Realizing the future of fast EV charging through CoolSiC™ based topology design

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Table of contents

1 Abstract

While consumers are keen to reduce their carbon footprint, the move to E-Mobility, especially private electric vehicles (EV), is hindered by the limited charging infrastructure, most notably in fast charging. This white paper reviews the charging landscape and examines implementation approaches for fast DC chargers. Specific focus is placed on chargers delivering 350 kW and more for fast electrical “refueling”. It also examines the role SiC power semiconductor devices and other supporting technologies in the Infineon portfolio offer in such applications.

2 Introduction

The EV market is set to grow exponentially, with massive investment in new vehicle models and infrastructure planned. Pushed by the need to reduce carbon emissions, many global government initiatives are in place to encourage vehicle manufacturers to electrify their fleets. As a result, it is expected that more than 50% of vehicles on the road after 2030 will include battery-powered traction. Availability of charging points is a key enabler. Slow charging can be undertaken at home, where vehicles typically sit unused overnight. However, during long journeys, a charge time of less than ten minutes is the goal for stops on the highway. This would make the time taken for a battery charge comparable with conventional gas refueling. According to data from Yole (Figure 1), it is the high-end power delivery segment of charging solutions which will see the most growth with more than 30% CAGR over the next few years. Such chargers will be built from a stack of high-efficiency power sub-units, enabling a range of multi-terminal and high power chargers.

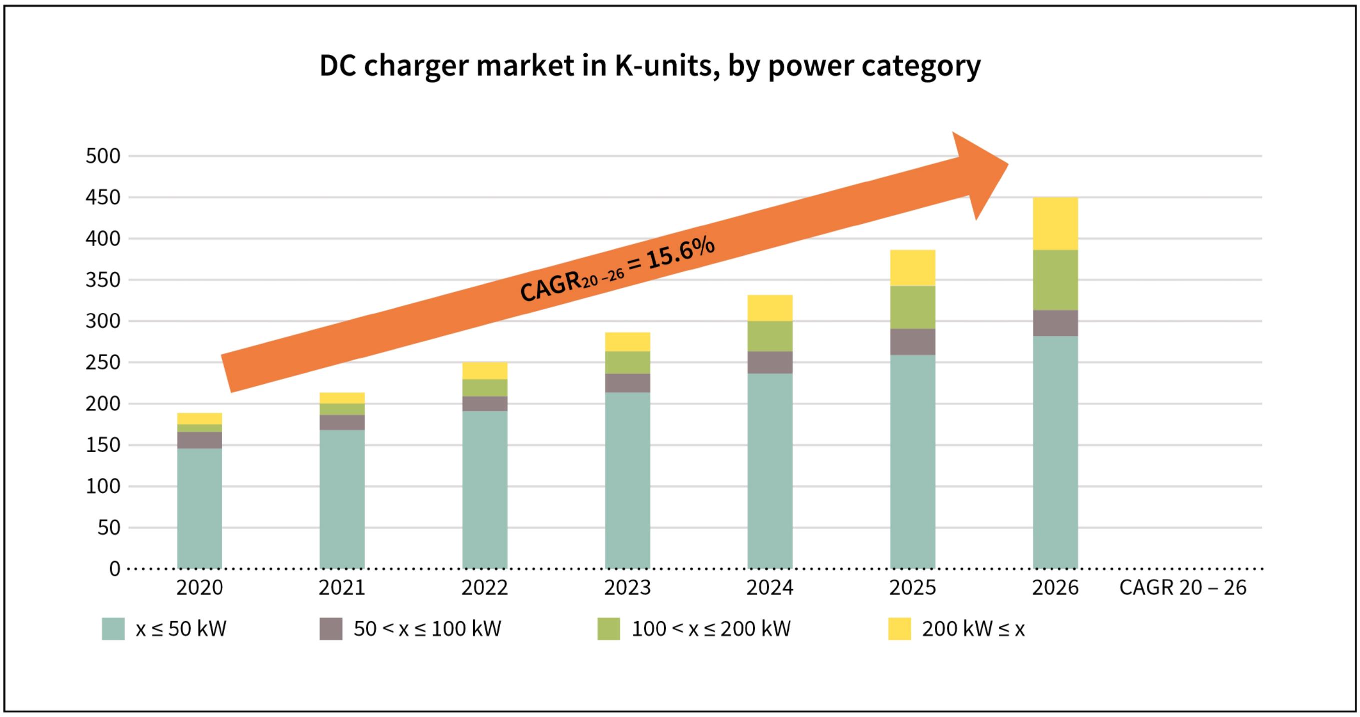

Figure 1 While sub-50 kW DC charging posts will grow at double-digit rates, it is the 100–200 kW solutions, supporting rapid charging for longer journeys, that will grow most quickly. (Source: Yole Développement, Press Release: DC charging for EV: a device outlook for the power electronics industry, Lyon, France, April 2021)

3 Charging options

The most basic EV charging option uses the On-Board Charger (OBC) integrated into the vehicle together with an AC Wallbox that includes charge control and protection. Fed from a consumer's domestic AC outlet, the power draw is limited to a maximum of around 1.5 kW at 120 VAC and around 3 kW for 220-240 VAC single-phase. Additionally, the wallbox offers safety features such as earth connection monitoring and current leakage. Due to its delivery power rating, this approach is only of use for charging overnight.

Faster AC charging is possible where a dedicated single- or three-phase AC outlet is installed, increasing available power to a maximum of 22 kW. However, whether the OBC can support charging at this power level is dependent on the vehicle model or, more specifically, the size of the installed battery. For example, the Nissan Leaf is limited to 6.6 kW, while Tesla's Model 3 is limited to between 11 and 15 kW (country dependent). If the 22 kW charging rate is supported, it typically adds around 200 km of additional range in two hours.

To attain OBC independ fast charging and provide bi-directional support for Vehicle-to-Grid (V2G), a DC charging point is required. In wallbox installations at home or as charging posts which can be primarily found at roadsides, shopping centers, and highway service stations, fast charging is enabled. Usually, these are fed from a three-phase AC source, although single-phase is used in some countries for installations below 22 kW. Since the charger provides the DC voltage required by the electric vehicle's battery directly to the Battery Management System (BMS), the OBC in the EV is bypassed. The chargers also include a secure billing solution and connectivity for linking to backend cloud infrastructure. Increasingly, charger designs will also be bi-directional, supporting smart electrical networks with power demand peak shaving (Figure 2).

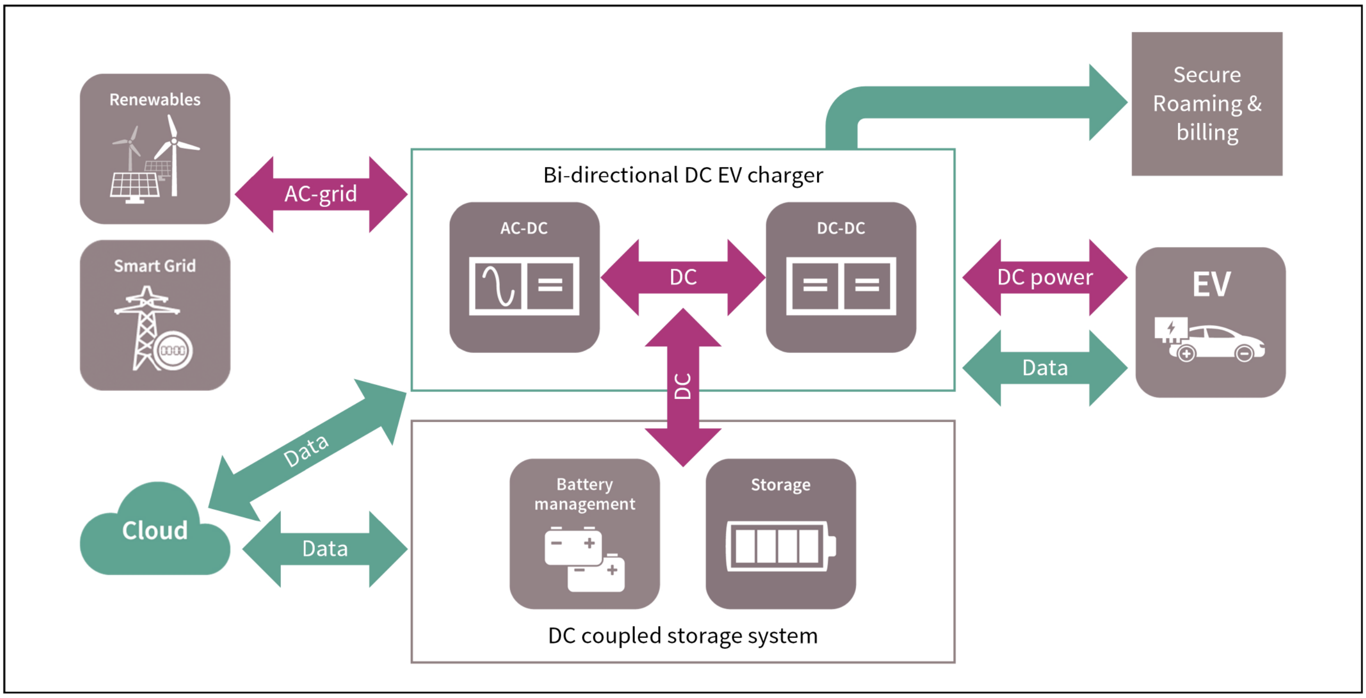

Figure 2 **Basic structure of a bi-directional DC charging system for EVs, complete with billing implementation and support for cloud infrastructure.**

Commercial high-power DC charging posts installed in urban centers typically deliver between 50 and 150 kW and are constructed from stacked sub-units. The “ultra rapid” or “hyper fast” chargers provided at highway service stations, targeting the same experience as traditional refueling, deliver 350 kW or more and are constructed similarly. Depending on the design approach, each sub-unit contributes between 30 and 75 kW. Charging post manufacturers are especially focused on power density, which allows either the volume of an existing design to be reduced or the power to be increased when using the same housing. Current charging post solutions deliver an output of 400 V to 920 V, and there are future plans for 1500 V implementations.

In order to increase life time of battery most EVs charge at power rates far below the peak power of those high power chargers and will only use highest power charging for exceptions like long distance traveling. Therefore, higher power charging posts often feature several power outlets to charge multiple cars at the same time, thereby increasing the number of available charging points.

4 Selecting an optimum charger topology

A DC EV charging system with a power rating between 30 kW and 150 kW typically relies on a two-stage power conversion architecture. This features an AC-DC power conversion stage on the grid side and an isolated high-frequency DC-DC power conversion stage on the battery side. The block outline for such a system is shown in Figure 3. The highest attainable efficiency throughout the entire battery charging solution is key for an EV charger, followed by high power density to provide maximum power output in minimum space.

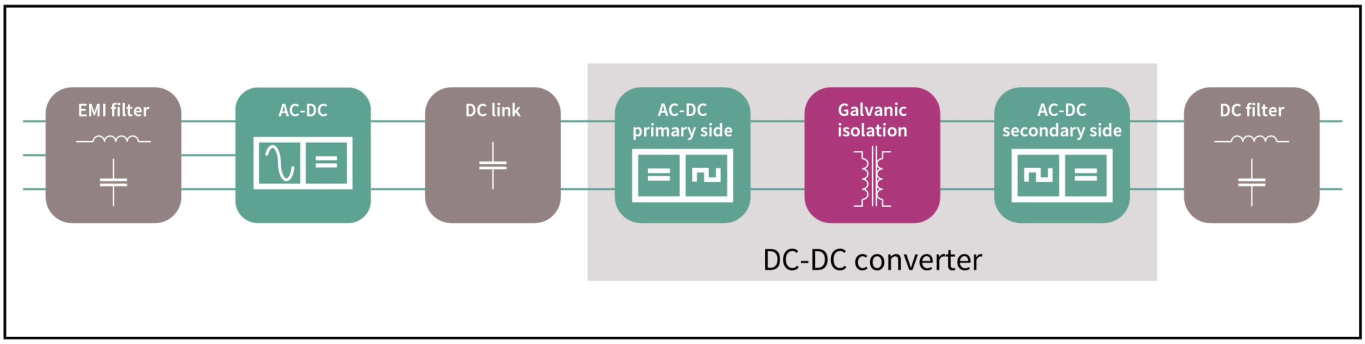

Figure 3 EV fast DC charger block diagram.

Following the EMI filter is the AC-DC Power Factor Correction (PFC) stage, converting AC into DC link voltage using a controlled rectifier. Here, a two-level Active Front End (AFE) (Figure 4) or three-level Vienna Rectifier topology is preferred. Both approaches usually target a stable DC link voltage of between 800 V and 900 V, with a high DC Link voltage decreasing losses in the overall system. The Vienna Rectifier is often selected thanks to its higher efficiency and softer EMI signature. Due to the flexibility in component selection, it also enables the use of smaller switches with 650 V voltage rating. However, the two-level AFE topology is growing in popularity, especially as the availability of highly efficient 1200 V power devices like silicon carbide grows. The simplified topology thereby enables bi-directional operation for future charging systems.

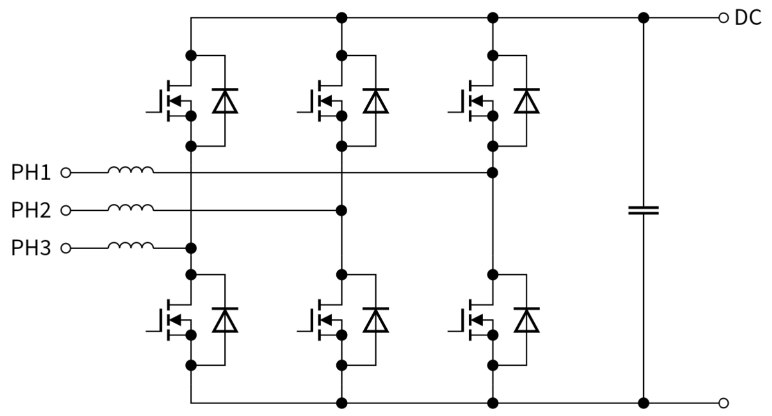

Figure 4 **A three-phase, bi-directional AFE AC rectifier/PFC correction stage.**

The DC-DC conversion stage provides isolation and there is a choice of topologies for both bi-directional operation and soft-switching for high efficiency. Resonant LLC or CLLC converter topology with a single bridge (1200 V SiC) or cascaded bridges (650 V) are widely used for this power conversion stage. The control scheme is also well understood, but the very wide output voltage requirements (typically 200 V to 1000 V) create challenges during implementation due to the frequency modulation control technique used. Alternatively, the Dual Active Bridge (DAB) is popular for implementing this power stage (Figure 5). A fixed frequency PWM converter, it can be designed to be soft-switched over a wide load range.

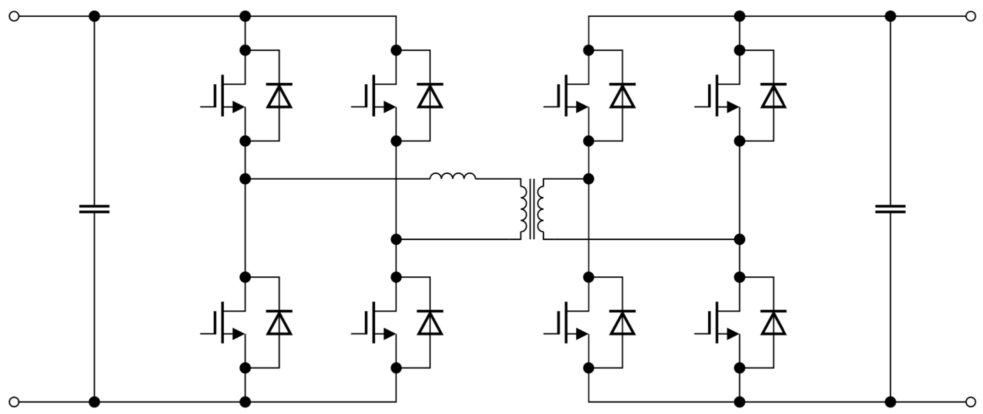

Figure 5 **The bi-directional dual active bridge DC-DC converter**

5 The inherent advantages of SiC MOSFETs in DC chargers

The advantages of SiC technology are rooted in the band-gap of the material. As well as having high electron mobility, SiC has a high critical breakdown voltage when compared with silicon. This allows it to be fabricated with a shorter channel length, resulting in a smaller die, and provides a lower on-resistance for a given voltage rating. The smaller die size also reduces the parasitic capacitances that, in turn, reduce switching losses. Figure 5 below compares the differences in material properties between silicon and SiC, highlighting how they translate to device- and system-level benefits.

SiC MOSFET body diodes have far less reverse recovery energy than IGBTs and Si MOSFETs, allowing them to be used in hard-switched topologies with a low resultant dynamic loss. Compared to its silicon counterparts, the body diode of a SiC MOSFET has a higher forward voltage drop. However, this only contributes to losses when the diode conducts through commutation during any dead time, i.e., before the channel is driven to its on state via the gate. Thankfully, most modern power converter controllers are able to actively minimize dead time to keep losses low.

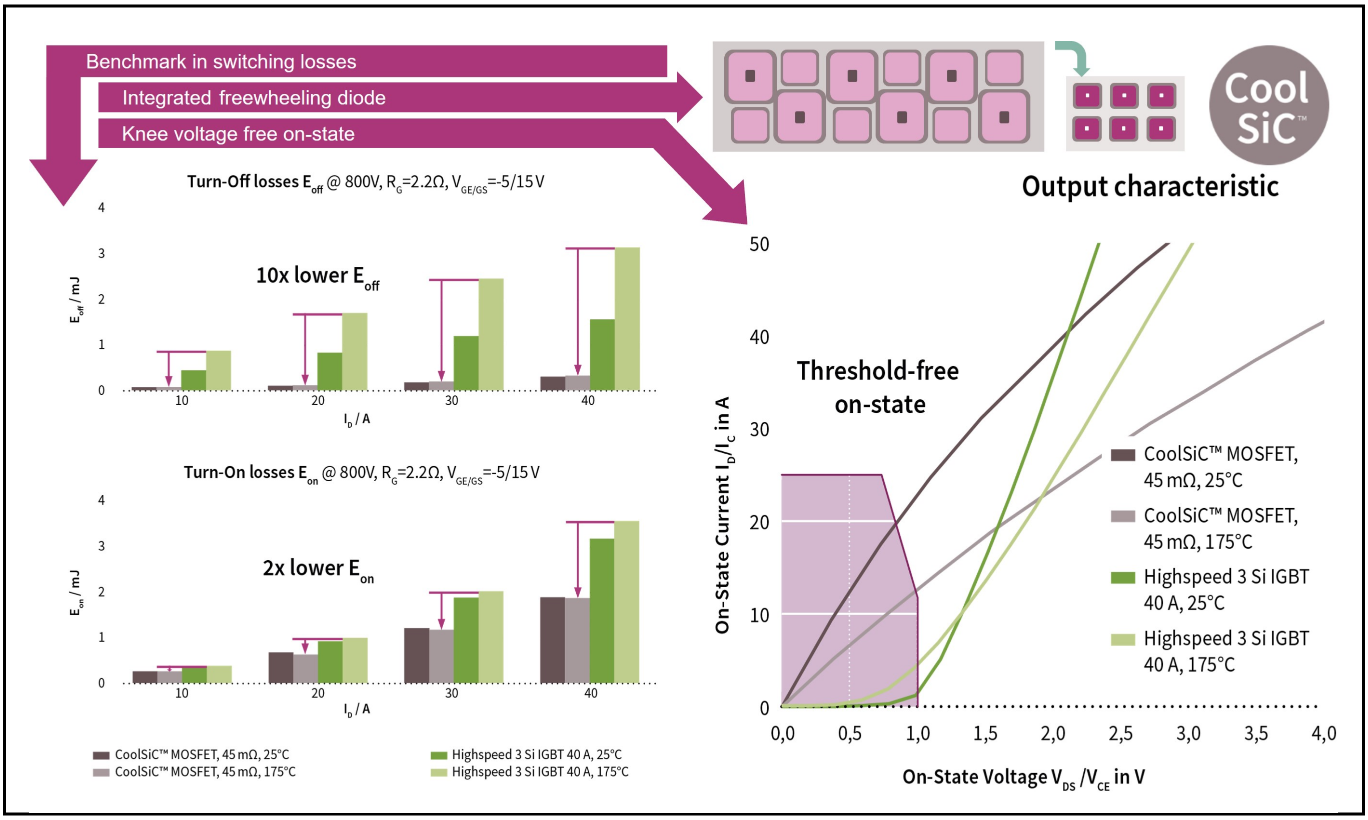

Figure 6 **Si vs. SiC characteristics relevant to efficient converter design.**

The Figure of Merit (FoM) should be reviewed when comparing different SiC devices for power converter designs. These are the most critical performance parameters and should be matched with the development team's planned topology and their understanding of the operating conditions. As summarized in Figure 6, different FoM values for potential SiC components must be reviewed depending on the topology to be used to attain the best performance.

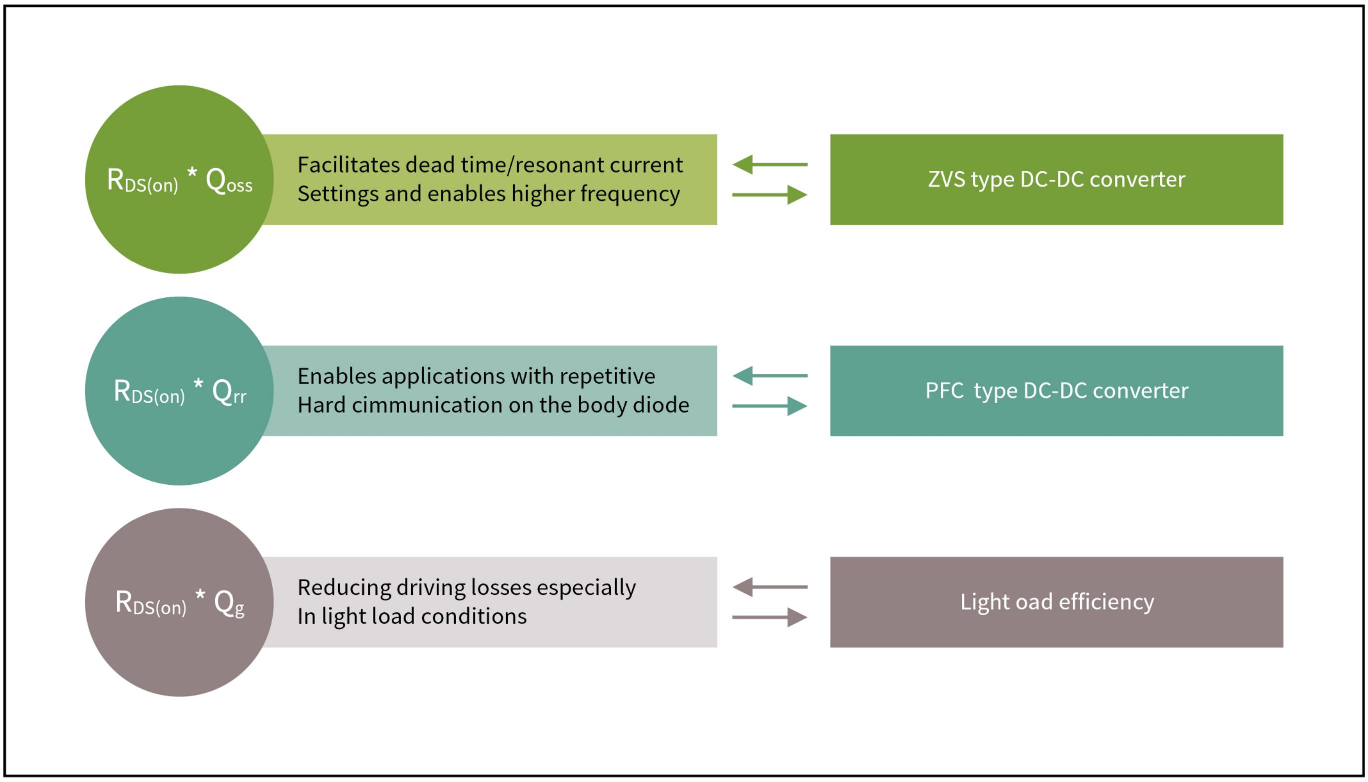

Figure 7 Recommended FoMs for Si and SiC MOSFETs for different topologies

- $R_{DS(ON)}$ * Q_{OSS}: The product of on-resistance and switching energy. A low value indicates a more optimal combination of conduction loss and quick energy discharge in the output capacitance, enabling operation at high frequencies where dead times are short. This is important in converters to maintain Zero Voltage Switching control and thereby maximize efficiency at high frequencies.
- $R_{DS(ON)}$ * Q_{RR}: The product of on-resistance and body diode recovery charge. It indicates the trade-off between conduction and body diode recovery losses that a device achieves that affects overall loss in hard-switched converters, as commonly used in PFC stages.
- $R_{DS(ON)}$* Q_g: The product of on-resistance and gate charge. This FoM is important when assessing light load efficiency which is very the norm and critical for charger electrical load in different modes.

6 Speeding up the design of EV DC chargers

With so many different design options, topologies, and power devices available, development teams are increasingly looking for support in selecting the optimal approach along with blueprint solutions to reduce their time to market. Such designs form a starting point that allows each element of the charger, from control to power stages, to be analyzed and optimized to the needs of a manufacturer's target markets. Filling this demand is Infineon's 50 kW modular reference design platform for a bi-directional DC EV charger, featuring CoolSiC™ devices. The unit's mechanical concept is based upon the 19" rack, a popular format for the sub-units from which existing high-density charger designs are constructed. This modular approach allows for faulty power racks to be easily exchanged while allowing the remaining units to operate, albeit at a lower total power output.

This building block concept splits the charger sub-unit into two core sections: a generic control board that is easily combined with other power stage boards; and uniform power boards that can be reused or modified for use in other designs. The passive components of the design consist of separate boards featuring an AC EMI filter, PFC inductors, DC link capacitors, 3-phase transformer, and DC EMI filter, all rated for 50 kW operation (Figure 7). The identical power conversions boards used in this design implement a two-level Active Front End for AC-DC conversion and a fully isolated, three-phase DAB converter, both of which are bi-directional. An auxiliary power supply board is also included.

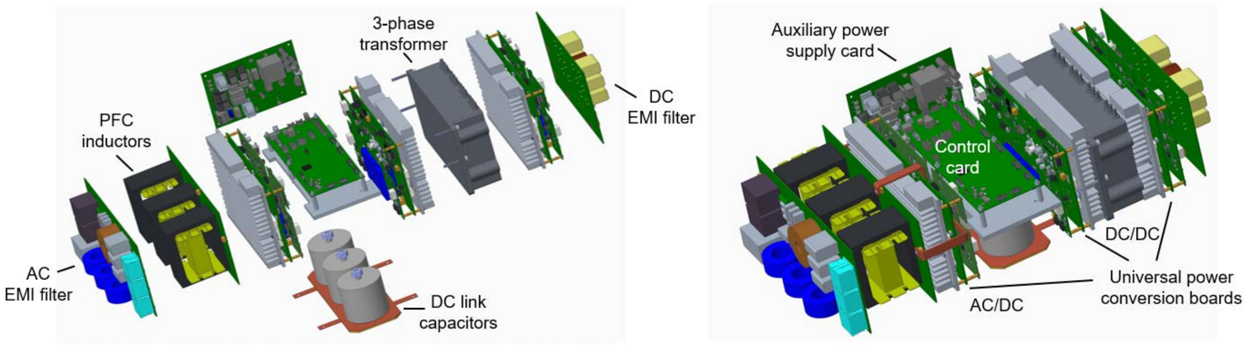

Figure 8 **This high-density DC charger reference design's passive components (left) and power stages (right) are rated for use at 50 kW.**

The layout of the power boards can accommodate three Easy1B or Easy2B CoolSiC™ MOSFET power modules attached to a heatsink. Modular construction simplifies the replacement of the heatsinks with cold plates attached to a coolant system, should this be desired. These boards also include XENSIV™ current sensors and several voltage and temperature sensors for control and diagnosis. Developers can thus acquire data on system operation as they modify and develop the reference design. The control board integrates the popular, automotive-qualified AURIX™ microcontroller. A Graphical User Interface (GUI) is also provided, delivering access to a wide range of measurements and metrics within the design.

7 Adding EVs to the sustainable energy mix

Reduction of our carbon footprint through the use of EVs can only happen if the electrical energy used comes from sustainable energy sources. Of course, the challenge with wind and solar energy generation is that they are dependent on the weather and, for solar, the time of day. Since these methods of energy generation do not perfectly intersect with usage patterns, the energy generation industry is transforming. Electrical grids worldwide are increasingly using battery-based Energy Storage Systems (ESS), charged from green energy sources. Operating as part of the “smart grid”, their energy is released back into the electrical grid to implement peak shaving and avoid brownouts and blackouts.

Peak electrical energy creation occurs during the day, a time when many of us are working. Commuter EVs will be attached to chargers during these hours, providing a ready source for energy storage like a massively distributed ESS that can function as part of the smart grid, helping with peak shaving (Figure 8). Assuming an average battery capacity of 40 kWh per vehicle, and with 100 million EVs projected to be on the roads in 2030, around 5.4 TWh of battery capacity should be available. As the energy sector’s business models and government regulations change, it is expected that EV owners will be provided with the opportunity to sell energy from their parked EVs to balance peaks in demand.

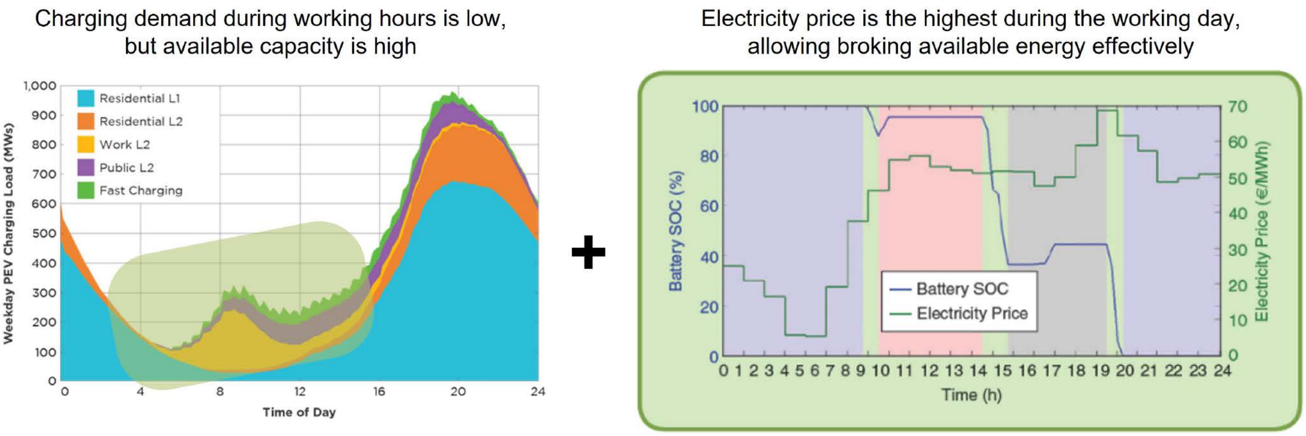

Figure 9 **It is expected that many EVs will be connected and available for V2G during the day (left) when the demand and price for electricity is at its highest.**

To enable bi-directional charging, the topologies of the inverter need to be adapted slightly. A key factor here is the body diode inherent in SiC MOSFETs as it can be used as the anti-parallel diode found in silicon-based MOSFET designs. Because of this, SiC MOSFET technology is an essential part of realizing cost-effective and high-efficiency bi-directional chargers.

8 Fast charger challenges beyond improving power density

While much of EV charger development focuses on power density and the challenges of high power delivery, charger operators are also looking for solutions that allow them to keep their operating expenses in check. Part of their challenge is implementing identification, authentication, and data encryption between vehicles, charging post, and back-end infrastructure. The ISO 15118 standard “Road Vehicles – Vehicle to grid communication interface” introduces the concept of “plug and charge”, replacing operator-specific charging cards with conventional payment solutions for both AC and DC chargers. Both EV charging and grid energy injection (V2G) are covered. Another concern is that of secure communication for distributing software updates and accessing charging post diagnostic information.

Tamper-resistant security devices, such as Infineon’s OPTIGA™ family, simplify the implementation of these requirements. Trusted Platform Modules, such as the OPTIGA™ TPM, are used in the gateway or edge computing devices within charging post (Figure 9). These are responsible for establishing data connections to back-end infrastructure, such as cloud services, supporting secure payments, delivering electricity consumption data, and handling secure software updates. Authentication, proving that a vehicle is who it says it is, can be implemented using OPTIGA™ Trust devices. Available as both a turn-key solution or a feature-rich programmable device, these products are easily integrated into Public Key Infrastructure (PKI).

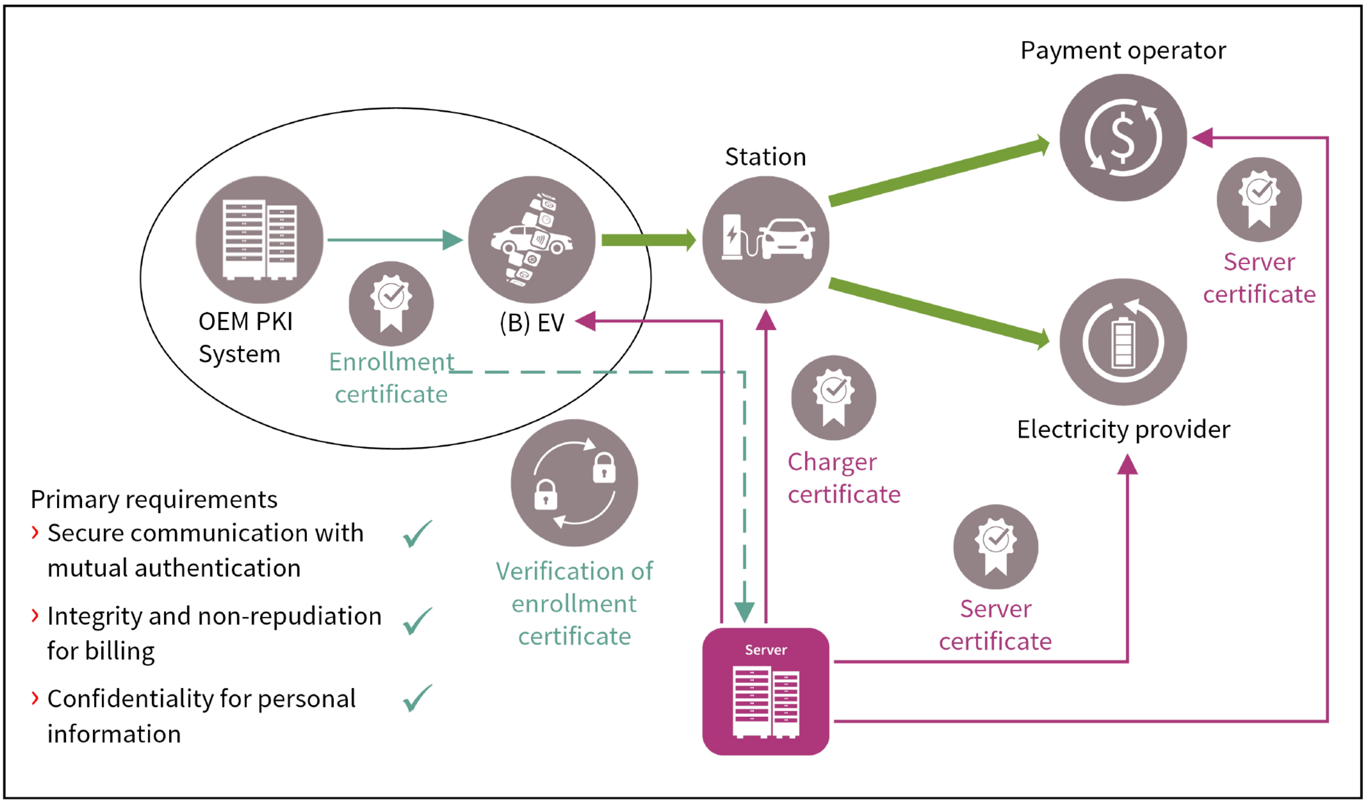

Figure 10 **Securing the EV charging ecosystem through authentication and encryption using OPTIGA™ security controllers.**

9 Conclusion

Charging infrastructure is an area of high interest, thanks to the predicted exponential growth of EVs on our roads over the coming decade. However, achieving a refueling experience comparable with visiting a gas station requires deploying a substantial number of fast DC chargers. This can be only achieved with a broad mixture of different power systems, from private installations and commercial chargers at work or in the city, to high power systems close to highways. With current designs targeting 350 kW, and future versions operating at up to 900 kW, developers depend on advanced switching power devices, such as CoolSiC™ MOSFETs, coupled with efficient power converter topologies, such as AFE and DAB. Furthermore, EVs are expected to become part of the smart electrical grid, demanding that fast DC chargers operate bi-directionally to support V2G.

In order to respond swiftly to these market requirements, development teams need access to competent reference designs that allow them to focus on devising differentiating features, not reinventing the wheel. With Infineon’s 50 kW modular reference design platform for a bi-directional DC EV charger, developers have a highly capable CoolSiC™-based DAB topology power converter. However, power conversion alone resolves only part of the challenge. In addition, developers require system-level support to implement the remainder of the charging post solution. This is also covered thanks to a CAN-connected MCU controller board for simple system integration, together with a family of tamper-proof security devices to implement secure connectivity, authentication, and payment. With its CoolSiC™ power solutions, security devices, decades of experience in automotive microcontrollers, and DC charging system competence, Infineon is your partner in creating a greener E-Mobility future for all.

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