Superior Solution for Wind Converter Designs

One of the major challenges of the 21th century is to contain global warming in order to limit the consequences of climate change. This target will only be reached by dramatically reducing the emission of greenhouse gases during the first half of the century.
For a perspective, in 2019 alone, energy and heat production were the biggest single contributor to the greenhouse effect with nearly one third of the global emissions worldwide.

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It is therefore essential and urgent to enable a clean energy infrastructure to reduce these contributions. In this strive, wind technology is a key player and already leading the way. In the last 20 years, wind turbines have tripled in size, and their power output has increased tremendously, soon to exceed the 15 MW mark. As a result, both the demand and the need for highly advanced wind power converters continue to grow. Operating under harsh environmental conditions, these converters require a high level of reliability and robustness to ensure a long life cycle. Moreover, high power density is needed to maximize power output while limiting the number of components in the cabinet. Furthermore, large production capacities are essential to support the rising demand. Finally, the upgrading of existing inverter designs helps to reduce both risk and development time.

Infineon's PrimePACK™ with IGBT5.XT technology (FF1800R17IP5) is an excellent solution for meeting these challenges. It has become the standard module of choice in wind converters since its release in 2016. Its combination of advanced interconnection technologies and improved chip design provides outstanding reliability as well as high power density [1].

Nevertheless, in light of the global challenges, further improvements are always welcome. Taking into account the specific operating conditions of modern wind converter systems, Infineon has developed two IGBT power modules specifically optimized for these conditions. The new modules enable a further step towards higher power density, while still providing the benefits of the FF1800R17IP5 PrimePACK IGBT power module.

In this article we describe the essential components of this optimization process and comment on the focal points of the development. Moreover, the resulting benefits for wind converter performance are highlighted. Finally, we discuss briefly how other applications can also benefit from the latest addition to the Infineon PrimePACK portfolio.

Considering wind converter systems and their respective industry, a clear trend towards a modular design of converter stacks and standardization is now discernible. This approach supports the growing need for power ratings, while keeping development cycles short. It also allows the multiple re-use of the same power stack for wind turbine with higher power ratings. However, due to the limited space in a wind turbine nacelle, increasing the number of cabinets might not be possible. Hence, the power density of the individual stack needs to be improved.

The electrical requirements of a machine-side converter (MSC) and a line-side converter (LSC) differ significantly in a wind converter system, another key aspect to be considered. This is particularly true for a fully-rated converter system as depicted in figure 1. Due to the power flow from generator to DC link, the diodes in the MSC are subject to the heaviest load. On the other hand, in the LSC, the power flow towards the AC grid makes the IGBTs the most stressed chips in the power module.

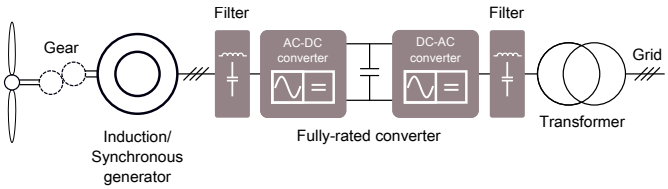


Figure 1: Schematic topology of a fully-rated converter-based wind turbine system.

In light of these differing requirements, two differently tuned power modules were developed to optimize each module to the specific needs of the generator-side and of the grid-side converter, respectively, while building on the reference module FF1800R17IP5. Two major steps in defining and optimizing these two power modules are discussed in the following section.

For wind applications, high switching frequencies are beneficial to reduce generator losses and to maintain a grid-side filter with a reasonable size in the converter cabinets. Generally, switching frequencies are significantly higher than for general-purpose motor drive inverters with similar power ratings.

In this context, it is important to note that in any given IGBT technology, there is always a trade-off between switching and conduction losses (see figure 2). In the optimized IGBT5 chip, this trade-off was modified to support higher switching frequencies by shifting the trade-off towards fewer switching losses. As both LSC and MSC suffer from the high switching losses of the IGBT, this trade-off modification was performed for both modules, targeting the two

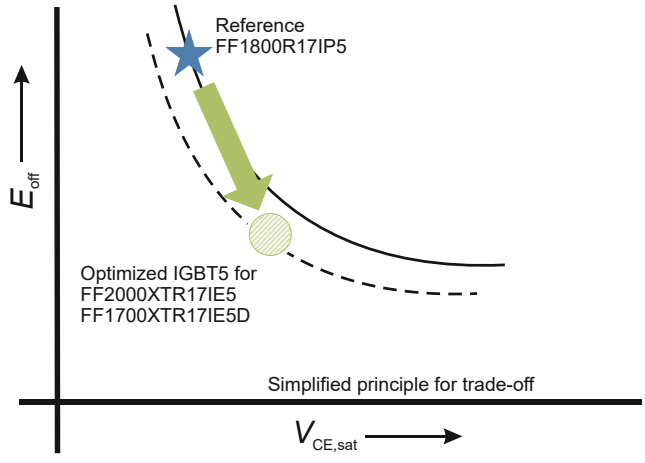


Figure 2: IGBT5 chip trade-off towards reduced dynamic losses for the two LSC- and the MSC-dedicated modules.

different converter positions. The resulting increase of $V_{CE,sat}$ was partially compensated by additional design measures [2,3,4]. The resulting optimization of the IGBT is depicted in figure 2.

As an additional step, a converter-dedicated optimization allowed for a further improvement in the performance of the modules. To this end, chip sizes were modified in order to reduce conduction losses, and furthermore, to improve the thermal conductivity of those chips facing the heaviest load. As shown in figure 3, the chip size ratio was shifted in favor of a bigger IGBT for the LSC-dedicated module, while a bigger diode was included in the MSC-dedicated module. These two design improvements led to the introduction of two modules designated as FF2000XTR17IE5 optimized for the LSC, and FF1700XTR17IE5D optimized for the MSC.

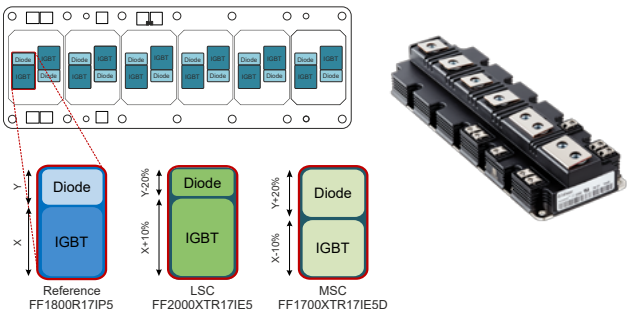


Figure 3: Different chip size ratios for LSC- and the MSC-dedicated modules compared to the reference module.

Figure 4 highlights the benefits of these two dedicated power modules in the context of an exemplary wind converter system. The corresponding operating conditions, upon which this simulation is based, are given in table 1. It is important to note that the significant increase in converter power with respect to the reference module shown in figure 4 has been done by simply swapping the power modules and leaving all other components in the converter and control untouched.

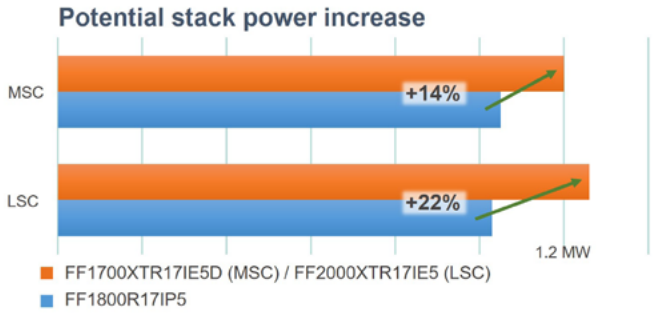


Figure 4: Simulated power improvement of a wind energy system with LSC/MSC-dedicated modules relative to the reference module.

DC link voltage V_{DC}	1200 V	
Switching frequency f_{sw}	5 kHz (DPWM1)*	5 kHz (DPWM0)*
Modulation index *M*	0.9	1
Power factor |cos(φ)|	0.9 (capacitive)	0.8 (inductive)
Rated current *Ir*	900 A	1000 A
Rated active power *Pr*	1 MW	
Thermal resistance heat sink to ambient $R_{th,ha}$	21 K/kW	
Coolant temperature T_{liquid}	40°C	

*Table 1: Reference LSC (left column) and MSC (right column) system parameters. *DPWM nomenclature according to [5]*

In this use case, the maximum virtual junction temperature $T_{vj,max}$ is the limiting design parameter with respect to the achievable converter power. For all PrimePACK modules with IGBT5.XT technology, this maximum is 175°C by design. However, in this simulation, it is limited to 145°C to allow for design margins for overload and fault conditions.

Life-cycle requirements, for which the cyclic loading stress of power semiconductor modules has to be taken into account, are another typical design parameter for wind energy systems. This aspect is particularly important due to the potentially low fundamental generator frequencies in combination with varying wind conditions surrounding a wind turbine. However, for the PrimePACK with IGBT5.XT technology, such as the modules mentioned in this article, this is not an issue, even for applications with strongly alternating loads. Here, .XT interconnection and IGBT5 chip technologies enable an outstanding performance in terms of cyclic load robustness [6].

Concerning the performance benefits of FF2000XTR17IE5 and FF1700XTR17IE5D, we have so far considered only one steady operating point. Indeed, in [4] a complete field of operating points derived out of wind speeds and grid requirements is considered, resulting in sets of different converter currents for LSC and MSC for various generator speeds. These different operating conditions result in different junction temperatures Tvj,max. Figures 5 and 6 show how the two dedicated modules extend the operation range considerably. This improvement is due to a reduction of the maximal temperatures in the LSC IGBT by 25% and of the MSC diode temperature by 13% with respect to the reference module.

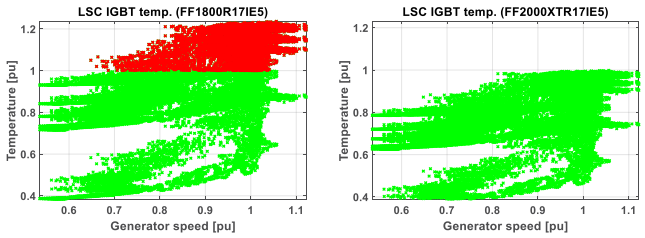


Figure 5: LSC semiconductor temperatures for different operating conditions for reference module (left) and LSC-dedicated module (right). The red area denotes junction temperatures above the design limit [4].

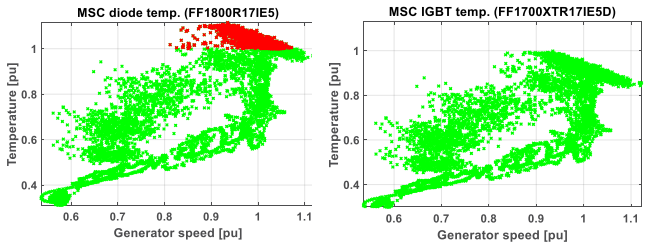


Figure 6: MSC semiconductor temperatures for different operating conditions for reference module (left) and MSC-dedicated module (right). The red area denotes junction temperatures above the design limit [4].

In conclusion, we emphasize that although the newly released power modules highlighted in this contribution are designed to target wind-energy applications, other high-power applications with a regular unidirectional power flow may also benefit if the modules are included in the design. For instance, high switching frequencies are beneficial for reducing motor losses in drive applications. Again, note that both modules have been optimized to support high switching speeds. Moreover, active grid converters for motor applications or electrolyzer applications might also benefit from the large diode in the FF1700R17IE5D.

In summary, Infineon's latest addition to the PrimePACK™ portfolio FF2000XTR17IE5 and FF1700R17IE5D support the upgrade of wind converter designs to higher power levels. Ultimately, these new products will enable our customers to reduce development time and costs while still providing the outstanding robustness of the IGBT5.XT technology.

References

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About the Authors

Marcel Morisse

With a background in electrical engineering and a PhD focusing on wind converter reliability, Marcel joined Infineon as a field application engineer in 2018. In this role, he supports industrial customers in the application areas of wind energy and drives systems in the design-in process, helping them to select right-fit products. Moreover, he provides feedback valued in the development of power semiconductors and fitting gate driver ICs for the next generation of power converters.

Michael Busshardt

Having a background in physics and economy as well as a PhD focusing on quantum measurement theory, Michael worked for 10 years as a system engineer for optical lithography systems. He joined Infineon as a project manager in 2021 and is currently working as a product definition engineer for high power semiconductor modules. In this position, he is responsible for the definition of the next generation of power semiconductor modules for wind converters and supports customers during their design process.