Developing a 25 kW SiC-Based DC Fast Charger (DCFC)

Part 1: Structure of a Fast EV Charger & Key Electrical Specifications

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DC fast charging (DCFC) market is thriving. Along with the acceleration in the adoption of electric vehicles (EVs), the demand for fast charging infrastructure is increasing. Growth projections range from 20% to 30% CAGR for the next five years. If you are an application, product, or design engineer working in the power electronics field, sooner or later, you could be involved in the design of one of such novel charging systems.

A fundamental question might arise here, especially if it is the first time you have faced such a challenge. How and where should I begin? What are the critical design considerations, and how should I address them?

onsemi helps designers address such a challenge, as we'll demonstrate by developing a 25 kW DC fast charger based on SiC power integrated modules (PIM).

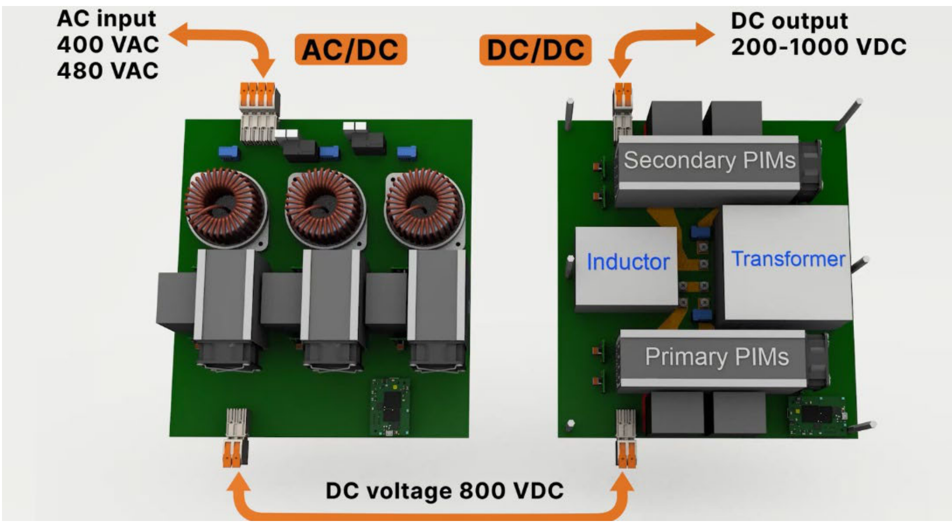

Figure 1. 25 kW DC Fast Charger Reference Design (Left – PFC Stage, Right – Dual Active Bridge)

Developing this type of high−power battery charger requires a diverse skill set. **onsemi** expert team led the project coordination on this design and undertakes all the activities related to hardware development. Our team developed firmware and software. The team brought year−long development experience in control and algorithm for power converters and motor drives.

We will walk through the development process of the DC charger, addressing different topics along the way. We will highlight the key challenges, trade−offs, and compromises and show how to design, build and validate such a system from scratch. We know the design journey is not straight, and the best way to move forward is to get running and iterate fast.

DC FAST CHARGER – WHAT ARE WE BUILDING?

In the e−mobility ecosystem, direct−current (DC) chargers provide "fast" and "ultrafast" charging capabilities, in contrast with slower alternating current (ac) chargers. In essence, EV chargers convert the AC power from the grid into DC power suitable for delivery into the batteries of the EVs. The power conversion in DC charging is handled outside the EV ("off−board") and then delivered to the vehicle with power levels ranging from below 50 kW to greater than 350 kW (with even higher levels in development).

Higher power DC chargers are typically built modularly, stacking power blocks of 15 to 75 kW (and above) in a single cabinet (Figure 2). In general, output voltages of DC chargers range from 150 V to above 1000 V, covering both the 400 V and 800 V standard EV battery levels, and may be optimized for the higher or lower voltage end.

The architecture of such power blocks is as follows: an AC−DC boost converter with power factor correction (PFC) at the front end, followed by a DC−DC stage that provides isolation between the grid and the load (battery of the EV) and regulates the voltage and current at the output (Figure 2). The system may also be bidirectional (particularly at lower power), and thus the topology and design should account for it.

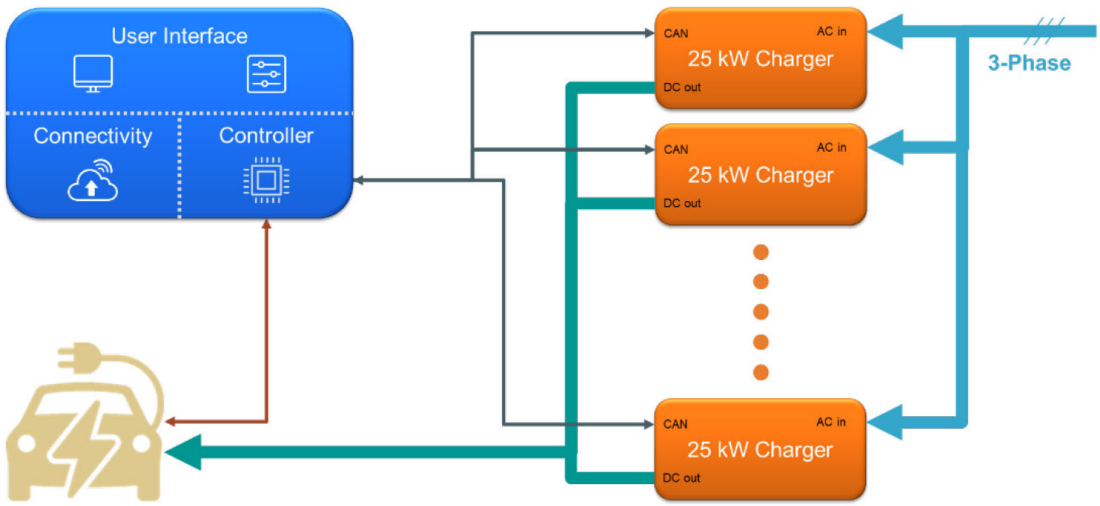

Figure 2. Overview of the Main Blocks in a DC Fast Charger

onsemi team is developing a 25 kW DC charger with bidirectional capability. The system shall cover a wide output voltage range, able to charge EVs with both 400 V and 800 V batteries, optimized for the higher voltage level. The input voltage is rated for EU 400 Vac and US 480 Vac three−phase grids. The power stage shall deliver 25 kW over the 500 V to 1000 V voltage range. Below 500 V, the output current will be limited to 50 A, derating the power in alignment with profiles of DC charging standards such as CCS or CHAdeMO (Figure 2).

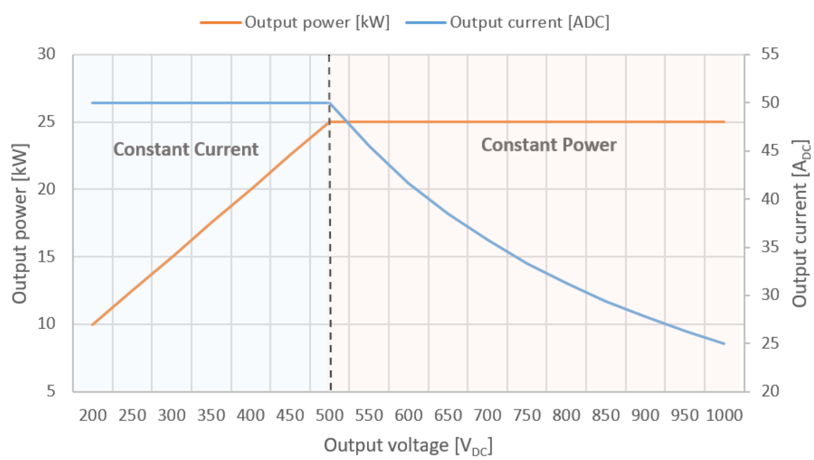

Figure 3. Power and Current Profile of the 25−kW DC Charger Power Stage. The Current is Limited to 50 A Below 500 V.

Regarding communication ports, the board will provision isolated CAN, USB, and UART infrastructure for external interfaces (between power blocks, charger system controller, vehicle, service, and maintenance). Overall, the design will follow guidelines from the IEC−61851−1 and IEC−61851−23 standards for EV charging. The table below summarizes the system requirements.

Table 1. REQUIREMENTS OF THE 25−KW DC FAST CHARGER

Complete System PFC + DC−DC Converter		
AC Input	Voltage Input Rating	Three−phase 400 Vac (EU), 480 Vac (US)
	Max. Input Current	40 A
	Frequency	50/60 Hz
	Power Factor	>0.99
	Efficiency	>96%
DC Output	Output Voltage	200 V to 1000 V
	Max. Output Power	25 kW
	Max. Output Current	50 A
Protections	Output	OVP, OCP, SC
	Input	UVP, OVP, inrush current
	Internal	DESAT (gate driver), thermal (NTC on power device)
User Interface	Push Buttons	Yes
	GUI	Yes. STRATA−based GUI for system evaluation
Communication Buses	Internal	SPI, I^2C
	External	Isolated CAN, USB, UART
Environmental	Operating Temperature	0°C to 40°C
Max. Mechanical Dimensions	PCB	450 x 300 x 280 mm (PFC and DC−DC stacked)
Standards	Regulation	Following guidelines described in EN55011 Class A. Will not be tested.
	EV Systems	Following guidelines described in IEC 61851. Will not be tested

THE DEVELOPMENT PROCESS

Our team follows the logic of hardware development processes of power conversion. The work starts with the definition of the actual DC charger power stage based on the requirements for the application. Summarized in the table in our case, these are per the market’s needs and follow the guidelines of IEC−68515. These requirements help the team understand their target.

The first feasibility studies help validate the initial requirements and assumptions, integrated as part of the system design that encompasses (in this project’s scope) hardware, software, thermal management and mechanical design, prototyping, and validation. All the essential system variables and most critical compromises and trade−offs for the solution happen during the feasibility studies.

Multiple iterations carry out these tasks and sub−designs, where outputs and assumptions from one part feed back to another. Two of the main design activities that provide significant outputs to move forward are:

* Power simulations with SPICE models
* Control simulation using MATLAB® and Simulink®

Power simulations are crucial to confirm the assumptions on working voltage and currents, losses, cooling requirements, selection of power, and passive components, among others. Once an implementation plan is ready, control simulations, including the power parameters, are carried out to confirm that the control loops are effectively executed with the power design.

Proving the design with the power and the control simulations greenlights the schematics drawing, PCB layout, and prototype manufacturing. (Once the board was developed, we carried out hardware bring−up, functionality testing, and system characterization. Please refer to Lessons Learned: Developing a 25 kW DC Fast EV Charging Module. In this reference note, we present a simplified summary of the design process that we will describe in detail below.) Developing a 25 kW EV DC charger from scratch entails more than that; the most valuable takeaways will come as we solve the challenges and issues along the way.

(*Please watch four webinar series of “Designing Silicon Carbide (SiC) based DC Fast Charging System” for more details.)

WHAT IS COMING?

In subsequent parts of this reference design series, we will be taking a closer look at some of the design and validation stages. The following topics will be addressed:

* Part 2: Solution Overview
* Part 3: The three−phase PFC rectification stage
* Part 4: The dual active full−bridge DC−DC stage
* Part 5: Control algorithms, modulation schemes and feedback
* Part 6: Gate driver system for SiC power modules
* Part 7: Auxiliary power units for 800 V bus
* Part 8: Thermal management

If you have a question about a 25 kW SiC−Based Fast DC Charger or this reference design series, please contact Technical Support.

REFERENCE

[1] Video − 25kW SiC Module Fast DC EV Charger Power Stage
[2] Designing Silicon Carbide (SiC) based DC Fast Charging System Webinar Series
Session 1: 6−Pack Boost Active Front End (AFE) Design
Session 2: Dual Active Bridge DC−DC Design
Session 3: Gate Drivers, Auxiliary Supply, and Thermal Management
Session 4: Measurement Results
[3] Application note − Demystifying three−phase PFC topologies

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