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New SiC module boosting the efficiency of power applications

Whether in an industrial environment or in and around our homes, electricity has become a synonym with our modern way of life. Living in big cities, we cannot even fathom a world in which electricity would not be available 100 % of the time. This ubiquitous character of electricity and the ever-increasing demand for it is creating a lot of challenges for this precious resource. The first challenge is the generation of electricity, which is not always environmentally friendly. The second challenge is the transport involved, which is, nowadays, addressed as well, especially with high-voltage direct current (HVDC), for improved efficiency.



The use of electricity has the greatest impact on energy efficiency, without a doubt. We know that up to one-third of the electricity used today is for electric motors, mostly in the industrial environment. When these motors are equipped with a variable speed drive (VSD), the energy savings can increase by up to 50 %. In the variable speed drive itself, the key component is the switching semiconductor. Various semiconductors are used in such VSD, from bipolar devices like thyristors and integrated gate commutated thyristors (IGCTs) to insulated-gate bipolar transistors (IGBTs) and metal-oxide-semiconductor field-effect transistors (MOSFETs). As for the packages, both press-pack packages and isolated modules are commonly used.

The LinPak

LinPak is Hitachi ABB Power Grids' semiconductor newest standard in high-power isolated modules. The module was developed over the last ten years, with requirements coming from traction OEMs. It delivers in terms of having a half-bridge topology, the lowest stray inductance in its class and the highest power density. With the separation of the DC plus and minus and AC terminals, and a lower profile for the gate connection, a remarkably simple and compact design for an inverter can be realized. When compared to the already established high-power IGBT isolated modules, like the HiPak (Figure 1), the LinPak is a smaller module, enabling better scalability in power for inverter designs.

Figure 1: Left: Insulated power module HiPak (190x140 mm). Right: Insulated power module LinPak (140x100 mm)



At the same time, it requires, for ideal usage of this device, to have an optimized parallel operation. Having this requirement in the electromagnetic design, the module exhibits excellent performance when it comes to parallel operation. As seen in Figure 2, four modules are switched in parallel with perfect current sharing. For this test, no selection criteria were applied to the modules for an optimized parallel operation.

SiC LinPak

SiC is a wide-bandgap semiconductor with key properties making it extremely attractive for applications in power electronics. Using the increased electrical field strength, higher temperature capability and better thermal conductivity, the SiC MOSFETs have much higher power densities than their Si counterparts. Moreover, since the devices are now more efficient, high-voltage MOSFETs (i.e., 3.3 kV and above) are possible. Nevertheless, the challenge for such devices remains the defect density which is significantly larger than that of Si. This, together with the high-power density, are the reasons for manufacturing SiC MOSFETs dies that are much smaller in size. Figure 3 shows a comparison of a LinPak substrate with Si (left) and SiC dies (middle and right). Since the SiC MOSFETs are much smaller, an increased granularity in the current rating is possible.

The design of the substrate (see Figure 3) is based on a multilevel structure presented previously [1]. It has the advantage of a flexible distribution of gate

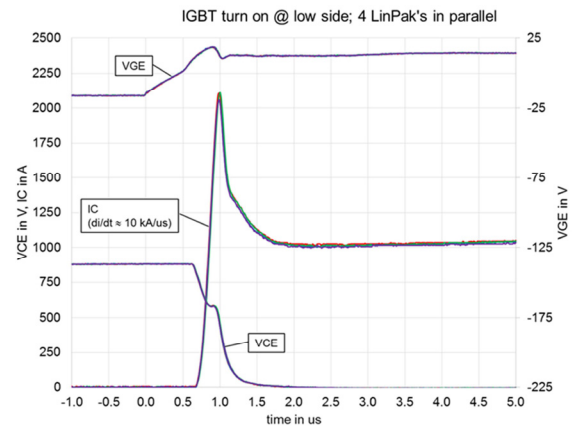
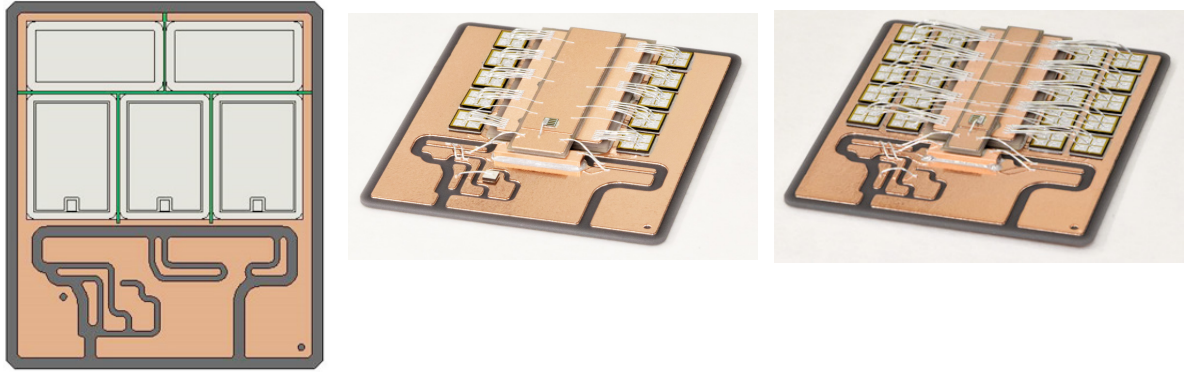


Figure 2. Parallel turn-on of 4 modules 1.7 kV 1000 A

control signals and the main switching current resulting in a well-optimized electromagnetic design. To achieve full compatibility with the housing of Si LinPak, a small unbalance between gate loops of two substrates connected in parallel has been introduced. Gate resistors are placed on each substrate to avoid oscillations caused by this unbalance. The value of the resistors has been optimized to provide both robust switching and low-loss operation. Despite the excellent switching performance of SiC LinPak [2], further optimization of its electromagnetic design is still possible. The improvements achieved by the combination of Ansys and SPICE simulations [3] will be implemented in the next module version.

Figure 3: Substrate with Si (left) and SiC dies (middle and right)



HV SiC MOSFET

As voltage increases, so too does the thickness of the epitaxial layer. With this, the chance of having defects, such as basal plane dislocations, edge dislocation, triangular defects, etc., also increases. As discussed in the previous chapter, significant improvements have been made in SiC MOSFETs over the last few years, especially in reducing the defect density. Therefore, it is possible to fabricate HV (3.3 kV and above) SiC MOSFETs with acceptable yields.

Furthermore, continuous optimization of the characteristics of these MOSFETs is targeted. For a reliable operation in high-power applications like traction converters, the semiconductor needs to withstand not only the nominal conditions but also fault conditions. It is expected that the current to be safely turned off in the reverse bias safe operating area (RBSOA) of these devices is at least double the nominal current. At the same time, the module needs to be able to withstand a short circuit current for 5-10 μs . A further fault requirement coming from the traction application is the diode safe operating area. To meet these stringent boundary conditions for HV SiC devices in demanding applications, Hitachi ABB Power Grids has designed a MOSFET with high-k dielectric gate technology. This technology reduces the density of the interface state and has a higher gate dielectric capacitance [4].

A further concern for the SiC MOSFET devices is the degradation of the channel when the device is used with negative channel voltages. Depending on the current levels it is beneficial to use the channel with a negative bias. Figure 4 shows the stability of the turn-on and the V_{th} after applying up to 10,000 pulses with $V_{GS} = +15\text{ V}$ and -15 V . This is an impressive feature since many competing designs available today only allow negative gate voltages down to -5 V .

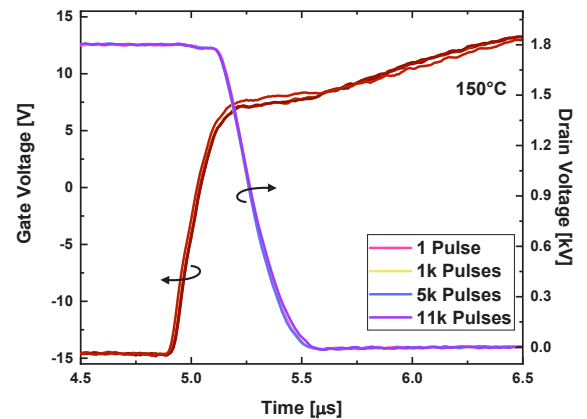


Figure 4: Turn-on waveform after repetitive nominal switching pulses (1.8 kV – 100 A/cm²) with $V_{GS} = \pm 15\text{ V}$ ($R_G = 4\text{ }\Omega$)

Application

The low switching loss SiC LinPak gives the opportunity, for instance, to use much higher switching frequencies in a 2-level traction converter. This, in turn, allows for a much smoother output sine wave curve, reducing the need for filters and protecting the motor. Figure 5 shows a comparison between the Si and SiC version of the LV 3.3 kV LinPak for a given mission profile of a local train. This follows the pattern of acceleration when leaving the station, cruising for several minutes, and then braking and stopping in the next station. The cycle continues then again. Due to the lower losses, the SiC module can be operated at a frequency more than four times higher than its Si counterpart.

Conclusions

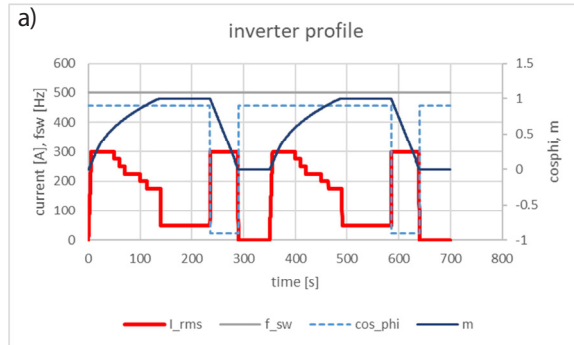
SiC LinPak will definitely do its part participating in improving the energy efficiency that we imperatively need. Hitachi ABB Power Grids is investing in developing cutting-edge SiC chips and packaging design to fully take advantage of the benefits of this new semiconductor technology.

References

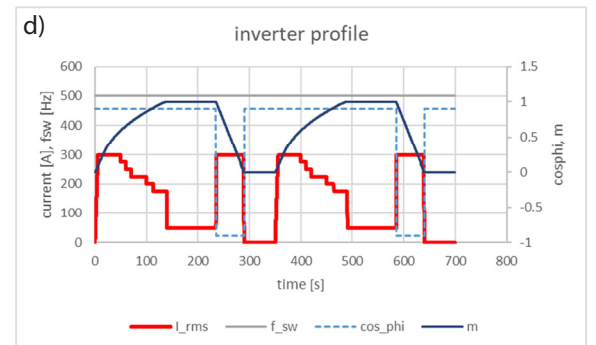
[1] S. Kicin, F. Traub, S. Hartmann, E. Bianda, C. Bernhard, S. Skibin, and F. Canales, A new concept of a high-current power module allowing paralleling of many SiC devices assembled exploiting conventional packaging technologies, Conf. talk at 28th International Symposium on Power Semiconductor Devices and ICs (ISPSD 2016), Prague, Czech Republic, June 12-16, 2016
 [2] Ultra-Fast Switching 3.3kV SiC High-Power Module Slavo Kicin, Ralph Burkart, Jean-Yves Loisy, ABB Power Grids Research, CH; Francisco Canales,

ABB Corporate Research, CH; Muhammad Nawaz, ABB Power Grids Research, S; Gernot Stampf, Pauline Morin, Tobias Keller, ABB Semiconductors, CH, PCIM 2020, 7th-8th July 2020
 [3] <http://www.ansys.com> / <http://bwrcs.eecs.berkeley.edu/Classes/IcBook/SPICE/>
 [4] G. Romano et al., "Rugged Dynamic Behaviour of 3.3kV SiC Power MOSFETs with High-K Gate Dielectric", The 33rd International Symposium on Power Semiconductor Devices and ICs (ISPSD), Nagoya, 2021

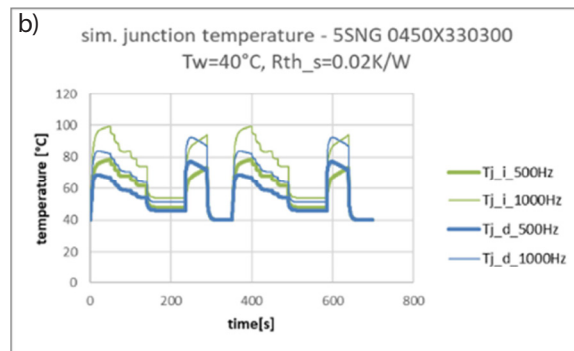
Figure 5: The mission profile for a local train (a-f)



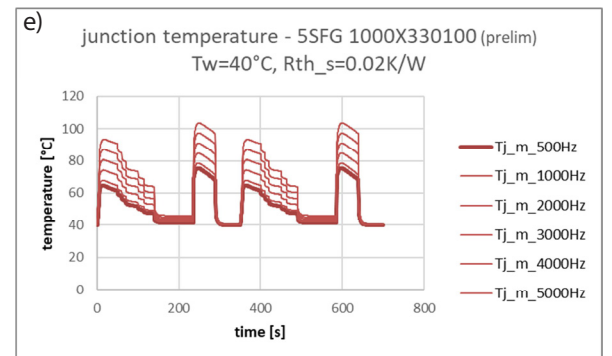
Acceleration at leaving the station, cruising and braking in the next station (a, d)



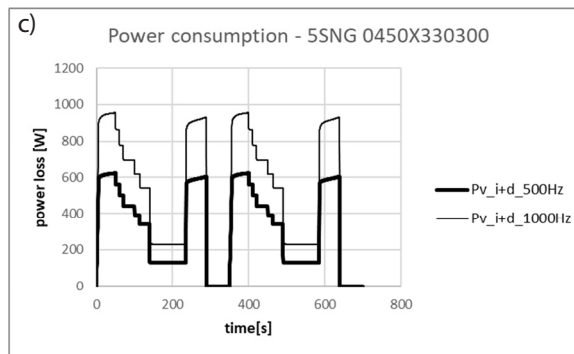
Acceleration at leaving the station, cruising and braking in the next station (a, d)



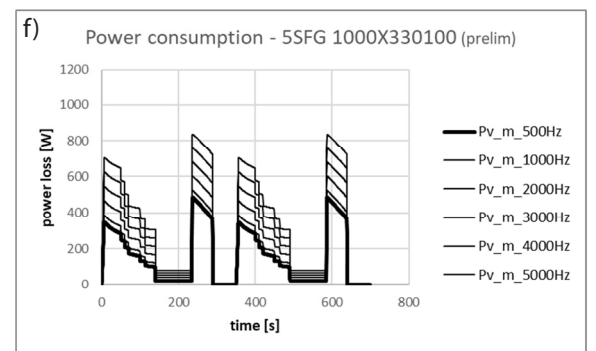
Junction temperature according to this mission profile for Si LinPak (b)



Junction temperature according to this mission profile for SiC LinPak (e)



Power consumption for Si LinPak (c)



Power consumption for SiC LinPak (f)