Power Supplies with Ultra-High Power Density

ECPE Demonstrator Programme

This article describes results of the "Power Supplies with Ultra-High Power Density" Demonstrator Programme performed by the Power Electronic Systems Laboratory (PES) at the Swiss Federal Institute of Technology (ETH) Zurich.

By Prof. J. W. Kolar ETH Zurich, Power Electronic Systems Laboratory (PES)

The power density of power electronic converters has roughly doubled every 10 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 characterized 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.

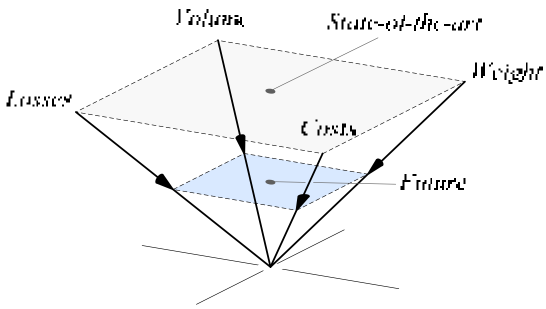

Figure 1. Driving forces for power electronics development

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, 10 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 the figure) that could limit the future increases in power density.

As part of the ECPE demonstrator programme, 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/liter (164W/in3). Two demonstrators have been constructed to prove the advanced concepts.

10 kW/liter, 10 kW, 3-phase Unity Power Factor PWM Rectifier
The 3-phase rectifier is based on a 3-switch, 3-level Vienna Rectifier topology. It is designed to operate over a wide line-to-line input voltage range of 160 to 480 VRMS, with a nominal input voltage of 400

Results of the ECPE Research Programme

ECPE European Center for Power Electronics is driving precompetitive research in power electronics jointly financed from an industrial research fund. Three Demonstrator Programmes have been started in 2003/2004 involving leading Competence Centers in Europe.
Experts from the Power Electronic Systems Laboratory (PES) at the Swiss Federal Institute of Technology (ETH) Zurich will present the Power Supplies Demonstrator with Ultra-High Power Density during the PCIM Europe 2007 exhibition. Presentations will take place at the ECPE Joint Stand 12-466 just vis-à-vis the PCIM Forum.

This Demonstrator Programme aims at the development of an ultra compact isolated DC power supply with three-phase PWM rectifier front end for applications e.g. in variable speed drives, IT systems and process technology. The focus is put on the application of advanced power semiconductors, integration and cooling technologies. Apart from the improved performance (efficiency, power density, size), reliability, EMI standards and cost reduction are considered.

In the first step, a 500 kHz unity power factor, three-phase AC/DC converter has been developed with the objective to realise in hardware a 10 kW/l three-phase PWM rectifier power circuit. The next step has the further objective of implementing a 10 kW/l isolated DC/DC converter.

To achieve the high power density goal, new control techniques and power electronics technology were developed. These developments include a dedicated power module with SiC diodes, an innovative water cooler, high speed gate drivers and current sensors, a low profile ´zero-ripple´ EMI filter, and high-speed digital control. The 10 kW/l rectifier has been experimentally implemented and exhibits excellent performance, and achieves a low THD current with unity power factor over a wide operating output power range.

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VRMS, output DC voltage of 800 V and nominal power output of 10 kW. The high power density is achieved by increasing the switching frequency to 400 kHz, which results in low volume EMI filters and boost inductors, while still maintaining a high efficiency over 95%. To minimize 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 optimized forced air cooled heat sink. The rectifier is fully digitally controlled using an Analog Devices DSP.

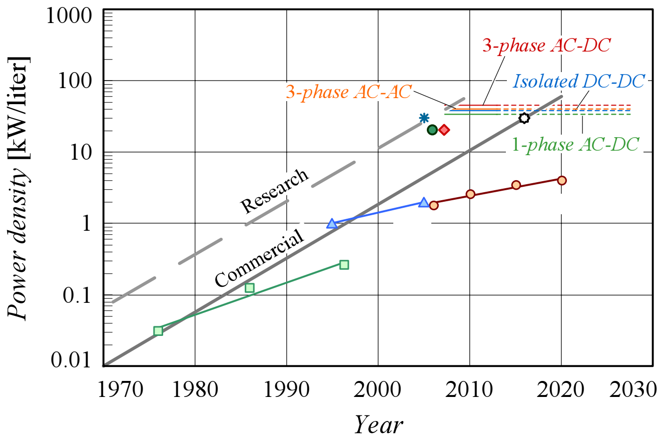

Figure 2. Power density trends of commercial and research systems and the Power Density Barriers.

The high power density, 5 kW DC-DC converter 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 100 kHz. For improving the thermal management of the converter a non-standard construction technique is used in which heat transfer components extract the heat from the transformer and conduct it to a second heat sink where it is dissipated. A high pressure fan is mounted between the copper semiconductors and transformer heat sinks. 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%.

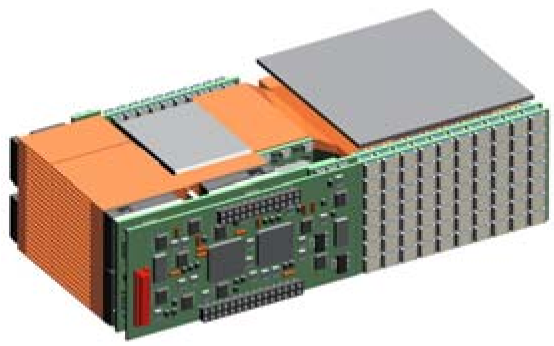

Figure 4. 10kW/liter, 5kW DC/DC converter, 3D CAD drawing

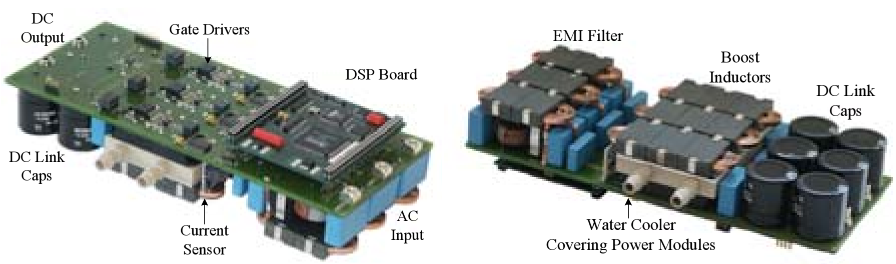

Figure 3. 400 kHz, 10 kW/liter, 10 kW, water-cooled Vienna Rectifier. Dimensions of 250mm x 100mm x 45mm. 10 kW/liter, 5 kW 400 V-48 V Isolated DC-DC Converter

Reference sources

J. W. Kolar, U. Drofenik, J. Biela, M. L. Heldwein, H. Ertl, T. Friedli and S. D. Round, “PWM Converter Power Density Barriers,” Proc. of 4th Power Conversion Conference (PCC’07), Nagoya (Japan), April 2007.

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