCS 6000 Rail) and Offshore Wind (PCS 6000 Wind)



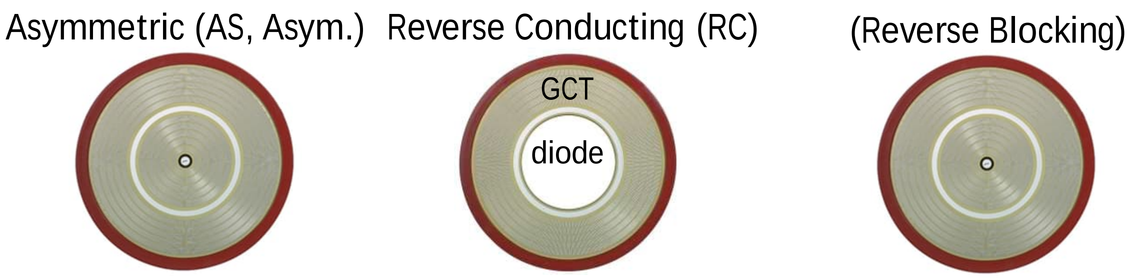
Source: ABB, Hitachi Energy

The Integrated Gate Commutated Thyristor (IGCT)

IGCT:
- Thyristor structure ensure very low On-state losses.
- Monolithic chip: Optimal ratio of edge termination to active area, especially of importance for higher voltage.
- IGCT chip in hermetic housing ensures optimal protection from environmental impacts.



IGCT Types



Increasing the Power Handling Capability: Gen 3 vs. Gen 2 devices – Features

Gen 3 features

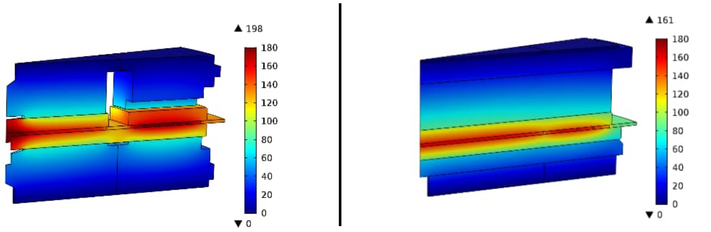
- Applied to our latest 85 mm pole-piece diameter (L-housing) RC and AS IGCTs with voltage rating of 4.5 kV
- Retain outer dimensions for compatibility with application and integrated gate unit.

Gen 3 optimization focus: turn-off and thermal performance

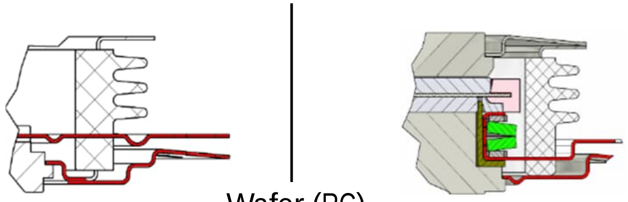
- Minimize gate-circuit impedance:
  - Moved gate contact infrastructure to device periphery.
  - Optimized routing of gate contact through the housing.
- Improved thermal performance by using monolithic Molybdenum disk and asymmetric anode and cathode side pole piece thickness.
- Increased device diameter through efficient use of raw silicon wafer.
- Turn-off current increased by adjusting doping profile

Previous versus New Generation 3

Packaging design



Gate contact infrastructure



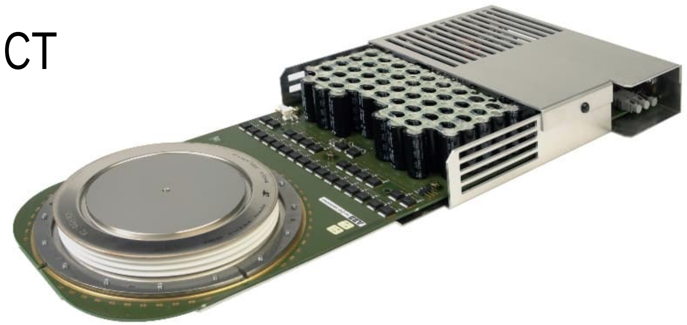
Wafer (RC)

Reference: T. Wikström, M. Alexandrova: A Technology Platform for Reverse-Conducting Integrated Gate Commutated Thyristor with 94mm Device Diameter, Proc. PCIM Europe 2017, pp. 806-810

Parameter improvement Gen 3 vs. Gen 2 - L-Size 4.5 kV AS device

Feature	Generation 2	Generation 3
IGCT	5SHY 55L4520	5SHY 65L4522 (low dynamic losses) 5SHY 65L4521 (low static losses)
Active area	1 a.u.	x 1.22 +22%
SOA	5.5kA	6.0kA (5SHY 65L4522) + 9% 6.5kA (5SHY 65L4521) + 18%
Rth_{JH}	11.5K/kW (@40kN)	9.2K/kW (50kN) - 20%
T_{Jmax}	125°C	140°C
Max RMS on-state current TC = 85°C	2940A	3640A (5SHY 65L4522) + 24% 4340A (5SHY 65L4521) + 48%
Diode	5SDF 20L4520	5SDF 34L4520
Structure	Planar	Structured Thinner silicon compared to Gen2
RthJH	9K/kW	7.8K/kW -13%
Max RMS on-state current T_C = 70°C	3100A	4220A +36%

IGCT



Gen 2 → Gen3

Further details see: U. Vemulapati et. al.; New Generation 4.5kV IGCT and Fast Recovery Diode for Railway Power Supply Application; PCIM 2024 Nürnberg

Gen 3 Platform – scaling to larger size and higher voltage

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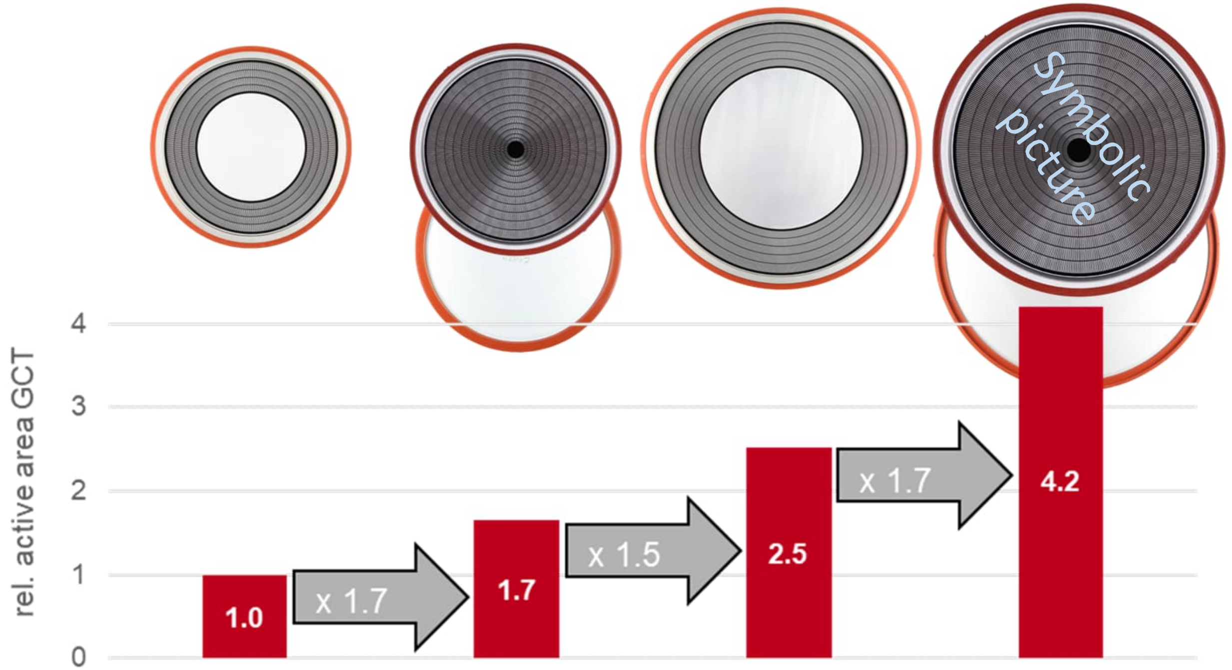
Scaling

Voltage scaling

- Optimizing of the vertical IGCT design
- adopting of edge termination to voltage class
- adopting of the packaging height (creepage distance, strike distance)
- Current handling capability reduces with voltage rating.

Current capability scaling

- RC-IGCT → asym. IGCT (& discrete FRD)
- Increased Device area
- Two size pole piece diameter: 85mm / 138mm
- Current handling capability scales with IGCT active area



Voltage	RC 85mm	asym. 85mm	RC 138mm	asym. 138mm
8.5kV 5kV (DC-link)	2kA	3kA	5.5kA	9kA
6.5kV 4kV (DC-link)	2.6kA	4.4kA	8kA	12kA
4.5kV 2.8kV (DC-link)	3.6kA	6.5kA	-	-

Product · Development

Turn-off capability (SOA)

8.5 kV asym. IGCT with pole piece diam 85 mm (L-size)

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8.5kV IGCT for 5kV DC-link

- Allow for converter current reduction, at same power handling capability.
- Reducing current particularly interesting for offshore wind application
- Converter standardization: Use of scalable device in voltage is essential to offer cost competitive solutions.
- A 8.5 kV device is the most cost effective and simplest way to increase the system voltage without replacing the well-known converter topology.

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8.5kV 5kV (DC-link)	2kA	3kA	5.5kA	9kA
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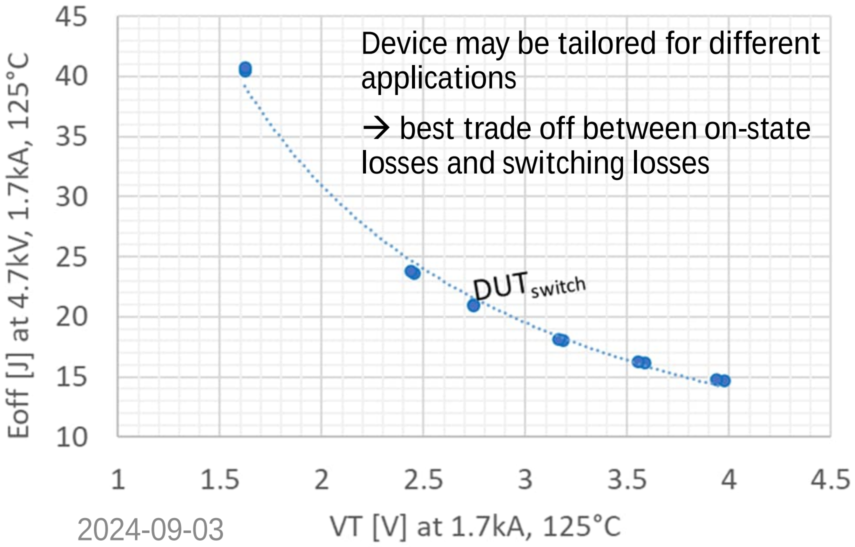
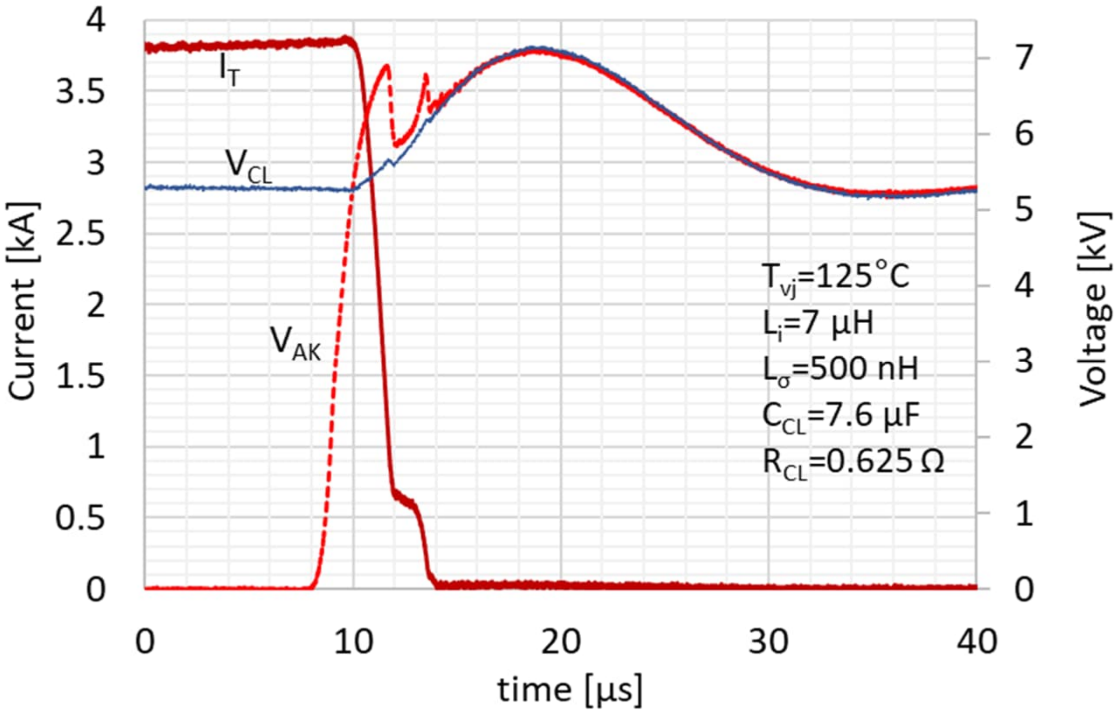
Product | Development — Turn-off capability (SOA)





8.5kV RC IGCT with pole piece diam 138mm (Y-size)

8.5kV IGCT for 5kV DC-link

- High voltage 8.5 kV and 138mm large size IGCT allow for increase of power handling capability and current reduction vs. smaller 85mm IGCT.
- Most compact and cost optimized design possible e.g. no separate freewheeling diode required. Preventing parallel connection of converters per turbine.

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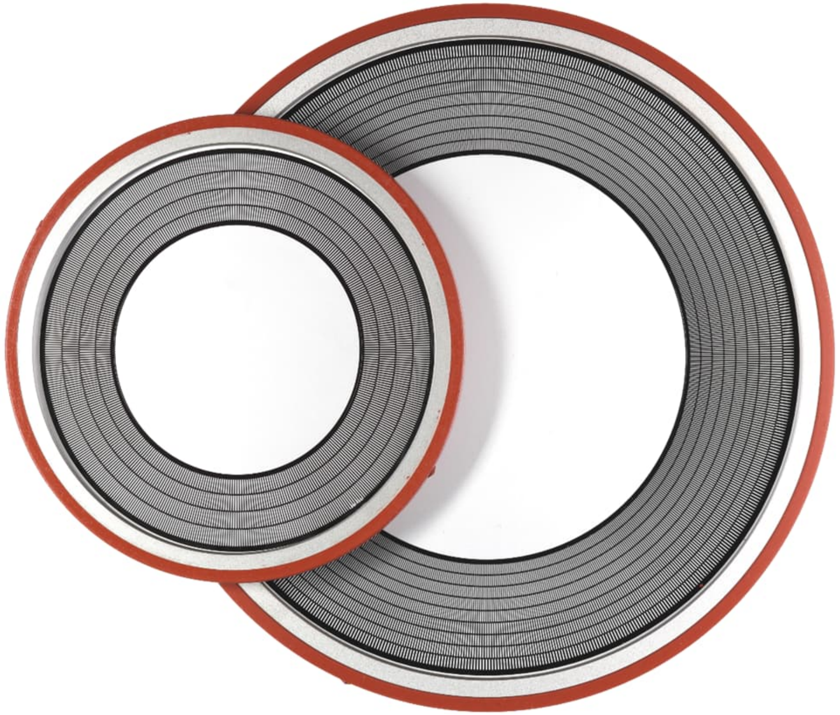
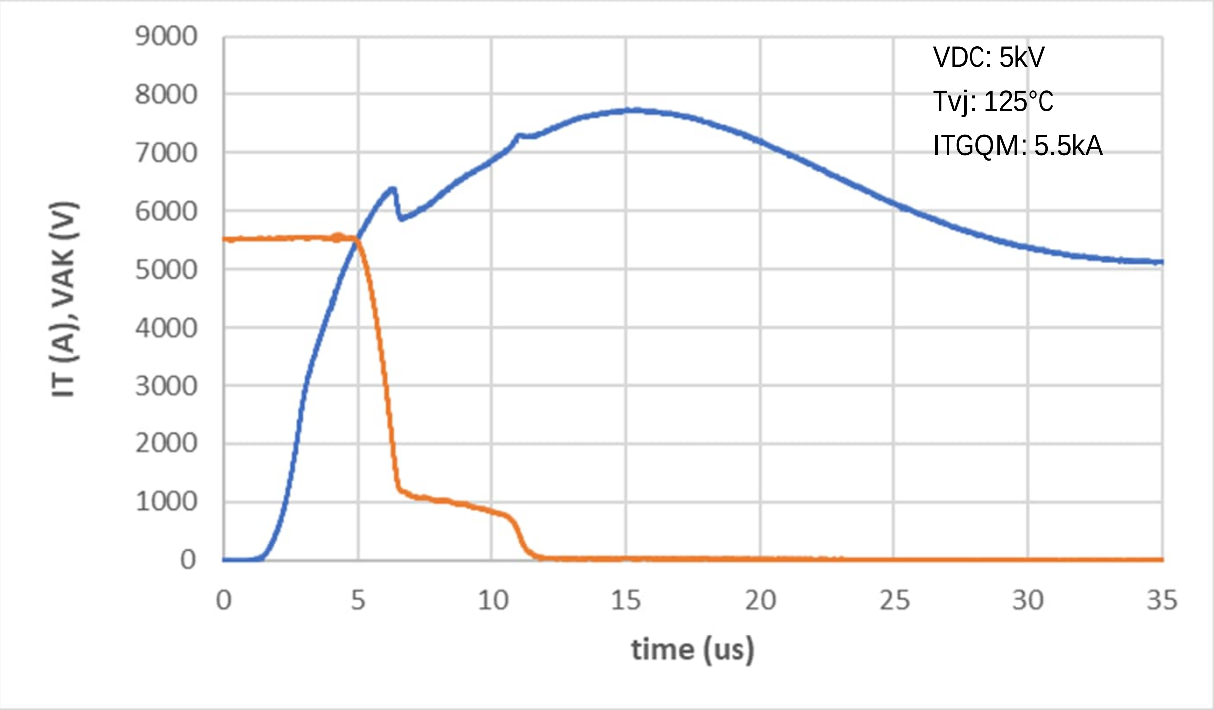
Product | Development

Turn-off capability (SOA)



85mm polepiece diameter 138mm



IGCT Reliability – Field Experience

IGCT design for reliability

Power semiconductor

- Optimal ratio between edge termination and active area
- Robust pressure contact design to guarantee high power cycling capability

Gate unit:

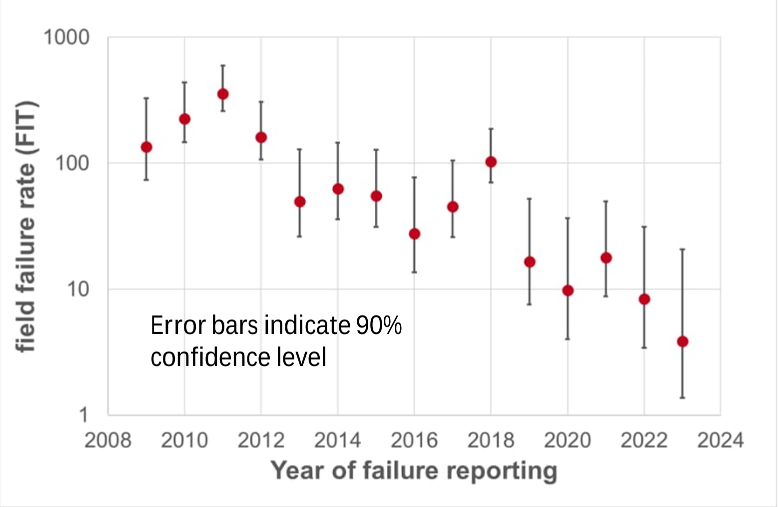
- Specifically designed for IGCTs
- Integrated with GCT as single unit
- Turn-off circuit designed with large margin

Package (hermetic press pack):

- Handles large fault currents
- Offers SCFM (no degradation in VT >4000h[2])

Failure rate during useful life [1]

- Field returns: from MVD application
- Comparison of reliability of Offshore wind and MVD applications with IGCTs states similar failure rate for both [3].
- Failure cause: 50% GCT, 50% gate unit.



- Decreasing failure rate due to continuous improvement

Device analysis after long term use

- IGCT from long term applications were returned from field, remeasured and analysed:

Application	Description	Operation time
MVD	Metal drive (severe load cycling)	8 years
MVD	Gravel lift Gotthard tunnel	15 years
Intertie	Rail intertie	17 years

- No degradation of the gate circuit impedance detected.
- Low mechanical wear-out of dry contact interfaces compared to reliability test power cycling.

IGCT shows excellent field reliability - the device of choice for high-power applications such as offshore wind

1) T. Stiasny, O. Quittard, C. Waltisberg, U. Meier: Reliability evaluation of IGCT from accelerated testing, quality monitoring and field return analysis. Proc. ESREF, Denmark, 2018.
2) D. Weiss et al.,: IGCT-based modular multilevel converter for an AC-AC railway supply, Proc. PCIM Europe, 2017.
3) J. Wahlstroem, Ch. Winter, "Scalable and reliable medium voltage converters for high power turbines", in Wind Europe 2022 annual event 5.- 7. April 2022, Bilbao, Spain, 2022.

Conclusion

- Scalability and Reliability is of particular importance for Offshore wind turbine application.
- The 85 mm, Generation 3 devices with 4.5 kV offer improved turn-off capability and higher power handling capability
- The Generation 3 IGCT is a powerful platform and ideal for scaling in:
  - blocking voltage (DC-link voltage)
  - current handling capability (GCT active area)
- IGCTs are high reliable devices proven by field data

The Gen 3 IGCT platform is is ideal for Offshore wind application with high reliability demands and scalability requirements towards higher power handling capability

Thank you for your attention!

I am happy to answer your questions, just visit me at our Hitachi Energy PCIM booth or contact me at christian.winter@hitachienergy.com