Tackling the Challenges of Electric Vehicle Fast Charging

The availability of a fast DC charging infrastructure is essential for the success of battery-powered electric vehicles. Infineon describes how to provide reasonable opportunities for fast charging with acceptable charging time.

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INTRODUCTION

Forecasts by market researchers indicate that within this decade the point will be reached where the majority of all new cars sold will have a partially or fully electric drivetrain. Many of these vehicles will have to be charged using an external power source. The main drivers of electric mobility will be statutory regulations. In Europe, for example, an average fleet emissions target of 95 g CO₂/km has to be met this year. By 2030, the target will be reduced even further to 59 g CO₂/km.

In addition, there are many countries that, in response to Covid-19, have set up financial programs for the economy.

Such government programs often benefit Battery-electric Vehicles (BEV), either directly through corresponding sales incentives or indirectly through infrastructure spending on charging stations. Against this background, the pandemic could even accelerate the revolution in e-mobility. Automobile manufacturers are investing billions in the development of electric and hybrid vehicles and corresponding sales efforts. The chicken-and-egg problem seems to be slowly disappearing, as user-oriented solutions for charging BEVs are now also available.

CHARGING OPTIONS TODAY

In order to facilitate charging at home, most vehicles provide support for charging via a household single-phase Alternating Current (AC) supply. This allows them to be charged overnight. Solutions range all the way from simple provision of a cable to connect the vehicle to a power outlet, to In-cable Control and Protection Devices (IC-CPD), or wall-box chargers that may include further complexity such as communication between the vehicle and power unit, with grounding and protection inside.

The batteries themselves, however, require Direct Current (DC) supply for charging, with the conversion from AC to DC occurring via charging electronics built into the vehicle. This approach requires every vehicle to be fitted with a charging solution that must be designed according to all the normal constraints of cooling, efficiency and weight – factors that ultimately limit charging power and thus charging speed. The obvious way forward is to develop universal, off-board DC chargers.

APPROACHES TO FAST DC CHARGING

A typical 22-kW AC charger delivers enough charge in 120 min to provide an additional 200 km of vehicle range, more than enough for topping up while at work. However, reducing the 200-km-range charging time to 16 min requires recourse to a 150-kW DC charging station. At 350 kW, the charging time for this range can be shortened to around just 7 min, somewhere approaching an Internal Combustion Engine (ICE)-powered vehicle refueling visit. These

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figures, of course, additionally assume that the target battery can support such charging rates. And, just like refueling at the pump, consumers expect the industry to provide a standardized fueling experience regardless of where they recharge.

In Europe, the organization CharIN e. V. focusses on developing and promoting the Combined Charging System (CCS). The specifications define the charging plug, charging sequence and even data communication. Other regions, such as Japan and China, have similar organizations, such as CHAdeMO and GB/T respectively, while Tesla has its own proprietary system. The CharIN specifications define support for both AC and DC charging via their plug-and-socket implementation. They also envisage a maximum constant current output of 500 A at 700 VDC, with support up to 920 VDC. System efficiency is also set at 95 %, although this will rise to 98 % in the future. It should be noted that a 1-% loss in efficiency for a 150-kW charger is equivalent to 1.5 kW. Thus, reducing losses to an absolute minimum is a priority in fast DC charger designs.

FAST DC CHARGER ARCHITECTURES

High-power DC charger design typically follows one of two basic approaches. The first converts a three-phase AC supply

FIGURE 1 Block diagrams for two potential high-power DC charger approaches (© Infineon Technologies)

into a variable DC output that feeds a DC/DC converter. The exact DC voltage is defined by communication with the vehicle being charged. The alternative approach is to convert the incoming AC to a fixed DC voltage, whereupon a DC/DC converter adjusts the output voltage to match the needs of the vehicle's battery, **FIGURE 1**.

With neither approach considered to have a clear advantage or disadvantage in comparison with the other, it is system challenges that determine the optimal approach. Such high-power solutions will not use a monolithic approach; instead, the desired power output will be achieved by combining multiple charging subunits, each contributing power of 15 to 60 kW. Thus, the key design goals are the minimization of cooling effort, delivery of high power density, and the reduction of overall system size.

Design efficiency starts at the front end with the AC/DC conversion stage. The implementation of this Power Factor Correction (PFC) stage is usually based on a Vienna rectifier topology. The possibility of using 600-V active devices with the advantages of the 3-level rectifier helps achieve the right balance of

cost and performance. With the availability of high-voltage Silicon Carbide (SiC) devices, a normal 2-level PWM-type AC/DC conversion stage is also becoming popular in the power range of 50 kW or higher. Both approaches can be used to achieve a controlled output voltage with a power factor above 0.95, a Total Harmonic Distortion (THD) of below 5 % and efficiencies of 97 % or better for sinusoidal input current. With applications where grid-side isolation by a medium-voltage transformer is a possibility, multi-pulse rectifier topologies with a diode or thyristor at the front end are becoming popular, since they offer simplicity and reliability along with higher efficiency.

In the DC/DC conversion stage, resonant topologies are often preferred due to their efficiency and galvanic isolation. Such a design fulfills demand for higher power density and smaller volume, and the Zero-voltage Switching (ZVS) reduces switching losses and contributes to overall higher system efficiency. The phase-shifting full-bridge topology with SiC devices also constitutes an alternative solution for isolated designs. For grid-isolated architectures, multi-interleaved

buck converters are the DC/DC topology of choice. This has the advantage of load sharing across phases, reduced ripple and filter size, but at the cost of a larger number of components.

In the 15- to 30-kW power range, subunits are most optimally implemented using discrete components, **FIGURE 2**. Implementing the Vienna rectifier using Trenchstop 5 IGBTs together with CoolSiC Schottky diodes is a good combination for more cost-sensitive applications. Slight efficiency improvements are gained by replacing the IGBTs with CoolMOS P7 SJ Mosfets. For the DC/DC converter, a resonant converter using CoolMOS CFD7 Mosfets achieves a respectable efficiency, while the selection of Mosfets from the CoolSiC portfolio is recommended when targeting highest efficiency. Despite the very good efficiencies that power converters can achieve today, a mere 1-% drop in efficiency is equivalent to 3.5 kW of power loss as heat which needs to be dissipated in the system.

With 15- to 22-kW stand-alone charger, the forced air-cooled converter approach is very common. A low-noise fan (lower than 60 dB) with proper air guide and

Typical solutions for 30- to 150-kW chargers: discrete devices

FIGURE 2 Typical topology for a charger made of discrete devices (© Infineon Technologies)

dust filter found wide acceptance in current installations. However due to outdoor installations, the dust and humid conditions create a lot of challenge on the reliability of the converter systems. With the necessity of a liquid-cooled cable for high-power charging installations for 120 kW and higher, the liquid-cooling converter concept is gaining momentum. The challenge here is that many liquid coolants have issues with flammability, degradation, corrosion, and toxicity. Today, a water-glycol mixture has shown itself to be a popular

coolant for both the cable and connector. Dielectric coolants have also been developed with successful deployment in high-power charging systems.

Thanks to modern power transistor technology, coupled with high-performance system-level controllers and advanced magnetic materials, highly efficient AC/DC rectification circuits can be easily implemented. These are needed to ensure sinusoidal current draw from the grid with power factor correction, low harmonic distortion ($\text{THDi} \leq 5\%$), and independent con-

trol of active and reactive power flow while maintaining high dynamic control. When choosing a suitable topology for implementation, engineers need to make some decisions concerning uni- or bidirectional mode operation, 2-level or 3-level topology, silicon- or silicon-carbide-Mosfet-based power semiconductors, depending on the priority of cost, performance, and power density.

One of the most widely used topologies for bidirectional operation is the so-called 2-Level Voltage Source Converter (2L-VSC). This consists of an array of six

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FIGURE 3 Typical solutions for a charger made of module devices (© Infineon Technologies)

switching devices, typically IGBTs or SiC Mosfets. Together with a capacitor as a DC link, these generate an output voltage higher than the input-phase voltages. The switching approach can make use of either Sinusoidal Pulse Width Modulation (SPWM) or Space Vector Modulation (SVM). This can be easily implemented using the single-package 1200-V CoolSiC Mosfet module for lower power stacks of 6.6 kW to 11 kW. For higher power stacks starting from 22 kW, half-bridge solutions with on-resistance as small as 2 mΩ in 62-mm package, up to 6 mΩ in Easy 2B, and up to 45 mΩ in Easy1B are available.

The three-phase, 3-level Vienna rectifier is becoming the popular choice when bidirectionality is not a criterion but the focus is on reducing the switching stress and EMI filter requirements. A symmetric Boost PFC Vienna rectifier can be implemented using SiC Mosfet modules as offered in an Easy 2B package. Each module contains two 1600-V slow rectifier diodes, two 1200-V fast 3-level diodes, and two 1200-V/15-mΩ SiC Mosfets. This is a perfect candidate for a compact high-current, low-loss design, **FIGURE 3**.

CONTROL, COMMUNICATION AND SECURITY

Power semiconductors are generally driven directly by galvanically isolated gate driver ICs, for example from the EiceDriver family. They are a perfect match for a great variety of Trenchstop 5 IGBTs, CoolMOS P7 SJ Mosfets or Mosfets of the CoolSiC portfolio. Control of the power stages is typically implemented using a microcontroller. Devices such as the XMC4000 series provide flexible Analogue-to-Digital Converters (ADC) along with highly configurable timers and Pulse Width Modulation (PWM) peripherals to implement the control loop. CAN connectivity ensures that subunits can communicate with one another and provides for data transmission of the different battery types. Service billing and authentication of software updates or hardware changes can be handled by the Hardware Security Module (HSM) of the Aurix family of microcontrollers; a family that is well-known for safety-relevant applications in the automotive industry. The authentication of replacement subunits can be ensured using devices such as the Optiga Trust B anti-counterfeit

security chip, while more demanding integrity protection is offered by the Optiga TPM trusted platform module.

SUMMARY

The roll-out of fast DC charging infrastructure is an essential part of the strategy to increase the numbers of BEVs. Without the availability of reasonable charging opportunities offering an acceptable charging time, BEVs will inevitably remain restricted to short-distance usage. The preparatory work, in specifying the chargers and connectors, has been done. In addition, the necessary offerings of innovative semiconductor solutions are available. These range from traditional silicon power devices to SiC solutions that offer higher-frequency switching and more efficient power conversion, ensuring that chargers are efficient and reliable. When coupled with appropriate microcontroller devices, and clever authentication and security solutions, it is clear that multi-subunit approaches to delivering the DC charging infrastructure are ready to power the future of transport.