SiC Devices Used in PFC for EV Charger Applications

This article analyzes the technological trends of the DC electric vehicle (EV) charger. It introduces the current status of silicon carbide (SiC) devices and their advantages, as well as the SiC technology development at Infineon. A three-phase, Vienna rectifier solution for unidirectional chargers, a two-level, three phase, active front-end topology, and a full-SiC device solution for bi-directional chargers are introduced.

By By Ming Zhou and Andrea Piccioni, Infineon Technologies

DC EV charger development

With continuing pressure on governments to reduce carbon emissions, electric vehicles are receiving more and more attention. However, when deciding which vehicle to select, consumers have to consider such factors as lack of infrastructure and long recharging times.

AC charging piles are suitable for recharging EVs at home or at the working place, as the power rating of current on-board chargers usually ranges up to 11 kW, which takes 8~10 hours to recharge to full battery status. However, for longer trips, such as vacations, consumers expect faster recharging during breaks.

Direct current (DC) EV chargers, with the conversion from AC to DC, and isolated DC to DC, have a higher power rating than AC charging piles. The power rating of DC EV charger sub-units using discrete devices is currently 11 kW-22 kW, but will increase in the near future to the 30 to 50 kW range.

Several DC EV charger sub-units in parallel could boost the power rating of DC charging piles from 120 kW up to 360 kW. With this kind of DC charging pile, consumers can recharge batteries to 80 percent of the battery capacity in less than half an hour. Owing to the benefits of quick recharging and the rapid development of EVs, the DC EV charger market has experienced an extraordinary growth in recent years. In the meantime, this market is meeting technical challenges in terms of reliability, efficiency, and power density. The next generation of power semiconductor SiC devices will be beneficial in meeting these challenges and development targets. In this paper, we introduce the SiC devices used in PFC for DC EV charger applications.

SiC at Infineon

Wide-bandgap materials and devices have been developed rapidly in recent years. With low switching losses, SiC devices, enable customers to increase the switching frequency. Thus, SiC products are widely used in DC EV chargers, solar inverters, uninterrupted power supply (UPS) and switched mode power supply (SMPS) applications.

Infineon has over 20 years of field experience with silicon carbide, using a trench structure, shown in figure 1, which facilitates performance without violating the gate oxide in on-state and off-state conditions. To demonstrate the gate-oxide reliability of trench structures, Infineon has done reliability evaluations for gate-oxide, resulting in the findings illustrated in figure 2. Besides the above-mentioned advantages, Infineon CoolSiC™ MOSFETs also have a higher threshold voltage, short-circuit capability, and wide controllable dV/dt. Infineon has expertise in the area of drift of gate threshold voltage ($V_{GS(th)}$) for SiC MOSFETs under long-term operation. It provides design guidelines to limit the related increase of on-state resistance ($R_{DS(on)}$) as the major impact for the user in the application. These advantages make Infineon CoolSiC MOSFETs easy to use [1][2][3][4][5][6].

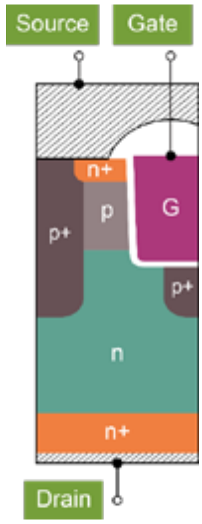

Figure 1: Sketch of the Infineon CoolSiC MOSFET cell structure

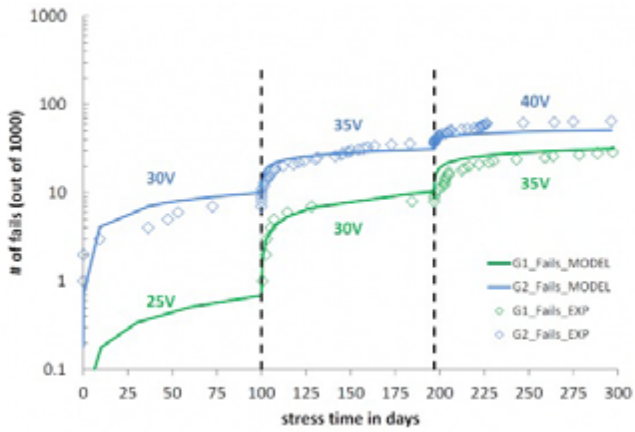

Figure 2: V_{GS} overstress test

PFC for DC EV charger applications

Unidirectional DC EV chargers usually use a Vienna PFC topology and DC-DC part with LLC resonant converter and a full-bridge rectifier topology, which is shown in figure 3. There is another common DC-DC topology, the phase-shift full bridge (PSFB), which has a different topology and control method. The PFC part in the DC EV charger can use Infineon products, such as 1200 V Si or SiC diodes for D1~D6, CoolMOS™ MOSFET and TRENCHSTOP™ IGBT5 for SW1~SW6. The LLC DC-DC primary side can use the CFD series CoolMOS MOSFET, and the secondary side can use 650 V Rapid Si diodes or 650 V Infineon CoolSiC diodes. Due to the wide output DC voltage range, usually from 200~1000 VDC, relays are used to connect full-bridge rectifiers either in series or parallel.

Bodo´s Power Systems® · bodospower.com

In this paper, we focus on PFC for DC EV charger applications. The Vienna PFC topology is widely used in unidirectional DC EV charger applications, as shown in figure 4. Because the reverse-recovery current of SiC diodes is lower than that of Si diodes, this kind of current will flow through SW1~SW6, when they are turned on. Therefore, if there is less reverse-recovery current, the turn-on switching loss for SW1~SW6 can be reduced. For this reason, 1200 V SiC diodes are widely used in unidirectional DC EV charger applications to achieve lower power losses and higher efficiency. Lower power loss means a lower junction temperature for the power device, which can improve reliability or increase power density.

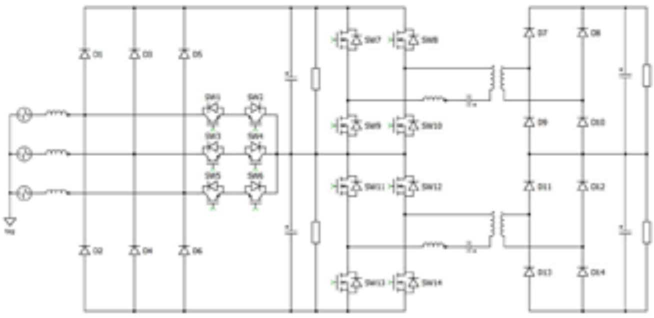

Figure 3: DC EV charger topology

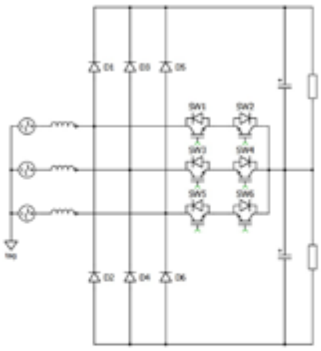

Figure 4: Vienna PFC topology

A three-phase, full-bridge topology (B6) is also widely used in DC EV charger applications, as shown in figure 5. As we know, this kind of B6 topology can also work as an inverter, therefore can be used for bi-directional applications. If the PFC diodes and rectifier diodes (D1~D14) in figure 3 change to switch devices, the topology changes to neutral point clamped 2 (NPC2, as shown in figure 6) and bi-directional DC-DC (CLLC, or dual active bridge) topology, which is a bi-directional charger topology, as shown in figure 7.

A bi-directional function in the DC EV charger usually means discharging the battery in EVs to the grid, electric equipment or other EVs, when the battery state of the charge is high, or under certain conditions, such as during a power cut or outdoor camping. Discharging to the grid is also known as vehicle-to-grid (V2G) technology, which includes benefits such as reducing the total cost of EV ownership and optimizing grid stability. This kind of technology will certainly be used in future chargers, and the bi-directional charger should become a trend among DC EV chargers.

As shown in figure 8, using 1200 V CoolSiC MOSFETs to replace 600 V/650 V CoolMOS in DC-DC, and using B6 to replace NPC2 as shown in figure 9, can reduce the number of power devices in the system and make it easier to control. These advantages also help bi-directional DC EV charger systems to achieve higher efficiency, higher power density and lower unit weight.

Introduction to 15 kW PFC with different devices and topologies

As seen in the introduction, there are several different solutions for unidirectional and bidirectional DC EV charger applications. The study has focused on PFC parts in order to compare efficiency and cost, and to make recommendations for both unidirectional and

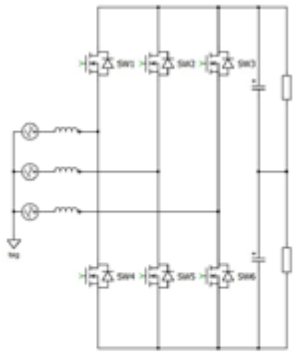

Figure 5: Three-phase, full-bridge topology (B6)

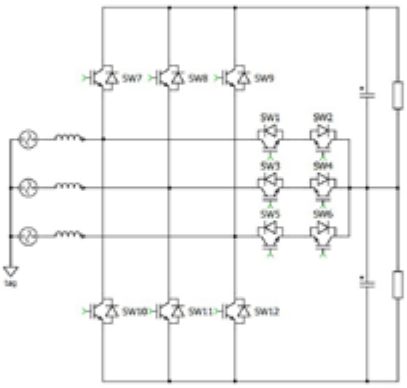

Figure 6: NPC2 topology

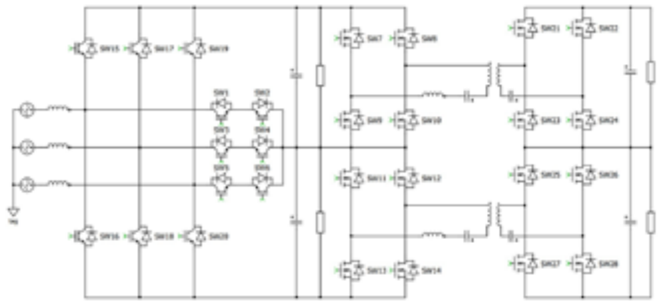

Figure 7: Bi-directional DC EV charger topology A

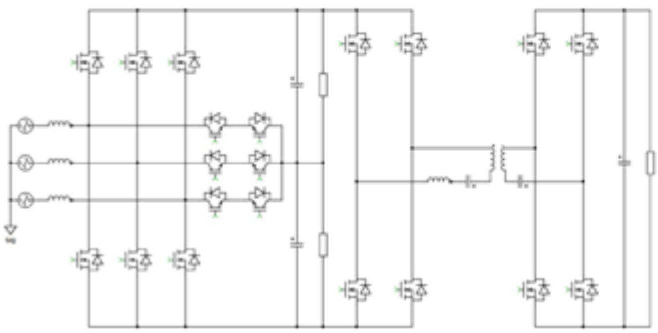

Figure 8: Bi-directional DC EV charger topology B

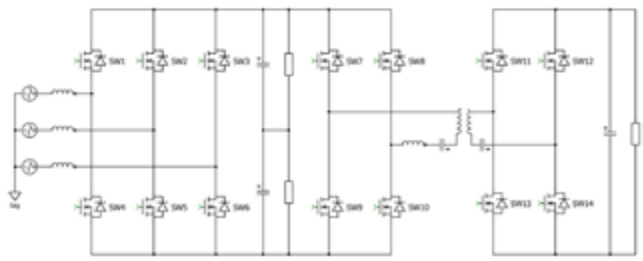

Figure 9: Bi-directional DC EV charger topology C

bidirectional applications. Three 15 kW, three-phase PFC solutions for both unidirectional and bidirectional PFC are shown in Tables 1 and 2. The solution using both Si devices and SiC devices is called a hybrid solution.

After simulation under the conditions shown in table 1 and table 2, the resulting curves for power loss versus switching frequency are displayed in figure 10 and figure 11. From the curve for unidirectional PFC solutions in figure 10, the Vienna PFC hybrid solution with 1200 V CoolSiC diode has almost the same power loss as the CoolSiC MOSFET B6 solution, and better cost performance than the B6 solution. From the curve for bi-directional PFC solutions in figure 11, the Si NPC2 solution has the highest power loss, the hybrid NPC2 has a lower power loss than the Si NPC2 solution, and the B6 with a CoolSiC MOSFET solution has the lowest power loss and the highest switching frequency. Owing to this high switching frequency, we can also use low inductance, small heat sinks and small PCB dimensions, which help to reduce the system cost.

Unidirectional PFC solution		
	D1~D6	SW1~SW6
Si Vienna PFC	Si Vienna PFC	650 V IGBT
Hybrid Vienna PFC	1200 V SiC Diode	650 V IGBT
SiC MOS B6	NA	1200 V SiC MOSFET

Table 1: Unidirectional PFC solution

Bi-directional PFC/Inverter solution		
	SW1~SW6	SW7~SW12
Si NPC2	650 V IGBT	1200 V IGBT
Hybrid NP C2	650 V Hybrid IGBT	1200 V IGBT
SiC MOS B6	1200 V SiC MOSFET	NA

Table 2: Bi-directional PFC/Inverter solution

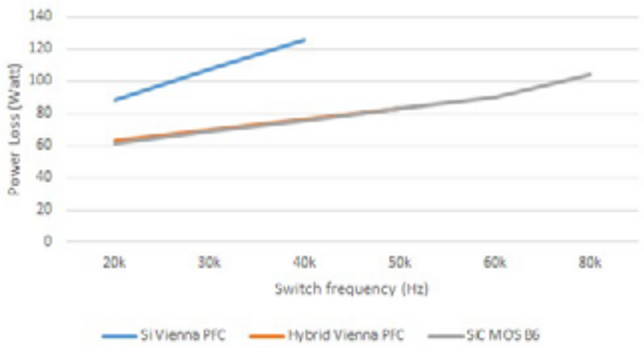

Figure 10: Unidirectional PFC power loss curve

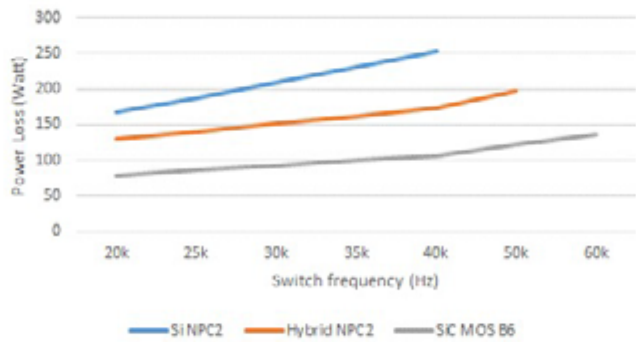

Figure 11: Bi-directional PFC/INV power loss curve

Conclusion

In this article, we introduce the unidirectional and bi-directional DC EV charger topology, in particular for PFC parts and SiC devices, including 1200 V SiC diodes and MOSFETs used in a hybrid Vienna PFC and B6 topology. From the power loss and switching frequency curves, we can recommend using 1200 V SiC diodes in the hybrid Vienna PFC for unidirectional DC EV charger PFC parts, which result in the best efficiency and cost performance. Using bi-directional DC EV charger PFC parts with 1200 V SiC MOSFET in a B6 topology results in the best efficiency and performance, with cost benefits for the whole system.

References

1. Dethard Peters, Thomas Basler, Bernd Zippelius, CoolSiC™ Trench MOSFET Combining SiC Performance With Silicon Ruggedness 2017 PCIM Europe
2. Marc Buschkühle, 1200 V CoolSiC™ MOSFET High Performance Complemented by High Reliability, Bodo's Power Systems, 64717,(05)2017
3. Fanny Björk, A SiC MOSFET for Mainstream Adoption Bodo's Power Systems, 64717,(04)2018
4. [4] Peter Friedrichs, High-performance CoolSiC™ MOSFET technology with silicon-like reliability, www.infineon.com
5. [5] CoolSiC™ - Revolution to rely on, SiC solutions enabling radical new product designs with best system cost-performance ratio, www.infineon.com
6. [6] Guidelines for CoolSiC™ MOSFET gate drive voltage window. AN2018-09, www.infineon.com

www.infineon.com