System Integration in Industrial Drives

The main goal of the ECPE Demonstrator Program 'Industrial Drives – System Integration' is to significantly reduce the converter size of an industrial drive for an asynchronous machine compared to state-of-the-art commercial units. The best power density on the market for inverters in the power range of concern (~2kW) is about 1kW/l. Thereby, the development of the key technologies in the project is focused on compact design, manufacturability and costs. **Prof. J. A. Ferreira, Electrical Power Processing research group (EPP), Delft University of Technology, The Netherlands**

Refinement of the currently employed construction and system integration methods might lead to some incremental improvement in the power density, but in order to increase the power density a few folds, novel and unconventional approaches are required. It is envisaged in this project that this goal can be achieved by pursuing the two concepts hybrid integration of power electronics and advanced thermal management. The demonstrator program is currently in its last phase, where the final demonstrator is being designed and built.

Integrated power modules

Benefits of integration in power electronics are manifold: it is a means to achieve compact products, reduce the number of construction parts in an assembly and thus, decrease the total cost, increase reliability by reducing the number of interconnections in the assembly etc. Since a typical power electronic assembly contains a large diversity of components, monolithic integration in the way that it revolutionised microelectronics is not feasible due to fundamental, manufacturing and economic limits. Therefore hybrid integration is an option of choice.

The converter is broken down into sub-circuits based on power level and heat density and each sub-circuit is manufactured in suitable technology. These sub-circuits are referred to as Integrated Power Electronic Modules (IPEMs). In this project, the converter is broken down into three IPEMs.

The Ceramic IPEM has a planar profile and makes use of the established power module technology base and contains the high heat density semiconductor power devices assembled on a ceramic DBC substrate. State-of-the-art power module packaging technologies from the industry partners (such as EasyPack by Infineon and MiniSkiiP by Semikron) that allow for small footprint, low profile IPEM necessary for achieving a high power density are used. Furthermore, SiC diodes are used as the freewheeling diodes in the inverter in order to reduce losses (a loss reduction of 30% has been achieved compared to Si devices).

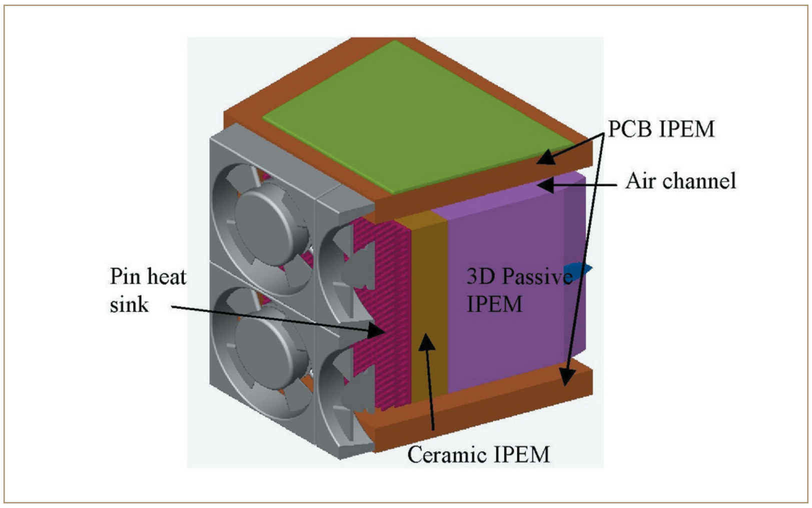
The planar PCB IPEM contains the auxiliary power supply, the electronic control circuitry and the gate drive circuitry assembled on a printed circuit board using PCB integration technologies for miniaturisation and low profile.

The 3D passive IPEM contains the large passive components of the converter such as the low pass filter and EMI filter. Due to the requirements for energy density, which implies volume, this IPEM makes use of the third dimension. Compared to the previous two IPEMs that use state-of-the-art technologies, this IPEM needed new integration concepts and is one of the main focuses of the project. The key technology utilised in this project is electromagnetic integration of passives, namely electromagnetic integration in electrolytic capacitor technology. A total reduction of the passive components volume of 40% compared to the benchmark converter is achieved by using this integration technology.

Advanced thermal management

Based on a review performed in the initial stages of the project, the volume occupied by heatsinks and air in commercial units exceeds 50% of the total volume. A different thermal management approach is needed to achieve a significantly higher power density, while keeping the components operating in their allowed temperature range. The approach taken in this project is based on the concept referred to as integrated converter housing (I-housing) which is an aluminium casing that contains the three IPEMs, is forced air cooled using a fan and serves as a heat collector and a heatsink for the three IPEMs. The overall shape and the texture/profiling of the surfaces is to be designed so that the heat is removed in a

Figure 1: 3D layout of the integrated drive converter



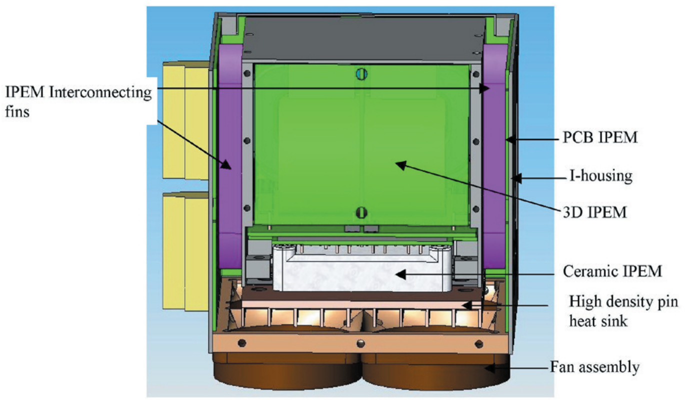


Figure 2: Complete assembly of the integrated drive converter

way that the components of the IPEMs will operate at their desired temperatures.

A number of I-housing concepts, differing in shape and profile of the I-housing as well as the type of air flow, were investigated. The concepts were evaluated on the basis of the heat removal effectiveness, shape complexity and ease of manufacturability. The first step in determining the concepts viability was an experimental approach, since a purely analytical approach was too time-consuming due to complex geometries and complex air-flow. Thermal mock-up structures of two concepts were built and the heat transfer was simulated by means of power resistors excited with the amount of heat predicted to be dissipated in each IPEM. Both were proven feasible with the maximum temperature rise under the full load excitation below 50°C, which means that with the maximum ambient temperature of 50°C the components still operate below their maximum allowed temperatures.

The concept referred to as the Turbine concept is chosen to be pursued further due to its simpler shape and manufacturability. In the next phase, a detailed thermodynamic and thermal modelling was performed, which resulted in a complete I-housing design. Experimental evaluation showed a good correlation between the designed and measured values of temperature rise. Figure 1 shows the cross-section of the system and the prototype of the I-housing.

Ease of assembly in manufacturing is of great importance for any new technology demonstrator or product as this significantly influences the cost and therefore the chances of the demonstrator becoming a successful product on the market. Each of the three modules, the Ceramic IPEM, the 3D IPEM and PCB IPEM are self-standing units that are plugged into each other to make the system. The electrical interconnections between the IPEMs are based on PCB connectors of different types and shapes. This allows for a simple plug-in principle assembly of the system. Figure 2 shows the cross section of the complete assembly, with the three IPEMs, I-housing and interconnecting structures.

Future vision and scope

The goals of this program are to lay the ground work of a new generation of technology that will give the European power electronics industry a competitive edge by introducing a new system integration and thermal management approach that allows for achieving very high power densities in air cooled systems, a few folds higher than that of the state-of-the-art products on the market. The approach is not limited to industrial drives and can be applied to any power converter in a few kW power range. Secondly, by filling the existing gap of integration technologies for hybrid integration of power electronic circuits, in particular technologies for integration of large passive components. By using the ECPE network, special technologies are being developed that can be used in industrial drives and also other applications. Thirdly, by developing an integrated design methodology that takes into account electrical, thermal and spatial issues of a power converter.

Only in this way, the ever-increasing demands for compact, efficient and reliable power converters can be successfully integrated into the system.