Discretely Get Up to 22kW on Your On-Board Charger

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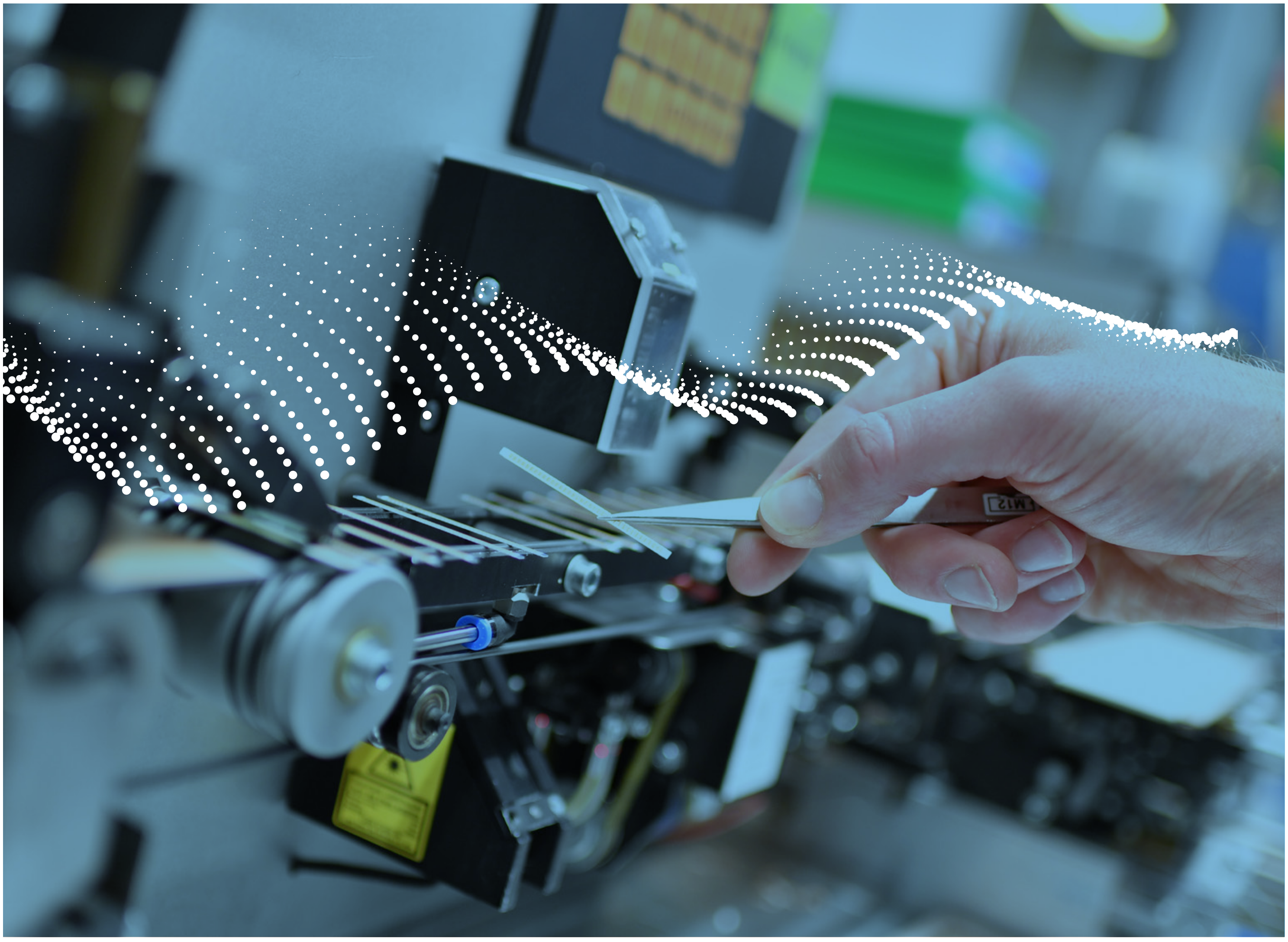

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Today's on-board charging (OBC) systems convert power from the AC grid into a DC voltage used to charge the high-voltage battery pack in either an electric vehicle or a plug-in hybrid vehicle.

As the trend toward fast-charging systems continues, the power demanded from OBC has been steadily increasing from 5.5kW to 11kW, and now up to 22kW. This development, paired with a high-efficiency and power-density demand at a low system cost, has driven the need for 3-phase topologies.

This 22kW OBC is designed to operate from a 3-phase input voltage (without a neutral) that ranges from $340V_{AC}$ to $480V_{AC}$ and provides an output voltage range from 250V to 500V with a maximum current of ~50A. The input stage **(Figure 1 and Figure 2)** utilizes a T-type Vienna rectifier, a common topology that is used for power factor correction (PFC), that meets the end requirements in terms of harmonics and reactive power, and allows the charger to operate over a wide input voltage range. This topology also works with a virtual neutral point that allows the DC bus to be split into two symmetrical stages.

With this approach, it is possible to use 650V silicon MOSFETs for the main DC/DC stage instead of much more expensive 1200V silicon carbide (SiC) devices required with other topologies. The T-type Vienna rectifier allows for power factor correction (PFC), but like all boost-derived topologies, it cannot handle the inrush current drawn by the DC link capacitors (C1/C2/C5/C6 in **Figure 2**) during the initial power-up. This bank of capacitors (either aluminum electrolytic or film, depending on the application requirements) is required to handle the high ripple currents generated by PFC switching.

Although the PFC diodes (D1-D6 in **Figure 2**) have excellent surge capability and the three PFC inductors (L1-L3 in **Figure 2**) are in series between the AC input and the DC link capacitors, active control of the inrush current is still necessary. This function could be accomplished with a mechanical relay, but this device would be very large (to handle the $40A_{RMS}$ current), and it would not meet the typical lifetime requirements of the OEMs. The Vishay VS-40TPS12LHM3 thyristors (TH1-TH4 in **Figure 2**) are connected as normally open bi-directional switches in two of the input legs.

In parallel with the thyristors are the Vishay high energy absorption PTCEL inrush current limiters (PTC1/PTC2 in **Figure 2**). They are switched on when the charger is first energized and then switched off when the DC bus is charged to the appropriate level. It is also worth mentioning that the necessary X/Y filter and safety capacitors (for example, the Vishay AY2 series) are located in the fuse block and EMI filter section in **Figure 2** that is not shown in detail.

The Vishay VS-E5PH6012LHN3 diodes (D1-D6 in **Figure 2**) and SQW61N65EF MOSFETs (Q1-Q6 in **Figure 2**) work together to provide the active rectification. The 650V MOSFETs are configured as bi-directional switches and are switched at 30kHz (with low losses)

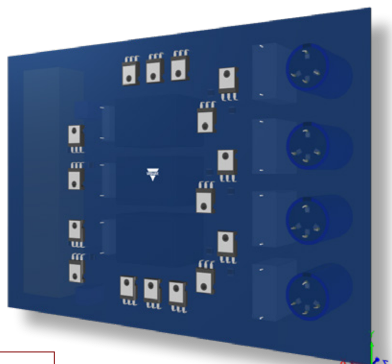

Figure 1: *The 22kW OBC power factor correction stage (Source: Vishay)*

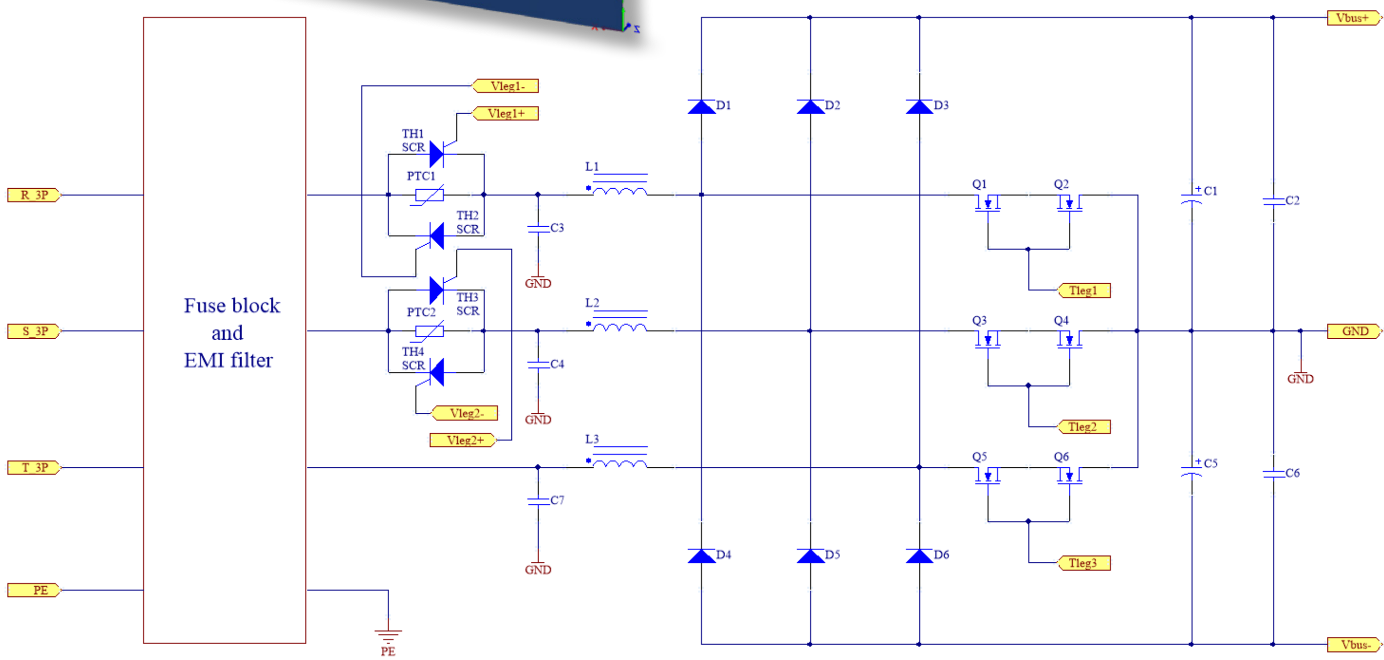

Figure 2: *The simplified schematic of the power factor correction stage (Source: Vishay)*

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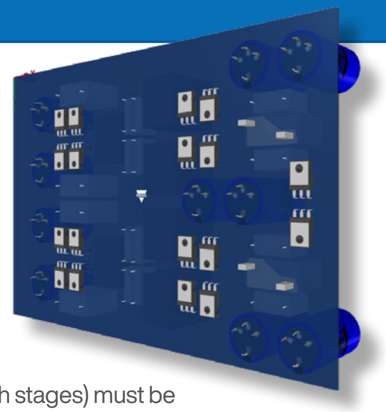


***Figure 3:** The 22kW OBC main DC/DC converter stage (Source: Vishay)*

because of the minimal reverse recovery current of the diodes, which are hyper-fast devices with soft recovery characteristics. This combination also reduces the induced noise back onto the AC power grid and simplifies the design of the input filter.

In the main DC/DC section of the charger (**Figure 3** and **Figure 4**), the Vishay SQW61N65EF MOSFETs (M1-M4 and M5-M8 in **Figure 4**) are configured in H-bridges across the positive DC link stage (M1-M4) and the negative DC link stage (M5-M8 in **Figure 4**). The two stages are symmetrical, and each form an LLC resonant converter that switches from 150kHz to 250kHz. Each stage utilizes two transformers to minimize the size and profile compared to a single transformer implementation. The two stages work independently, but in the case of a difference in the respective output voltages, they shut down simultaneously to avoid an imbalance in the DC bus. An important component in the LLC converter is the resonant capacitor (C5 and C15 in **Figure 4**) because it must handle high peak voltages, large ripple currents, and high di/dt.

Using a single film capacitor for this function is usually not possible because of the ripple current requirement, so multiple capacitors connected in parallel are usually required. In this case, the Vishay MKP385e series of high-voltage resonant capacitors was used; seven 15nF/2000V capacitors in parallel to handle the $35A_{RMS}$. The output of the main DC/DC converter (both stages) must be rectified to provide a DC voltage for the charging of the battery pack. A full-bridge rectifier configuration is used for each stage of the converter. The Vishay VS-E5PX7506LHN3 was used for each diode in the bridge (D7-D10 in **Figure 4** in the positive stage, D11-D14 in **Figure 4** in the negative stage) because they are optimized for low-voltage drop at the peak sinusoidal current and low reverse-recovery energy at the resonant frequencies involved. In this application, the VS-E5PX7506LHN3 provides high-efficiency performance under all operating conditions, with a maximum efficiency of ~96.7 percent at $400V_{AC}$ input and 500V/45A output (and coolant temperature at 60°C).

In terms of the mechanical design, a liquid-cooled cold plate is sandwiched between the power factor correction (PFC) board and the main DC/DC board on the other side. The TO-247 power devices (MOSFETs, diodes, thyristors) are all secured to the cold plate with screws and Kapton film for the insulation barrier.

A discrete OBC design has been presented that is capable of operating up to 22kW with a 3-phase AC input. It utilizes a cost-effective topology that can still provide operating efficiencies up to nearly 97 percent.

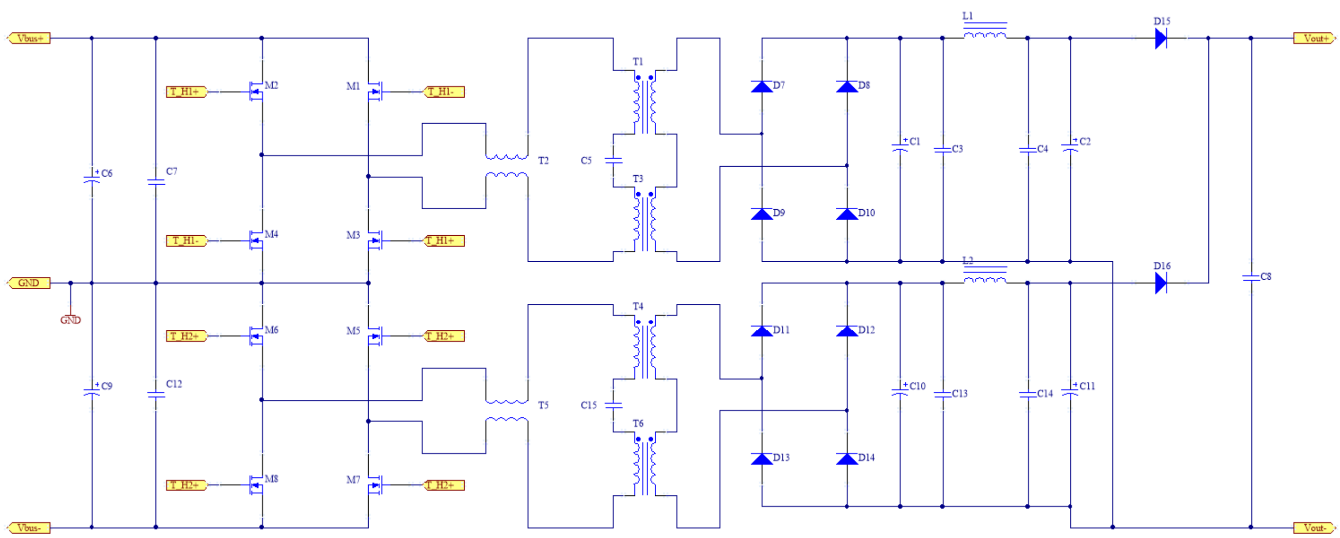
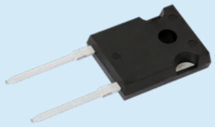


Figure 4: *Simplified schematic of the main DC/DC converter stage (Source: Vishay)*

VS-E5PH6012LHN3
Hyperfast Rectifier,
60 A FRED Pt® G5



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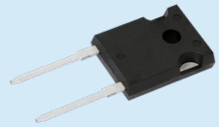

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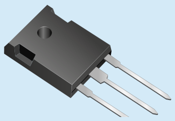

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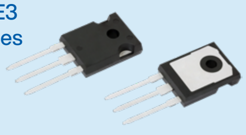

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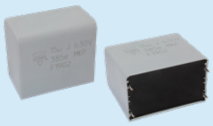

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MUSTAFA DINC has over 23 years of experience in the automotive industry, currently serving as Vishay Intertechnology's Vice President of Business Development Automotive. He joined the company in 1999 as an automotive field application engineer and went on to become Senior Director of Global Automotive Field Application Engineering and EU FAE Engineering. At Vishay, Mr. Dinc has worked with a wide variety of product lines—from semiconductors to passive components—in most automotive designs for applications, including Powertrains, Chassis, ADAS, EV/HEV, Sensors, and more. He has also been deeply involved in product definitions for 48V mild hybrid vehicles, onboard chargers for electric and plug-in hybrid electric vehicles, and DC/DC converters for hybrid vehicles. He holds a Diplom-Ingenieur (Dipl.-Ing.) in electrical engineering and electronics from RWTH Aachen University in Germany.