Replenishing the Grid with A SiC-Based Bi-Directional On-Board Charger

Range anxiety and charger availability have long been the main hurdles to the adoption of electric vehicles. But even as car makers have demonstrated their batteries can go longer distances and charging stations have proliferated, challenges with EV charging remain as well as opportunities to load balance power grids.

The migration to electric vehicles also means looking at how they can better interact with power grids. Not only are they being equipped with lighter, high power density batteries that can increase their range and potentially be used to support standalone loads, but there's also been a shift toward on-board chargers that pull power from the grid and send it back to the grid to help replenish it.

Wolfspeed's award-winning 6.6 kW Bi-Directional On-Board Charger (OBC), enabled by its new 650 V SiC MOSFET, has the smarts to play a critical role in the evolution of electric vehicles and the power grids that power them.

OBCs' one-way challenge
It's rare that drivers worry about running out of fuel between gas stations, except in the most rugged and isolated areas, but range concerns for electric vehicles have existed since their inception. While charging stations are becoming more common place and being integrated into new housing developments, how far a car can travel as well as its battery capacity and how long it will hold its charge remain areas for improvement.

The number of OBCs is growing and evolving along with the electric vehicles themselves, but an OBC is not as powerful as a fast charger, which charges a vehicle in an hour or so. An OBC requires six to seven hours for charging. An even more significant drawback of a one-way OBC is that a vehicle sitting idle is losing its charge—that's both energy and money lost. This problem does create a solution, however. It opens the door for electric vehicles to give power back the grid, rather than letting it slowly “leak.” By having a bi-directional OBC that not only pulls charge from the grid but also replenishes it, an electric vehicle can play a role in load balancing the overall electric infrastructure of a city.

Bi-directionality is also good for the vehicle’s battery as it needs to be cycled—rather than always being charged at 80 percent, it’s better for it to be completely discharged occasionally, much like a smartphone. Keeping the battery fully powered most of the time means all your components are in a stage of charge all the time, which reduces their life span. This means replacing the battery sooner than later, and like a smartphone, this can be an expensive undertaking. Ideally, an OBC should intelligently sense you’re at 30 percent, for example, and cycle down the battery by replenishing your home with its remaining energy, and then recharge the car back to full power.

The goal is to a have a bi-directional OBC that moves power back and forth efficiently with minimal loss during transmission, which for electric vehicles is called conduction. While there are several solutions available, Wolfspeed silicon carbide MOSFETs offer several advantages over other components in optimizing bi-directional OBCs.

The grid-powering opportunity for OBCs

OBCs have addressed anxieties over station availability for offboard charging. Although offboard chargers are fast, they’re only available at a charging station, and sometimes are proprietary or have limited access. In addition, a visit to a station and the waiting time may not be worth the top up for a daily commute.

As much as OBCs offer advantages over offboard charging at a station, they are slower to charge, which means it needs to be done overnight at home or during the day at work, in the same way most people keep their smartphones powered up. This is why the battery in an OBC vehicle needs to be cycled which, in turn, makes the case for bi-directionality.

In China, this is being sold as a value proposition to customers, as it essentially turns their car into a mobile power bank.

Another scenario made possible by bi-directional OBCs is that several vehicles can be linked together in an energy network to create a large source of power to feed a grid, with individuals being able to “buy” energy during the night at low rates and “sell” it back during the day at peak rates.

Today’s bi-directional OBCs can be either Isolated Gate Bi-Polar Transistor- (IBGT-) or Silicon Carbide- (SiC-) based. SiC components are the optimal solution for OBCs because compared to Si components, they are smaller, deliver a lower overall system cost, and are more efficient.

A SiC solution for an efficient bi-directional OBC

Given the benefits of SiC, Wolfspeed, A Cree Company, set out to design a SiC MOSFET-based 6.6 kW bi-directional electric vehicle OBC.

The goal was to create a high efficiency bi-directional OBC with high power density and battery capacity that can potentially be used to support standalone loads and to supplement grid power. This was realized in the form of a digitally-controlled prototype with a switching frequency of 67 kHz for CCM totem pole PFC, and 150–300 kHz for a CLLC resonant converter, which were demonstrated with 54 W/in_3 power density exceeding 96.5% in peak efficiency.

The high density and maximized efficiency were essential, given the need to optimize space and weight in an electric vehicle. Wolfspeed’s OBC solution consists of a bi-directional AC-DC converter followed by an isolated bi-directional DC-DC converter, as it was found to provide high efficiency and a wide output voltage range in both charging and discharging modes.

To address conduction losses, the company eschewed a conventional PFC boost converter as the conduction losses of the diode bridge rectifier are not efficient, nor does it support bi-directional operation. Because of the favorable reverse recovery performance of the body diode of SiC MOSFETs, an interleaved CCM totem pole PFC is enabled as the front-end stage of a 3.3 kW OBC instead.

Thermal management is also critical when designing an OBC. Normally, MOSFETs in a TO-247 package are reverse-assembled on the PCB then mounted on a flat cooling baseplate. However, since MOSFETs are bent down, the PCB area is increased. This negatively impacts the overall power density of the system. So, a tooled heat sink was used to accommodate both semiconductors and magnetics. Vertical MOSFET assembly is made possible by mounting power semiconductors on the outer side of the heat sink which, in turn, reduces the PCB footprint. Magnetics are then potted using a thermal compound inside the slots of the heat sink. As a result, thermal resistance from the tooled aluminum heat sink to the system cooling baseplate is low.

The experimental results for the SiC MOSFET-based 6.6 kW bi-directional OBC's converter operating in the charging mode and discharging mode manifest both high efficiency and power density so that a bi-directional OBC not only charges and cycles the battery efficiently, it can also more effectively feed power back to the grid.

A power-efficient prototype

By designing and evaluating a 6.6 kW bi-directional OBC using its new 650 V SiC MOSFET, Wolfspeed has demonstrated how a DC-link voltage range can be optimized to 385-425 V per a common battery voltage range of 250–450 V for an OBC.

Further, the prototype built verified the performance and thermal integrity of the design. By integrating the power semiconductors and power magnetics on the same tooled heat sink, high power density and high efficiency can be achieved in bi-directional high-power conversion applications such as an OBC, owing to the low power loss of the 650 V SiC MOSFET.