Scalable and Reliable IGCT Power Semiconductor Platform for Offshore Wind Turbines

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Abstract

The offshore wind market is expected to maintain high growth rates and additionally, wind farms expanding in terms of total power output, turbine numbers and turbine ratings. The largest offshore wind turbines currently have a capacity of 15MW, and there are expectations for further increases to 20 MW or more.

The shift towards larger turbine ratings will require less turbines per wind farm to achieve the same power output, what is underscoring the critical importance of component reliability, particularly MTBF (Mean Time Between Failures) and availability. Furthermore, there is an increasing interest in transitioning from low voltage (LV) to medium voltage (MV) systems due to the smaller footprint and reduced component count of MV systems as the power threshold increases.

1 Introduction

The offshore wind market is anticipated to sustain substantial growth over the next few decades, supported by government strategies that foresee significant investments in offshore wind until the 2050s.

Currently, global offshore wind turbine manufacturers offer turbines with ratings of 14 to 15 MW, such as the Haliade-X (14 MW) from GE Renewable Energy [1], the SG-14-236 DD (14 MW) from Siemens Gamesa Renewable Energy [2], and the V236-15.0 MW™ (15 MW) from Vestas [3]. This trend of increasing power is expected to persist, potentially leading to offshore wind turbines reaching 20MW within the next decade.

The shift towards larger turbine power ratings aligns with the goal of reducing the Levelized Cost of Energy (LCoE) of a wind farm by requiring fewer turbines to achieve the same power rating.

In the context of fewer but more powerful turbines, component availability and reliability, and high efficiency becomes a decisive factor.

In line with the global goal of zero net emissions, Hitachi Energy is developing reliable, powerful, and efficient IGCT power semiconductors for wind turbines [4].

The IGCT power semiconductor offers exceptional reliability and robustness.

Extensive reliability qualification during device development, regular Reliability Quality Monitoring, statistical analysis, and post-field failure analysis are instrumental in continuously enhancing the quality and reliability of these devices.

1.1 The Integrated Gate Commutated Thyristor (IGCT)

The IGCT is a monolithic silicon chip housed in a hermetic press pack. The device conducts like a thyristor in the on-state, resulting in low conduction losses and turns-off like an IGBT in open base transistor mode (hard switching turn-off capability due to the integration of the low inductive gate unit). State-of-the-art IGCTs are available as symmetric or reverse blocking, asymmetric and reverse conducting devices: The symmetric device blocks full voltage in forward and reverse direction. The asymmetric IGCT can block the full voltage in forward direction but has limited blocking capability in reverse direction. A free-wheel diode is required for operation in Voltage Source Inverter (VSI) topology. The Reverse Conducting device (RC) does not require a dedicated free-wheel diode, it is fully integrated on the same wafer as the GCT.

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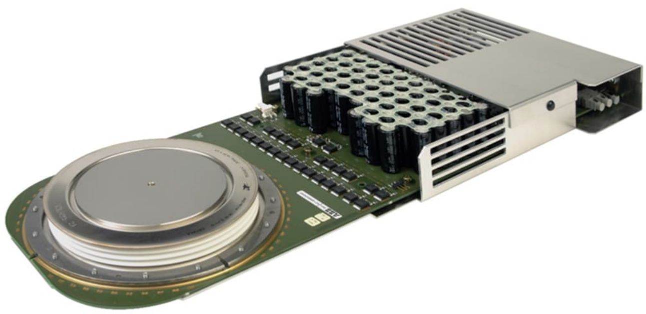

Fig. 1. IGCT with 85 mm pole piece diameter

2 IGCT Reliability and Field Experience

2.1 Design for Reliability

The power device is packaged in a hermetic ceramic press pack housing, ensuring the protection of the sensitive structures of the power semiconductor from environmental influences. Therefore, issues like influence of humidity on the blocking capability, observed for non-hermetic packages can be eliminated by design. The package design offers high power cycling and large fault current handling capability. In addition robust Short Circuit Failure Mode (SCFM) with no degradation in forward voltage drop (VT) for more than 4000 hours is reached [5].

The Gate Unit is specifically designed for IGCTs and fully integrated with the GCT as single unit. Considering appropriate design margin philosophy, the main failure causes on the gate unit parts was never found in the high current path (MOSFET or electrolytic capacitor). Especially the most suspicious component the electrolytic capacitor was never found to be the failure root cause of any field return [6].

2.2 Failure rate and MTBF

The IGCT failure rate and MTBF calculations are based on customer field return data. Early failures are considered negligible compared to random failures during the device's useful lifetime. Aging failures are not within the scope of this study. The estimated failure rate (λ) is expressed as λ=n/(N×T), where T is the operation time (estimated at 6000 hrs/year), n is the number of failures, N is the number of devices in operation, and λ is the estimated failure rate. The results are expressed in FIT (Failures In Time), denoting the probability of failure (unit = device failures/10^9 hours). A confidence level of 0.9 was used, and confidence intervals were estimated using the Chi-square distribution.

The evaluation of IGCT field data is based on Medium Voltage Drive application, see Figure 2. A comparison of the reliability of Windmill applications and Medium Voltage Drive applications with IGCTs states a similar failure rate for both applications [7]. The FIT rate is constantly improving and dropped well below 100 failures in 10^9 device hours for the past 5 years. For a more detailed evaluation of IGCT reliability and associated failure modes refer to [6].

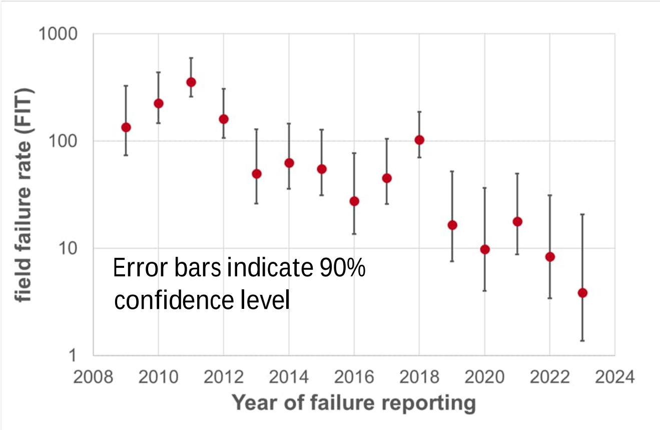

Fig. 2. Field failure rate FIT (in fail/10^9 hrs) for one IGCT. The error bars indicate a confidence interval of 90%

2.3 IGCT Reliability – Cosmic Ruggedness

The cosmic ray ruggedness is evaluated with artificial particles and tested in an appropriate laboratory. Out of the tests an empiric model is generated. It provides the user with a simple failure rate calculation tool. The mathematical model covers the three most important influences: blocking voltage, junction temperature and altitude. The cosmic ray failure rate is expressed in FIT i.e. number of failures within 10^9 element hours [8]:

$$\mathrm{FR}(V_{DC}, T_{vj}, h) = C_3 \cdot \exp\left(\frac{C_2}{C_1 - V_{DC}}\right) \cdot a_2 \cdot a_3$$

with the temperature correction:

$$a_2 = \exp\left(\frac{25 - T_{vj}}{47.6}\right)$$

and the altitude correction:

$$a_3 = exp\left(\frac{1 - \left(1 - \frac{h}{44300}\right)^{5.26}}{0.143}\right)$$

The table shows the device specific parameters for generation 3 asymmetric IGCTs with a pole piece diameter of 85 mm and voltage classes 4.5, 6.5 and 8.5 kV. More information regarding generation 3 IGCTs can be found in the following chapter:

Device	C_1	C_2	C_3
5SHY 30L8520*	2650	5500	1.48E+07
5SHY 44L6520*	3100	16800	8.52E+07
5SHY 65L452x	3946	31321	8.50E+08

* preliminary data

Fig. 3. Device specific parameters C_1-C_3 for generation 3 IGCTs with pole piece diameter 85 mm and voltage class 4.5, 6.5 and 8.5 kV.

The cosmic ray FIT value evaluation shows excellent cosmic ray ruggedness for the three devices:

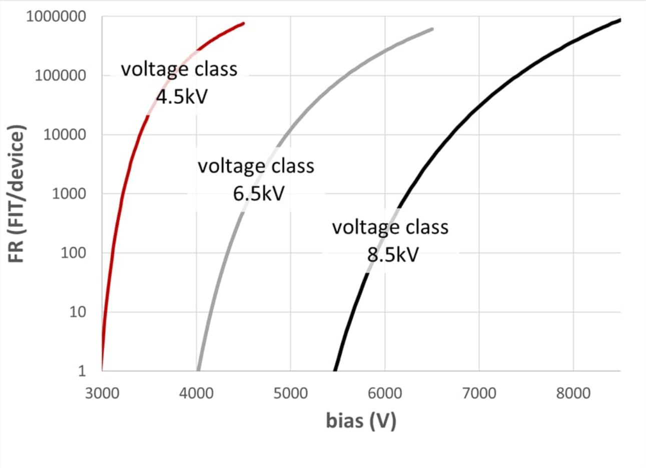

Fig. 4. Cosmic ray failure rate for IGCTs (Generation 3, 85 mm pole piece diameter, at Sea-level, 25°C).

3 IGCT Power Handling Scalability

The IGCT is a mature component used in demanding applications like industrial motor drives, offshore wind turbines, and rail supply, all of which demand highest availability, efficiency, and power handling scalability.

IGCT technology is evolving to support higher power applications with elevated current and voltage ratings. The IGCT device currently used in converters for large offshore wind turbines is the L-type, Generation 2 or 3 Asymmetric IGCT with an 85 mm pole piece diameter and 4.5 kV blocking voltage.

Pole piece diam. (mm)	Blocking voltage / DClink (kV)	Status	Type	Generation	IT(RMS) *) (A)	Turn-off capability (A)
85	4.5 / 2.8	product	asym.	Gen 2	2940	5,000
85	4.5 / 2.8	product	asym.	Gen 3	4340	6,500
85	4.5 / 2.8	product	RC	Gen 3	2010	3,600
138	6.5 / 4.0	prototype	RC	Gen 3	3700	8,000
85	8.5 / 5.0	prototype	asym.	Gen 3	2042	3,000
85	8.5 / 5.0	prototype	RC	Gen 3	1234	2,000

*) IT(RMS): RMS on-stat current at half sine wave, semiconductor case temperature 85 degC.

Fig. 5. Overview of selected types of IGCTs for todays or possible future use in offshore wind application

For development of latest Generation 3 IGCT devices, a platform approach is chosen. The platform is fully scalable in voltage and current capability, see Figure 6 for an overview.

For voltage scaling, optimization of the vertical IGCT design and adopting of edge termination to voltage class is done. Higher blocking voltage require adjustment of the packaging in terms of height due to creepage and air strike distance. DC-link voltage directly impacts the current handling capability, the lower the voltage requirement the higher the current rating.

Current capability scales with IGCT active area. To enhance power handling capability in respect to RC devices, an asymmetric IGCT with a discrete antiparallel freewheeling diode or, increased device area can be employed.

The Generation 3 platform approach with full scalability offer advantages particularly interesting for offshore wind application:

Higher IGCT voltage ratings allow for lower currents at same power handling capability and enabling lighter converter design due to smaller requirements for cross-section of bus bars and cabling. In addition, IGCTs with increased area allow to gain in power handling capability, parallel connection of devices or converters can be prevented. This allows for compact converter design with increased power output.

Devices with a pole piece diameter of 85 mm and 138 mm and higher blocking capability are under development. Turn-off measurements of 6.5 kV and 8.5 kV RC devices with 138 mm pole piece diameter are presented in Figure 7 and 8.

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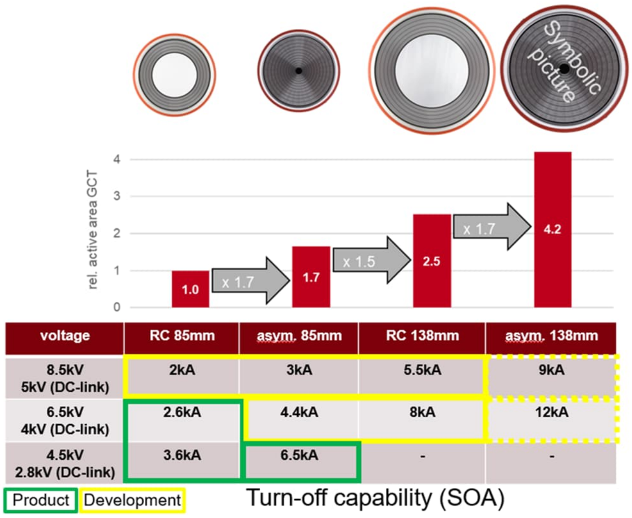

Fig. 6. IGCT Generation 3 platform approach – Voltage and Current Scaling.

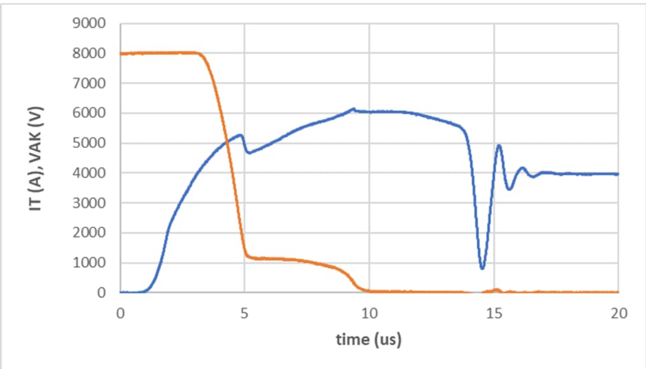

Fig. 7. Turn-off event for RC IGCT with 138 mm pole piece diameter rated 6.5 kV. VDC: 4 kV, Junction Temperature: 125°C. Turn-off current: 8 kA.

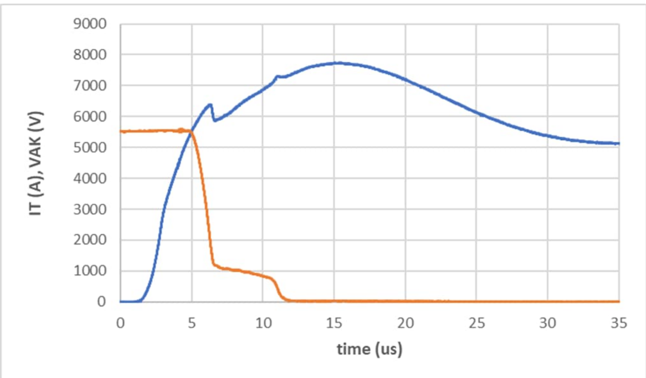

Fig. 8. Turn-off event for RC IGCT with 138 mm pole piece diameter rated 8.5 kV. VDC: 5 kV, Junction Temperature: 125°C. Turn-off current: 5.5 kA.

4 Conclusion

The future power demand for offshore wind application is moving towards 20MW turbine ratings. The architecture is ready for upcoming power advancements, thanks to ongoing system and IGCT semiconductor platform enhancements.

The Generation 3 IGCT platform offers improved turn-off capability and higher power handling capability, and its structure is ideal for scaling in blocking voltage (DC-link voltage) and current handling capability (GCT active area). Scaling of current turn-off capability with GCT area was demonstrated within voltage classes.

Continuous improvements in the power handling capability of the IGCT semiconductor, along with system upgrades, enable higher conversion power ratings without a substantial increase in component count. This ensures the reliability and efficiency of the MV solution, ultimately reducing operational expenses for wind farms.

MV converter solutions can meet these requirements, proven by extensive field experience.

5 References

[1] 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].

[2] Siemens Gamesa Renewable Energy, "SG 14-236 DD," Siemens Gamesa Renewable Energy, [Online]. Available: https://www.siemensgamesa.com/en-int/products-and-services/offshore/wind-turbine-sg-14-236-dd. [Accessed 18.06.2024].

[3] Vestas, "V236-15.0 MW™," Vestas, [Online]. Available: https://www.vestas.com/en/products/offshore/V236-15MW. [Accessed 18.06.2024].

[4] Tobias Wikstrom, “New IGCT platform for offshore wind converters exceeding 15 MW”, IEEE Global Spec, 2020.

[5] D. Weiss et al. “IGCT-based modular multilevel converter for an AC-AC railway supply”, Proc. PCIM Europe, 2017.

[6] 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.

[7] Jonas Wahlstroem, Christian Winter, “Scalable and reliable medium voltage converters for high power turbines”, in Wind Europe 2022 annual event 5.- 7. April 2022, Bilbao, Spain, 2022.

[8] Hitachi Energy, “Failure rates of IGCTs due to cosmic rays” [Online]. Available: https://publisher.hita-
chienergy.com/download?Documen-
tID=5SYA2046&LanguageCode=en&Document-
PartId=&Action=download&DocumentRevi-
sionId=D&paren-
tURL=68747470733a2f2f7075626c69736865722
e686974616368869656e657267792e636f6d2f646f
63756d656e74733f6369643d394141433931303O
32392663733d7363735f4170706c69636174696f
6e5f6e6f7465. [Accessed 18.06.2024]