Novel Mega Power Dual IGBT modules for Renewable Energy Applications

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Abstract

As environmental issues have attracted increasing worldwide attention in recent years, renewable energy such as wind power and solar power are playing more and more important role in creation of a low carbon society. The renewable energy applications expect the Insulated Gate Bipolar Transistor (IGBT) to exhibit not only high reliability but also low power loss, high rated current and high robustness. This paper presents the features and evaluation results of a novel Mega Power Dual IGBT module (named new MPD IGBT) which satisfies the performance requirements for large power wind turbine converter and solar inverters.

1 Introduction

In 2002, Mitsubishi Electric released its original Mega Power Dual (MPD) series IGBT featuring 2-element, including 1400A/1200V, 900A/1200V and 1000A/1700V IGBT modules that could handle megawatt-class power generation. In 2009, the company released the new-MPD Series to accommodate the expended volumes handled by power generation system. Compared with the original MPD series IGBTs, the new-MPD series' current rating exceeds to 2500A and 1800A for 1200V and 1700V IGBT respectively, and features a dedicated package with a rearranged internal structure. Advanced technologies and performance of the new MPD IGBT modules are described in this paper. Small inductance internal wiring structure is developed in this large current new MPD series IGBT modules. Semiconductor chips are arranged in an optimized layout for the purpose of increasing thermal capability. The baseplate of the new MPD IGBT modules is separated into several sections to achieve a lower contact thermal resistance between baseplate and cooling fin.

The key to the successful implementation of power electronics is to include the device designer as a member of the system design team during the entire product development. To ensure the optimal use of new MPD IGBTs for product longevity, experts from wind power and solar power fields shared their abundant experience in using the new MPD IGBTs.

2 Features of the new MPD IGBT modules

The new MPD-IGBT module lineup consists of two IGBT modules: one is 1800A/1700V IGBT with P/N of CM1800DY-34S, which is used for wind turbine converter. The other is 2500A/1200V IGBT with part number of CM2500DY-24S.Both of the two IGBTs share the same package and external view, as is shown in Fig.1.

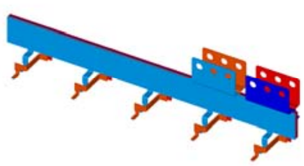
Part number	Ratings	Target application
CM1800DY-34S	1800A/1700V	Wind power
CM2500DY-24S	2500A/1200V	Solar power

Fig. 1 external view of new MPD IGBT modules

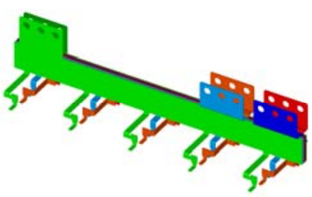
Besides dedicated package, this new MPD IGBT module has other outstanding features, including

• Mitsubishi 6th Generation IGBT with CSTBT™ Chip Technology
• For 1200V module: VCE(sat) = 1.7V(typ) @ Tj = 125° C;wide SOA @ Vcc = 900V
• For 1700V module: VCE(sat) = 2.2V(typ) @ Tj = 125° C;wide SOA @ Vcc = 1200V
• Tj(max) = 175° C
• New solderless Al-baseplate to achieve high ΔTc temperature cycling capability
• Wide internal chip layout to achieve low Rth(j-f)
• Minimized internal package inductance Lint = 5.25nH
• Separated AC and DC main terminals for easy DC-bus design
• Integrated NTC for Tc-sensing
• Auxiliary C-terminals available for P-side and N-side IGBT

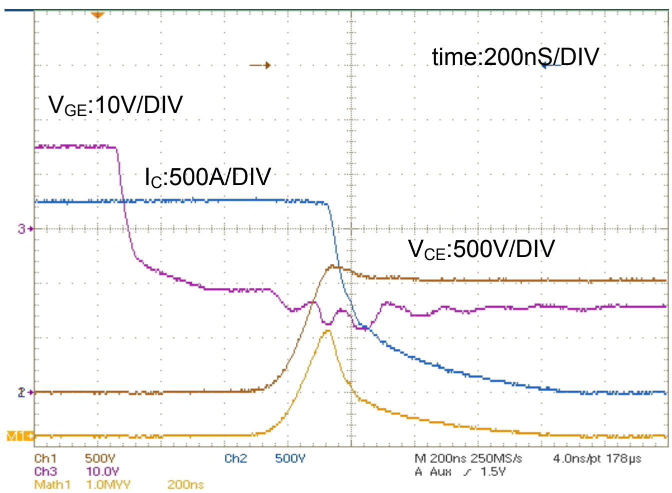
High current, high voltage IGBT modules require the paralleling of many IGBT and diode chips inside one package. For fast switching operation, all internal package inductances must be kept small to minimize voltage overshoots during turn-on and turn-off. A novel laminated busbar design inside the IGBT module is applied in this new MPD IGBT, as is shown in Fig.2(a) and (b).This advanced technology enables the production of the new MPD IGBTs with an internal inductance as low as 5.25nH. Fig. 2(c) shows the turn-off waveform of an 1800 A, 1700 V new MPD IGBT module CM1800DY-34S. The DC voltage was set to 1000 V, the collector current to 1800 Amp. Under these conditions, the V_{CE} surge voltage is only 168V, showing good performance in reducing voltage overshoots at hard turn off switching. The low internal stray inductance of the IGBT module can achieve an improved high power inverter construction which results in a total parasitic inductance of only 40 nH for an inverter in the MW range, as will be described in wind power application.



(a)4-layers P-N busbar



(b)6-layers AC out busbar



(c)turn-off waveform of CM1800DY-34S

Fig. 2 internal busbar design of new MPD IGBT modules and turn-off waveform

A conventional IGBT module's structure is illustrated in Fig.3. The IGBT and diode chips are soldered to a substrate with one copper layer patterned to form the electrical connection to the chip. There is also another solder layer between copper baseplate and insulation ceramic. This solder layer is subjected to degradation by temperature stress resulting an increasing thermal resistance Rth(j-c) over lifetime of the IGBT module. The new MPD IGBT modules apply an aluminum baseplate instead of copper baseplate used in conventional IGBT modules(Fig.4). What's more, the aluminum baseplate is directly bonded insulation substrate, therefore is able to remove the solder layer between base plate and insulation ceramic and improve the thermal cycling ability significantly.

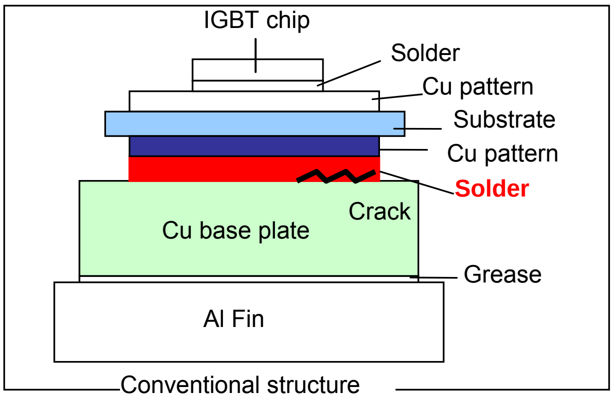


Fig.3 Structure of conventional IGBT with copper baseplate

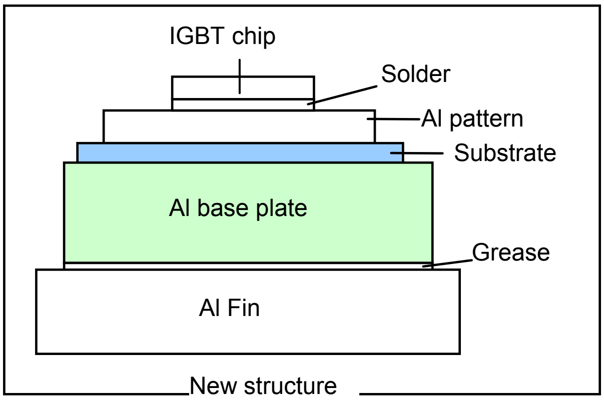


Fig.4 Structure of new MPD IGBT with aluminum baseplate

Power cycling ability of the new MPD IGBT modules is also improved by using ultra sonic welding(Fig.5). Test results of short time power cycling on IGBT module showed the new MPD IGBT's power cycling lifetime is improved more than 3.5 times of that of conventional IGBT modules. This improvement is of great importance in wind power application, which often leads to special requirements in reliability of power cycling and thermal cycling.

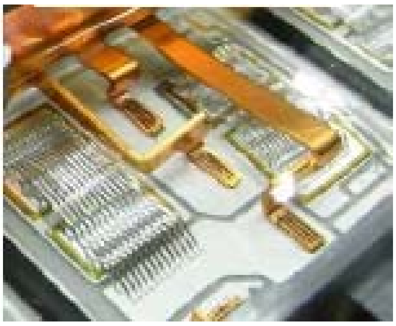


Fig.5 Ultra sonic welding

3 1800A/1700V new MPD IGBT for wind turbine converter

To help customers use new MPD IGBT modules well, Mitsubishi Electric developed MPDStacK^{TM} for customers' reference. The MPDStacK^{TM} for renewable energy is a high power, one half-bridge cell that uses Mitsubishi new MPD IGBT module with integrated water-cooling heat sink, polypropylene capacitors, snubber, driver and protective sensors, and is optimized for renewable energy applications. It allows for a power rating around 1MW in full-scale wind power application.

Fig.6 MPDStacK^{TM} for renewable energy comprises of half bridge cell

A low-cost plug-and-play driver named VLA553 is developed by Isahaya Electronics Corporation (IDC), as is illustrated in Figure.7. An isolated DC/DC converter for gate driver is built in the driver core, short circuit protection, soft shut-down and active clamping function are also designed in the driver board. All the devices chosen for this driver board are standard components to reduce costs and to simplify design.

Fig.7 Photo of driver board VLA553

The measured short circuit test waveform of a 1800A/1700V new MPD based on VLA553 is shown in Fig. 8. In this case, the DC link voltage is 1200V,junction temperature is 25° C, and Rg(on)=0Ohm, Rg(off)=1Ohm. It can be seen both the soft shut-down and active clamping function operated in the short circuit condition.The effect of the active clamping function starts from a voltage of approximately 1600V.Actually, the thermal stress on the components of the driver board depends on the DC link voltage, the ratio of the collector current changing during switching and the stray inductance of the communication circuit.

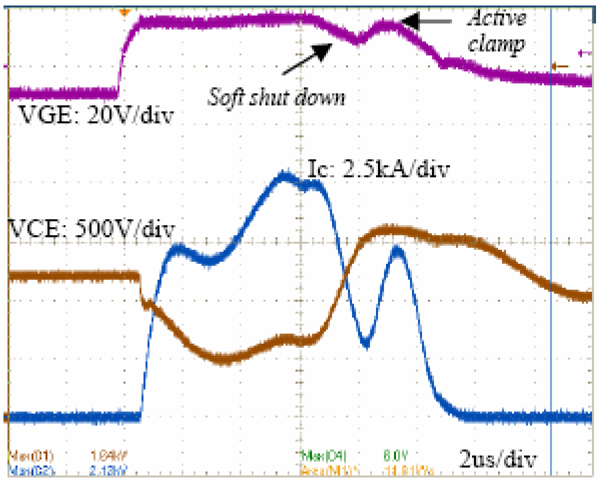


Fig.8 Short circuit test waveform of 1800A/1700V new MPD IGBT module

In order to handle large heat fluxes, a cost-efficiency water-cooling plate was designed for the new MPDStacK™. Plate thickness is 30mm and material of the plate is Aluminum. Material of tubing is stainless steel, which gives a tough design that withstand rough environments. The water-cooling pipe is located just under the chips to achieve most optimized heat dissipation, as is shown in Fig.9. In order to verify the performance of the heat dissipation and get the approximate temperature distribution, a thermal analysis simulation of the plate in ANSYS was made. It is assumed that the thermal power is 5.3KW,inlet water temperature: ≤50° C, pressure drop between the inlet and outlet: ≤ 0.3bar, water flow: 10L / min.Fig.10 shows the simulation result. It can be seen that the maximum temperature of water-cooling plate is 74.03° C, which is kept in a very reasonable value.

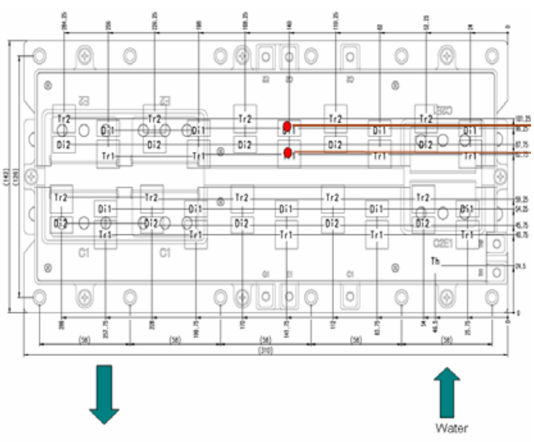


Fig.9 water-cooling plate

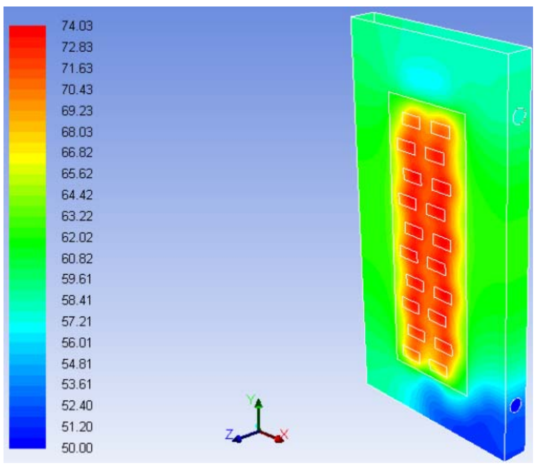


Fig.10 Simulation result

The MPDStacKs were fixed in 1MW full-scale wind turbine converter for heavy load power-fed test. The diagram of power-fed test is shown in Fig.11.In this test, the rms current of generator side is 990A, rms current of grid side is 985.9A, active power of generator side is 1190kW, active power of grid side is 1154kW, efficiency of the converter is 96.93%. Test waveform is demonstrated in Fig.12, displaying the DC-link voltage (dark blue),grid voltage (blue), current of grid side (red) and current of generator side (green).Temperature test results showed in full-load conditions, the temperature of main components were kept in design target well.

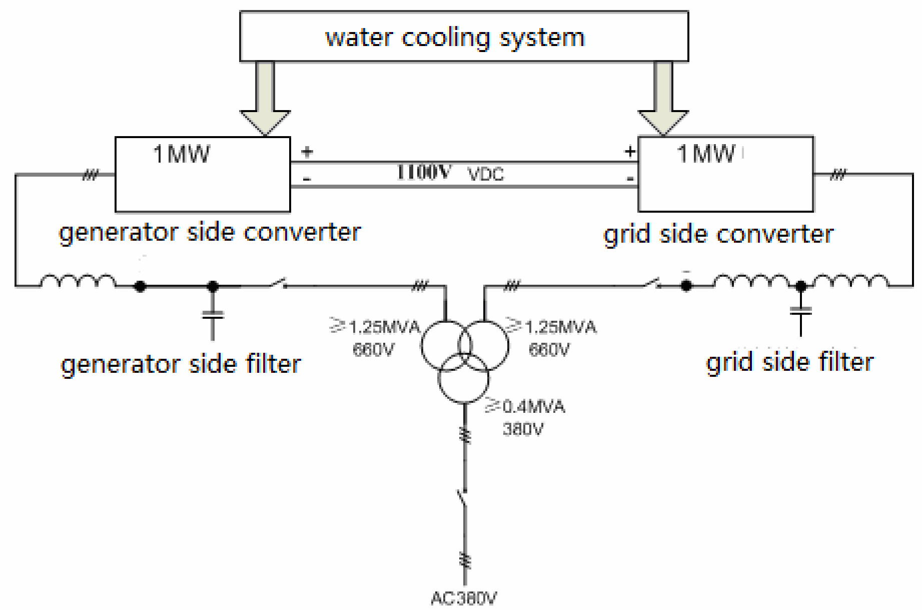


Fig.11 Diagram of power-fed test based on 1MW converter

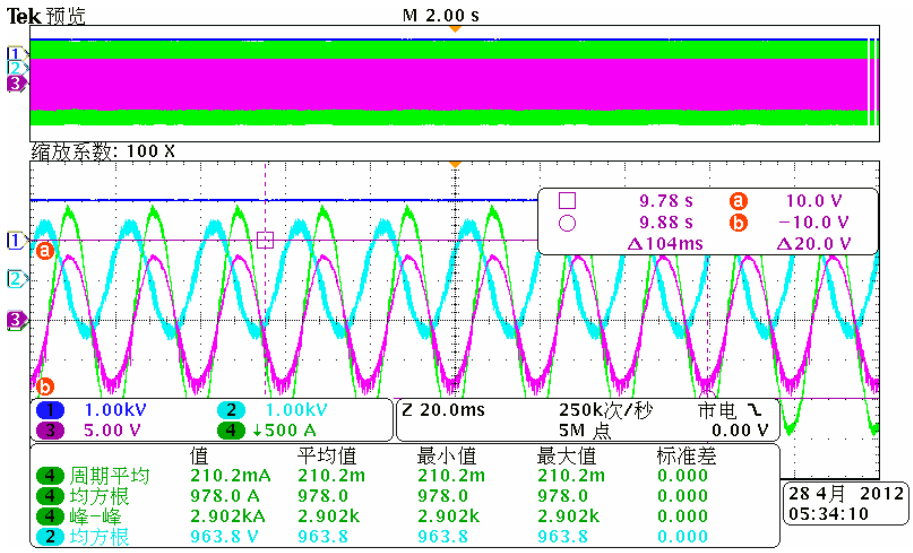


Fig.12 Test waveform of power-fed test

4 2500A/1200V new MPD IGBT for solar inverter

In solar applications of China market, power technology trends for grid connected systems typically range up to 500 kW per individual inverter with some new developments underway at 1 MW plus. In such case, the 2500A/1200V new MPD IGBT module has unique advantages in this application because of its high rating current to achieve 500kW solar inverter directly without parallel connection of IGBTs, thus the volume and cost of the total inverter are reduced. In addition, by avoiding the parallel connection of IGBT modules, the 2500A/1200V new MPD IGBT could reduce power loss and therefore improve the solar inverter's efficiency significantly.Fig.13 shows the power loss comparison for 2500A/1200V new MPD IGBT CM2500DY-24S with 2-parallel solution of 1400A/1200V IGBTs in a 500kW solar inverter. A three-phase 500kW solar inverter consists of three 2500A/1200V new MPD IGBTs, but uses six 1400A/1200V IGBTs if takes 2-parallel solution. This power loss calculation is based on a 500kW solar inverter, that is to say, the comparison is made between three 2500A/1200V new MPD IGBTs and six 1400A/1200V IGBTs. The calculation conditions are:Vdc=460V,$V_{GE}=\pm 15V$, Tj=125° C, 3 phase simusoidal,switching frequency=3kHz,power factor=0.99,modulation ratio=1. Simulation result showed that under the same simulation condition, for 100kW output, the efficiency of inverter based on CM2500DY-24S is 0.2% higher than that of 1400A/1200V 2-parallel solution. For 200kW output, the efficiency of inverter based on CM2500DY-24S is 0.13% higher than that of 1400A/1200V 2-parallel solution.

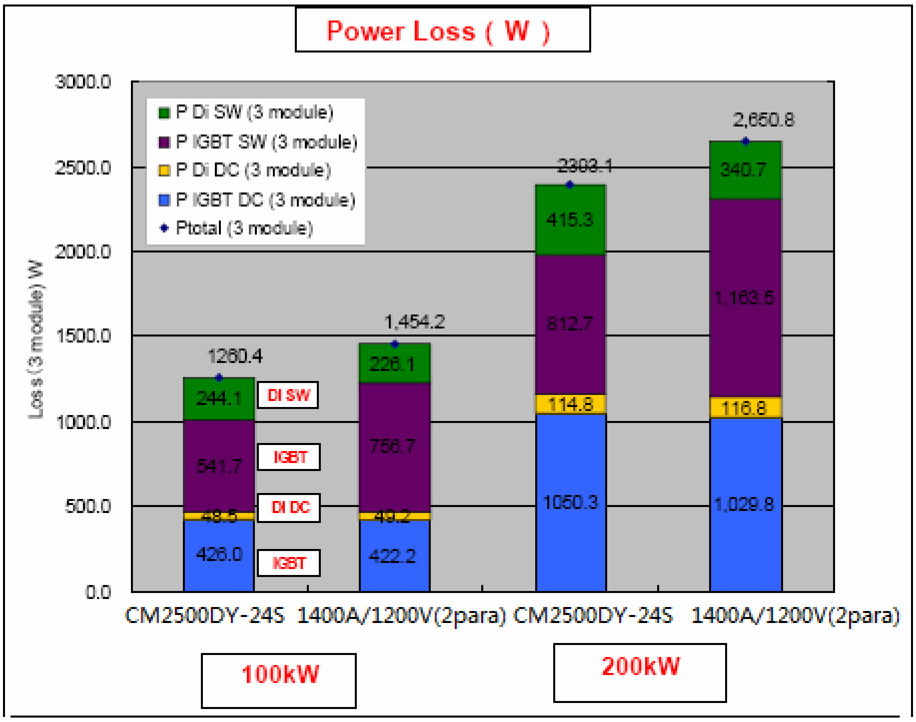


Fig.13 power loss comparison for2500A/1200V new MPD IGBT CM2500DY-24S with 2-parallel solution of 1400A/1200V IGBTs in a 500kW solar inverter

Besides active clamping function of the driver, snubber and laminated busbar are also key measures to lower the voltage overshoot at an over-current or short-circuit turn-off of IGBT module. Two kinds of customer-specified snubber capacitors are developed for the new MPD IGBT module. One is 1200V/3.3uF snubber capacitor from Vishay(Fig.14), the other is 1250V/2.0uF snubber capacitor from Soshin(Fig.15).Both of the two snubber capacitors can suppress voltage overshoot well.

Fig.14 1200V/3.3uF snubber capacitor specified for new MPD IGBT from Vishay

Fig.15 1250V/2.0uF snubber capacitor specified for new MPD IGBT from Soshin

PV inverters are specially designed for each energy source. This translates to smaller volume and, consequently, lower weight for the system. The 2500A/1200V new MPD IGBT can match these requirements well by providing flexible structure design of the 500kW solar inverter. Fig. 16 shows an example of 500kW solar inverter's layout. The DC busbar consists of two copper plates laminated together with epoxy glass insulation between different layers. Output AC busbars are separated to connected the three phase output. This inverter could be designed to a very compact size, and assembling time and cost are minimized by placing all components such that the terminals are on the same level.

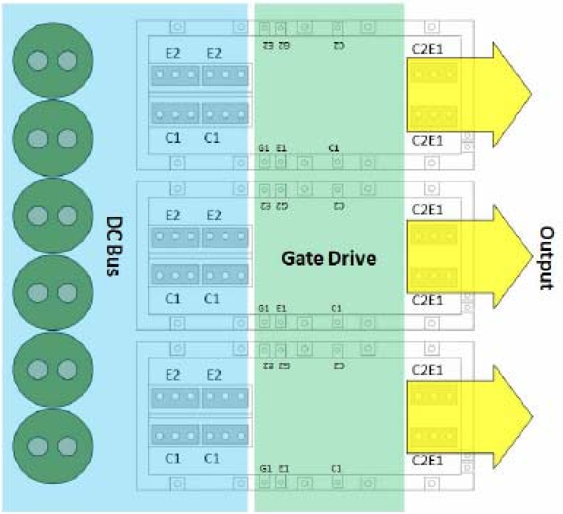


Fig.16 Transparent view of a three phase solar inverter based on 2500A/1200V IGBT

5 Conclusions

Latest technologies and features of Mitsubishi Electric new mega power dual IGBT modules are presented. Small inductance internal wiring structure make the turn-off voltage overshoot keep in low level. Semiconductor chips are arranged in an optimized layout for the purpose of increasing thermal capability. Separated baseplate achieves a lower contact thermal resistance between baseplate and cooling fin. Solderless process between base plate and insulation ceramic improves the thermal cycling ability and ultra sonic welding technology improves the power cycling ability significantly. All the features make the new MPD IGBT modules well match requirements of power devices from wind power and solar power applications.
To ensure the optimal use of new MPD IGBTs in renewable energy applications, key design items including driver, snubber, busbar are discussed also for designers' reference.

6 References

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