Comparison of PIM modules with separate inverter and rectifier schemes in inverter applications

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Introduction—The main circuit topology of the inverter is shown in **Fig. 1.**

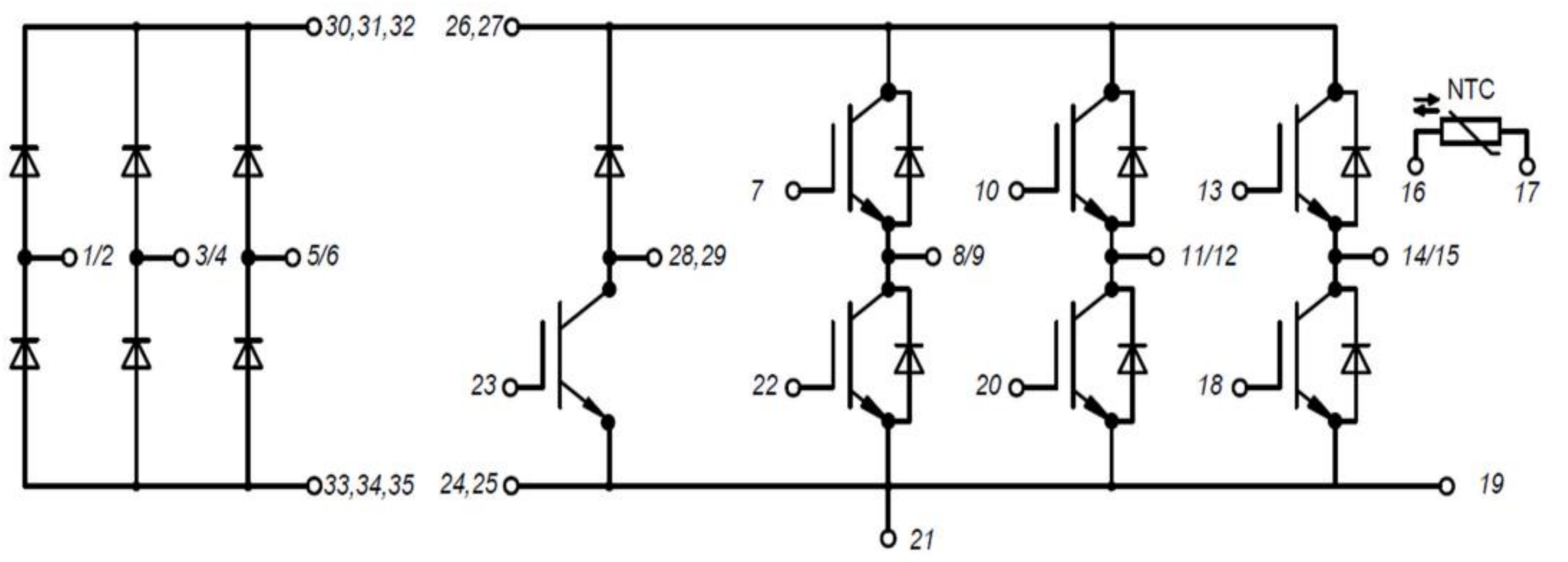

Fig. 1. Frequency converter application topology

It is composed of the rectifier bridge + brake unit + inverter.In the small power segment frequency converter, we usually use a single tube scheme at the beginning, in the same power segment of the frequency converter, the advantage of the single tube scheme is small size, the whole machine structure is more flexible, and the cost of solving the process problem is lower than the module. The advantages of modular scheme are simple manufacturing process and high reliability. In the module scheme, there is a PIM module with a relatively high degree of integration, and there is also a scheme that the inverter and the rectifier are separated.

Package size comparison

Take the IGBT module 75A 1200V as an example. Before we developed the latest generation of 7th technology, customers usually chose the following solution, **Fig.2** .By reducing the package size of the IGBT, the customer's machine volume can be reduced by at least 30%-40%. This greatly reduces the cost of the customer's complete machine. Which makes customers more competitive and advantageous in the market.

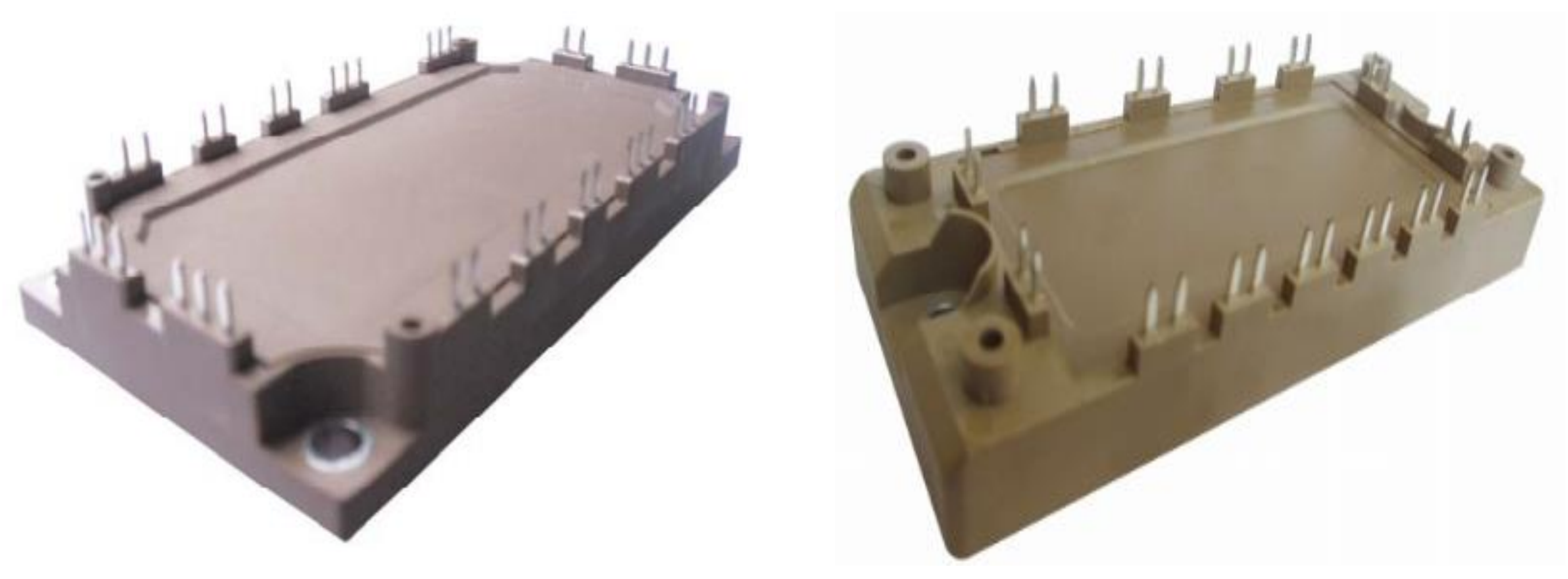

Fig. 2. 17mm package shape

Cost comparison

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Fig. 3. IGBT module with copper base plate and without copper base plate

Feature comparison

In the 18.5Kw power range, there is little difference in heating between the two schemes using the same chip. But in small packages, the rectifier diode chip size limits its surge current. On the contrary, the rectifier chip can be packaged separately to avoid the failure caused by insufficient surge resistance.

			PIM		sixpack+rectifier	
			1#	2#	1#	2#
I_{FSM}/A	10ms single	25 ℃	770 OK	771 OK	1010 OK	1023 OK
			856 FAIL	857 FAIL	1134 FAIL	1139 FAIL

Table. 1. below shows the test results.

From the test data, we can see that the chip size of the rectifier chip is limited due to the limitations of the package of the PIM module. This also results in inrush currents that are not sufficient to compare with comparable current specifications in larger packages. Therefore, we sometimes choose to separate the inverter and rectifier parts of the scheme.

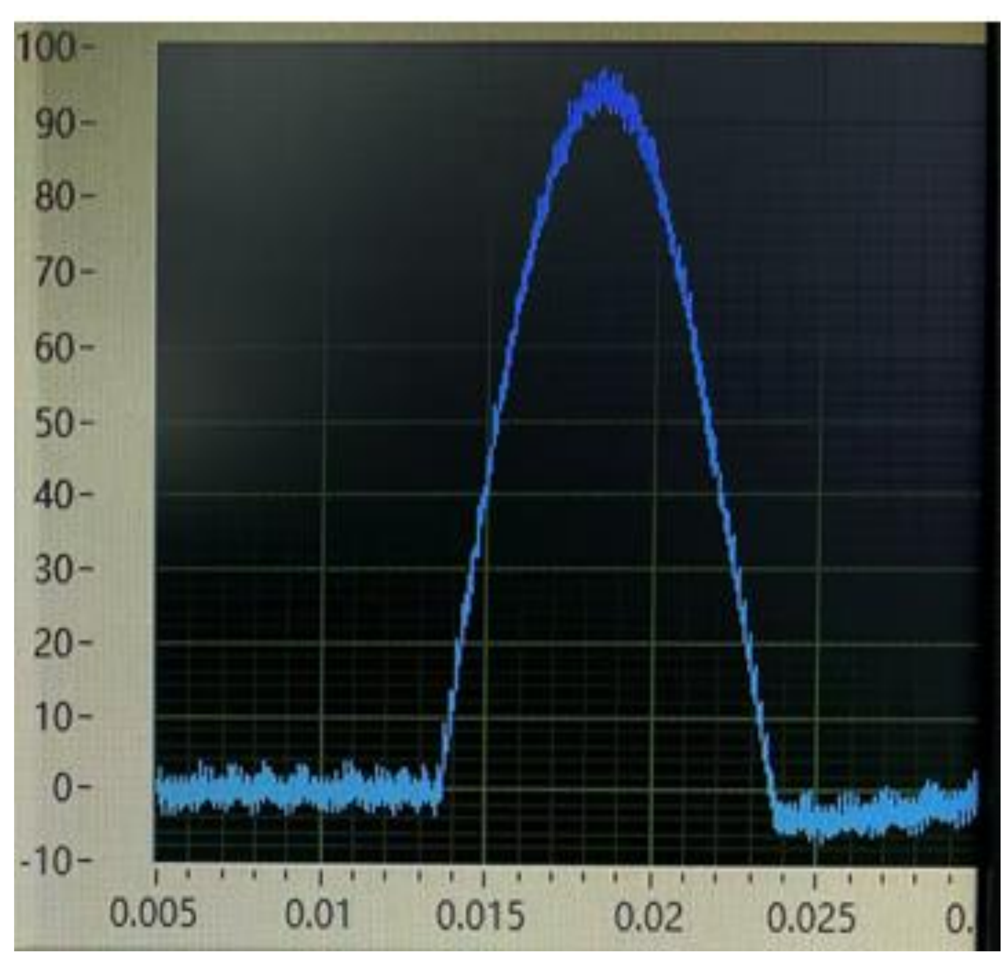

Fig. 4. Inrush current test diagram

If the power is increased by a level, although the chip size can still be placed in a small package, the high heat brought by a small chip can not be solved well in this package. Here I will verify my conjecture through simulation.

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Simulation Result

Conduction Losses

IGBT Conduction losses can be calculated using an IGBT approximation with a series connection of DC voltage source (uCE0) representing IGBT on-state zero-current collector-emitter voltage and a collectoremitter on-state resistance (rC):

$$U_{CE}(ic) = \mathrm{U}_{CE0} + r_C \cdot i_C$$

The same approximation can be used for the anti-parallel diode, giving:

$$U_D(i_D) = \mathrm{U}_{D0} + r_D \cdot i_D$$

If the average IGBT current value is Icav, and the rms value of IGBT current is Icrms, then the average losses can be expressed as:

$$P_{CT} = \frac{1}{T_{SW}} \int_0^{T_{SW}} P_T\,(t)dt = \frac{1}{T_{SW}} \int_0^{T_{SW}} \left(U_{CE0} \cdot i_C(t) + r_c \cdot i_c^2(t)dt\right)$$

If the average diode current is IDav, and the rms diode current is IDrms, the average diode conduction losses across the switching period (Tsw=1/fsw) are:

$$P_{CD} = \frac{1}{T_{SW}} \int_0^{T_{SW}} P_{CD}\,(t)dt = \frac{1}{T_{SW}} \int_0^{T_{SW}} \left(U_{D0} \cdot i_D(t) + r_D \cdot i_D^2(t)dt\right)$$

Switching Losses

The circuit for the examination of the IGBT switching losses is presented in **fig. 11.** It is a single-quadrant chopper supplying an inductive type load. The IGBT is driven from the driver circuit, providing a voltage Udr at its output. The IGBT internal diode is used as a free-wheeling diode, because in the majority of applications, such as 3-phase AC motor drives, bi-directional DC-motor drives, full-bridge DC/DC converters,etc., the power electronics converter consists of one or more IGBT-based half-bridges. If an external free-wheeling diode is used, the calculations are still valid, provided the diode parameters are taken from the diode data-sheet.

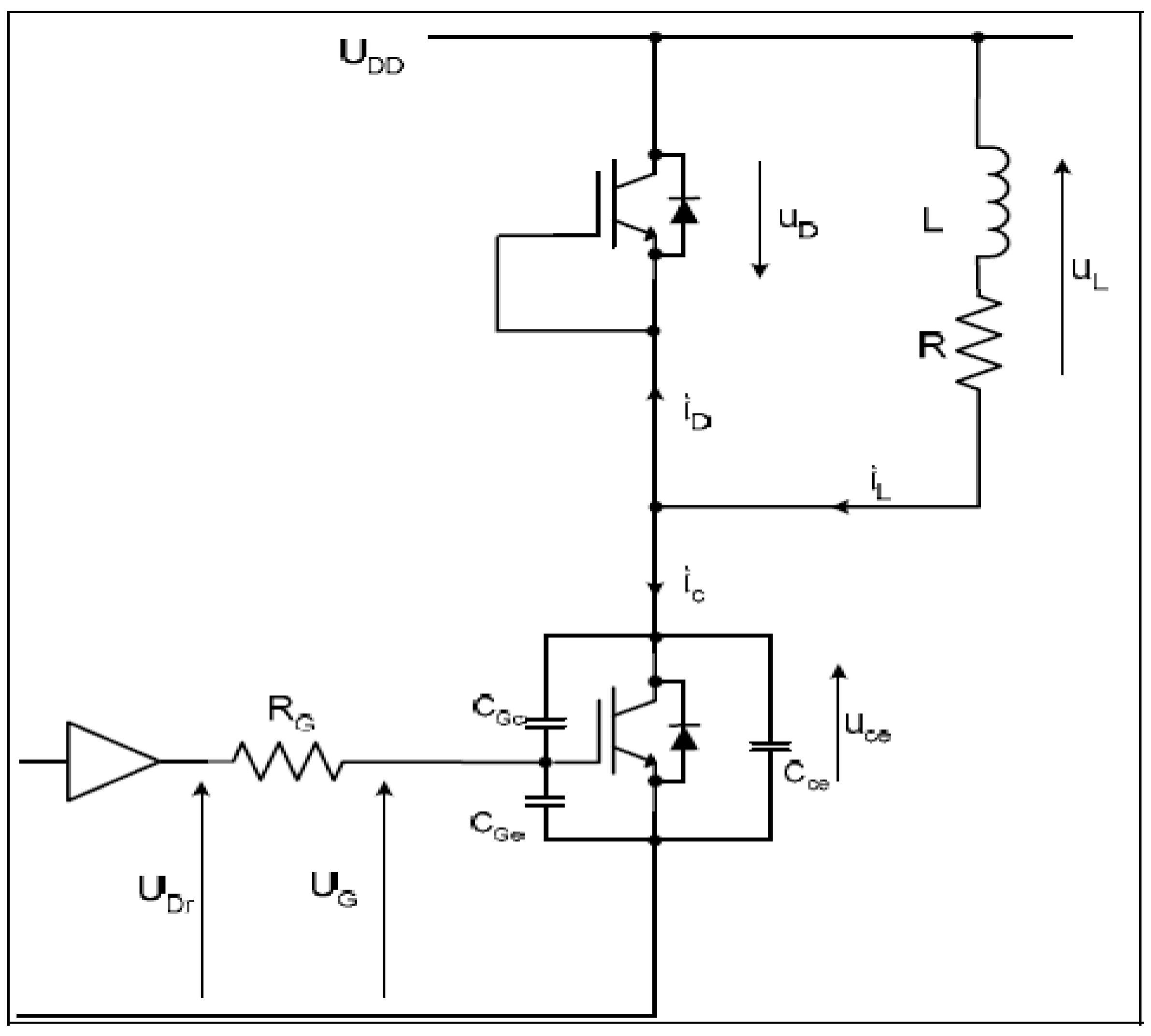

Fig. 5. IGBT chopper driving an inductive load

The turn-on energy losses in IGBT (EonT) can be calculated as the sum of the switch-on energy without taking the reverse recovery process into account (EonTi) and the switch-on energy caused by the reverse-recovery of the free-wheeling diode (EonTrr):

$$E_{onT} = \int_0^{tri+tfu} U_{ce}(t) \cdot i_c(t)dt = E_{onMi} + E_{onMrr}$$

Turn-on energy in the diode consists mostly of the reverse-recovery energy (EonD):

$$E_{onD} = \int_0^{tri+tfu} U_D(t) \cdot i_F(t)dt \approx \frac{1}{4} \cdot Q_{rr} \cdot U_{Drr}$$

Loss calculation

Simulation result		PIM		sixpack+rectifier	
IGBT	P_cond	31.05	w	31.32	w
	Psw	43.34	w	50.01	w
DIODE	P_cond	6.53	w	6.52	w
	Psw_rr	7.20	w	4.15	w
Ptot		74.39	w	81.33	w

Table. 2. Simulation result

From the simulation results, it can be seen that the module loss with copper base plate will be lower.

Experimental result

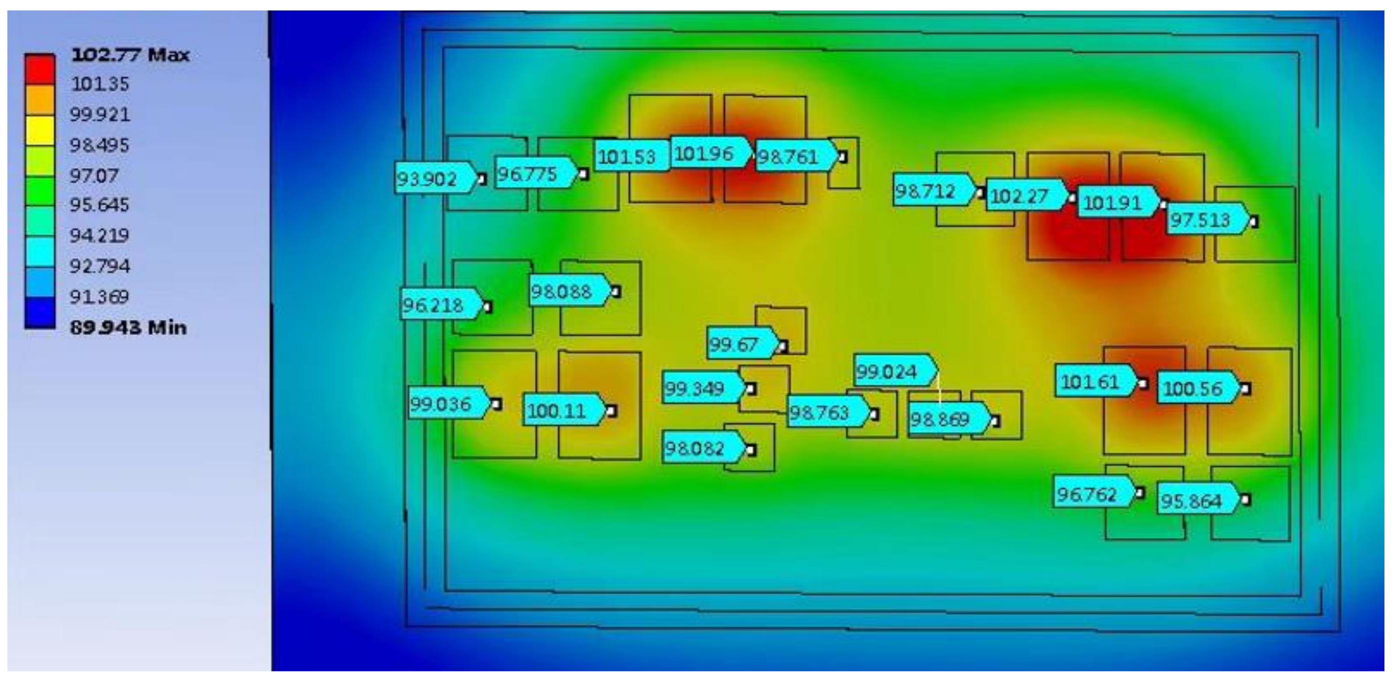

Fig. 6. Thermal simulation without copper base plate

According to the simulation results, in the high-current module module, the heat dissipation of the module with copper base plate is better than that of the module without copper base plate. If it is a low-power machine, in order to meet the requirements of the surge current, we recommend that the rectifier and the inverter be separated.

Conclusion

Based on the 7th generation IGBT chip technology, the overall package size has been reduced a lot. As a result, a lot of power segments have been improved without changing the original package size. However, the capability of the rectifier chip is not enough to support the upgrade of the product. The lack of resistance of rectifier chip to inrush current has become the bottleneck in some application fields. Therefore, the rectifier bridge will be packaged separately, and the limitation of the package size to the rectifier chip will be laughed at. To sum up, both schemes are feasible. The option you choose often depends on the impact during actual use. The scheme is fixed, but the people who use it are flexible. The first element we choose in the scheme is to facilitate our practical application.