The Application of IGBT5 Module in Wind Power Design of High Reliability and High Power Density

With the wide application of wind power technology in the global new energy market, and the market demand for affordable access to the power grid and subsidization is declining. At present, the single unit capacity of wind turbine is developing in the direction of larger capacity. As one of the core components of wind power converter, the design of high reliability and high power density has become the main technical goal and direction of product design, which further improves the system power generation efficiency and reduces capex investment cost. In particular, offshore wind power has become the main application of wind power technology. It is in the harsh operating environment of high humidity, high salt and high corrosion, which puts forward higher technical standards for the reliability of power devices.

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In order to meet the requirements of the application design, Infineon [1] has launched PrimePACK$^{\text{TM}}$ series IGBT module, which integrates the fifth generation IGBT5 chip technology and high reliability. XT packaging technology. The PrimePACK3$^{\text{TM}}$ + package improves the current density, and the half bridge module reaches 1800A [2], which is one of the products with the highest current density in the industry, and meets the reliability standard of HV-H3TRB [3].

At present, wind power topology circuit is mainly divided into two forms: doubly fed and direct drive, as shown in Figure 1 and Figure 2. The main power coverage of doubly fed induction generator ranges from 400KW to 6MW. Its converter capacity is only slip s power, and the rotor side frequency is about 0-15Hz, which is related to the slip of wind turbine generator. Low frequency operation causes high junction temperature fluctuation, which requires high reliability and service life. In the direct drive model, the maximum coverage of PMSM power can reach more than 10 MW, and self excitation is different from doubly fed. The amplitude and frequency of output voltage and current of the Gen side depend on the speed of the generator. The output voltage is converted to DC voltage through rectification. The capacity of the wind power converter is the same as that of the generator, and the junction temperature fluctuates greatly. The fluctuation of junction temperature will directly affect the core component IGBT's working life and reliability. Combined with the characteristics of the converter, it will determine the whole operation cost, life, mean time between failures, power generation and other indicators of the system.

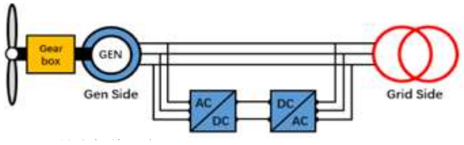


Figure 1: Main topology of DFIG

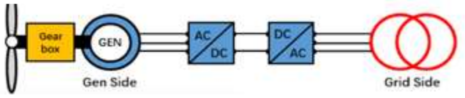


Figure 2: Main topology of direct drive

1. Brief introduction of IGBT5 chip technology and. XT packaging technology [4] [5], as shown in Figure 3:

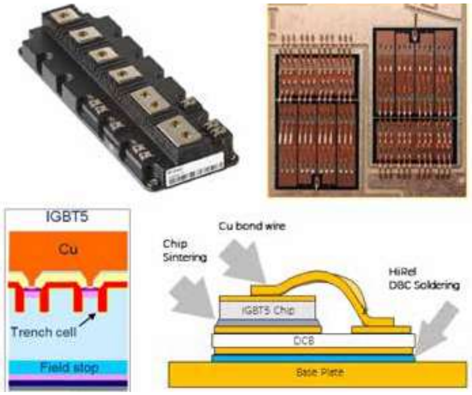


Figure 3: Introduction of IGBT5 &. XT Technology

Compared with PrimePACK$^{\text{TM}}$ module based on IGBT4 chip and traditional packaging technology, IGBT5 module has the following characteristics:

IGBT5 chip thickness: reduce the thickness to optimize the chip characteristics.

Surface metallization layer on IGBT5 chip: upgrade from traditional aluminum alloy to copper layer, increase heating capacity, enhance short circuit capability of devices, and lay the foundation for copper binding process of chip.

Copper binding wire on chip surface: copper metallization based on IGBT5 chip can realize copper binding wire process on chip surface. Compared with traditional aluminum binding process, in addition to increasing current carrying capacity of binding wire, it can also greatly improve reliability of chip in the second-level power cycle (PC (sec)).

Silver sintering on the lower surface of the chip: compared with the traditional solder technology, silver sintering technology can greatly improve the solder shedding and failure phenomenon between the chip and DBC, so as to further improve the second power cycle (PC (sec)) reliability of the chip.

High reliability welding of DBC: the specially optimized patented HiRel - high reliability DBC welding technology significantly improves the ability of temperature cycle (TC) and minute power cycle (PC (min)). Therefore, the technology is also widely used in Infineon related automotive IGBT module products to meet its stringent requirements for temperature cycling and temperature shock capability.

In summary, compared with IGBT4 products, the advantages of IGBT5 module are as follows:
1. Increase the rated current of the module to 1800A, and increase the current capacity by nearly 30%
2. The life of PC is more than 10 times of that of conventional package
3. Chip Tvj-op with maximum operating temperature of 175 ℃

Therefore, IGBT5 module is the best choice to achieve high reliability and high power density.

2. Based on the typical application of wind power converter, the advantages of high reliability and high power density of IGBT5 scheme are expounded

Taking the 690Vac two-level wind power converter with 1MW direct drive (without high-speed gearbox) as an example, in the traditional IGBT4 scheme, the 1MW three-phase rectifier or inverter unit is generally composed of three power units. In each power unit, there are usually two FF1000R17IE4 modules in parallel, plus driver board, bus bar, capacitor, structure and power cable, cooling plate and waterway design. In the IGBT5 scheme, only one power unit is needed to realize 1MW three-phase inverter or rectifier function, as shown in Figure 4 below:

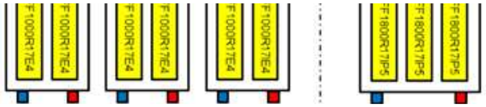


Figure 4: Power unit comparison of IGBT4 and IGBT5 schemes

Therefore, from the aspects of STACK, power components and functional system, IGBT5 has obvious advantages:
-The power density of STACK is greatly improved
-Reduce the number of power components, optimize the system -cost of inverter or rectifier unit
-The number of power components is reduced, the structure of the whole system is simplified and the reliability is improved

Similarly, taking the above-mentioned 1MW direct drive 690Vac two-level as an example, the output frequency of the grid side inverter is usually 50 Hz / 60 Hz, while the output frequency of the rectification part of the Gen side is relatively low, usually 8 Hz-12 Hz. Therefore, the junction temperature fluctuation of freewheeling diode (FWD) on the Gen side is often the bottleneck of IGBT module life calculation.

Taking the Gen side parameters of a group of typical 1MW direct drive converters (as shown in Table 1) as an example, through simulation calculation, the differences between the traditional IGBT4 scheme and the new IGBT5 scheme (as shown in Figure 5) are compared and analyzed:

Bus Voltage Vdc / V	1100
Output voltage Vac rms/V(line-line)	690
Output current lo_ rms/A	1000
IGBT switching frequency / Hz	2.5k
Gen side output frequency / Hz	8.8
SVPWM modulation ratio M	1.024
Power factor PF	-1

Thermal resistance of water cooling plate (Rth(h-a) per switch) / K / W：0.015

Time constant of water cooling plate (Tau) / S	5
Water inlet temperature of water cooling plate Tinlet / ℃	50
Glycol content in water cooling solution	53%

Table 1: Parameters of typical 1MW direct drive on Gen side

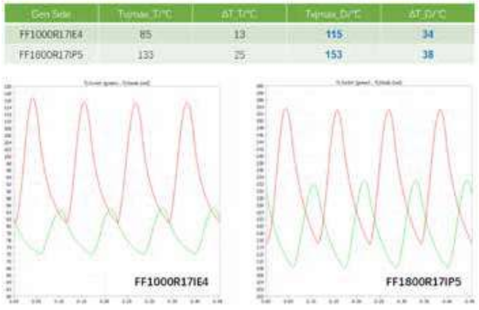
Figure 5: Comparative analysis of IGBT4 and IGBT5 schemes

The module loss and chip junction temperature of IGBT4 and IGBT5 are obtained by simulation with IPOSIM [6] on Infineon's official website, as shown in Fig. 6 and Fig. 7 respectively:

Gen Side, Rg=Datasheet	2 x FF1000R17IE4 /W	1 x FF1800R17IP5 /W
Power Losses per phase	2X2X(426+486)=3648	1X2X(1197+991)=4376

Figure 6: Comparison of IGBT4 and IGBT5 schemes on the Gen side

In Figure 6, the loss of IGBT5 is larger than that of IGBT4. In addition to the difference in chip generation, it is mainly due to the differences in the characteristics and technical positioning of P-Series and E-Series chips. P series is a typical high-power slow chip, while E series is a medium power fast chip; therefore, the switching loss of P series will be relatively large [5].



Gen Side	Tjmax_T/°C	ΔT_T/°C	Tjmax_D/°C	ΔT_D/°C
FF1000R17IE4	85	13	115	34
FF1800R17IP5	133	25	153	38

Figure 7: Comparison of junction temperature of IGBT4 and IGBT5

As shown in Figure 7, the maximum junction temperature of IGBT4 is significantly lower than that of IGBT5, and the junction temperature fluctuation is slightly lower than that of IGBT5. However, this does not mean that the power cycle (PC) times of IGBT4 module is more (or the PC life is longer) than IGBT5.

According to the simulation of T_{vjmax} and $\triangle T_{vj}$ of the above two schemes, combined with the typical PC curve of IGBT4 and IGBT5 provided by Infineon [8], we can get the approximate times of power cycle (PC), as shown in Figure 8 below:

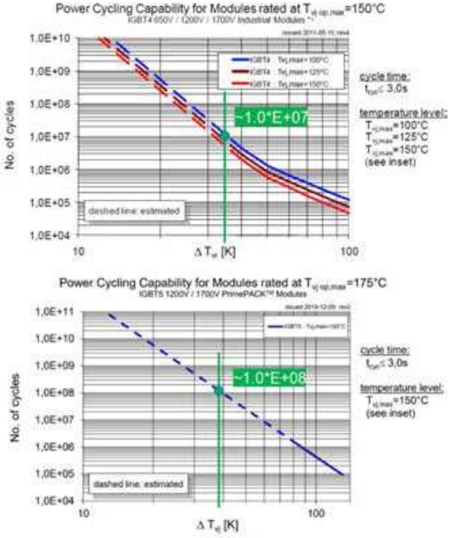


Figure 8: PC curve and times comparison of IGBT4 and IGBT5 modules

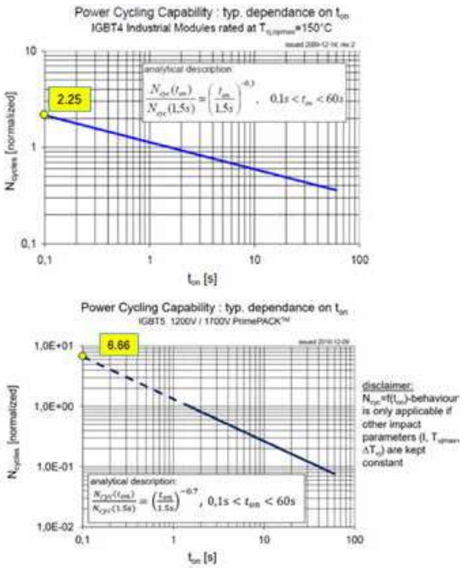


Figure 9: Ton time conversion formula and curve of IGBT4 and IGBT5 modules

Combined with the Ton time conversion formula and curve of IGBT4 and IGBT5 given by Infineon, the power cycle (PC) times of IGBT4 and IGBT5 are corrected, as shown in Figure 9 below: (When Ton time is less than 0.1s, the data of 0.1s will be used temporarily)

Finally, the theoretical power cycle (PC) times of IGBT4 and IGBT5 can be obtained, as shown in Figure 10.

Gen Side / Tj_FWD	Tvjmax_D/°C	ΔT_D/°C	PC cycles	%(PC)
FF1000R17IE4	115	34	2.3*E+07	100%
FF1800R17IP5	153	38	6.7*E+08	2900%

Figure 10: Comparison of PC times of IGBT4 and IGBT5 modules

From the above simulation results, we can see that the PC times / lifetime of IGBT5 scheme is still 30 times as much as IGBT4 scheme, even in the case of higher junction temperature fluctuation!

Therefore, the module life and reliability of IGBT5 scheme are greatly improved compared with the traditional IGBT4 scheme!

3. Combined with advanced water cooling technology, the power density limit of IGBT5 scheme is continuously broken

According to the previous theoretical calculation and analysis, IGBT5 (FF1800R17IP5) still has margin under 1MW typical Gen side conditions. Therefore, combined with advanced water cooling technology, the power density limit of IGBT5 scheme is evaluated by measurement and simulation.
At present, the thermal resistance reference of water-cooling plate with different performance in the market is shown in Figure 11,

Normal Heatsink	0.015	100%
Good Heatsink	0.013	87%
Excellent Heatsink	0.010	67%

Figure 11: Thermal resistance reference of water cooling plate with different performance

Among them, Mersen, the cooling plate supplier, customized a high-performance water-cooling plate sample based on ISOMAXX technology. In order to verify the heat dissipation characteristics of the water-cooling plate, the thermal resistance calibration test of the cooling plate was carried out under the conditions of flow rate of 35L / min, pressure drop of 480 mbar, coolant of 53% glycol and inlet temperature of 50 °C. The test setup is shown in Figure 12. The IGBT5 module is replaced by the heating block. The temperature rise of the cooling plate under each heat source is measured to get the corresponding thermal resistance.
The measured results of temperature rise and thermal resistance of water cooling plate are shown in Figure 13 below:

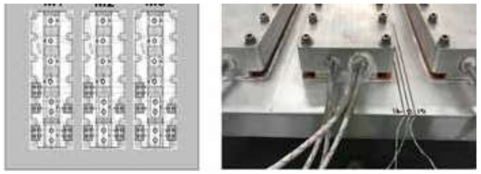
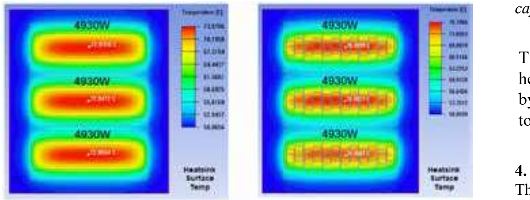


Figure 12: Mersen cooling plate schematic diagram and thermal resistance measurement diagram (heating block as heat source)

Module	Power losses /W	ΔT_heatsink /°C	Rth(h-a) per switch /K/W
M1	5405	23.5	0.0087
M2	5423	23.6	0.0087
M3	5394	22.3	0.0083

Figure 13: Measured results of temperature rise and thermal resistance of Mersen high performance water cooling plate

Considering that the measured thermal resistance is based on the heating block, while the actual module is based on the multi chip heat source, the latter is relatively more severe, which will lead to the increase of the actual thermal resistance of the cooling plate. Therefore, the thermal simulation tool of finite element can be used to simulate the equivalent heat dissipation conditions through HTC. The heat source of heating block (measured) and multi chip heat source can be used to simulate respectively, and the approximate proportion between them can be obtained, so as to correct the measured value of thermal resistance before, as shown in Figure 14 below：



Power losses /W	ΔT_heatsink /°C	Rth(h-a) per switch /K/W	Rth %
4930	23.07	0.0094	100%
4930	26.39	0.0107	114%

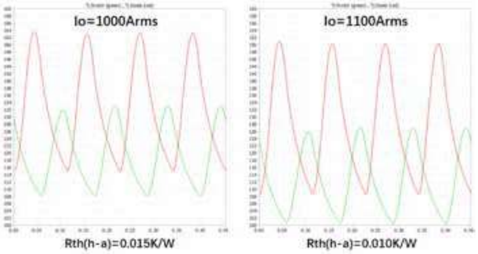
Figure 14: Influence of heating block heat source and multi chip heat source on heat resistance of cooling plate

According to the simulation results in Figure 14 above, the thermal resistance of the cooling plate increases about 14% when the heat source of the heating block is replaced by the actual multi chip heat source. Combined with the previous thermal resistance test of the heating block, the thermal resistance of the cooling plate corresponding to the actual module is about:
Rth(h-a) per switch=0.0087*114%=0.01 K/W
The thermal resistances of the cooling plate with different performances (0.010K/W, 0.013 K / W, 0.015 K / W) are loaded into the IPOSIM simulation calculation on Infineon's official website, and the junction temperature of IGBT5 under different heat dissipation conditions can be obtained, as shown in Figure 15 below:

Rth(h-a)_switch/ K/W	FWD_ΔT@Tvjmax	Power Losses per module /W
0.015	38℃@153℃	4376
0.013	38℃@148℃	4313
0.010	38℃@140℃	4225

Figure 15: Junction temperature fluctuation and module loss of IGBT5 (FF1800R17IP5) under different heat dissipation conditions

Obviously, the junction temperature of Gen side FWD is reduced by 13 ℃ due to the high performance water cooling plate.
At the same time, if the maximum junction temperature T_{vjmax} and junction temperature fluctuation $\triangle T_{vj}$ of FWD chip are kept unchanged, the current output capacity and power density of IGBT5 can be further improved with high-performance cooling plate, as shown in Figure 16 below:



Rth(h-a)_switch/ K/W	FWD_ΔT@Tvjmax	Power Losses per module /W	Iorms /A
0.015	38℃@153℃	4374	1000
0.010	42℃@151℃	4708	1100

Figure 16: High performance water cooling plate improves current output capability and power density of IGBT5 (FF1800R17IP5)

Therefore, IGBT5 module (FF1800R17IP5) combined with efficient heat dissipation technology can increase the current output capacity by about 10% when the junction temperature of FMD is close, so as to further improve the power density of IGBT5 scheme.

4. Summary

Through the introduction of advanced IGBT5 chip technology and. XT packaging technology in IGBT5 module, as well as the actual application scenarios, the unique advantages of IGBT5 module in the application of high reliability and high power density of wind power are illustrated by comparing with the traditional scheme of IGBT4. At the same time, combined with efficient heat dissipation technology, the high power density potential of IGBT5 scheme can be further explored.

【 Reference 】

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