900 A 1200 V EconoDUAL™ 3 Has Highest Power Density and Performance Using New IGBT7

The development of the new semiconductor generation targets a current density increase with the aim to reduce system costs for inverter manufacturers. It is crucial that the new technology be implemented in a given module footprint to facilitate the upgrade of existing inverter systems. This approach leads to a fast market penetration.

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For this to happen, the switching characteristics of the improved IGBTs and diodes have to fit the characteristics of the selected module housing. This is true especially with regard to oscillation behavior, since the module current is higher, and the reduction of module stray inductance is limited. At the same time, improving the housing is an important consideration to be able to handle higher currents and temperatures.

For the user of the new device, the benefits are clear: higher inverter output current for the same frame size, and avoidance of paralleling of IGBT modules. Both of these advantages help to simplify inverter systems and to lower costs. In this paper, the technical aspects of the new EconoDUAL™ 3 with TRENCHSTOP™ IGBT7 for general-purpose drives application will be discussed.

Target application

One target application for the new IGBT7 generation is the general-purpose drive (GPD) application in a power range above 90 kW. It is important to take into consideration the typical application parameters to understand the improvement levers to achieve a benefit compared to the predecessor IGBT4 technology. Typically, switching frequencies for GPDs in the power range above 90 kW are in the range of 2 to 2.5 kHz [1,2]. Most inverter manufacturers use advanced modulation methods such as discontinuous pulse width modulation (DPWM) [3] that leads to a reduction of switching losses by half compared to traditional continuous modulation [4].

For the IGBT7 development and for the following study, a switching frequency of 1 kHz and 2.5 kHz, both as continuous PWM, are selected to evaluate the new technology. The results are thus valid for higher switching frequencies using DPWM. Furthermore, a characteristic of this application is the use of an air-cooled heatsink of extruded aluminum at a maximum ambient temperature of 40°C. The nominal current of the GPD inverter is dimensioned taking into account normal and heavy-duty overload pulses at different overload current levels. Therefore, the maximum allowed IGBT operation temperature has also to take into consideration this type of operation.

Finally, the maximum steepness of the voltage slope ($du/dt_{10-90\%}$) during IGBT turn-on and turn-off is typically limited to maximum 5 kV/µs due to the motor winding lifetime and drive-shaft corrosion [5] as well as to electromagnetic compatibility (EMC). A simulation using the above-mentioned application parameters is implemented with the power electronic module FF60012ME4_B72 and the results are shown in figure 1.

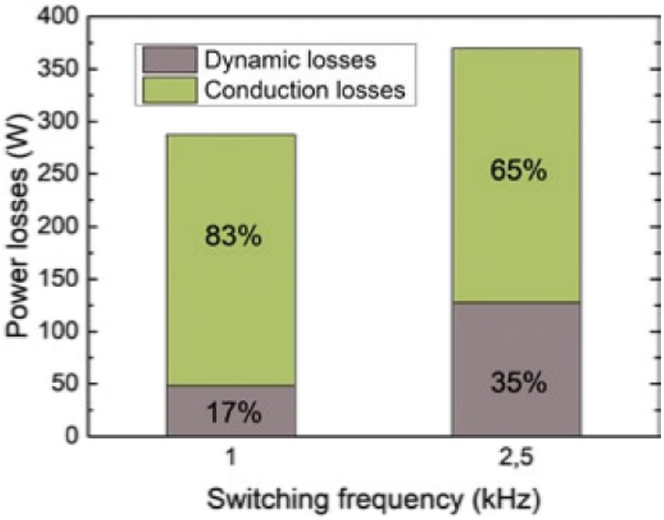

Figure 1: Loss distribution FF600R12ME4_B72 at 350 A and typical GPD conditions for this power class

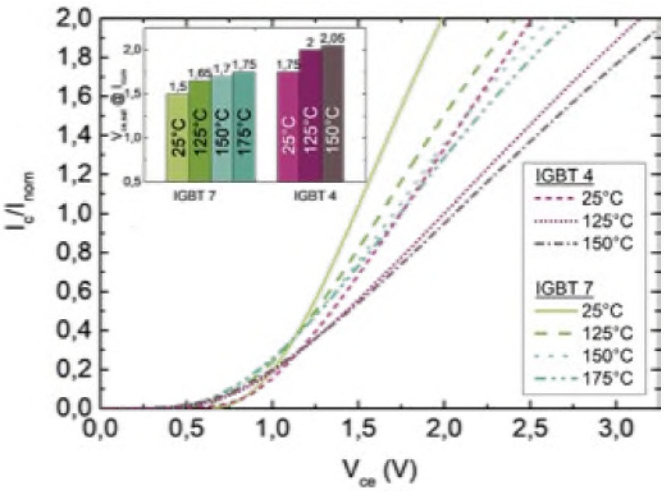

Figure 2: Normalized output characteristics of the 1200 V TRENCHSTOP™ IGBT4 medium power compared with the 1200 V TRENCHSTOP™ IGBT7, measured at Vge=15 V

It becomes visible that the conduction losses of the IGBT and diode predominate over the dynamic losses. At 1 kHz these losses represent 83%, and at 2.5 kHz 65% of all semiconductor losses. This, together with the fact that the switching speed for electrical-motor-related applications cannot be increased above 5 kV/µs, leads to the conclusion that the main lever for device optimization is the static loss reduction.

Static losses

The corresponding normalized output characteristics of the IGBT7 micro-pattern trench MPT technology and the IGBT4 are presented in figure 2 for temperatures 25°C, 125°C and 150°C; and for the TRENCHSTOP™ IGBT7 additionally 175°C.

A reduction of $V_{CE,sat}$ from 2.05 V to 1.70 V by 350 mV at nominal current is observed when comparing both IGBT technologies, which demonstrates the optimization of the device.

Dynamic switching

The turn-on losses (E_{on}) of the 900 A IGBT7 module are lower than those of the 600 A IGBT4 module when a similar collector current is turned on. In fact, the reduction of the saturation voltage and the given device softness result in higher turn-off losses for the 900 A IGBT7 compared with the 600 A IGBT4 at similar collector currents. In figure 3, the values are presented for both chip technologies.

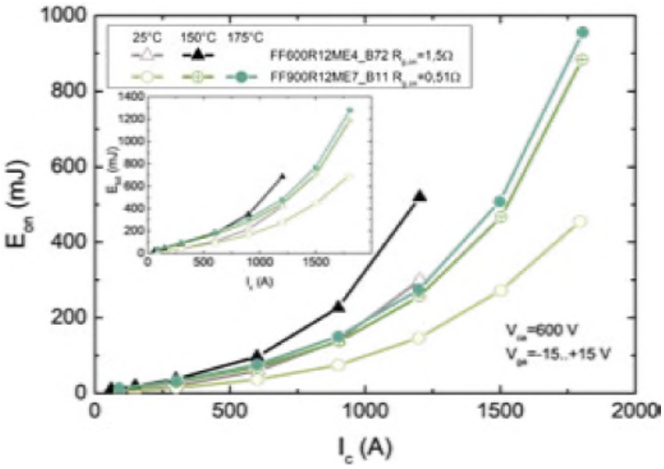

Figure 3: Turn-on losses E_{on} of the FF600R12ME4_B72 and the FF900R12ME7_B11 as a function of the collector current I_c. The insert shows E_{tot}, the sum of E_{on} and E_{off}

The chosen external gate resistances coincide with the data sheet values, which have been defined in such a way that switching without cut-off oscillations of the IGBT and diode at 25°C is ensured. Moreover, quite similar du/dt values are present for the FF600R12ME4_B72 and the FF900R12ME7_B11 at those gate resistances for turn-on as well as for turn-off. As a result, the total IGBT losses (E_{tot}) which are the sum of E_{on} and E_{off} remain nearly the same (insert in figure 3). Especially, below 600 A, both modules show identical losses.

IGBT and FWD junction temperature specification

While the IGBT4 has a specified absolute maximum temperature of $T_{vj,op}$ equal to 150°C, without differentiation between continuous and overload operation, the IGBT7 $T_{vj,op}$ specification is made taking into account the typical overload scenarios specified by the drives manufacturers, and can cover the 3 seconds as well as the 60 seconds overload pulses. For continuous operation, the IGBT7 is specified for 150°C and for overload operation 175°C for a maximum of 60 seconds. Details about the specification is described in [6].

Application tests and results

All the characteristics of the newly developed FF900R12ME7_B11 described above will lead to an improvement in performance compared to the FF600R12ME4_B72 device. To evaluate and compare the performance of these two devices, a series of application tests was performed, and the temperatures evaluated with an infrared camera. The test parameters were set taking into account the information described in Chapter 1 and listed in Table 1:

Topology	H-Bridge
Heatsink	Air cooled heatsink
Switching frequency	1 and 2.5 kHz
Modulation method	Continuous PWM
Gate-Emitter voltage	-8 V to +15 V
DC-Link voltage	621 V
Modulation index	0.95
cos phi	0.9
$du/dt_{10\text{-}90\%}$	< 5 kV/µs
IR-camera picture rate	30 pictures per second
Ambient temperature	20°C* (40°C)

*Table 1: Typical GPD parameters used to compare IGBT7 with IGBT4 in the application. *The required ambient temperature of 40°C cannot be adjusted with the test setup.*

Output current and temperature reduction

The results of the experiment are exemplary for a switching frequency of 1 kHz visualized in figure 4.

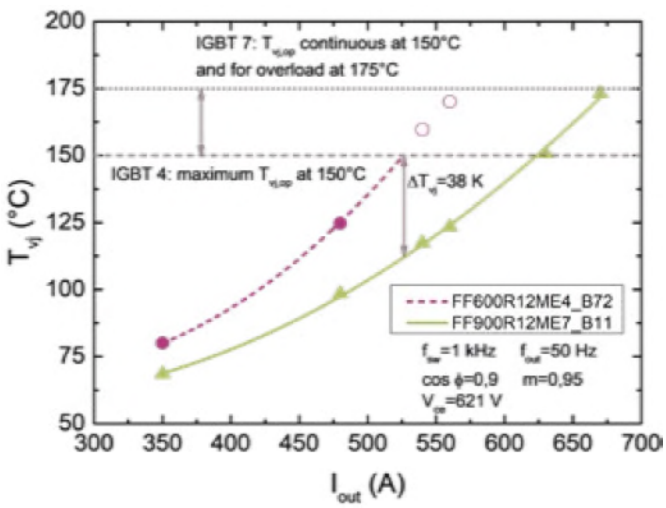

Figure 4: IGBT junction temperature as a function of output current at 1 kHz and conditions described in table 1

It becomes visible that at 1 kHz continuous PWM and the same output current, the module using the IGBT7 technology operates at 38 K lower temperature compared to the IGBT4 device. Pushing the new module to the limit of the specified temperature leads to 150 A higher output current. At 150°C the IGBT7 still has the advantage of 95 A more compared with the IGBT4.

Also at 2.5 kHz continuous PWM modulation, the benefit of the new technology is significant: 33 K lower temperature at the same current and 70 A at 150°C, and 110 A at 175°C more maximum output current are possible.

DC-terminal temperature reduction

Figure 5 illustrates the temperature reduction achieved using the new housing of the FF900R12ME7_B11 compared with the FF600R12ME4_B72.

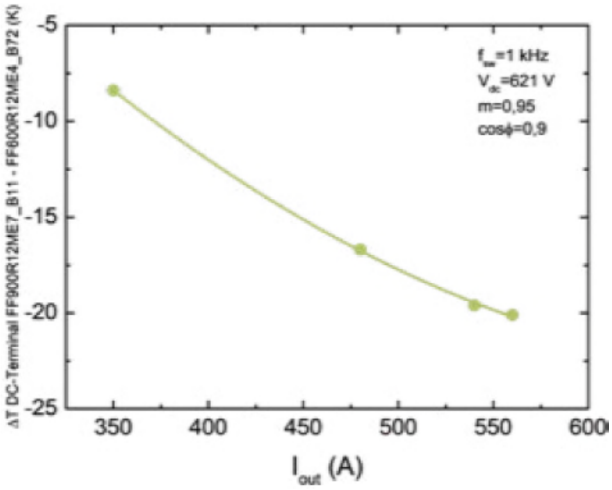

Figure 5: Temperature improvement comparing the DC-busbar temperature of the new and former housing

The new housing of the FF900R12ME7_B11 module leads to a temperature reduction of up to 20 K on the DC busbar compared to the FF600R12ME4_B72 at the same output current

GPD frame size

In this part of the test, the parameters regarding output current for normal duty (ND) and heavy duty (HD) of a GPD manufacturer [1] were selected to evaluate the maximum possible frame size current for the different technologies. The parameters are listed in table 2.

	Frame size 370 A (A)	Frame size 477 A (A)
Rated current I_{ND}	370	477
Normal-duty 60 s 1.1 x I_{ND}	407	525
Normal-duty 3 s 1.5 x I_{ND}	555	716
Rated current (I_{HD})	312	370
Heavy-duty 60 s 1.5 x I_{HD}	468	555
Heavy-duty 3 s 2 x I_{HD}	624	740

Table 2: Selected parameter to test the frame size capability of the two modules.

The rated output current was applied on the semiconductor at the conditions described in table 1, at 2.5 kHz. The temperature of the entire system was in steady state before overload current application. The thermal behavior of the system is shown in the example in figure 6. The IGBT4 solution is at the temperature limit with frame size 370 A. During the 3 seconds heavy- duty overload pulse, the IGBT T_{vj} achieves a value of 142°C.

The IGBT7 device is able to fulfill the requirements of the 477 A frame size. At all required current levels, the FF900R12ME7_B11 is still within the IGBT7 specification presented [6]. Since the ambient temperature in the test was 20°C instead of the required 40°C, the achieved results are valid for the purpose of comparison. Hence, inverter manufacturers can achieve the same output current at 40°C by using an improved heatsink, using discontinuous PWM, and/or reducing the switching frequency.

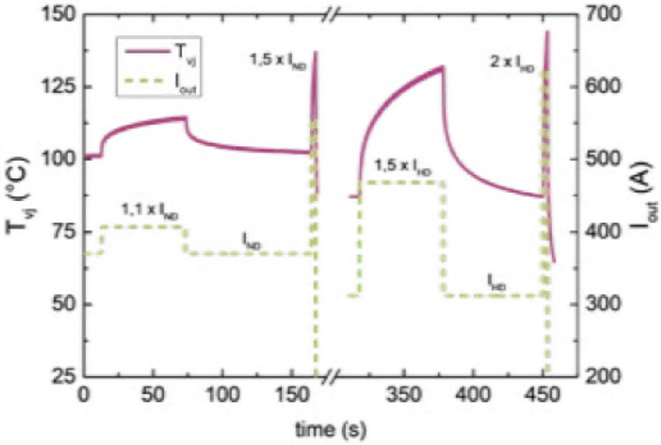

Figure 6: Frame size 477 A, FF900R12ME7_B11 device: Measurement results at rated current ND and HD, normal duty and heavy-duty overload pulses.

Summary

The newly developed chipset of IGBT7 and emitter-controlled 7 diode is user-friendly and optimized to fulfill the general-purpose drives (GPD) requirements. A significant reduction of static losses, good controllability, sufficient softness at all application-relevant current levels, and high short-circuit capability has been achieved. The improvement in the EconoDUAL™ 3 housing and the new temperature specifications for covering the drives overload requirement result in a high degree of freedom for the inverter design engineer.

The conducted application tests have demonstrated impressively an improved performance when compared to the former generation. The new FF900R12ME7_B11 achieves 38 K lower temperature compared to the FF600R12ME4_B72 module at the same current. Alternatively, up to 150 A higher output current can be achieved. Bearing in mind the typical GPD normal-duty and heavy-duty design criteria, a frame size jump from 370 A to 477 A is possible with the EconoDUAL™ 3 housing using IGBT7 instead of IGBT4.

References

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