Power Supplies with Ultra-High Power Density

The pre-competitive research in power electronic systems in ECPE is based on long-term research roadmaps, and has its focus on automotive and industrial power electronic systems. The research activities are focussing at so-called demonstrator projects where new ambitious power electronic systems or sub-systems are developed and realised by leading European Competence Centres. This article describes results of the Demonstrator Programme 'Power Supplies with Ultra-High Power Density'.

Prof. J. W. Kolar, Electronic Systems Laboratory at the Federal Institute of Technology (ETH) Zurich, Switzerland

The power density of power electronic converters has roughly doubled every ten years since 1970. Propelling this trajectory has been the increase of converter switching frequencies, by a factor of 10 every decade, due to the continuous advancement of power semiconductor device technology. The continual development of power electronic converters is characterised by the requirements for higher efficiency, lower volume, lower weight and lower production costs. Power density is one Figure of Merit that indicates the improvement in the power electronic technology (Figure 1).

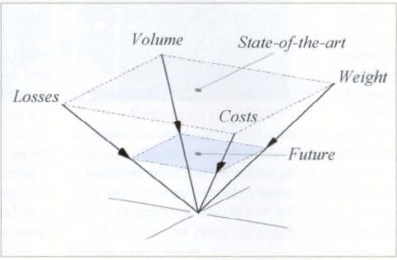

Figure 1: Driving forces for power electronics development

The trend has been for a large increase in the power density over the last few decades and covers the complete cross-section of applications and converter types. The trend line, in the figure below, for industrial systems is differentiated from research only systems, since typically, ten years is needed for the full introduction of a new concept into industry. Based on today's technology there are power density barriers (marked in Figure 2) that could limit the future increases in power density.

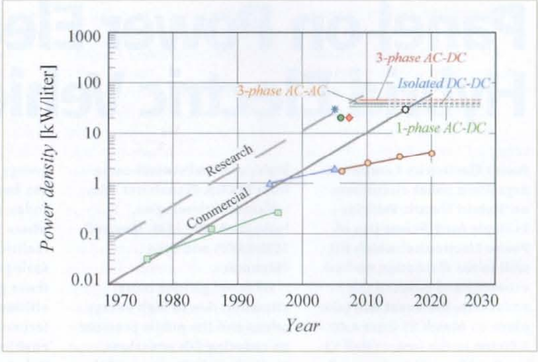

Figure 2: Power density trends of commercial and research systems and density barriers

ETH Zurich has been striving to push towards the power density barriers for both AC/DC and DC/DC converters. Only through considering the complete system, in terms of topologies, semiconductors, modulation, thermal, magnetics and packaging has it become possible to reach power densities of 10kW/litre (164W/in^3). Two demonstrators have been constructed to prove the advanced concepts.

Three-phase 10kW unity power factor PWM rectifier

The three-phase rectifier (Figure 3) is based on a three-switch, three-level Vienna Rectifier topology. It is designed to operate over a wide line-to-line input voltage range of 160 to 480VRMS, with a nominal input voltage of 400VRMS, output DC voltage of 800V and nominal power output of 10kW. The high power density is achieved by increasing the switching frequency to 400kHz, which results in low volume EMI filters and boost inductors, while still maintaining a high efficiency over 95%.

To minimise the switching losses, a combination of a CoolMOS and SiC diodes are used in a custom power module. Semiconductor device cooling is provided by a water cooler, although it is possible to achieve a similar power density using an optimised forced air cooled heatsink. The rectifier is fully digitally controlled using an Analog Devices DSP.

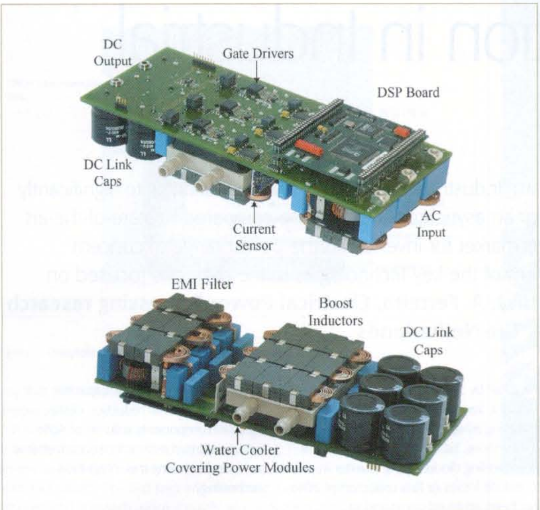

Figure 3: **40 kHz, 10kW/litre, 10kW, water-cooled Vienna Rectifier with dimensions of 250 x 100 x 45mm**

5kW isolated DC/DC converter

This high power density, 5kW DC/DC converter (Figure 4) is based on a series-parallel resonant converter topology. ETH Zurich has developed an optimisation procedure that considers the switching frequency, semiconductor and passive losses, and thermal performance in order to maximise the power density. The optimal operating switching frequency of the converter is in the range of 100kHz. For improving the thermal management a non-standard construction technique is used in which heat transfer components extract the heat from the transformer and conduct it to a second heatsink where it is dissipated. A high pressure fan is mounted between the copper semiconductors and transformer heatsinks. Ceramic capacitors are used for the high voltage and low output voltage bus capacitors in order to reduce the volume. Furthermore, the converter is fully digitally controlled using a TI DSP and Lattice FPGA. The predicted efficiency is approximately 96%.

Figure 4: **3D CAD drawing of 10kW/litre, 5kW DC/DC converter**