

## **Design considerations for fast DC chargers targeting 350kW**

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### **Introduction**

The car owner has, unknowingly, been spoiled for many decades by a seamless network of refuelling stops. The thought of having to plan a journey optimised around the location of gas and service stations is utterly unfamiliar. However, this is probably one of the initial thoughts going through the minds of those considering purchasing or leasing a battery electric vehicle (BEV). Although the automobile is used by many primarily for short journeys well within the range of a BEV, it is the exceptions, such as a weekend away or the annual vacation, that cause concern.

When parked at home our BEV can be charged, slowly, overnight. Many of our larger cities and towns have also started to provide municipal charging piles, enabling us to top-up our vehicle's charge while shopping. The reality is, for longer journeys at least, the charging time has to come somewhere close to that required for refuelling an internal combustion engine vehicle. A 22 kW home AC charger can deliver charge equivalent to around 200 km of range in a time frame of 120 minutes. Reducing this to seven minutes would require a fast DC charger supplying 350 kW.

### **Standards are in place**

Workings groups within standards organisations have, around the world, defined everything from the operational envelope and charging sequence, to the communication and connectors of High Power Chargers (HPC). In Europe and the US interested parties have coalesced around CharIN and the Combined Charging System (CCS). Elsewhere other alternatives have developed, such as CHAdeMO in Japan and GB/T in China. Some vehicle manufacturers have also placed value on developing proprietary charging solutions.

For manufacturers looking to address this market it quickly becomes clear that a modular approach is required. This allows reuse of some aspects of the end solution, such as a common housing and cooling concept, while connectors, cables and the power electronics can be selected to match the specifications of the target market.

### **Approaches to the fast DC charger power electronics design**

Fast charging HPC refuelling points will require dedicated electrical low or medium voltage (LV/MV) infrastructure as their supply. It is expected that this will be installed primarily in locations such as motorway service stations along key routes between cities. The incoming AC supply feeds into an isolating transformer whose secondary will be converted to DC. Transformers with a double secondary  $\Delta$  and Y winding are a popular solution.

These phase-shifting transformers are then combined with multi-pulse rectifiers operating in series or parallel that reduce harmonic content at the input. In such designs the transformer is mandatory even if isolation can be provided through the chosen topology for the DC/DC stage, mainly due to the harmonic content improvement its presence provides. The first design decision to be made here is whether to take a common AC or common DC bus approach.

In the common AC bus approach, the secondary side of the transformer feeds multiple AC/DC rectifying stages that feed their own DC/DC stages. This has the benefit of simplifying the overall design concept for the charger. However, it does require a replication of the AC/DC stage that results in higher total cost due to the need for several sets of filters, control stages and sensing. Currently, support for injecting energy back into the grid, such as Vehicle-to-Grid (V2G) and Vehicle-to-Building (V2B), is not mandatory. However, should this change, this approach would result in further cost and complexity.

The common DC bus approach uses a single AC/DC stage to create a DC output that supplies all the DC/DC stages. In many cases, this proves more optimal as it reduces device count and cost, and improves overall efficiency. Should V2G and V2B become mandatory it would also be simpler to retrofit. A DC bus is also easier to integrate with other energy systems (local battery storage, photovoltaic) that may be implemented. Finally, current DC charger standards support the idea of a centralised charging station operating as an active front end for several battery chargers. The main downside surrounds dimensioning such a high power-rated active front end.

Charging parks supporting 2 to 3 MW of power prefer the common DC bus, using it to supply between six and eight high-power DC/DC charging stages.

### **Focussing on the AC/DC rectification**

Thanks to modern power transistor technology, coupled with high performance microcontrollers (MCU) and digital signal processing (DSP), highly efficient AC/DC rectification circuits can be implemented. These ensure a sinusoidal current draw from the grid, low harmonic distortion ( $THDi \leq 5$  percent), and independent control of active and reactive power flow while ensuring high dynamic control. Operation at unit power factor ensures there is no reactive power consumption from the grid. Finally, if the chosen topology supports it, bi-directional power flow between the AC and DC sides is relatively straightforward.

One of the most widely used topologies is the Two-Level Voltage Source Converter (2L-VSC). This consists of an array of six switching devices, typically insulated-gate bipolar transistors (IGBT) or silicon carbide (SiC) MOSFETs, together with a capacitor as a DC link, generating an output voltage higher than the input phase voltages. This active front end also supports bi-directional energy flow and provides a fully adjustable power factor. The switching approach can make use of either pulse-width modulation (PWM) or space vector modulation (SVM).

This can be easily implemented using the single-package 1200V CoolSiC™ MOSFET Module FS45MR12W1M1\_B11 (figure 1). This contains six switching devices in the EasyPACK™ 1B package that features a low inductive design and contains an integrated NTC temperature sensor. Half-bridge solutions, such as the FF11MR12W1M1\_B11 in the EasyDUAL™ 1B package, could also be considered. Designs based on these components could support 60 to 100 kW at switching frequencies of 25 to 45 kHz.

((Fig. 1))

If bi-directional current flow is deemed unnecessary, the three-phase, three-level Vienna rectifier is becoming the popular choice. It requires only three active switches and provides dual boost power factor correction (PFC). In the event of a malfunction in the control circuit it is protected against a short-circuit of the output or front end, and can even operate with the loss of one input phase. Assembly effort for such designs can be high using discrete components, but in such high-power applications, integrated power modules are more commonly used.

A Symmetric Boost PFC Vienna rectifier can be implemented using SiC modules such as the F3L15MR12W2M1\_B69, offered in an Easy 2B package (figure 2). Each module contains two 1200V fast rectifying diodes, two 1600 V slow rectifier diodes, and two 1200 V, 15 mΩ MOSFETs. Three such Easy 2B packages can easily be combined to create a compact high current, low loss design (figure 3).

((Fig. 2))

### **Delivering the variable DC charging voltage**

The CharIN specification for DC chargers defines that the supported output voltage must lie between 200 V and 920 V, supply a maximum of 500 A, and operate within a power envelope of 350 kW. There is a range of DC/DC topologies, both isolated and non-isolated, that can be used to tackle this challenge.

Regardless of the topology chosen, there are several key requirements that need to be fulfilled. Physical size and overall cost are focus areas, while electromagnetic interference (EMI) regulations must also be observed. Zero voltage or zero current switching (ZVS/ZCS), highest efficiency and support for the high power required are also on the list. Finally, low ripple of both voltage and current at the output are essential to avoid battery heating.

Topologies utilising a high-frequency (HF) isolation transformer, such as a full bridge LLC resonant converter, are known for their high efficiency at their resonant frequency. They are also inherently compact thanks to their ZVS primary side switches and ZCS secondary side diodes. Unfortunately, supporting the desired wide output voltage range makes charger development exceptionally challenging with this approach.

Above 100 kW power outputs, and since the galvanic isolation is guaranteed by the grid transformer, a non-isolated Buck-Boost converter can be used. In a multi-phase configuration, it can provide efficiencies of up to 98.5 percent. This approach also significantly reduces current pulsation due to the shifted voltage pulses. Its modular design allows its dimensions and operational parameters to be easily adapted to changes, both in output and performance or physical shape.

((Fig. 3))

### **Managing heat dissipation**

Despite the incredible efficiencies that power converters can achieve today, a mere 1 percent drop in efficiency is equivalent to 3.5 kW of power dissipation, emitted as heat, when a fast DC charger is operating at full power. The cable alone can add an additional loss of 100 W per metre length. HPCs require more than a forced air-cooling approach to heat dissipation. Additionally, it is not only the power electronics but also the connector and cable that requires manufactures to move to liquid cooling.

The challenge here is that many liquid coolants have issues with flammability, degradation, corrosion, and toxicity. Today a water-glycol mix has shown itself as a popular coolant for both the cable and connector. Dielectric coolants have also been developed, such as the 3M™ Novec™, with successful deployment in the ITT Cannon HPC. The cooling system is then coupled with a separate or centrally located heat exchanger, depending on the configuration of the charging park.

### **Summary**

The uptake of BEVs is, to some degree, dependent on the available charging infrastructure. Some worries could be alleviated through better promotion of the existing network of charging points, although investment in fast DC charging HPCs, specifically to diminish range-anxiety for those worried about their longer journeys, is also required. Liquid cooling will be an essential part of the heat dissipation strategy, requiring that the selected electrical topologies and components are both highly efficient and provide easy integration with the mechanics of the heat extraction approach. SiC devices, including diodes and switches, will form an essential part of the design choices made, starting at the rectification stages and moving through to the DC/DC topologies chosen to deliver the battery charging output.

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### **Image Captions**

Figure 1: An Active Front End can be easily implemented using a single 1200 V CoolSiC™ MOSFET module.

Figure 2: Half-bridge modules integrated into Easy 2B packages, such as the F3L15MR12W2M1\_B69, are ideal for a Vienna rectifier

Figure 3: High efficiency 60 kW design utilising Easy 2B Vienna rectifier phase leg modules

### **Short Bio**

Pradip Chatterjee joined Infineon Technologies AG in 2018 as Application Owner of EV Charging. In his role, he focuses on EV charging applications, working on requirements and trends, as well supporting design-ins. Pradip Chatterjee holds a master degree in power electronics and has around 15 years of experience in the design of converters and systems.