Obtaining Highest Efficiency in DC/DC Converter Applications

While improvements in Silicon power devices have been incremental, the introduction of wide-bandgap devices, such as Silicon Carbide (SiC), allow a jump in performance to be attained. Thanks to reference designs, such as Toshiba's bidirectional DC/DC power supply, design engineers can significantly speed-up evaluation of suitable design approaches and topologies and get up to speed on the intricacies of using SiC MOSFETs. **Dr. Matthias Ortmann, Chief Engineer, Application Support,Toshiba Electronics Europe**

As the world weans itself from its dependency on fossil fuels, there has been a focus on innovative electronic systems to deliver clean, efficient electrical power. Government initiatives to reduce vehicle emissions have seen the automotive industry move to electric drivetrains. This requires a charging infrastructure that is efficient and robust to keep this method of mobility on the move. Electricity generation has also moved to renewable sources of energy, such as solar and wind. Unlike fossil fuel and nuclear alternatives, such power generation is dependent on the weather and time of day. Since these do not always match with grid demand, storage of energy such sources in batteries helps to improve its effectiveness in the energy supply mix.

Over the years, Silicon devices have advanced enormously, demonstrating continuous improvement in their capabilities. Microcontrollers offer clever pulse-width modulated (PWM) timers coupled with synchronous analogue to provide engineers with highly customizable platforms that can be programmed to meet exacting power conversion needs. Simultaneously, Silicon power devices have been optimized in terms of on-resistance and their parasitics to minimize their losses.

A jump in performance

SiC MOSFETs offer significant improvements in switching losses when compared to silicon IGBTs. Thanks to the high drain-source voltage supported, they are increasingly displacing IGBTs in power factor correction and other high-voltage power conversion stages. The SiC-based integrated diode incorporated into these devices is also support high surge currents, making them a robust component in the design.

Perhaps the most desirable characteristic is their high switching speed compared to IGBTs. Not only does this significantly reduce turn-on and turn-off losses, it allows higher switching frequencies to be used. In turn, this leads to a reduction in size of inductors, resulting in compacter designs when targeting the same output power compared to IGBT-based converters. Under the same conditions, the Toshiba TW070J120B SiC MOSFET has a turn-on loss of just 0.6 mJ compared to a similarly specified IGBT, which required 2.5 mJ (Figure 1).

Bidirectional DC/DC converters

Bidirectional DC/DC converters enable power stored in batteries to be used for other purposes once charging is complete. For EVs, there is interest in providing Vehicle-to-Grid (V2G) capability, allowing vehicles to provide power during outages or even to stabilize the grid locally when required. Renewable energy plants also make use of this capability, storing energy generated during optimal weather conditions and delivering back to the grid when it is required. As a result, fossil-fuel power sources, such as diesel generators, are required less often or not at all.

Efficiency is essential in such designs. One approach to construct two separate converters, each dedicated to the needs of the application, but this results in a bulky solution with a high component count. To achieve higher power density, designers turn to the Dual Active Bridge (DAB) topology (Figure 2). This allows the use of soft-switching, a lower device count, attain high efficiencies, while also providing galvanic isolation – often a critical design requirement – at a more attractive total system cost.

The DAB topology consists of two full-bridges connected by an inductor and a high-frequency transformer (Figure 3). The transformer's primary and secondary windings set the conversion ratio between

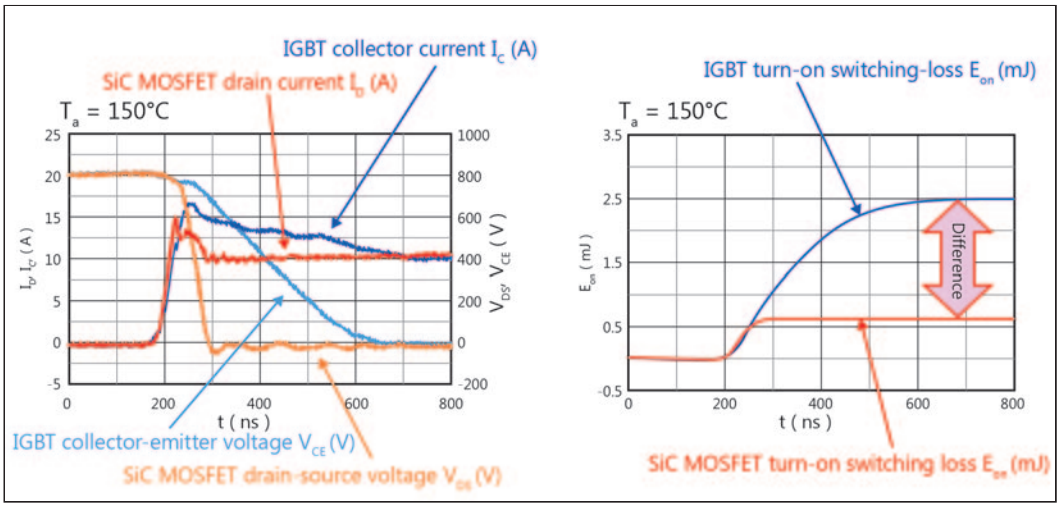

Figure 1: Compared to latest-generation IGBTs, the TW070J120B SiC MOSFET shows considerably faster switching speeds that deliver higher efficiencies in power converters

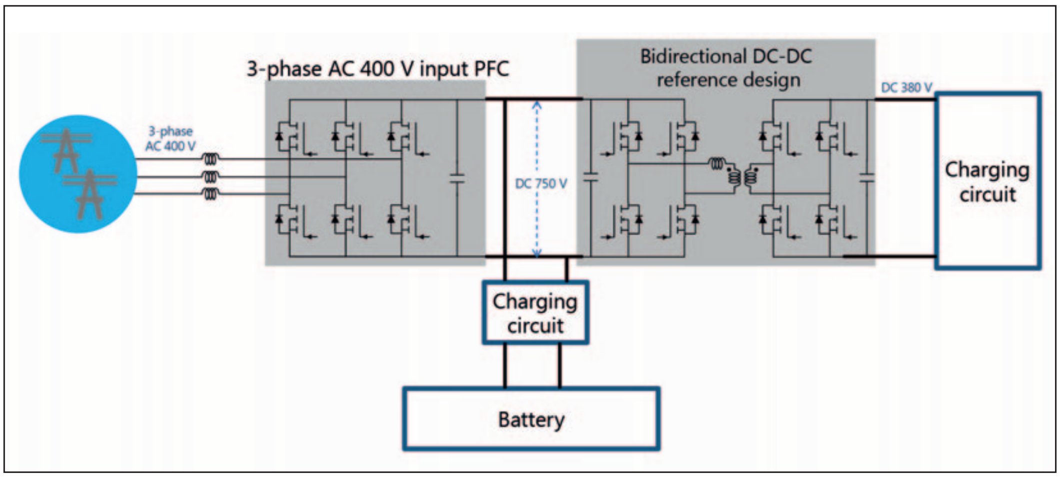

Figure 2: Role of bidirectional DC/DC converters in photovoltaic (left) and electric vehicle charging (right) applications

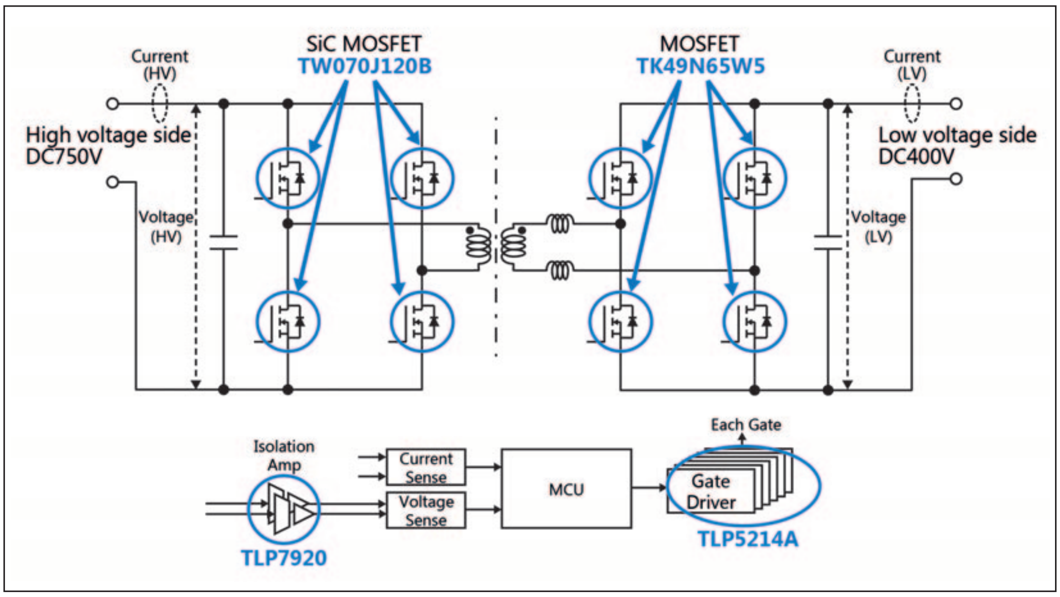

Figure 3: The DAB bidirectional DC-DC converters based upon the TW070J120B SiC MOSFET and TK49N65W5 silicon superjunction MOSFET

the two sides. The series inductor is not a requirement. In some cases the transformer can fulfill both roles, but this is typically at the expense of increase losses and a loss in efficiency. Both sides are controlled using complementary PWM control signals. Modification of the phase of the signal applied to the two sides defines the direction of energy transfer. The side connected to the high-voltage DC link is well suited to the capabilities of SiC MOSFETs. They support the high voltages being applied while supporting the high switching frequencies used. Thanks to the use of zero-voltage switching (ZVS), high-voltage Silicon MOSFETs are matched to the needs of the opposing side.

This is the approach taken in a new bidirectional DC/DC power supply reference design (RD167). Supporting high-side voltages of 750 V DC, and outputting 380 V DC, the supply can deliver 5 kW at a power efficiency of 97 % in either direction (100 % step-up load) using a 50 kHz switching frequency. The design uses the 1200 V TW070J120B SiC MOSFET rather than IGBTs to take advantage of the low switching losses, and the low 70 mΩ RDS(ON). The gate threshold (Vth) lies between 4.2 V and 5.8 V, which contributes to the robustness of the design by making it less prone to gate voltage fluctuations and noise.

On the low-voltage side, the design uses the 650 V TK49N65W5, a Silicon N-channel MOSFET, taking advantage of the performance improvements compared to IGBTs. Its high-speed parasitic diode, coupled with the DTMOS superjunction structure, contribute to the high efficiency thanks to the low switching losses and fast reverse recovery time (trr = 145 ns typical). With a low on-resistance of 0.051 Ω (typical), it can support drain DC currents (ID) of 49.2 A and drain pulse currents (IDP) of 192 A.

To provide optimal gate control to both the SiC and Silicon MOSFET, the TLP5214A gate drive is used. Its 4 A sink and source capability provide adequate drive and discharge currents at elevated voltages and the high switching frequencies used. It also provides a safeguard to the design thanks to its over-current protection and under-voltage lock-out function.

Conclusion

Continuous innovation in the domain of power devices is supporting power converter engineers to attain ever higher efficiencies with their products. It also helps ensure that the move from fossil-fuel to electric energy makes optimal use of our available resources. Whether targeting higher powers, or looking to move to greater power densities, IGBTs are increasingly being exchanged for alternatives. At high voltages (> 1000 V) SiC MOSFETs provide lower losses and, thanks to their support for higher switching frequencies, enable more efficient power conversion. Around 650 V, superjunction Silicon MOSFETs, with low reverse recovery times, low on-resistance, and support for higher switching frequencies, are also displacing IGBTs. Thanks to reference designs, such as Toshiba's bidirectional DC/DC power supply, design engineers can significantly speed-up evaluation of suitable design approaches and topologies and get up to speed on the intricacies of using SiC MOSFETs.