Charger topologies for high power electric vehicle charging

E-mobility demands rapid and efficient charging to increase adoption of electric vehicles

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While much of the discussion surrounding e-mobility has been around driverless vehicles and their ability to navigate crowded streets safely, developing and deploying compact and efficient charging facilities is a critical pre-requisite for these vehicles reaching significant adoption levels.

Not only will charging stations be required in metropolitan areas and alongside highways, but also in residential areas. The billing systems associated with the charging stations will also need to be sophisticated and secure. Each vehicle will need to be identified so that all electricity usage can be charged for correctly.

Standardisation of charging connectors will be another important aspect. Organisations such as CharIN (www.charinev.org) are working to standardise not only the connectors but also the communication protocols by which the vehicle communicates with the charging station.

As grid operators wrestle with peak demand, the roll-out of electric vehicles will demand significant amounts of power to recharge vehicles and load balancing will remain a significant challenge. However, within the problem lies the solution. Vehicles that have fully charged batteries but are only used for short journeys will have excess energy that can be returned to the grid at times of peak demand, while leaving enough energy for the commute home.

At the very start of the automotive revolution, there were more electric vehicles on the road than internal combustion engine cars. However, with the invention of the electric starter, combustion engine driven cars became the mainstream and electric vehicles vanished. Events such as the 1972 oil crisis or the Californian Zero Emission Mandate during the 1990s rekindled interest in electric vehicles but history shows, they never reached the mass market.

More recently, the availability of new battery technologies, global environmental concerns and customer demand for cleaner alternatives to fossil fuels, electric mobility is once again becoming a viable technology.

With electric vehicles (EV) currently offering a range of several hundreds of kilometers per charge, all day use is now a realistic possibility. Nonetheless, range anxiety relating to making longer trips in an EV remains a hurdle, preventing many customers from adopting the new technology. Similarly, potential adopters without dedicated overnight charging or even without predictable access to electricity still seek assurances that they will be able to refill the EV’s energy storage in an acceptable time frame.

Typical chargers currently installed in public spaces offer output power levels up to 50 kW. While this is a significant amount of power, it also means that charging the EV to drive for another 100 km takes about half an hour, assuming a consumption of 25 kWh/100 km. By the same token, charging an empty 100 kWh battery would take in excess of two hours – considered by many users to be a significant amount of time.

For chargers sited on a highway, recharging is expected to be completed in a matter of minutes rather than hours. The combination of larger batteries to increase the per charge range coupled with the desire to shorten the charging time resulted in a new generation of chargers, capable of delivering up to 350 kW of power.

As well as rapidly charging EVs, these new designs will also facilitate the charging of the electric coaches and e-trucks that are currently under development. Battery capacity for these vehicles is expected to be around 250-400 kWh to allow a reasonable distance per charge, while the charging duration is desired to remain below one hour.

The design of high power chargers poses several challenges, in particular the efficiency of the charging system due to the limited space available for additional cooling. Delivering 350 kW of output power at an efficiency of 97% leads to losses of around 10 kW, making thermal management a challenge. With currents up to 500 A, every semiconductor in the power path contributes to system losses. For bipolar devices such as IGBTs, their forward voltage defines the static losses whereas channel resistance mainly defines the losses for unipolar devices such as MOSFETs.

Given the high levels of current, devices are often used in parallel to increase their capacity. In the case of IGBTs, this does not materially improve efficiency, although with MOSFETs parallel operation reduces the channel resistance, thereby increasing the efficiency. Consequently, Silicon Carbide (SiC) MOSFETs are a perfect match for this application.

Creating a modular charger design based on paralleled subunits with individual power levels between 15 and 30 kW is key to having an installation that can be upgraded in line with market demand and technical trends. Future designs will target to increase subunit power to around 60 kW without increasing the size, thereby more than doubling current power density.

A common approach to charger design consists of an input stage with line filter and PFC-stage, a DC-link and a transformer based DC-DC-converter with galvanic isolation, similar to that shown in Figure 1.

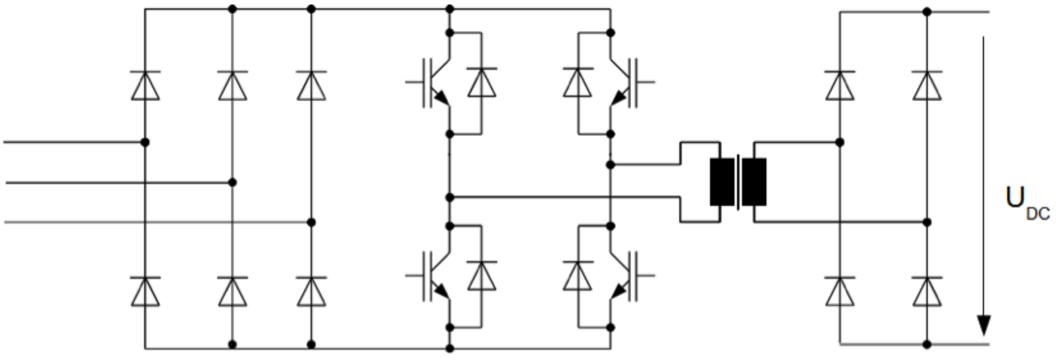

Figure 1: Most basic scheme of a DC charger power section

This rudimentary approach includes several drawbacks as there is no control over the DC voltage and square-wave currents disturb the grid. On the positive side, this is a simple approach with cost advantages due to the limited number of components. Figure 2 depicts a more advanced solution that has become popular.

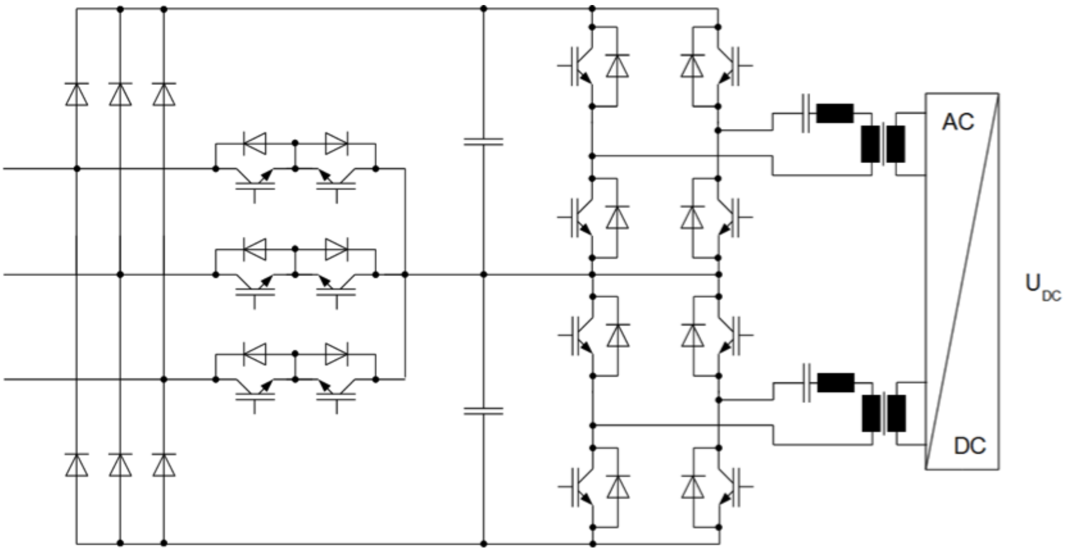

Figure 2: DC-Charging power stage including Vienna Rectifier and series-connected LLC

In this topology, the Vienna Rectifier at the input introduces sinusoidal grid currents as well as controlling the DC link voltage in boost mode. In addition, key semiconductors can be selected with lower blocking voltage levels, meaning that 650 V devices replace the 1200 V devices in the simpler approach, thereby improving efficiency. Changing from a hard-switching approach to resonant DC-DC converters as an output stage further contributes to loss reduction.

As always, the improved efficiency does not come for free. The larger number of semiconductors installed, the increasingly complex gate driver design and the higher number of isolated power supplies remains a drawback of the approach that needs to be considered. The control algorithms are also somewhat complex, making the design more challenging.

With the recent availability of high voltage MOSFETs based upon wide band gap materials, a reduction in complexity can be achieved without sacrificing efficiency. Figure 3 displays a charger using a single building block with a half-bridge topology:

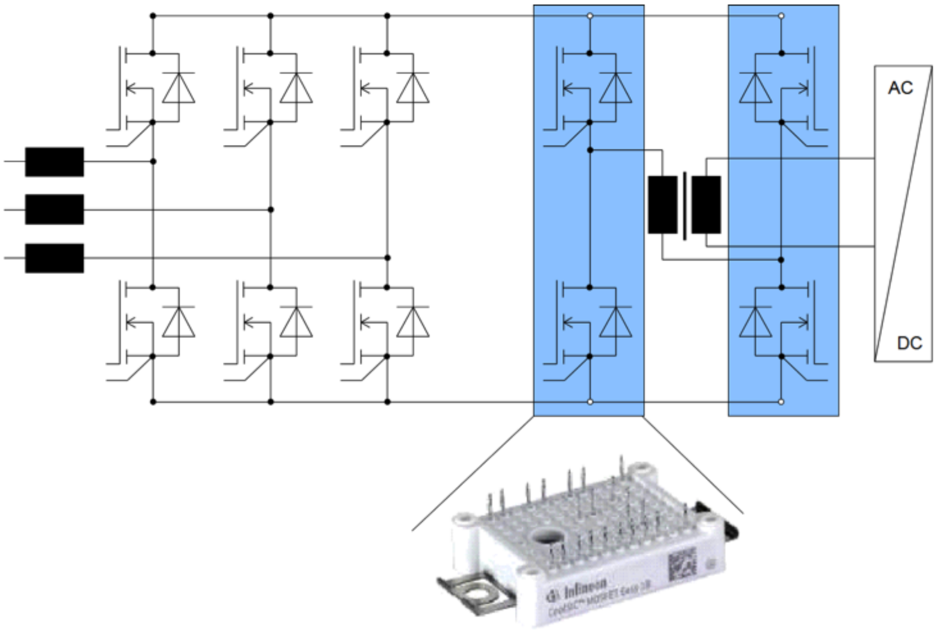

Figure 3: Power section using SiC MOSFETs in half-bridge topology as building blocks

The blue shaded box in Figure 3 represents Infineon’s FF11MR12W1M1_B11, an Easy1B power module that contains 1200 V SiC MOSFETs in a half-bridge configuration that offer a channel resistance as low as 11 mΩ at 25°C. Where galvanic isolation is not required, the half-bridge can be operated in buck-boost mode. Interleaving several modules allows the handling of higher power levels.

Using MOSFETs as an active front end allows the design to be operated as a PFC stage and inherently offers the capability to regenerate energy to the grid. This approach combines a low part count with the highest efficiency while keeping the system complexity as low as possible. Additionally, it offers the option to integrate the charger into vehicle-to-grid (V2G) or vehicle-to-home (V2H) applications.

With the high switching frequencies used in MOSFET-based designs, input filter components can be reduced in size which in turn leads to more compact designs. Techniques such as synchronous rectification reduce losses, thereby reducing the thermal management effort.

As the market for EV charging develops, it is expected that there will be many new entrants entering the market from a variety of different backgrounds, all requiring different levels and types of support. As a preferred distribution partner of Infineon, EBV is strongly positioned to support the needs of customers of all types due to their strong market-focused organisation and depth of technical support and field-based application engineers.

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Martin Schulz, Principal, Application Engineering is with Infineon Technologies since 2005. In 2011 he joined the application engineering group. His responsibilities are in the area of industrial battery chargers and electrified commercial and agricultural vehicles (CAV). Furthermore, thermal management is his field of expertise. Martin Schulz holds a Dr.-degree in electrical engineering, gained at the University of Siegen at the Department of Power Electronics and Electrical Drives. He is a Senior IEEE-Member

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