Enhanced IGBT Technology for High-Power Solutions

A closer look at Fuji's HPnC modules, their features and benefits, and how they can be incorporated into traction, renewable energy, low voltage drives, and more

Fuji Electric

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Driving the Market: Unmatched Performance in an Industry-Leading Package

James E. Usack, Division GM - Semiconductor Devices, Fuji Electric Corp. of America

1. What distinguishes Fuji's HPnC Modules from other SiC MOSFET and/or IGBT solutions in the market?

HPnC modules contain 7th-generation Insulated Gate Bipolar Transistor (IGBT) or SiC MOSFET devices that leverage our latest chip technology to achieve significantly lower power loss during operation compared to other HPM solutions.

2. For organizations looking to make the shift, why should they consider HPnC Modules?

Our HPnC modules offer unmatched performance by combining the superior properties of SiC and advanced manufacturing processes. The modules offer industry-leading low on-resistance, high energy density, and enhanced thermal performance.

3. How does Fuji's HPnC technology benefit end-users in terms of cost savings?

HPnC modules offer cost efficiency in several ways. By minimizing energy losses during power conversion, they ensure maximum energy is obtained from renewable systems. These modules are also designed with robust components, such as magnesium and silicon carbide baseplates, to ensure durability and avoid frequent replacements.

4. Are there industry partnerships or collaborations that Fuji is exploring to accelerate the adoption of these modules?

We are currently collaborating with Gate Drive developers for the FE HPnC modules. We also maintain strong relationships with major distribution channels to put our products in front of a global customer base.

5. Should users be aware of any safety concerns or limitations when transitioning from traditional HPMs to SiC IGBT modules?

HPnC modules are safe for use and contain the highest quality components to ensure longevity. They also contain a thermal sensor element for overtemperature protection.

6. How is Fuji Electric planning to tackle the challenges of market competition as more companies start to adopt and manufacture SiC IGBT modules?

Fuji is committed to continuous research and innovation. Our HPnC modules leverage our latest "X Series" chip technology to achieve significantly lower power loss compared to HPM solutions on the market. We plan to release subsequent iterations of these modules in the near future.

7. What support does Fuji Electric offer engineers and professionals who want to adopt this technology?

We offer technical support on our HPnC modules via our official website. For application-specific inquiries, please send us an email at x-fea-semiapplicationengineering@fujielectric.com

8. How does Fuji's HPnC Module align with the sustainable renewable energy future vision, especially regarding material reuse and recycling?

For these modules, we have gone with ultrasonic bonding technology to minimize the use of flux, lead, and other potentially toxic materials. Our HPnC modules are also RoHS compliant.

TECHNICAL ARTICLES

Fuji Electric 7th Generation IGBT Technology Powers Today's High Efficiency Energy Conversion Systems

James E. Usack, Division GM - Semiconductor Devices, Fuji Electric Corp. of America

Today's Power Electronic market is driving development of compact, low-loss, and, high-reliability IGBT modules to optimize power conversion systems.

In response Fuji Electric has developed our 7th generation X-Series IGBT technology combining enhanced semiconductor chip characteristics and improved packaging structure. Our unique design concept increases the IGBT performance and allows continuous 175 °C $T_{j(op)}$ operation. In particular, the Fuji Electric X-Series Dual XT module is the first IGBT module to achieve 800A-1200V rating in a 62mm x 150mm 2:1 package.

To support the development of the high-efficiency power conversion systems needed to address these applications, Fuji Electric developed an enhanced insulated gate bipolar transistor (IGBT) technology. The new Fuji Electric 7th generation technology combines innovations in the intrinsic characteristics of our trench gate IGBT structure and free-wheeling diode (FWD) to improve and optimize performance and increase efficiency.

Fundamentally the Fuji Electric 7th generation IGBT technology simultaneously and significantly reduces IGBT and FWD losses, power dissipation, and, accomplishes chip miniaturization. Though the following enhancements, internally and externally, the development addresses and successful overcomes the various operational areas that tend to be problematic at high-temperature operation thus enabling the 7th generation IGBT to support continuous 175 °C $T_{j(op)}$.

In particular the improvements in the collector-emitter saturation voltage in our Dual XT 2:1 module was achieved through optimizing the thickness of the IGBT drift layer and ensuring any voltage oscillation and voltage withstand performance degradation at device turn-off associated with thinner drift layer is suppressed through a concurrent optimization of the device field stop (FS) layer. In a similar optimization, the enhancements to the FWD anode-cathode forward voltage characteristics was accomplished by reducing the FWD drift layer thickness.

Additionally, through the optimization of local life-time control, the 7th generation FWD exhibits soft reverse recovery behavior during turn-off and thereby avoids potential over-voltage due to stray-inductance and high diode current di/dt. The total FWD reverse recovery energy was significantly lessened by reducing the turn-off reverse recovery and tail current. By optimizing the reverse surface of the 7th generation FWD we prevent the depletion layer from reaching the reverse surface side to minimize voltage oscillation and reverse recovery surge voltage.

Figure 1 displays the basic IGBT cross-sectional structure between Fuji Electric 6th & 7th generation IGBT technology which by comparison utilize a similar front surface trench gate structure and field stop layer back-side. The 7th generation enhancements are primarily drift and field stop layer thickness reduction and optimization of trench gate structure. Fundamentally these refinements in the front surface enable the suppression of p-channel hole pull-out during device conduction and simultaneously increase the injection-enhanced (IE) effect by increasing the carrier concentration on the IGBT front surface. These refinements significantly improve the trade-off between on-state voltage and turn-off loss of the IGBT.

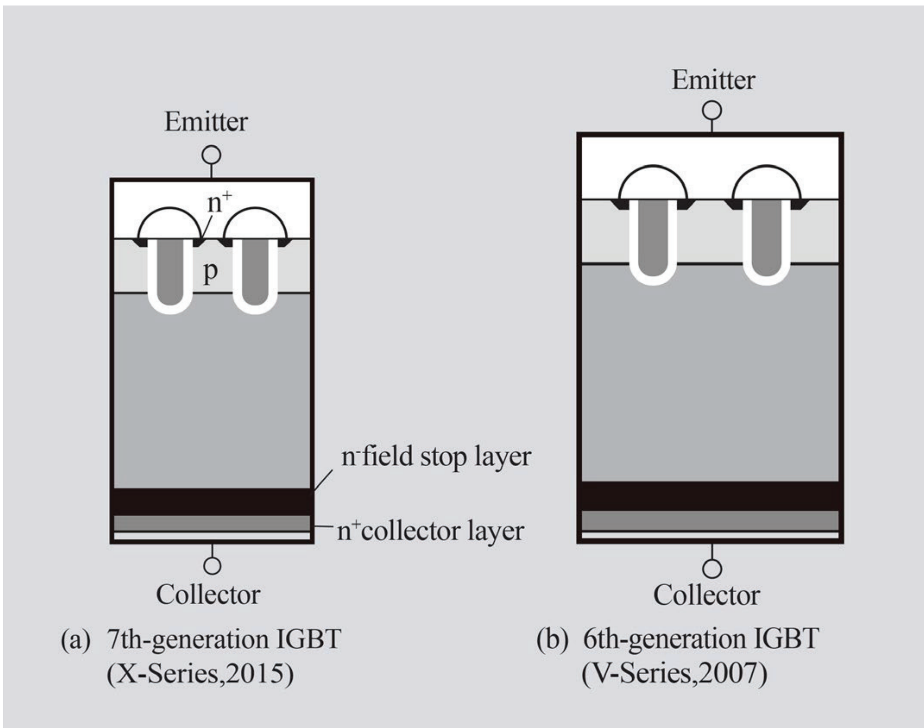


Figure 1: GBT cross sectional structure

The enhancements made in the IGBT and FWD characteristics result in a power dissipation improvement in the 7th generation IGBT; in particular the 7th generation Dual XT 2:1 module achieves an approximate 12% reduction in power dissipation at a 1kHz carrier frequency when compared to similar conventional IGBT modules.

The trade-off characteristics depicted in following figures differentiate the various IGBT trade-off characteristics: Figure 2 compares the 6th and 7th generation on-state voltage (V_{ce}) and turn-off energy and the 0.4V reduction in on-state voltage, $V_{ce(sat)}$ and a 7% reduction in device turn-off energy.

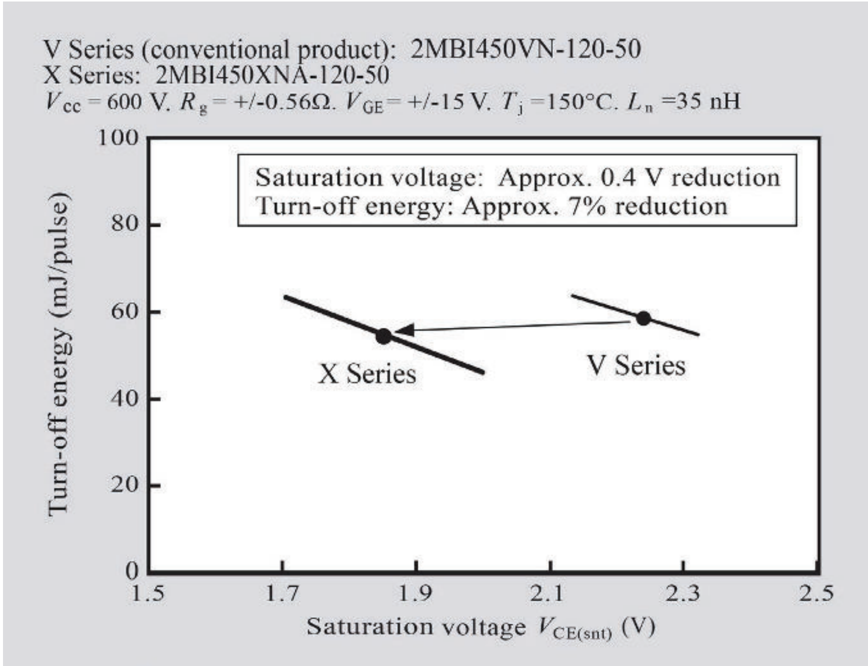


Figure 2: Trade-off characteristic (IGBT).

Figure 3 similarly depicts the FWD characteristic improvements of the 7th generation with an approximately 0.1V forward voltage (V_f) reduction and 9% reduction in reverse recovery energy.

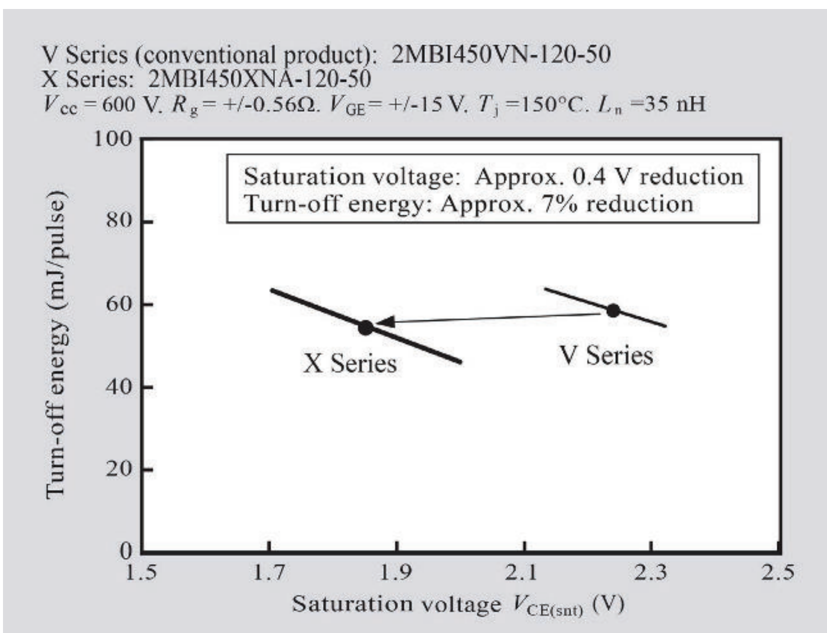


Figure 3: Trade-off characteristic (FWD).

In addition, the 'softer' reverse recovery behavior achieved with 7th generation FWD is evidenced by the reverse recovery waveforms depicted in Figure 4.

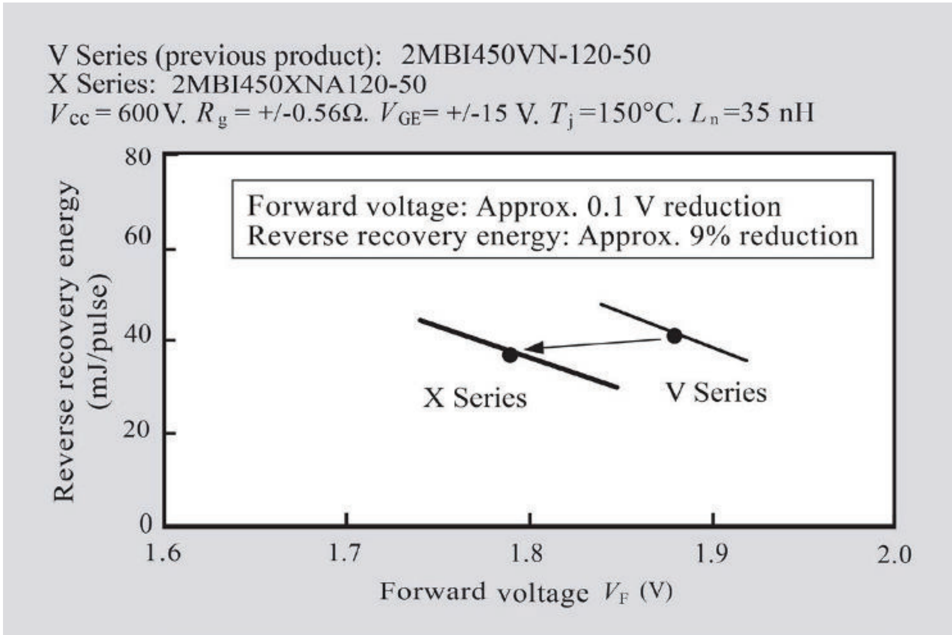


Figure 4: Reverse recovery waveforms.

A key feature of Fuji Electric 7th generation IGBT modules is our new packaging technology. Basically, the miniaturization of IGBT modules necessitate reducing the size of the IGBT and FWD which results in a higher device power density. Unless properly managed, the increased power density will result in higher chip temperature and ultimately reduced IGBT reliability. In order to solve the issue Fuji Electric developed a high-heat dissipating package technology.

The new 7th generation packaging technology improves both package exothermicity and overall thermal conduction to suppresses chip temperature rise, and the improvements enable continuous 175 °C $T_{j(op)}$ operation, and, maintains our 7th generations IGBT's high-reliability performance capability.

To start, the internal insulating substrate represents the largest portion of the thermal resistive materials within the IGBT and though an obvious target to improve exothermicity there are inherent challenges to overcome when making changes to the substrate particularly with AlN.

To overcome these challenges Fuji Electric developed a new thin type AlN substrate with enhanced strength achieved by optimizing the ceramic sintering process and also effectively distributed the thermal stress with a highly innovative substrate circuit pattern to insure dielectric strength and resistance to cracking was maintained. The isolation properties were also improved by revising the creepage distances.

The result is the 7th generation Dual XT 2:1 premium module using a newly developed highly thermally conductive AlN insulating substrate which achieves a 45% reduction in thermal resistance compared to the widely used Al2SO3 insulating substrate.

An additional consideration is internal heat generation from the internal device wire-bond connections. Conventional wire-bonds are aluminum and have a high specific resistance and hence a low thermal conductivity. The 7th generation wire bonds are copper which has a lower specific resistance and hence a higher thermal conductivity. (Table 1)

Product type	Pin type	Rated voltage (V)	Rated current (A)	Package type	Insulating substrate
2MBI225XNA120-50	Solder pin type	1,200	225	M254	Al_2O_3
2MBI300XNA120-50	Solder pin type	1,200	300	M254	Al_2O_3
2MBI450XNA120-50	Solder pin type	1,200	450	M254	Al_2O_3
2MBI600XNE120-50	Solder pin type	1,200	600	M285	AlN
2MBI800XNE120-50	Solder pin type	1,200	800	M285	AlN
2MBI225XNB120-50	Press-fit pin type	1,200	225	M282	Al_2O_3
2MBI300XNB120-50	Press-fit pin type	1,200	300	M282	Al_2O_3
2MBI450XNB120-50	Press-fit pin type	1,200	450	M282	Al_2O_3
2MBI600XNF120-50	Press-fit pin type	1,200	600	M286	AlN
2MBI800XNF120-50	Press-fit pin type	1,200	800	M286	AlN
2MBI225XNA170-50	Solder pin type	1,700	225	M254	Al_2O_3
2MBI300XNA170-50	Solder pin type	1,700	300	M254	Al_2O_3
2MBI450XNA170-50	Solder pin type	1,700	450	M254	Al_2O_3
2MBI600XNE170-50	Solder pin type	1,700	600	M285	AlN
2MBI225XNB170-50	Press-fit pin type	1,700	225	M282	Al_2O_3
2MBI300XNB170-50	Press-fit pin type	1,700	300	M282	Al_2O_3
2MBI450XNB170-50	Press-fit pin type	1,700	450	M282	Al_2O_3
2MBI600XNF170-50	Press-fit pin type	1,700	600	M286	AlN

Table 1: X Series Dual XT product line-up z

The use of copper bond wires and the optimization of the circuit pattern on the AlN insulating substrate to ‘unpack’ the bond wire concentration between the terminals and insulating substrate results in a significant improvement in lowering the internal temperature rise and coupled with the external changes in the shape and thickness of the IGBT copper main terminals has significantly reduced overall heat generation.

Another key development realized with the 7th generation technology and the Dual XT 2:1 IGBT module in particular is the expansion of the continuous operating junction temperature $T_{j(op)}$ from 150 °C to 175 °C.

T_j power cycling capability is a key figure of merit for today’s IGBT modules and is directly impacted by a $T_{j(max)}$ operational excursions exceeding 150 °C. Previously sustained $T_{j(max)}$ operation above 150 °C would dramatically degrade the IGBT modules ΔT_j power cycling capability.

Figure 5 depicts the relationship between operating temperature and ΔT_j power cycling capability, in cycles; the graph shows a comparison of Fuji Electric 6th and 7th generation and two-fold improvement in power cycling capability at 175 °C $T_{j(max)}$ and ΔT_j = 50 °C.

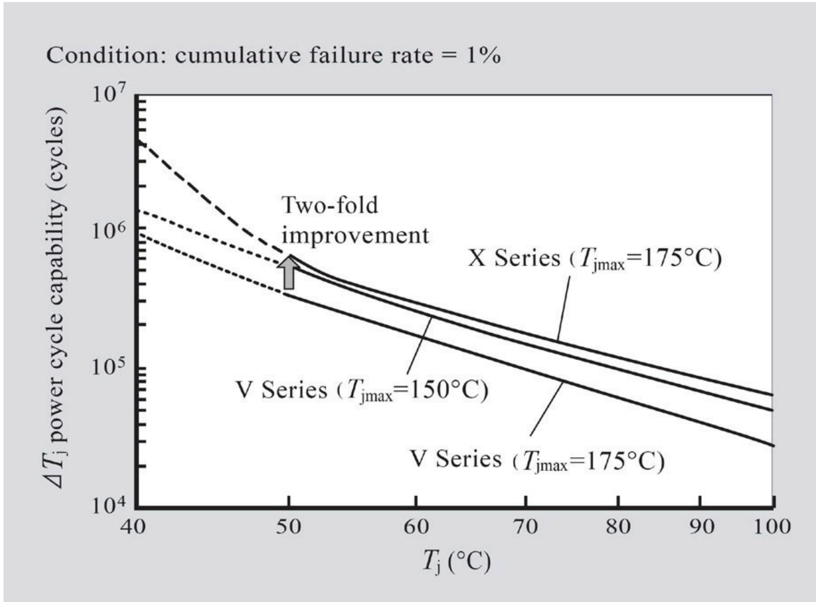


Figure 5: ΔT_j power cycle capability.

The relationship between temperature and silicone gel lifetime shown in Figure 6 clearly depicts the improvements in the 7th generation silicone gel. The conventional silicone gel could sustain a 10- year lifetime at 150 °C, however rapidly degraded to 2-year lifetime at 175 °C; the newly developed 7th generation silicone gel is able to sustain 10+ year lifetime when operated at 175 °C.

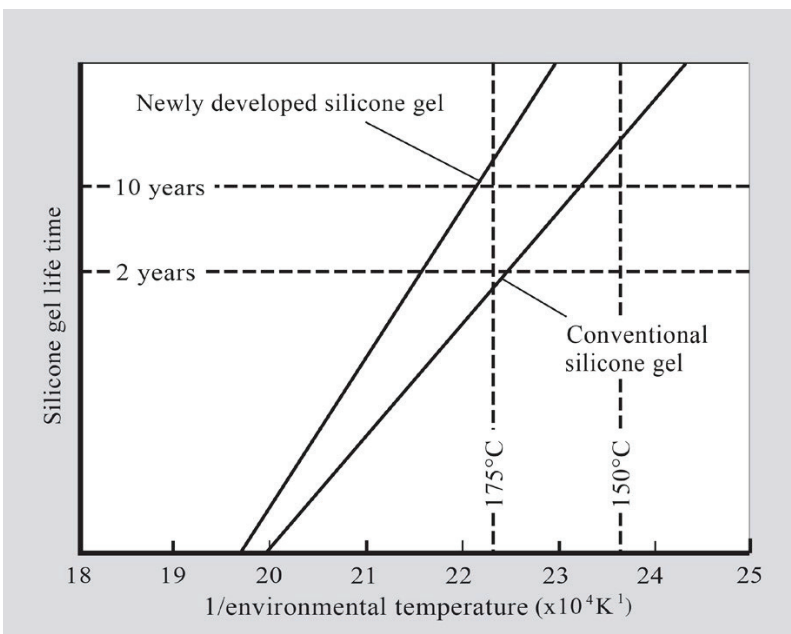


Figure 6: Relationship between silicone gel temperature and life time.

The Fuji Electric 7th generation Dual XT 2:1 module is offered in standard configuration 225A, 300A, 450A, & 600A at 1200V & 1700V with V_{iso} = 2.5kV and 3.4kV respectively and resin-based case with a comparative tracking index range of 175 ≤ CTI < 250.

The Dual XT 2:1 premium configuration is available in 600A & 800A at 1200V and 600A at 1700V with Viso = 4kV and high comparative tracking CTI ≥ 600 resin-based case material for demanding applications requiring high isolation and high tracking CTI, i.e. 1500V 3-Level NPC inverters. All 7th Dual XT IGBT modules are available with press-fit or solder pin connections.

Typical applications are in Renewable Energy: Wind Turbines and Solar Inverters; Industrial Drives for Factory Automation, HVAC, UPS, and etc.

We believe the 7th generation IGBT technology with reduced power dissipation made possible through the innovative technical enhancements of the semiconductor chip, improvements in currentcarrying capability, and, improved thermal packaging design with the ability for sustained 175 °C $T_{j(op)}$ operation offers a powerful and compelling solution for power system designers seeking a high-efficiency and high-reliability solution for today’s demanding applications requirements.

In particular the 7th generation premium Dual XT 2:1 IGBT module provides a robust, highly efficient, and, high- reliability option to power today’s energy conversion systems.

TECHNICAL ARTICLES

More Power by RC-IGBT Technology

Ben Bradel, Fuji Electric Europe GmbH

Fuji Electric introduces a new product in a well-known package to increase the output power of IGBT modules by applying “RC-IBGT” (RC stands for Reverse Conducting) technology for high-power applications. The PrimePACK™3 and 3+ are suitable for high power applications in the common 1,700 and 1,200V ratings.

The market demand for power semiconductors has been increasing for years and is requiring a miniaturization of power conversion systems, a reduction of cost and an increase in performance. Such a gain in performance is achieved by increasing the output power in a given package size, which goes hand-in-hand with elevated temperatures within the system. This results in a risk of a shorter product lifetime, due to a reduced number of power cycles at elevated temperatures.

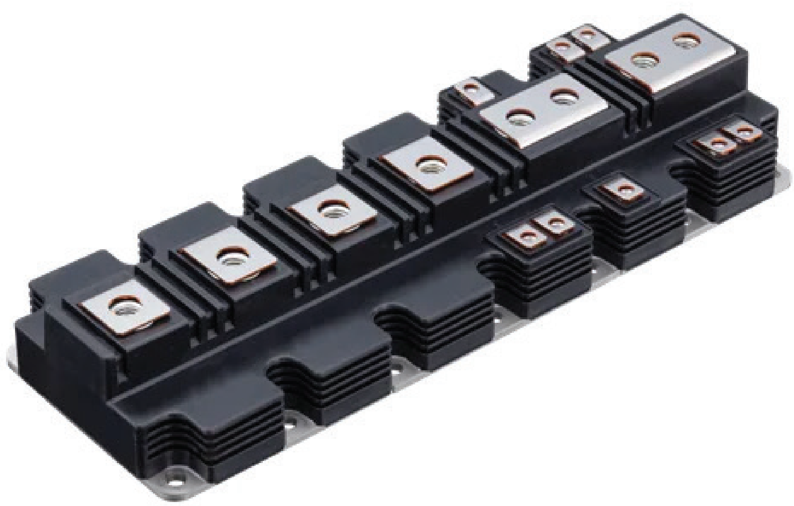


Figure 1: Outline of a PrimePACK™3+ with the two characteristic output terminals.
*Image used courtesy of **Bodo’s Power Systems**.*

Due to this phenomena, Fuji Electric accepted the challenge to develop chips and packages, which can withstand these higher performance levels, and presented the 7th generation, the “X series”, IGBT module technology some years ago. It combines high power density with high reliability by reducing the power dissipation. Furthermore, Fuji Electric developed the RC-IGBT technology, which integrates IGBT and FWD in a single chip. This enables not only a reduction of chip amount and chip area by keeping the same level of rated current, even higher currents can be realized.

This results in an increase of the rated current in the same package size and smaller power dissipation by combining the X series technology with the RC-IGBT technology. The reliability of the RCIGBT portfolio exceeds the level of conventional IGBT modules. In this article, Fuji Electric presents the PrimePACK™3+ with a nominal voltage of 1,700V (and 1,200V) for industrial applications.

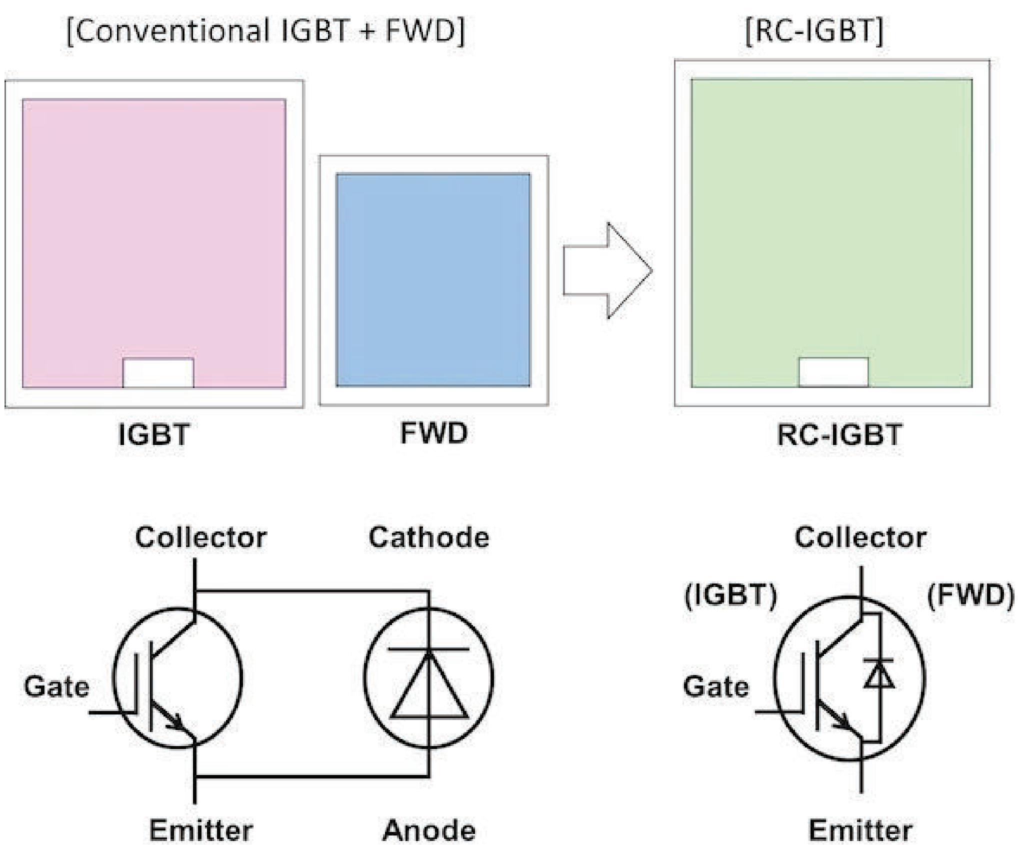


Figure 2: Schematic diagrams of the X series RC-IGBT and equivalent circuits.
Image used courtesy of ***Bodo's Power Systems****.*

RC-IGBT Technology

The RC-IGBT technology combines patterns of IGBT and FWD regions with a suitable structure on a single chip. The portion of active area to the total chip area increases because the chip's edge termination decreases relatively and generates more space in the module housing for bigger chips for an even higher output current. Another benefit is that the extended chip area reduces the thermal resistance between junction and case, $R_{th(j-c)}$, drastically.

The bigger chip area acts like a thermal buffer zone: the generated heat in the IGBT region is transferred also to the FWD region and vice versa. Thus, the I^2t capability of the RC-IGBT is 3.8 times higher compared to the predecessor V series generation.

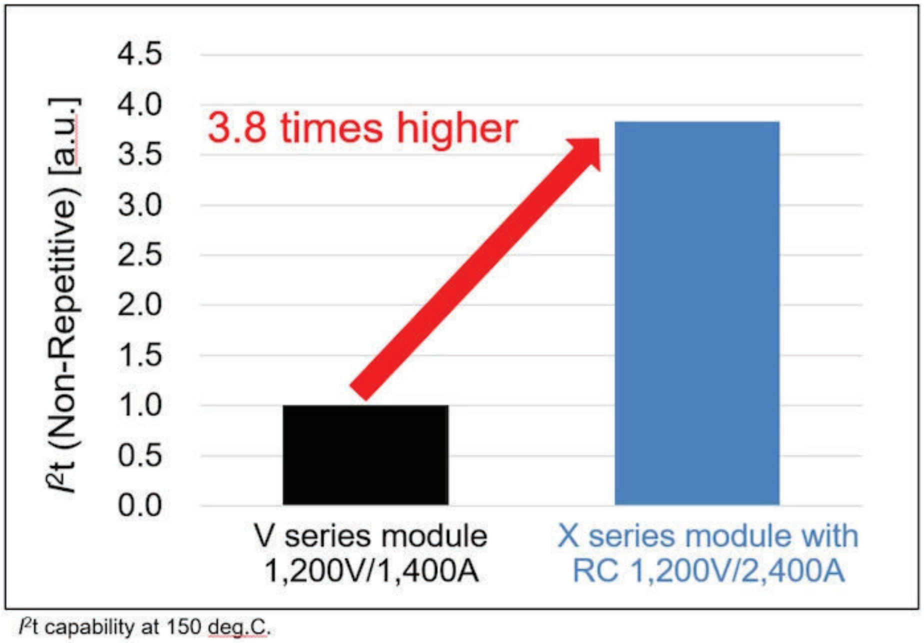


Figure 3: I^2t capability at 150 °C. Image used courtesy of ***Bodo's Power Systems****.*

The switching waveforms (Figure 4-6), taken at an elevated temperature of 150 °C, underline the smooth operation of the RC-IGBT chips. The overcurrent and overvoltage peaks are tidy and oscillations occur on a very limited level. The tail current is quite small and prevents the existence of a big energy loss during turn-off.

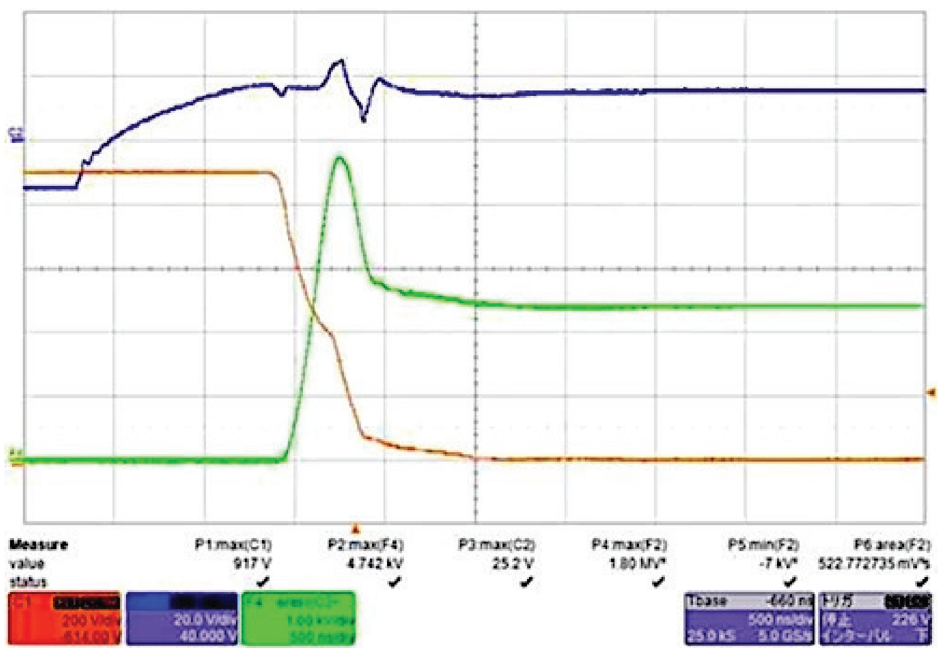


Figure 4: Switching waveform for turn-on at 150 °C. Smooth switching of VCE and IC without bigger oscillations. Image used courtesy of ***Bodo's Power Systems****.*

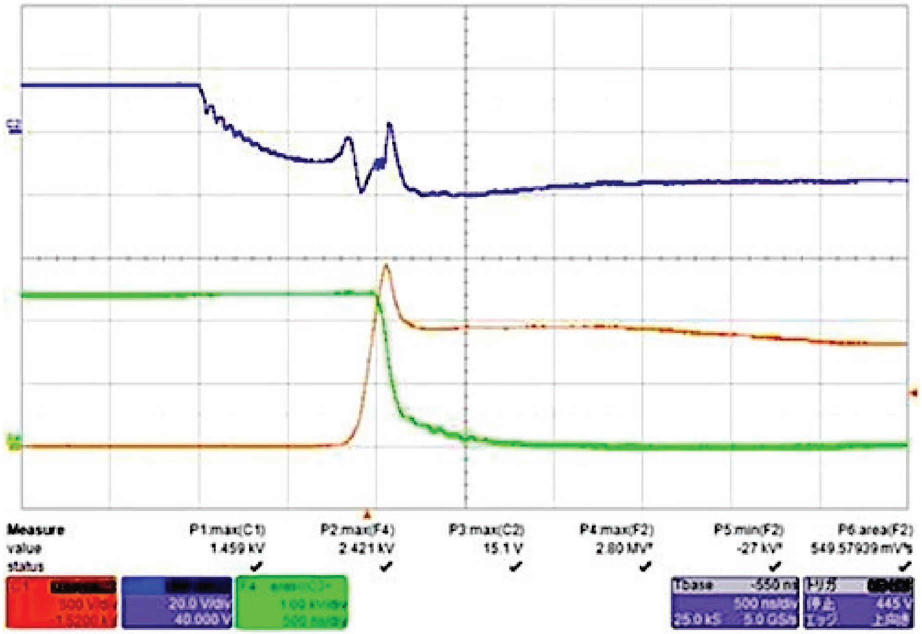


Figure 5: Switching waveform for turn-off at 150 °C. The small tail current prevents the existence of a big energy loss. Image used courtesy of ***Bodo's Power Systems****.*

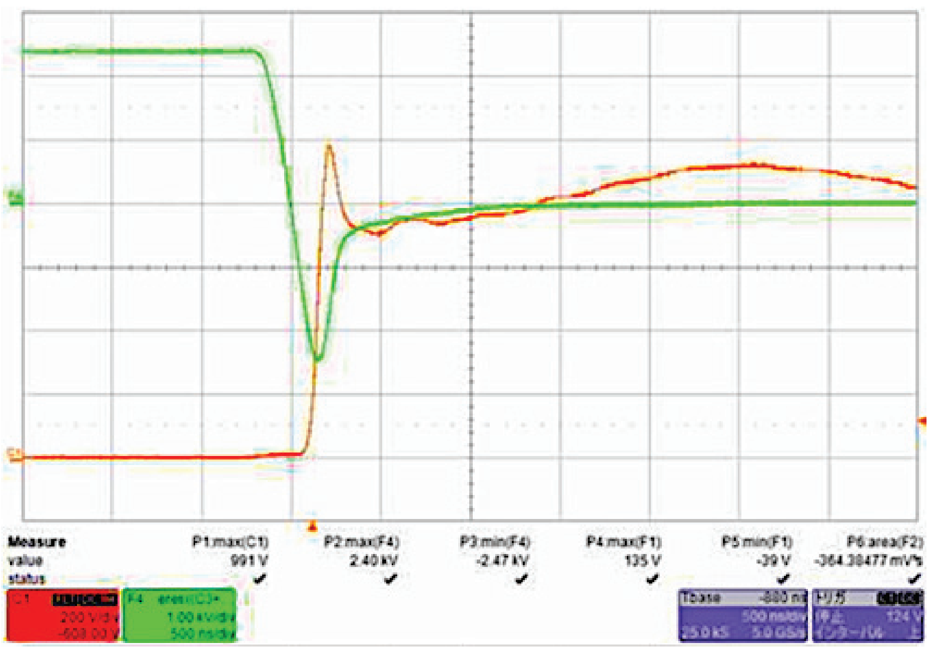


Figure 6: Switching waveform for reverse recovery at 150 °C, with very low oscillations. Image used courtesy of ***Bodo's Power Systems****.*

Some examples of the proper RC-IGBT design-in and use depict the advantages:

A large-scale grid-connected photovoltaic system, where IGBT modules are connected typically in parallel for enlarging the output current. This topology requires usually much system space and a well-planned electrical setup with lowest current imbalances. PV systems operate normally at relatively constant power. In cases where two 1,400A PrimePACK™s were used in the past, they can now be replaced with a single RC-IGBT module rated for 2,400A, thus reducing the footprint by 50%. Simulations and use-in-field experience show and underline the benefits of this technology leap.

A high-power Drive system has a low output frequency during the motor start-up period. That is the most critical phase, since the load prevails on a single chip for a relatively long time. The resulting high temperature swings cause thermal stress on the die attached bonding wire connections and eventually decrease the power cycling lifetime. By applying RC-IGBT technology and its bigger relative chip area, these temperature swings are strongly reduced, which results in a longer lifetime. If such an application has two V series (6th generation IGBT) modules in parallel use, they can be exchanged with a single RC-IGBT module of the X series, which increases the lifetime.

In Wind power applications, the input wind power is transformed twice by some power electronics. On the generator side, an inverter converts the rotation of the wind turbine which provides AC electric power, into DC electric power. The turbine rotation starts slowly and the high load stresses the IGBT and FWD to a high extent. RC-IGBT chips would prevent these high temperature swings. On the grid side, the electrical power is converted back to AC electric power and is fed into the grid network. Both sides need to fulfill different roles because the functions are also different. However, the need for higher performance unites those AC/DC and DC/AC converters. The RC-IGBT technology helps to increase the system's output current to 165% of previous V series technology solutions.

The operation comparison of a 1,800A 7th gen IGBT module with a 2,400A RC-IGBT module underlines the longer lifetime of the module with RC-IGBT technology. Due to the smaller temperature swings at the same output current, the lifetime is increased vastly.

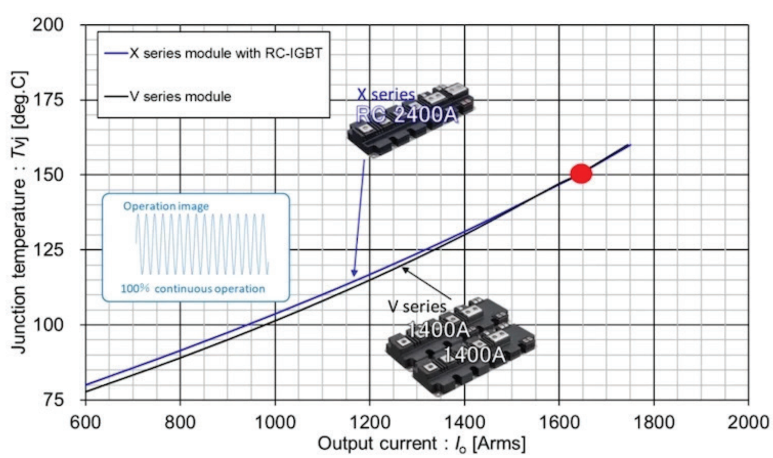


Figure 7: Calculation conditions: I_o = Vari., f_c = 3kHz, f_o = 50Hz, V_{cc} = 600V, p_f = 0.9, m = 1.0, R_G = +0.22/-0.22Ω(X), +1/-1Ω(V), $R_{th(s-a)}$ = 0.006k/W, $R_{th(c-s)}$ = 0.0014k/W (with 3W thermal grease), T_a = 50 °C. Calculation results of the relationship between IGBT $T_{vj(max)}$ and I_o during continuous operation of X series module with RC-IGBT. Image used courtesy of ***Bodo's Power Systems****.*

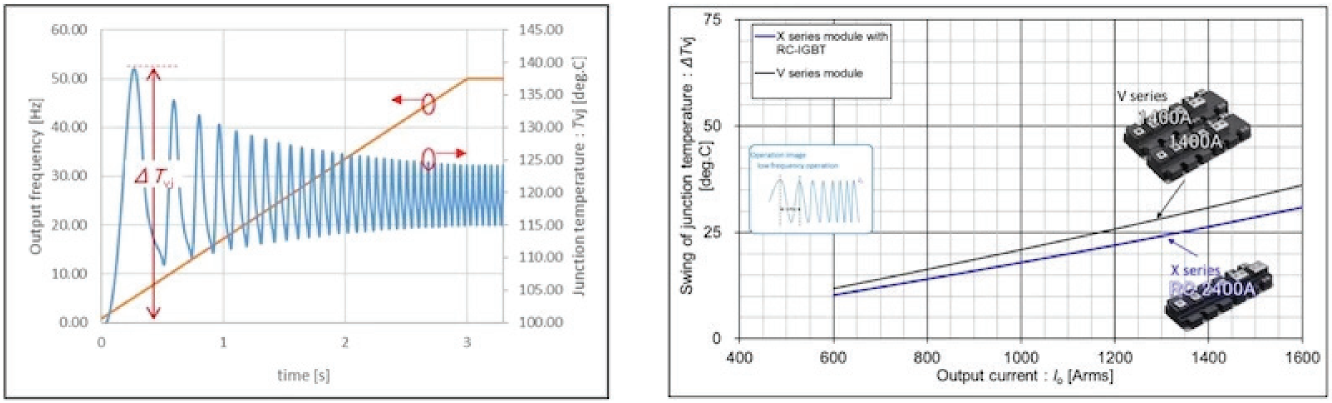
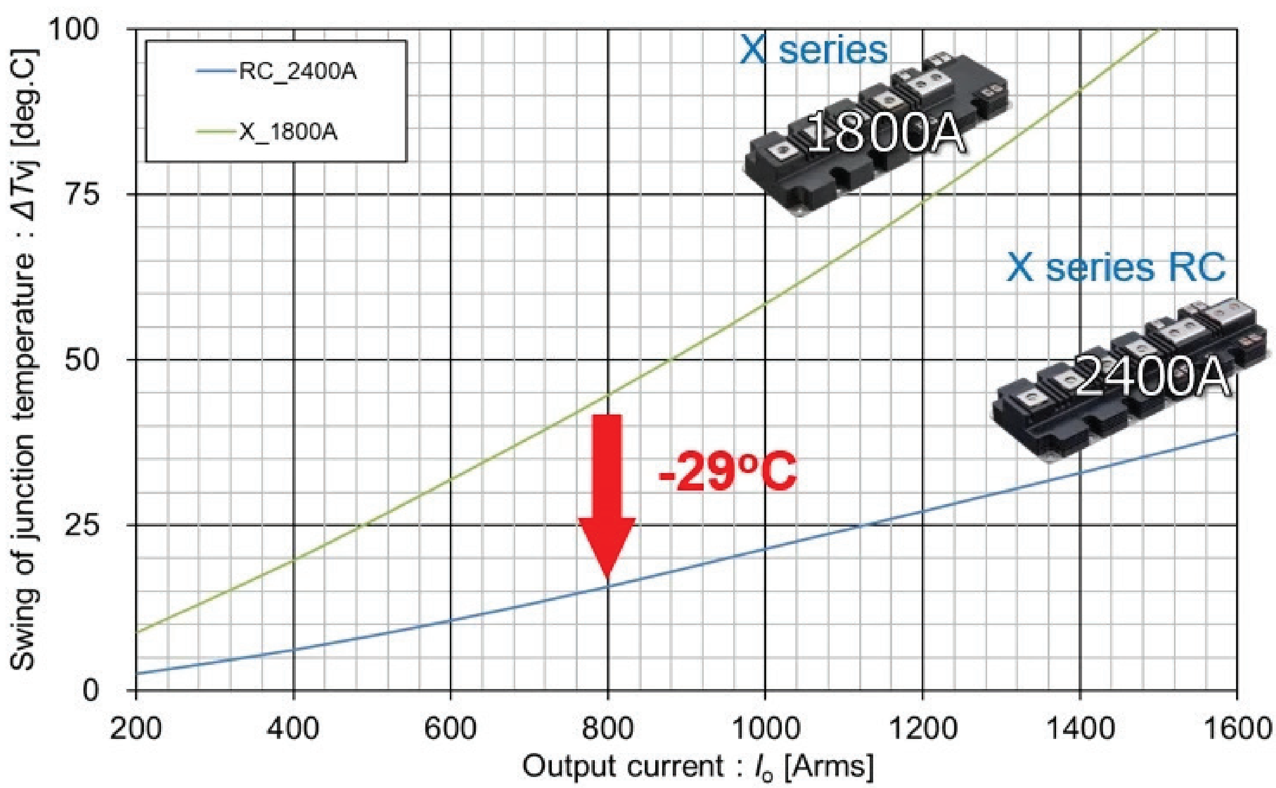


Figure 8: Increasing output frequency pattern and temperature swing ΔT_{vj} during motor start-up.
(top) Calculation conditions: I_o = Vari., f_c = 3kHz, f_o = 1Hz, V_{cc} = 600V, p_f = 0.9, m = 0.01,
R_G = +0.22/-0.22Ω(X), +1/-1Ω(V), $R_{th(s-a)}$ = 0.006k/W, $R_{th(c-s)}$ = 0.0014k/W (with 3W thermal grease),
T_a = 50 °C, low-frequency start-up to continuous condition. (bottom) Image used courtesy of ***Bodo's Power Systems****.*

Another approach in utilizing the RC-IGBT PrimePACK™ is to achieve smaller footprints by replacing 16 pieces of a 600A Dual XT modules with four 2,400A RC-IGBT PrimePACK™s. Besides the fewer amount of driver units, which makes the system easier to control, the footprint also shrinks to only 40% of the initial system size. This downsizing trend will be more common in the future with the increased lineup of various RC-IGBT packages.



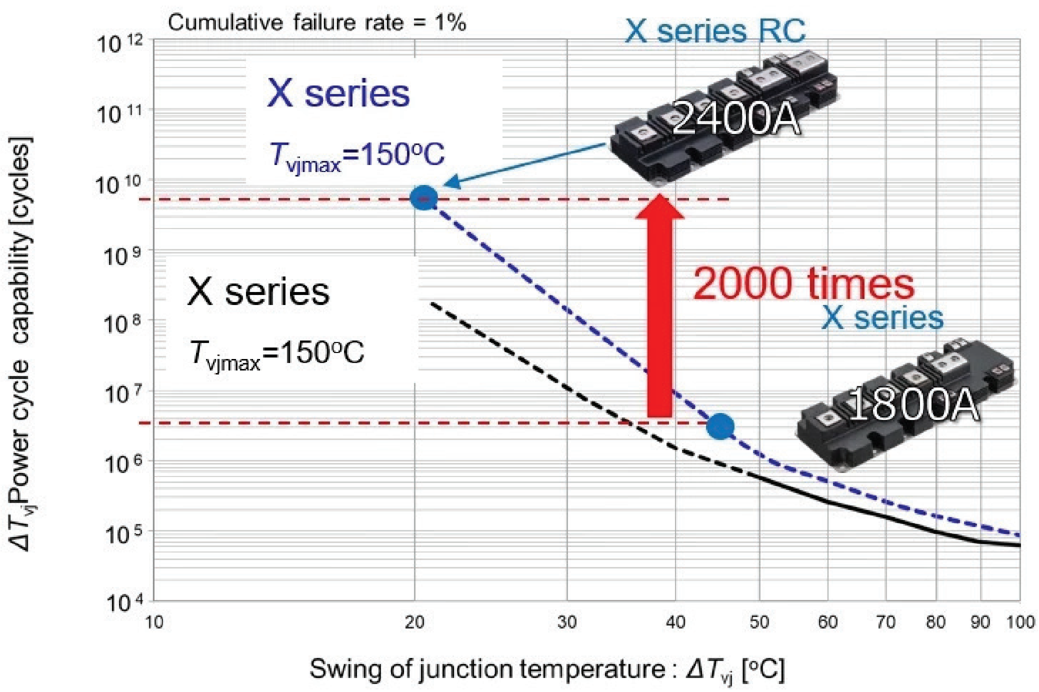


Figure 9: Comparison of junction temperature swing curves of a common 7th gen X-series 1800A module and a RC-IGBT 2400A module also using a 7th gen X-series IGBT. The RC-IGBT achieves a smaller temperature increase at the same output current. Calculation conditions: I_o =Vari., f_c = 3kHz, f_o = 5Hz, V_{cc} = 1200V, p_f = -0.9, m = 1, Standard RG, $R_{th(sa)}$ = 0.0047 °C/W, $R_{th(c-s)}$ = 0.0014 °C/W (with 3W thermal grease), T_a = 35 °C. (top)
*The power cycle capability curve comparison shows the increase of statistical expected lifetime of the 2400A RC-IGBT. (bottom) Image used courtesy of **Bodo's Power Systems**.*

2-Pack PrimePack™	1200V						1700V					
Rated Current	600A	900A	1200A	1400A	1800A	2400A	650A	1000A	1200A	1400A	1800A	2400A
V Series (6 Gen.)	PP2			PP3			PP2	PP3		PP3		
X Series (7. Gen)		PP2		PP3		PP3+	PP2	PP3	PP2	PP3		PP3+

RC-IGBT

Note: PrimePACK™ is registered trademark of Infineon Technologies AG, Germany

*Figure 10: Line-up of X series IGBT modules, also including the RC-IGBT technology in comparison to the predecessor V series. Image used courtesy of **Bodo's Power Systems**.*

Fuji Electric's PrimePACK™ portfolio is designed for Industrial application and provides up to 2,400A rated module current in the 1,700 and 1,200V classes. This is an increase of 33% of nominal output power compared to the conventional X series technology. Since handling currents of 2,400A is challenging due to the generated heat in the output terminal, the PrimePACK™3+ package with two output terminals was chosen.

The increased output power of RC-IGBT technology contributes to the improvement of the performance of power conversion systems. Realizing higher currents within the same footprint supports the ongoing miniaturization of systems. Fuji Electric offers this technology in the PrimePACK™3+ to meet the market demands and strives to realize a safe, secure and sustainable society.

TECHNICAL ARTICLES

High-Power Next Core for Solar, Wind and Rail

Ben Bradel, Fuji Electric Europe GmbH

The High Power next Core module is the latest in Fuji's high-power portfolio, covering a range of industrial applications, predominantly for solar, wind, and rail.

In 1923, a company now called Fuji Electric Co., Ltd. was founded as a joint venture of Japanese Furukawa Electric Co., Ltd. and German Siemens AG. Throughout the 100 years of company history, many branches and markets have been penetrated with electric equipment. Within the last decades, sustainability and a stable supply of clean energy came into focus. The HPnC (High Power next Core) module from Fuji Electric is the latest in the high-power portfolio. It covers a range of industrial applications, predominantly for solar, wind, and rail. Different chip technologies, Silicon and Silicon Carbide, with trench gate structures, are applied to fulfill the demand for energy efficiency and performance.

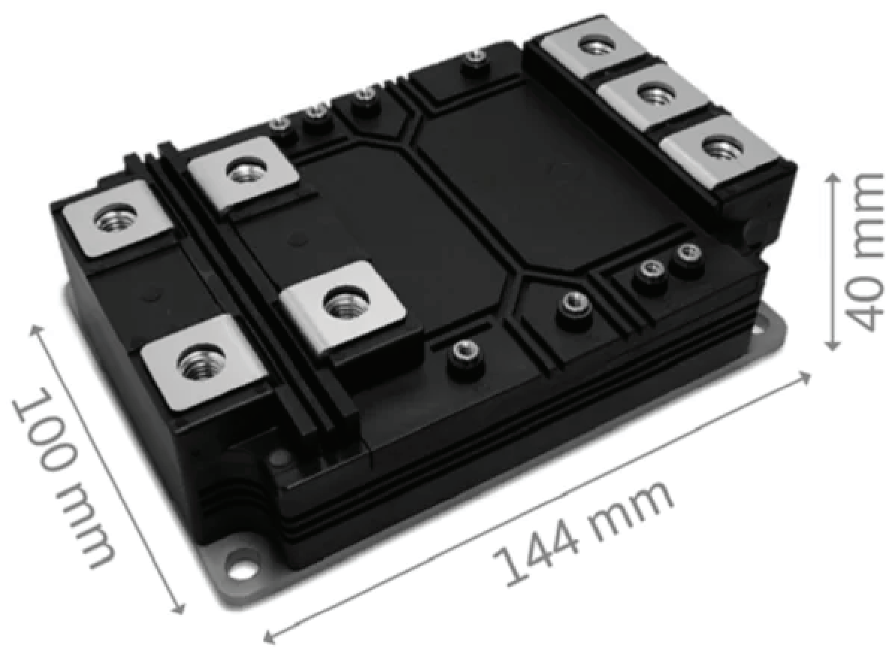


Figure 1: HPnC package with dimensions. Image used courtesy of ***Bodo's Power Systems****.*

HPnC for Traction Market

The traction market also strives for power semiconductors with increased efficiency and lower weight, especially with the blocking voltage of 3300V. By using SiC instead of Si technology, almost doubling the power density can be achieved. This performance boost combined with the option of an omitted SiC-SBD (SchottkyBarrier-Diode) for further MOSFET space – 15% gain has been achieved – is paving the way for SiC-dominated propulsion converters in traction application.

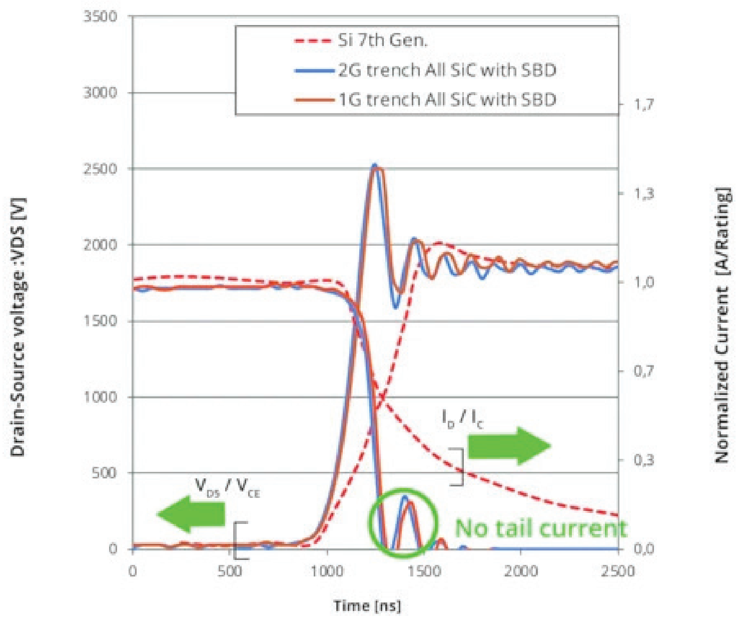
The HPnC's low internal package inductance with only 10nH is also suitable for high-speed switching at the lowest switching losses and only minor oscillations. The rolling stock also has harsher requirements than industrial applications: The package complies with parameters like isolation capability, partial discharge, fire, and smoke as defined in common standards (EN 50124-1, EN 45545- 2). Especially the dTc power cycling capability needs to be high for the long acceleration and deceleration phases. For this purpose, another baseplate material, MgSiC, is chosen over the standard copper type used in the industrial version of the HPnC, offering better thermal performance due to lower thermal resistance. MgSiC is superior in terms of thermal resistance compared to AlSiC baseplates used by competing products while maintaining the same mechanical robustness.

A comparison of chip configurations in SiC-HPnC modules with 750A/3300V is summarized in Table 1. The finer trench gate structure of the 2nd gen technology results in a lower on-state voltage $V_{DS(on)}$ value compared to the 1st-gen SiC-MOSFETs. The SiC-SBD is optional since the MOSFET body diode can handle the currents. However, keeping the body diode in the module brings some benefits, which are increasing the I^2t capability and lowering the V_{SD}. As various operating conditions are present, the module chipset is versatile and comes with or without the SiC-SBD. The recommended gate voltages for 2nd gen technology are the same as Si-based modules to simplify the switch from Si to SiC technology.

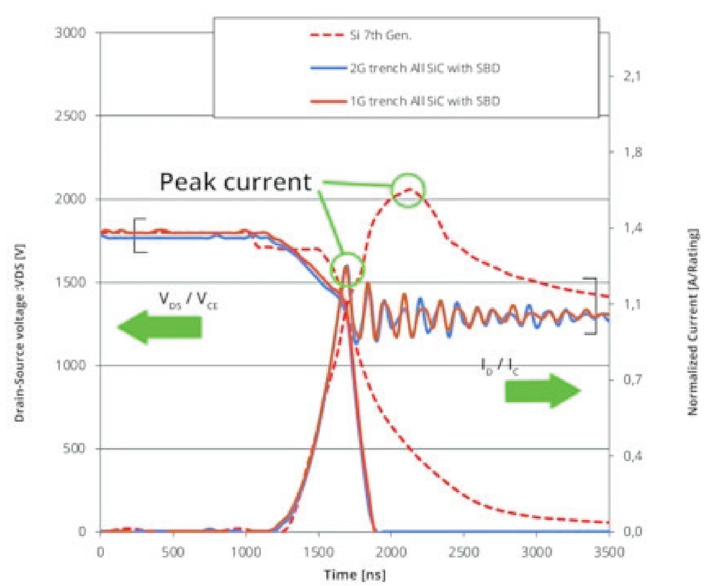
A comparison of the dynamic characteristics of 1st and 2nd gen SiC technology versus the latest Si technology is shown in Figure 2, where the gate resistances have been chosen to get the same di/dt for turnoff, turn-on, and reverse recovery. Additionally, the current displayed on the second vertical axis is normalized. The SiC tail currents are negligible for the turnoff waveforms, and the voltage rise is much faster than the Si module. In the case of turn-on and reverse recovery, the peak currents are less distinctive for the SiC modules. The switching energies E_{off}, E_{on} and E_{rr} are 81%, 66%, and 98% lower in the SiC modules than in the Si modules. There is no significant difference between the switching energies of 1st-gen and 2nd-gen SiC modules with SBDs.

	1st Gen trench gate SiC MOSFET	2nd Gen trench gate SiC MOSFET	2nd Gen trench gate SiC MOSFET
	With SBD	With SBD	Without SBD
$V_{DS(on)}$ at 150 °C	3.80V (V_{gs} = 20V, I_d = 750A)	3.40V (V_{gs} = 15V, I_d = 750A)	3.40V (V_{gs} = 15V, I_d = 750A)
V_{SD} at 150 °C	2.45V (V_{gs} = 20V, I_d = 750A)	2.25V (V_{gs} = 15V, I_d = 750A)	3.40V (V_{gs} = 15V, I_d = 750A)
1700V	3.30V (V_{gs} =-3V, I_d = 750A)	3.30V (V_{gs} = -3V, I_d = 750A)	4.80V (V_{gs} = 15V, I_d = 750A)
$V_{gs(th)}$ at 25 °C	4.7V	5.0V	5.0V
I^2t (V_{GS}=-3V,T_{vj} = 25 °C)	70.2kA²s	70.2kA²s	42.9kA²s
Gate voltage level	+20/-3V	+15/-3V	+15/-3V

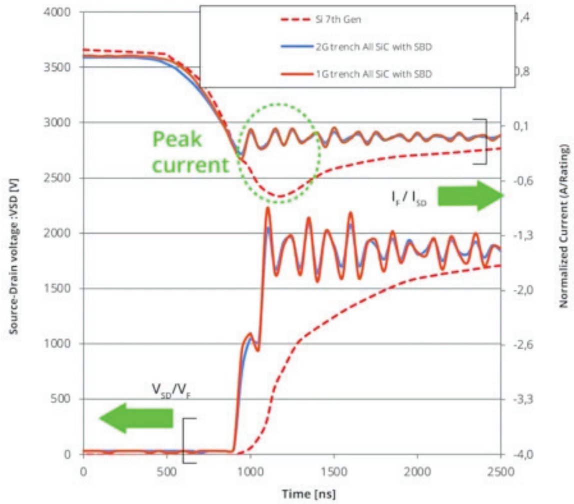
Table 1: Comparison of different chip configurations (1st and 2nd gen) in SiC-HPnC modules with 750A/3300V.


Si 7th Gen.
2G trench All SiC with SBD
1G trench All SiC with SBD
Drain-Source voltage :VDS [V]
Normalized Current [A/Rating]
Time [ns]
V_{DS} / V_{CE}
I_D / I_C
No tail current

(a)


Si 7th Gen.
2G trench All SiC with SBD
1G trench All SiC with SBD
Peak current
Drain-Source voltage :VDS [V]
Normalized Current [A/Rating]
Time [ns]
V_{DS} / V_{CE}
I_D / I_C

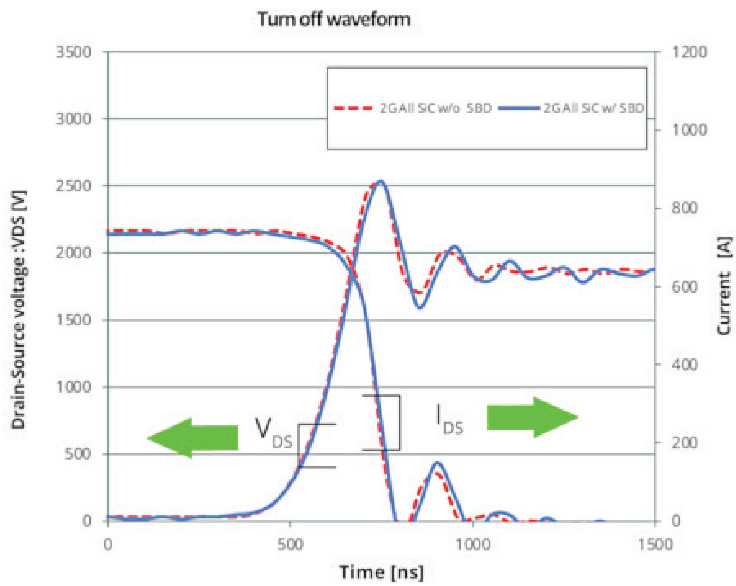
(b)



(c)

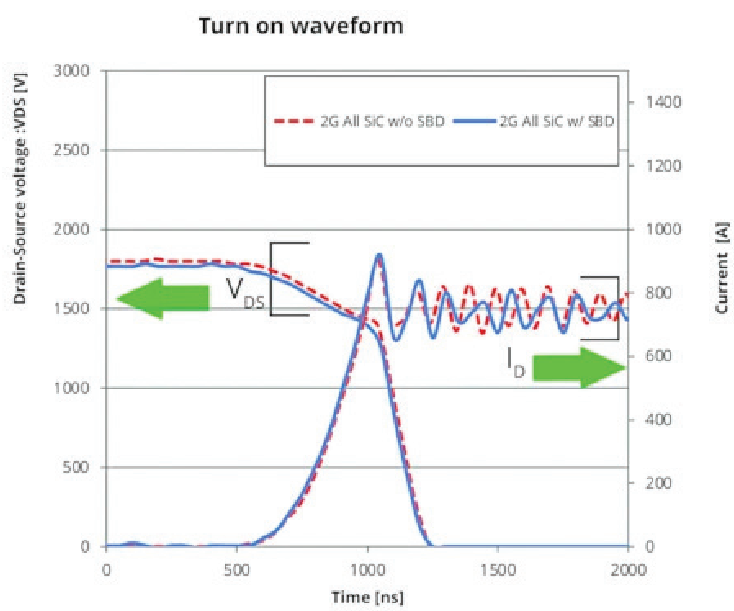
Figure 2: Turn off (a), turn on (b) and reverse recovery (c) waveforms of different SiC and Si modules.
Image used courtesy of ***Bodo's Power Systems****.*

There is, however, a discrepancy between 2nd gen SiC modules with and without SBDs. Figure 3 depicts the switching waveforms of turnoff, turn-on and reverse recovery for a rated current of 750A. Clearly visible is that the turnoff and turn-on waveforms are almost identical. In contrast, the recovery waveform is different and a much steeper rise of the Source-Drain voltage can be noted for the module without SBD. These facts are supported by the related switching energies and dv/dt values obtained from the graphs: the turn-on losses are 319.2mJ for the module with SBD and 326.0mJ for the module without SBD; for turnoff, the values are 218.4 and 226.9mJ, and in case of reverse recovery 9.8 and 8.5mJ can be reported. In the case of reverse recovery, a slightly lower switching loss is observed for the module with SBD contrary to higher values for turn-on and turn-off. The biggest difference is the reverse recovery dv/dt: 26.2 to 39.7kV/µs for the modules with and without SBD.



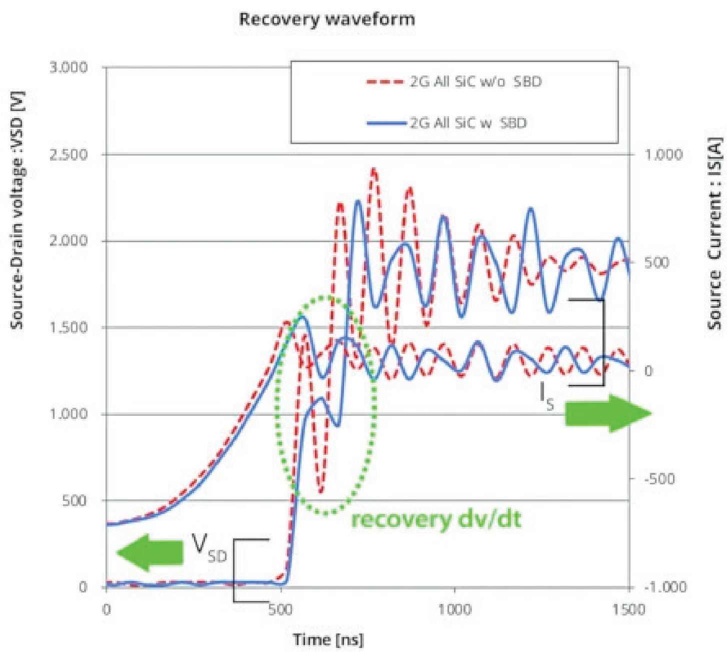
Turn off waveform
2GAll SiC w/o SBD
2GAll SiC w/ SBD
Drain-Source voltage :VDS [V]
Current [A]
Time [ns]
V_{DS}
I_{DS}

(a)



Turn on waveform
2G All SiC w/o SBD
2G All SiC w/ SBD
Drain-Source voltage :VDS [V]
Current [A]
Time [ns]
V_{DS}
I_D

(b)



(c)

*Figure 3: Turn off (a), turn on (b) and reverse recovery (c) waveforms of different 1st and 2nd gen SiC modules. Image used courtesy of **Bodo's Power Systems**.*

Using the Fuji IGBT simulator, some simulated losses from a real traction mission profile can be compared for various modules. The operating conditions are taken from a 180kW and 1500V_{DC} train, which uses the following parameters: V_{cc} = 1500 V, I_o = 510 Arms, cosφ = +/-0.85, λ = 1.0, fc = 1kHz, T_{vj} = 150 °C for acceleration and deceleration. For this example, the following modules were chosen: 450A/3300V Si module (two in parallel connection), 750A/3300V 1st gen SiC module with SBDs, 750A/3300V 2nd gen SiC modules with and without SBDs, and 850A/3300V 2nd gen SiC module without SBDs.

Voltage	Application	Chip	Current							
			450A	600A	750A	850A	1000A	1200A	1500A	1800A
1700V	Industrial	Si						√	√	√
		SiC w/ SBD					√		√	√
	Traction	Si						√	√	
		SiC w/ SBD					√		√	√
3300v	Traction	Si		√						
		SiC w/o SBD			√	√				

Figure 4: Preliminary HPnC product lineup for modules being under consideration and development.

As a result of the acceleration case, the total loss dissipation of 1st gen SiC module is 7% bigger than the alternative of two parallel Si-IGBT modules. The 2nd gen SiC modules with SBDs are 5% lower compared to Si modules with two parallel modules. The lowest losses of 644.1W were achieved by the 2nd gen SiC module without SBDs and a rating of 850A/3300V. The total power dissipation of the 2nd gen SiC module with a nominal rating of 850A without SBDs is 8% lower than the 2nd gen SiC module with SBDs with a nominal rating of 750A.

The picture for the deceleration case is different, where the 2nd gen SiC module with SBDs and 750A creates the lowest losses of 601.4W due to the SBD characteristic. This finding results in the statement that SiC modules with SBDs and without SBDs are available to satisfy the various operating conditions.

Lineup Plan

The package itself is suitable for traction use. Current considerations of an industrial version rely on the market's feedback and might be realized at a later point in time. There are slight but important differences in conditioning the traction module for higher thermal reliability and the harsher environment. The major change affects the baseplate, MgSiC instead of Cu, and was already mentioned above. The maximum temperature is limited to $T_{vj,op(max)}$ = 150 °C and $T_{c(max)}$ = 125 °C, where in general, the industrial modules are each approved for 25 °C higher. The isolation voltage also differs: $V_{AC,isol}$ = 6kV (1 min) for the traction module instead of 4kV (1 min).

The preliminary lineup is split into the two application fields, industrial and traction, and Si and SiC technology, as shown in Figure 4.

2300V Device for 1500V_{DC} Applications

Since chips with a nominal breakdown voltage of 1700V cannot be used in 1500V_{DC} applications and 3300V chips have too high on-state voltage and switching losses, a new class of 2300V chips is introduced. Thus, the upcoming 2300V devices will enable efficient and cost-effective two-level topologies over the three-level NPC topologies with 1200V devices. As the latest generation of wind turbines are equipped with 900VAC, compared to the predecessor 690VAC systems, realizing 1500 V_{DC} in the DC-link is key for a power upgrade. In addition, the solar installations and their grid balancing batteries will subsequently be shifted to 1500V_{DC}.

The 2300V chips are the latest 7th generation "X-series" Si technology or 2nd/3rd generation SiC technology. Both technologies have high breakdown voltages, low losses, and high-temperature capability, whereas the SiC MOSFET is inherently superior in high switching frequency applications.

The 2300V Si-IGBT has a trench-gate structure, and a Field-Stop layer is incorporated in the chip backside layer. The overall chip thickness could be reduced compared to the previous generation. For the 2300V **SiC MOSFET**, additional improvements were accomplished, like a narrower cell pitch and increased channel mobility. The MOSFET's body diode can handle the current which would normally pass through the additionally installed, anti-parallel connected, free-wheeling diode (SBD). The 2nd gen SiC-Trench-Gate-MOSFET cell pitch could be reduced by 35% compared to the predecessor 1st gen technology. The schematics can be seen in Figure 5.

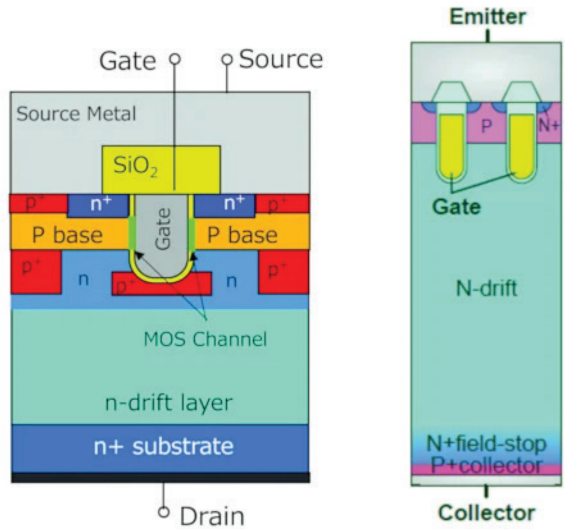


Figure 5: Schematic cross-section of Si-IGBT (left) and SiC-MOSFET (right) chip technology. Image used courtesy of ***Bodo's Power Systems****.*

The static characteristics of the 2300V chips at T_{vj} = 150 °C are: $V_{CE(on)}$ = 2.55V (Si-IGBT) and V_F = 2.15V (Si-FWD), and $V_{DS(on)}$ = $V_{SD(on)}$ = 2.40V (SiC MOSFET). The recommended gate voltages are +15/-15V for the Si IGBT and +15/-3V for the SiC MOSFET.

Figure 6 depicts the forward voltages $V_{CE,sat}$ and $V_{DS(on)}$ versus the currents IC and ID. The red dashed line indicates the nominal current rating. The 2300V chips in 2-level topology with Si IGBT and SiC MOSFET have a 33% and 37% lower on-state voltage than the 3-level NPC topology with 1200V Si-IGBT chips. The difference can be increased by operating at lower current ratings.

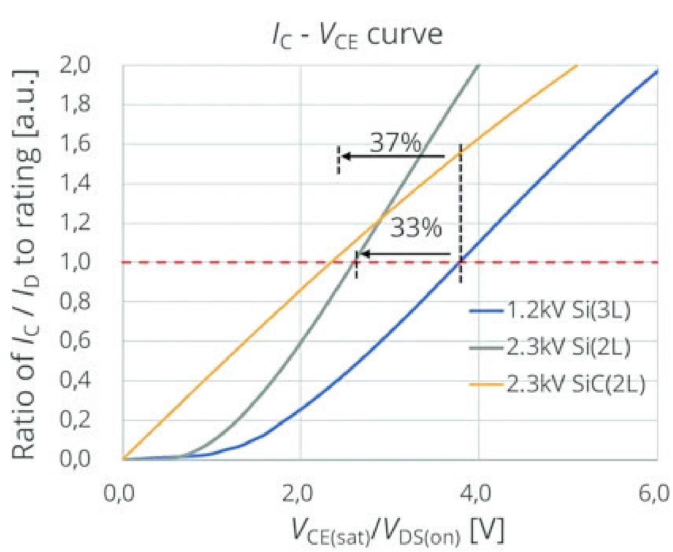


Figure 6: Simulated I-V curves for Si and SiC devices of different voltage classes at 150 °C. Image used courtesy of ***Bodo's Power Systems****.*

In Figure 7, the free-wheeling behavior of the chips is shown. The Si-FWD and the SiC MOSFET forward voltage V_F and $V_{SD(on)}$ are plotted as a function of I_F and I_{SD} in the same way as in Figure 6. Here, the advantage over the three-level NPC topology with 1200V SiIGBT is 33% and 26% for the 2300V Si IGBT and SiC MOSFET.

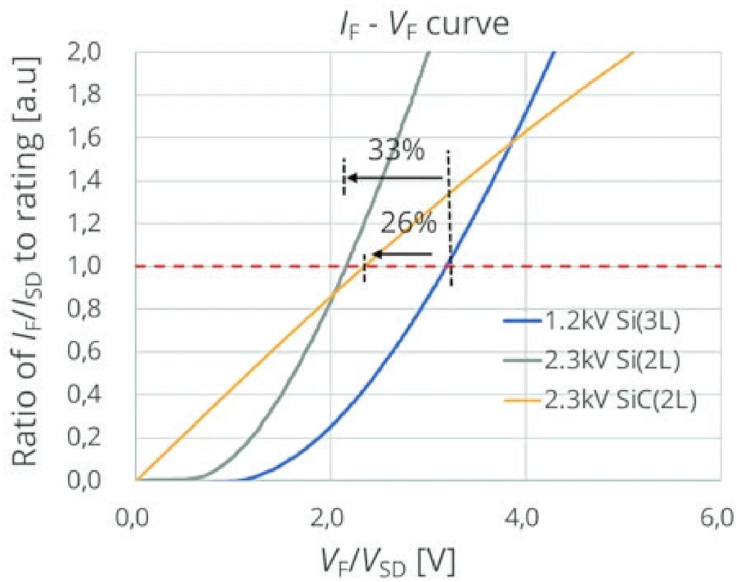


Figure 7: Simulated I-V curves for Si-FWD and SiC-MOSFET chips of different voltage classes at 150 °C.
Image used courtesy of ***Bodo's Power Systems****.*

By comparing two-level and three-level **NPC topology**, it becomes clear which advantages the 2300V chips have instead of using several 1200V chips. In theory, three modules must be connected and controlled by an individual gate driver channel each in a three-level inverter, for 12 gate driver channels. In the case of A-**NPC topology**, two additional IGBT switches are required for 18 gate driver channels. As opposed to this, a two-level topology requires only one module taking one-third of the footprint and 6 gate driver channels. This leads to less space needed and lesser costs. Another advantage the two-level topology has is the lower commutation inductance since the commutation current passes through a single module. The ultimate improvement is eventually using SiC technology, with which the total losses can be decreased by more than half.

TECHNICAL ARTICLES

How the HPnC High Power Modules Benefit Next Generation Railway Systems

Ben Bradel, Fuji Electric Europe GmbH

Introduction

From electric vehicles to new energy systems, power electronics have steadily demanded more power capability in a smaller package. Designers are pushed to develop modules with a high power density, better thermal efficiency, and scalability in order to both miniaturize the solution and push it further up on the power spectrum without too many thermal management constraints. Railway applications also call for high reliability, where potential weakness such as mismatches between the chip, baseplate, and heatsink are optimized. IGBT power modules are often used in electric railways for their reduced internal inductance, improved heat dissipation, and ease of connection. The power handling of these modules have steadily increased since their initial employment in high-powered locomotives in the mid 90s from gate turn-off (GTO) thyristors. However, in order to achieve the high current ratings, these devices must be easily paralleled. The increased efficiency reduces power losses, which ultimately leads to a smaller number of components and an improved reliability.

All of these parameters must be optimized at the device level and then the package level in order to yield optimal results in the end design. Fuji Electric developed the “High Power next Core” (HPnC) IGBT modules based upon the 7th generation “X series” chip technology. The parallelable module has been specifically tailored for railcars by reducing its power dissipation, increasing its power density, and improving its reliability. This article dives into some of the design advancements of the HPnC modules and how these are well-suited for railway use cases.

IGBTs in Railway Systems

Railway systems can span from electric trams and trolleys and city metros/subways, to electric locomotives and high-speed electric trains (Figure 1). Typically, overhead lines, or the catenary system, is used to supply electricity to the train car to transmit current to the train where a top-mounted pantograph, often made of metalized carbon, will press against the underside of the overhead wire to optimally transfer a large amount of current while in motion. The propulsion system will take the AC or DC catenary and convert it to the proper voltage to supply the motor, providing a safe and smooth ride for the passengers.

Many high-speed rails have shifted to employing a distributed rail traction system where the motor drive is supplied to most the passenger compartments, as opposed to the traditional concentrated traction system where the motor drive is supplied to only the end cars. Different from the propulsion system, the auxiliary power supply will convert power for the less-power-consuming circuits of the train (e.g., lights displays, HVAC, etc.).

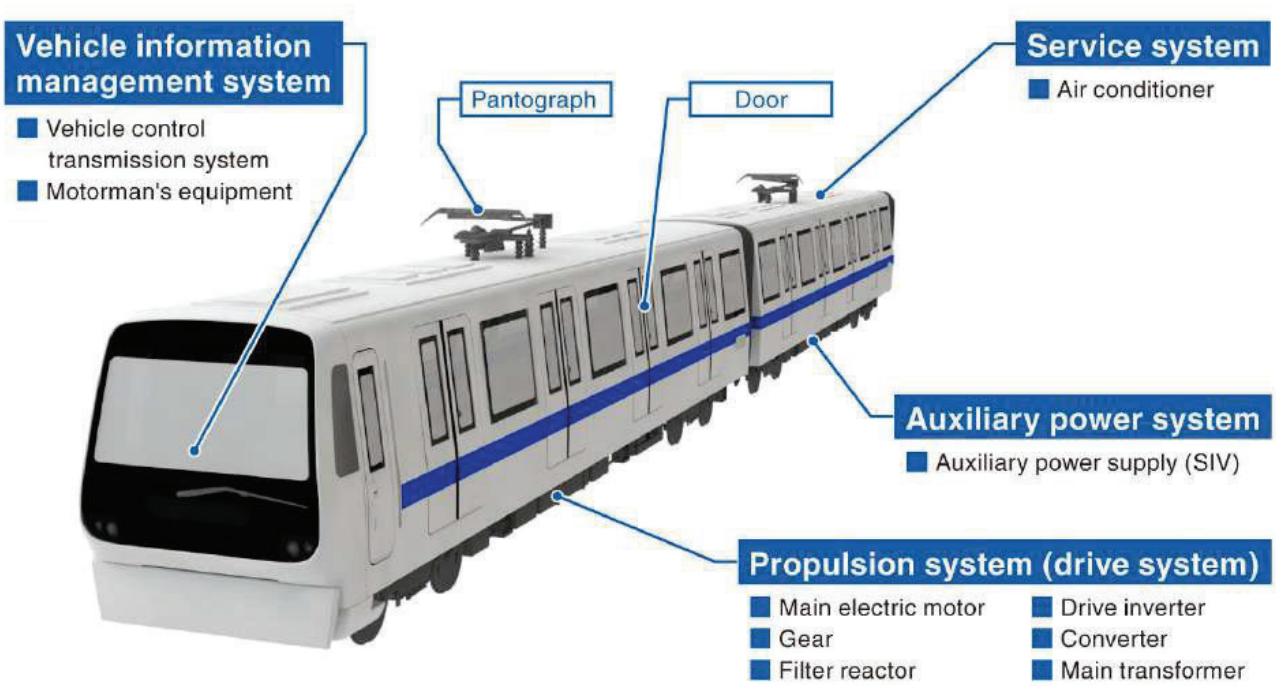


Figure 1: Electric railway subsystems.

Railway Subsystems

Propulsion System

DC Catenary

The electric drive in the railway system consists of the machine that is the main electric motor, the main transformer, a filter, the power electronic converter, and the circuits used to control it. Generally, DC catenary converters are used such as the classic two-level converter (Figure 2). Variable Voltage Variable Frequency (VVVF) inverters will input voltage to the motor drive and frequency to, for instance, feed the motors a relatively high power delivery in order to accelerate the railcar as opposed to the lower power delivery during coasting. Feedback controls will also regulate motor torque in the event of slips and skids for the powering train.

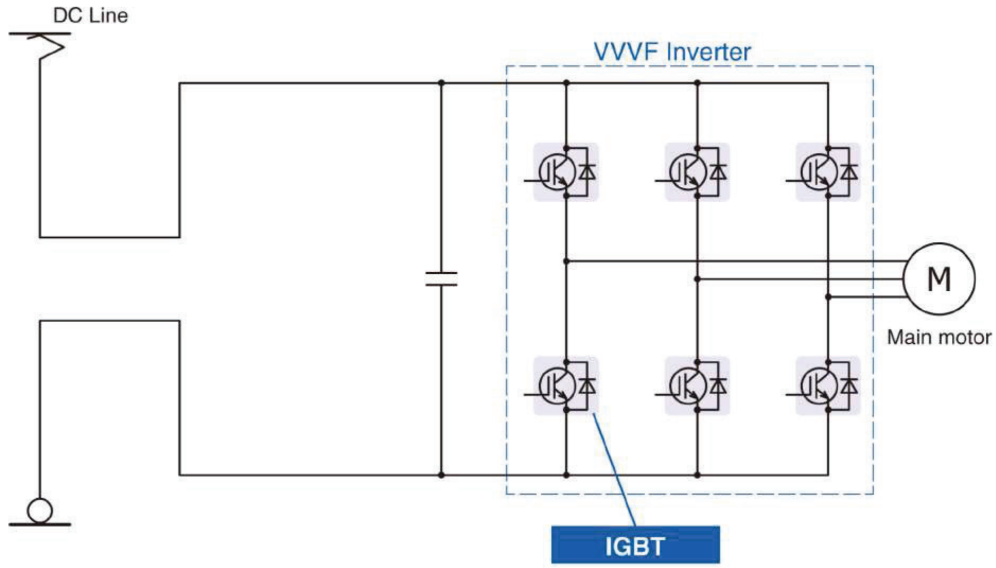


Figure 2: Sample schematic of main converter for DC powered trains.

AC Catenary

Alternatively, an AC catenary can be employed where the AC power line is stepped down and converted to the DC-link voltage that supplies the three-phase converter that supplies the traction motor (Figure 3). Typically, the first stage is composed of a four-quadrant, single phase converter that takes the input AC voltage and converts it to DC and the second stage is a three-phase inverter to supply the traction motor. The ratio of the transformer is normally chosen in order to step-down the catenary voltage (15kV or 25kV) and obtain a desired DC-link voltage of the converter.

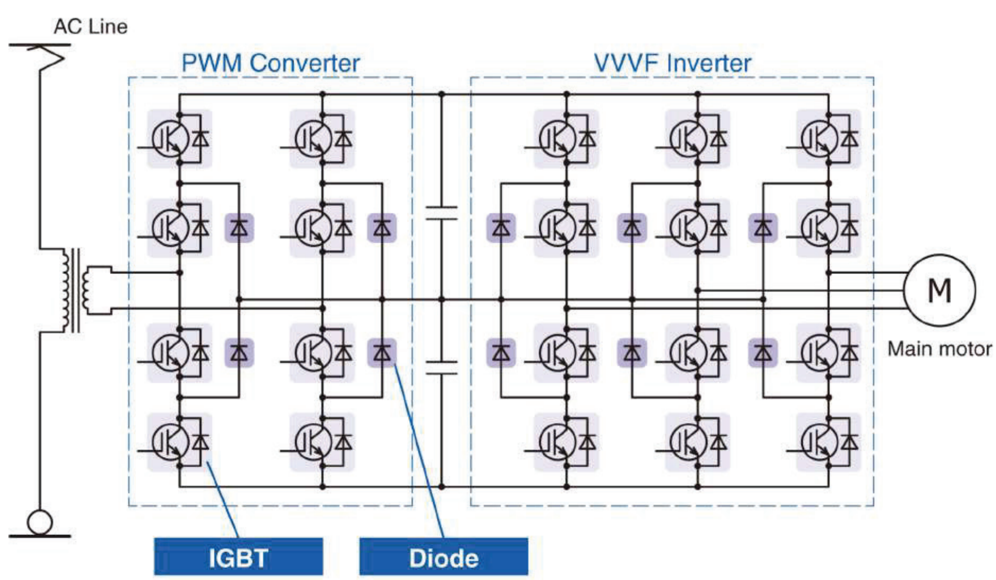


Figure 3: Sample schematic of main converter for AC powered trains.

Regenerative Braking

Train braking systems include resistance braking, air braking, and regenerative braking. DC-electrified railways are also equipped with a regenerative braking system that adds several design considerations. In regenerative braking, the motors and traction controller converts the kinetic energy of the railcar to electrical energy during deceleration/braking. The energy can supply the train's onboard auxiliary loads, where surplus power can be sent back to the third rail where another train that may be accelerating within the same power apply section can recycle this power. Energy storage systems (ESS) such as flywheels, batteries, and supercapacitors can also be installed alongside the third rail or onboard to store this energy and supply it whenever demanded. For an onboard ESS, the braking train can charge the ESS while the accelerating/powering train will discharge the ESS to increase the overall system efficiency.

Auxiliary Power Supply

The auxiliary power supply will provide the lower voltage and constant frequency for the internal systems of the railcar. In this case, a transformer is used to step down an AC catenary with a rectifier and chopper and an inverter to supply all auxiliary loads (Figure 4). In the case of a DC supply, an inverter simply converts the DC to AC and a circuit breaker is used to protect the unit.

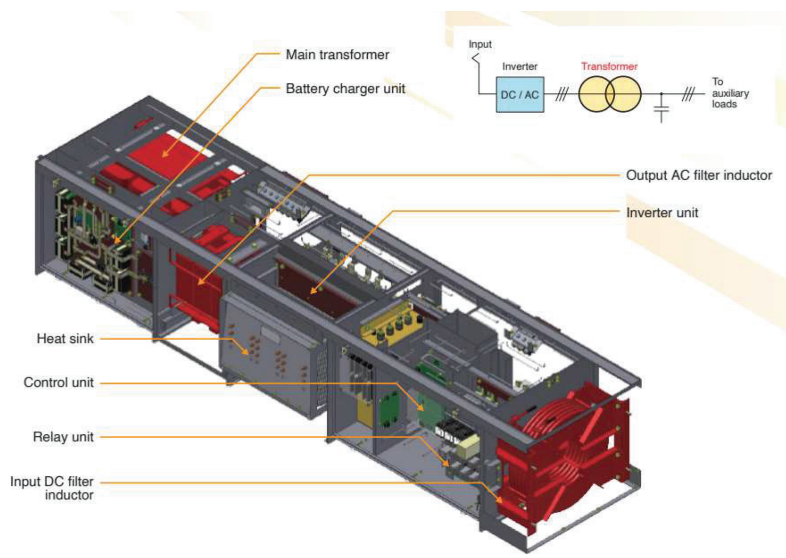


Figure 4: Diagram of a sample auxiliary power supply.

Power Modules for Railway Applications and Their Considerations

Power semiconductors are essential for the various subsystems deployed in these applications. The transition from GTOs to semiconductors created considerable improvements in overall reliability and passenger experience. IGBTs are most commonly used for their balance in voltage/current rating and relatively high switching frequencies, thermal characteristics, reduced internal inductance, blocking voltage, and leakage current; parameters such as these are critical for both performance and field reliability.

These power modules are also relatively straightforward to connect--an important factor for successfully scaling up power in railway systems. Higher blocking voltages are necessary in order to control loads of hundreds of kilowatts, and a high blocking voltage can also reduce the number of levels in inverter drive applications. Generally, trams will have a nominal voltage of 750VDC and require an IGBT with a blocking voltage of 1700V, while subways will have a nominal 150VDC and a 3000V blocking voltage. Electric locomotives and high-speed trains have a 3000VDC nominal DC-link with IGBTs that have preferred blocking voltage of 6500V.

Power modules in electric rails will undergo a high level of thermal stress; the traction inverter feeds the electric motors a high power to start and stop the train. This high number of thermal load cycles can lead to a number of failure mechanisms including causing the module's baseplate and junction to degrade, corrosion of wires, heel cracks, and bond lift-offs. This calls for a highly robust power module structure where every aspect is carefully designed including the baseplate, die-attach technology, and top-side interconnections.

The HPnC Module

Fuji has a long legacy in the railway business since the 1960s, evolving with the industry's needs in DC car control, AC car rectifier control, high-speed railcar control and door systems. The latest generation of IGBT modules - the High Power next Core (HPnC) - uses the 7th chip generation (X series) of IGBTs and FWDs to replace the older High Power Module (HPM). Table 1 shows the improvements between the HPM and HPnC module. The 7th generation chip technology is optimized within the new HPnC package and a thermistor is incorporated to detect the temperature rise inside the module. The combination of these technologies allows the HPnC to exhibit:

- A small internal inductance
- An increase in current density with new 7th generation chip technology
- Improvements on the assembly of parallel connections, and
- A high reliability with ultrasonic bonding technology and improved base plate materials

Package	HPM(Conventional)	HPnC	Improvement ratio(%)
External appearance/dimensions(mm)	L:130 D:140 H:38 	L:100 D:140 H:38 	-
Circuit	1in1	2in1	-
Rating(typical)	1700V/1200A	1700V/1200A	-
Module internal inductance(Lp)	42nH(in case of 2 in 1)	10nH	76.2
Surge voltage(V)	**1336**	**1192**	**10.8**
Foot print(cm^2)	**173.7**	**140**	**19.4**
Current density (A/cm^2)	**6.91**	**8.57**	**24.1**
Parallel connectivity	**Poor**	**Excellent**	-
Inductance during 2 in 1 parallel connection	**21nH(2400A 2pararell)**	**2.5nH(4800A 4pararell)**	89.0
Weight	**915g**	**790g**	13.6
RoHS	**Not compliant**	**Compiant**	-

Table 1: Package characteristics: HPnC vs. HPMs.

Small Internal Inductance

Both the internal inductance and the external stray inductance will impact the speed of the current rise (di/dt) which will increase over voltages and cause more turn-off loss. The increase in this surge voltage generated by the IGBT turn-off could also potentially destroy the device if that breakdown voltage is exceeded. In order to minimize these losses and maintain a higher switching frequency, it is important that both of these sources of unwanted inductance be minimized, allowing the module to operate much more efficiently.

As shown in Table 1, there is a massive reduction in internal inductance. This is due to the laminated, antiparallel structure between the collector and emitter terminal to realize low inductance (Figure 5). Experimental comparisons between the HPM and HPnC surge voltages during turn-off have shown a 144V drop in the voltage spike for the HPnC [3].

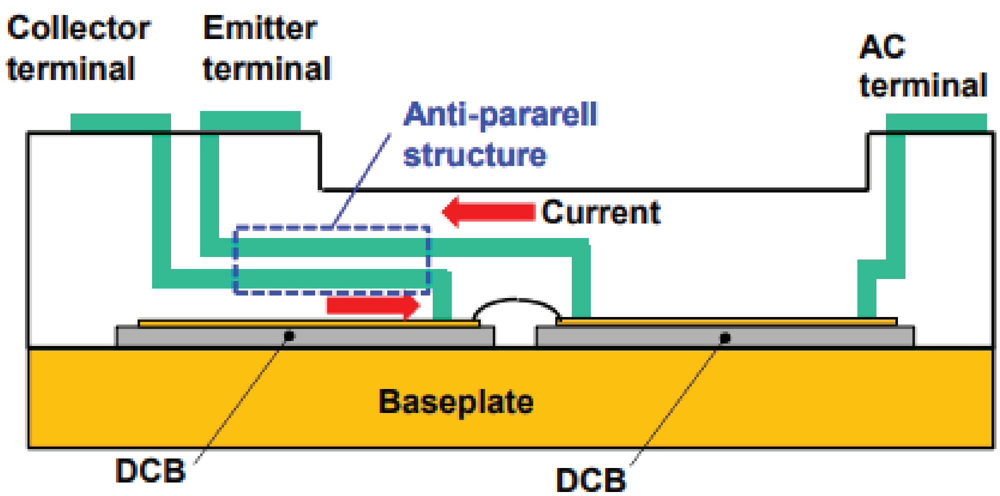


Figure 5: Anti-parallel structure found in the HPnC module that reduces internal inductance.

Enhanced Current Density

The HPnC exhibits an improved chip current density for two reasons:

- The enhancements made in the 7th generation IGBT chip
- Improved thermal resistance of the package

The baseplate of the HPnC is MgSiC - a material that has nearly twice the thermal conductivity of AlSiC - allows for more optimal heat transfer between the chip and the heat sink. This limits any thermal fatigue, reduces power losses and makes it possible to achieve a significant size reduction.

Easy Parallel Assembly

Railway subsystems need modules paralleled in order to meet application current requirements. Paralleling semiconductor power modules can be a tricky task, where any asymmetries present in the package will cause current imbalance and imperfect current sharing and thermal stress between semiconductors. Static current-sharing is typically influenced by differences in the on-state characteristics of the parallel IGBT devices, the resistance of connections such as the bus bar, and the junction temperature of the devices [4]. The quality of current sharing ultimately depends upon the quality of the power modules themselves and the interconnections between them.

The HPM package was more complex to parallel than the HPnC package as shown in Figure 6 with a three-layered structure overlapping the collector, emitter and AC busbar--a configuration that may be difficult to mount to the main circuit. The position of the emitter terminal is not close to the capacitor causing designers to lengthen the emitter bus bar, adding unnecessary parasitic inductance.

The HPM parallel configuration includes two parallel 1-in-1 modules with a 1200A current rating, resulting in a current rating of 2400A for the entire construction. The HPnC configuration has double the current rating at 4800A with four, 2-in-1 modules with a 1200A current rating each.

For the HPnC modules, the AC terminals are on the opposite side of the collector and emitter terminals allowing for simpler mounting to the main circuit. The AC busbar also does not require the previous extensions, eliminating the additional inductance. Experimental results have shown the current imbalance of the parallel connection of the HPnC packages lie within the 6% difference tolerance (current ranges between 985A and 1030A at turn-off) and can therefore be safely considered as identical and sufficient for railway applications.

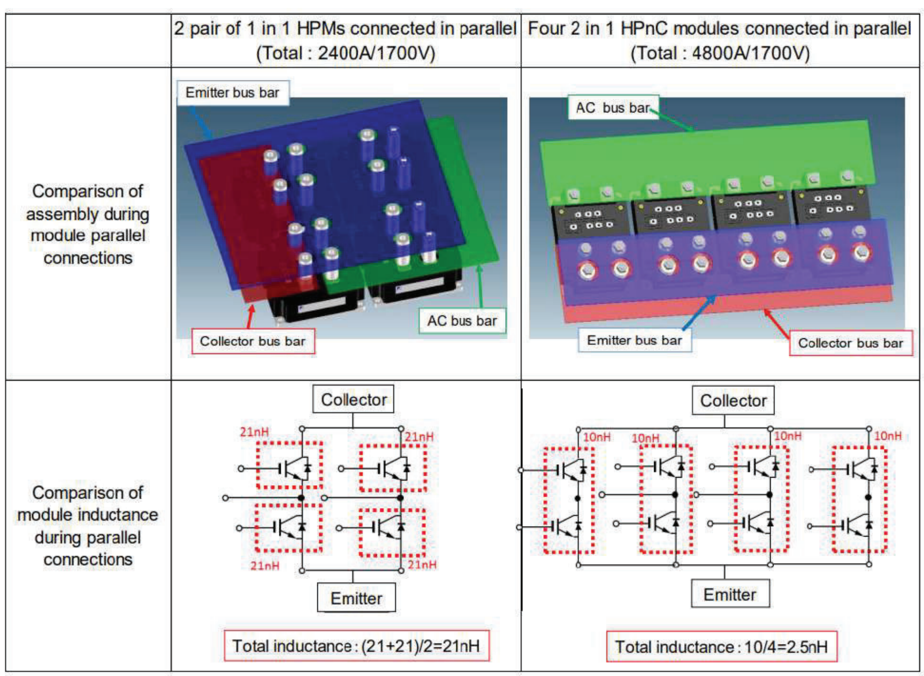


Figure 6: An experimental comparison of the HPM and HPnC. The parallel connections between the previous HPM and newer HPnC modules show a massive reduction in total inductance as well as a simplified parallel layout; factors that impact ease of implementation, current sharing, and efficiency.

Enhanced Reliability

As stated earlier, the improved base plate material with a high thermal conductivity to allow for much more efficient thermal performance and therefore a higher reliability for railway applications. Ultrasonic bonding technology is also used to join the terminal and insulating substrate of the HPnC instead of solder bonding. This improves the thermal cycling capability of the module where the coefficients of thermal expansion (CTE) are more similar, preventing wire cracks in thermally overstressed power modules.

Conclusion

The HPnC module has implemented significant advances at both the chip and package level to yield much more efficient operation, a higher reliability, and a smaller package size. These improvements lead to immense benefits for the railway application where cost, size, and ease of thermal and electrical design are key. The upgrades found in the HPnC module allow engineers to rapidly implement a high powered railway propulsion system and auxiliary power supply with a quicker time to market.

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TECHNICAL ARTICLES

Assessing the Benefits of Fuji's HPnC Modules in Renewable Energy Applications

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Abstract

The renewable energy sector has undergone significant advancements in recent decades with initiatives in technological innovation, environmental considerations, and global renewable energy. Critical to renewable energy systems are power electronics such as metal-oxide-semiconductor field-effect transistors (MOSFETs) and insulated gate bipolar transistors (IGBTs).

Fuji Electric has developed its high-power next core (HPnC) modules to address the limitations of its previous high-power modules (HPMs) for power conversion in energy applications. Fuji's HPnC modules leverage the unique properties of silicon carbide (SiC) in MOSFETs and IGBTs to achieve high performance and energy efficiency. This white paper delves into the advantages of integrating HPnC modules into renewable energy applications such as solar and wind.

The Evolution of High Power Module Technologies

The introduction of silicon as a semiconductor material revolutionized the design of high-power modules, making the material the choice for decades. However, the development of advanced materials like gallium nitride (GaN) and silicon carbide (SiC) allowed engineers to increase the energy efficiency while reducing the size. The shift from discrete to modular designs also improved integration in space-constrained applications.

MOSFETs gained attention because they operate at high temperatures, high frequencies, and high voltages. MOSFET design and manufacturing processes have now matured, leading to improvements such as lower on-resistance and faster switching performance.

IGBTs integrate the benefits of MOSFETs and bipolar transistors, such as high input impedance and low saturation voltage and are widely adopted in applications demanding higher voltage and current capabilities. With advancements in chip design and packaging, IGBTs achieve increased switching speeds, improved thermal performance, and high reliability.

Advanced Power Modules in Renewable Applications

Solar panels and wind turbines are intermittent energy sources that generate electricity in forms that are not directly usable by most appliances or the grid. For example, solar panels generate direct current (DC) while the grid operates on alternating current (AC). Similarly, wind turbines generate variable AC depending on wind speed and weather conditions.

Power modules play a crucial role in enhancing power conversion efficiency and overall system performance. MOSFET and IGBT modules enable power regulation or control in energy storage systems and inverters for solar and wind, ensuring high performance and reliability. High-power modules based on SiC operate at higher frequencies and temperatures, reducing energy losses when compared to silicon-based modules.

Fuji Electric's High-Power Next Core Modules

Fuji Electric HPnC modules are state-of-the-art 7th generation IGBT or SiC MOSFET devices for converting and controlling electrical power. HPnC modules leverage Fuji's 7th-generation "X Series" chip technology to achieve significantly lower power loss during conversion compared to HPMs. The design incorporates an aluminum nitride (AlN) insulating substrate with excellent heat dissipation capabilities; the innovative baseplate materials are a blend of magnesium and silicon carbide (MgSiC).

Fuji's HPnC modules leverage the superior properties of SiC to offer unmatched performance in renewable applications. SiC offers a wide bandgap, high thermal conductivity, and high electric field breakdown strength. The wider bandgap allows for a thinner drift region compared to pure silicon devices, resulting in lower on-resistance, and its high thermal conductivity improves heat dissipation. Similarly, the high field breakdown strength allows the material to withstand higher voltages, enhancing its reliability. These properties make SiC MOSFET/IGBT devices inherently more efficient and reliable than pure silicon modules.

HPnC Modules vs. HPM

Fuji's HPnC Modules offer several benefits over traditional High Power Modules, including lower internal inductance, compactness, high energy density performance, and more as described below.

Reduced Internal Inductance

Internal inductance refers to the intrinsic inductance within the power module due to its physical construction and layout. This inductance often results in voltage overshoots, increased switching losses, and potential failure during high-frequency operation. Typically, as switching frequencies increase, the effects of the internal inductance become more pronounced.

Fuji's HPnC modules place semiconductor devices in an anti-parallel configuration separated by laminated layers to minimize internal inductance. This design minimizes the loop area between devices, reducing the inductance. The reduced loop area also ensures faster switching speeds and reduced electromagnetic interference (EMI).

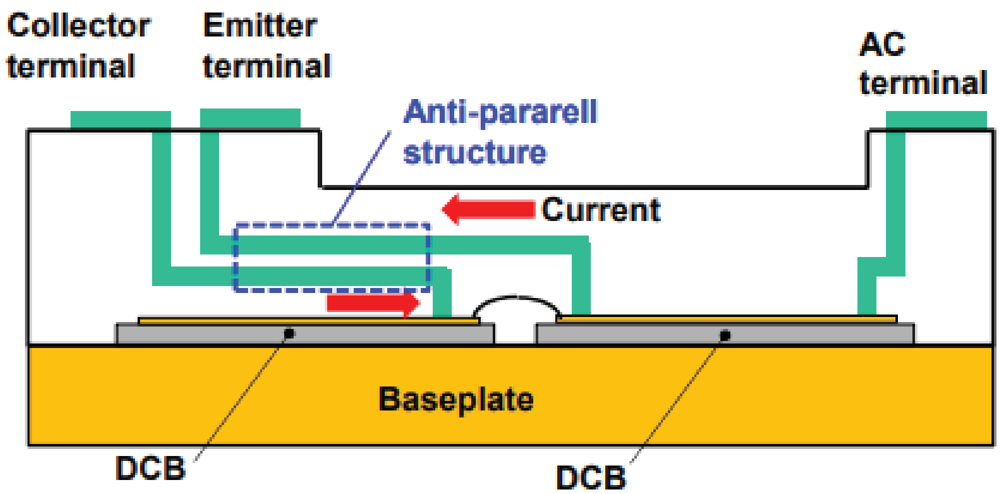

Figure 1: Anti-parallel structure of Fuji's HPnC modules.

Improved Current Density

Due to the wide bandgap, SiC MOSFET and IGBT modules can operate at higher temperatures, voltages, and frequencies. These material properties allow HPnC modules to achieve higher current densities in more compact module designs.

Low Loss Performance

By optimizing the package structure, the internal inductance, which affects switching speeds, has been reduced by up to 76% compared to conventional products. This optimization translates to reduced losses in HPnC modules. Inverters equipped with HPnC achieve up to an 8.6% reduction in power losses during operation compared to HPMs.

Enhanced Substrate Materials

One of the primary causes of IGBT module failures is the deterioration of the interfaces between components (thermo-mechanical fatigue). Temperature variations typically induced thermal stress, causing the failure. To mitigate this issue, Fuji has replaced the baseplate material of aluminum silicon carbide (AlSiC) in HPMs with magnesium silicon carbide (MgSiC) in the HPnC.

Ultrasonic Bonding

Fuji has moved away from conventional solder joints toward the ultrasonic bonding method in its HPnC modules. Ultrasonic bonding uses high-frequency vibrations to create high-integrity bonds between the terminal and insulating substrate.

Ultrasonic bonding offers the following advantages:

- Minimizes potential defects that can arise from soldering, such as cold joints or voids

- Maintains high integrity even under extreme temperature conditions (unlike solder, which can melt or weaken at high temperatures)
- Eliminates the need for flux, lead, and other potentially toxic materials, making it a more environmentally sustainable option

Simplified Parallel Assembly

One of the limitations of Fuji's HPM product was the requirement of three separate overlapping busbars (DC+, DC-, and AC busbars) when building a circuit. This requirement made the wiring configuration complex, especially when using a parallel connection. With the HPnC module, Fuji optimized the terminal arrangement, allowing the busbars to be arranged in the same direction. This facilitates easy parallel connections of power semiconductors and inverter assemblies.

Enhanced Efficiency

Fuji Electric HPnC modules are designed with advanced semiconductor materials that minimize switching losses, ensuring the module operates at optimal efficiency at higher frequencies. The design of the HPnC module allows for improved heat dissipation, ensuring that it remains cool during operation, further enhancing the efficiency.

Compactness and Modularity

HPnC modules are designed to be compact, allowing for a reduction in the overall size of the systems in which they are used. Their modular construction allows scalability and customization, enabling users to tailor the module configuration to their specific needs. The figure below shows the package characteristics of Fuji's HPnC modules compared to HPMs:

Package	HPM(Conventional)	HPnC	Improvement ratio(%)
External appearance/dimensions(mm)	L:130 D:140 H:38 	L:100 D:140 H:38 	-
Circuit	1in1	2in1	-
Rating(typical)	1700V/1200A	1700V/1200A	-
Module internal inductance(Lp)	42nH(in case of 2 in 1)	10nH	76.2
Surge voltage(V)	**1336**	**1192**	**10.8**
Foot print(cm^2)	**173.7**	**140**	**19.4**
Current density (A/cm^2)	**6.91**	**8.57**	**24.1**
Parallel connectivity	**Poor**	**Excellent**	-
Inductance during 2 in 1 parallel connection	**21nH(2400A 2pararell)**	**2.5nH(4800A 4pararell)**	89.0
Weight	**915g**	**790g**	13.6
RoHS	**Not compliant**	**Compiant**	-

Table 1: Package characteristics: HPnC vs. HPMs.

Reliable Operation in Harsh Environments

HPnC modules perform over a wide temperature range, making them suitable for high or low-temperature applications. Their sturdy construction can withstand mechanical stresses such as shock and heavy vibration without significant degradation in performance.

Applications in Large-Scale Renewable Energy Installations

Large-scale renewable energy systems, such as solar farms and wind turbines, play a pivotal role in the renewable energy industry by reducing carbon footprints and offering a sustainable way to meet global energy needs. Advanced power electronics, like Fuji's HPnC modules, are critical in ensuring systems' efficiency, reliability, and cost-effectiveness.

Solar Farms

HPMs in photovoltaic systems face several issues, including inadequate thermal management, limited power density, and sub-optimal efficiency. In solar farm applications, these limitations can impact the energy harvest, expand overall system size (due to additional thermal management components), and increase operational costs. HPnC modules are designed to address these limitations of HPMs. These modules ensure maximum energy is harvested from the solar panels by minimizing power losses during conversion. Their excellent thermal performance allows for optimal operation under typical high-temperature conditions of solar installations, and the higher power density allows for more compact solar inverter designs, providing cost savings.

Wind Turbines

Wind energy conversion systems require robust power electronics that handle fluctuating power levels while maintaining reliable operation in harsh environments. Integrating HPnC modules in inverters for wind turbines can significantly improve the efficiency and reliability of wind turbines while lowering maintenance costs. The enhanced thermal performance of SiC MOSFETs/IGBTs in the modules minimizes the need for extensive cooling systems, leading to cost savings.

Applications in Distributed and Small-Scale Renewable Energy Systems

Smaller-scale renewable systems, like home solar setups, battery storage units, and microgrids, are crucial components of the global renewables infrastructure. Their decentralized nature offers flexibility, resilience, and the ability to adapt to a dynamic energy landscape. The efficiency and reliability of these systems are contingent upon the performance of integrated components, such as SiC MOSFETs/IGBT power converters.

Residential Solar Systems

With the increasing awareness of sustainable energy, there's a growing demand for small-scale solar installations for residential power. However, these systems often face challenges related to power conversion, especially due to fluctuating solar energy input. The high efficiency and high power density of Fuji's HPnC modules ensure that maximum energy is harvested from the solar panels under varying weather conditions. Their compact design also allows for easy integration into most residential setups, making them an ideal choice for home solar systems.

Energy Storage Systems

As renewable energy is inherently intermittent, efficient energy storage systems are essential components of renewable energy infrastructure. Battery storage systems require efficient power converters to minimize energy loss during storage. Fuji HPnC modules, with their high efficiency, ensure that maximum energy is stored with low losses. The robust design of these modules also ensures reliable operation under fluctuating power levels.

Microgrids

Microgrids are decentralized energy systems requiring robust and efficient power converters to provide reliable power supply. For engineers and designers working on microgrid systems, the integration of high-power modules can optimize performance, reduce operational challenges, and increase system longevity. With their advanced features, Fuji's HPnC modules enhance the performance and reliability of microgrid elements. The modules are designed to ensure minimal energy loss during power conversion and distribution while their robust construction guarantees reliable operation, even in challenging environments.

Conclusion

With the increasing demand for clean and sustainable energy, Fuji Electric's HPnC modules with 7th generation IGBT and SiC MOSFET technology are facilitating the clean energy transition. Integrating these HPnC modules offers efficiency, performance, and reliability improvements in renewable energy applications such as solar and wind installations. However, the implications of using the modules extend beyond engineering improvements. By optimizing energy production and consumption, the immediate challenges of energy wastage and system inefficiencies can be addressed while contributing to a larger global narrative of sustainability.

Contact Fuji Electric

For additional information on Fuji HPnC modules and application-specific inquiries, please visit the **Contact Us page** on the Fuji Electric website.

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