ELECTRONIC ENERGY PROCESSING AS ENABLING TWIN FOR INFORMATION PROCESSING

by Daan van Wyk

The continuous growth of information processing systems depends on the supply of reliable, clean power to these systems. The present generation of power electronics technologies will not be able to meet the future challenges if the trends are merely extrapolated. Integrated electronic power processors represent the required paradigm shift in the entire approach to future power electronics technology.

For its very survival, our 21st century society has become entirely dependent on the enormous information processing capabilities that we have developed. Information processing has diffused into all activities of everyday life and work, with information networks the main enabler. The fundamental electromagnetic nature of information processing implies that only energy in electromagnetic form can power this worldwide capability.

Also, the continuous decrease in electrical energy per bit of information processed has not led to a reduction in the required electrical power, since the rate of processing and the growth of processing capacity has fuelled an exponential growth in electrical power for this purpose—as evidenced by the hundreds of megawatts going into data hotels in many areas. It is this power hunger of the information processing networks, as well as the requirement for electromagnetically clean and ultra-reliable electrical power, that has made it clear that the only viable long-term solution is to use electronic energy processing (power electronics) to deliver this energy.

The use of electronic energy processing has to enable much higher energy efficiency, as well as enable the necessary reliability and electrical power quality. Furthermore, against the background of the ever increasing density in information processing equipment, as well as the requirement for small overall size and portability, the additional requirements of much higher density and much lower profiles for the power electronics used to supply power to the information processing equipment, have developed.

Unfortunately, in the recent past it has also become clear that the existing power electronics technology is not up to this task. Most of the power electronics systems are still constructed in a quasi-discrete technology by interconnection of large numbers of discrete electrical components to achieve the desired functionality – whereas the information processing parts of the systems have long since reverted to integration as the paradigm shift to achieve the necessary density and processing capability. The present construction technology for power electronics does not only make the power electronics solutions too costly, but the existing technology cannot be extrapolated to conform to the required future capabilities and power densities.

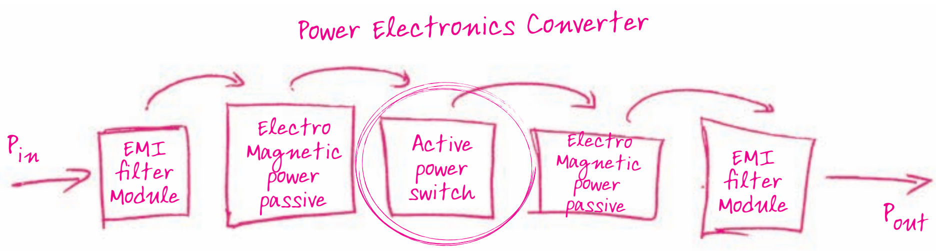
It became clear that a paradigm shift in the entire approach to future power electronics technology would be necessary – and Integrated Electronic Power Processors is such a paradigm shift in the technology.[1, 2]
It is with this objective of researching the development of technology for Integrated Electronic Power Processors that the Center for Power Electronics Systems came into existence in 1998, supported by the National Science Foundation in Washington DC as one of their engineering research centres. It is a five-university centre, with Virginia Polytechnic Institute and State University as the lead university. The Center is also supported by a worldwide consortium of some 80 industries. They contribute financially and give their expertise. → 2 details some outputs and parameters of the Center to give an idea of the scale of the operation.

Although this article specifically concerns integrated power processors for powering information processing systems, the work of the Center is, however, not only concentrated on this area of application. The uses of this new generic technology extend to a multitude of other applications such as electrical drives for industry, drives and power supplies for appliances, applications in automotive and aerospace and the like.

The technology for Integrated Power Processors

The research has shown that for the purpose of technology development, the power processor should be partitioned into sub-modules, as shown in → 1. The power processor is connected to the electrical supply side and the load side by filters for electromagnetic interference (EMI filters) to keep the high internal switching frequencies of the processor from interfering with the supply and the load, enabling clean power. The electromagnetic energy storage functions are integrated into the passive module, while the electromagnetic switching functions that control the actual electrical energy flow are integrated into the active module. Some more detail will be explained subsequently. This partitioning is dictated by differences in materials and especially by differences in thermal management of the different types of module.

The technology developed for the integrated power processor shown in → 1 is based on planar concepts (ease of manufacturing by stacking, very low profiles, good thermal management through large surface areas) and all the sub-modules use the same technology steps, i.e. chemical and plasma cleaning processes, photolithography, large area metallisation by sputtering/electroplating, etching, electrical/thermal contacting by sintering or large area soldering, laser machining and encapsulation technology, with the input materials being ceramic dielectric sheets, ceramic magnetic sheets, semiconductor chips and polymers in various



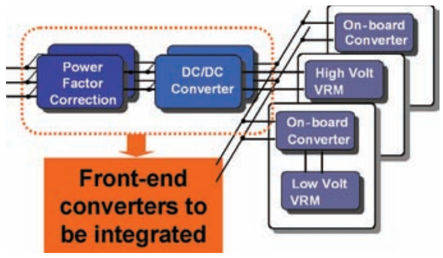
→ 1. Partitioning of an electronic power processor into different sub-modules. [2]

forms. The process development has also kept in mind integration at the process level, achieving the integration of many functions with one parallel step.[2]

An example of integration

As example of one of the many possible applications of the technology for integrated power processors developed at the Center, the integration of the front-end part for a distributed power system (DPS) as used in supplying power to data servers, will be illustrated. A schematic layout of a typical system is shown in → 2. The front-end converter consists of a so-called power factor correction converter and a DC/DC converter in series. Although this is only a small part of such a system, it will illustrate the practical implications.

The power factor correction converter changes the input AC power to DC, while maintaining the required power factor at its input. The DC/DC converter is the link in the DPS chain that provides galvanic isolation. It also changes the input voltage of 300V to 48V, as distributed to the individual data processors. It contains a power electronic converter that operates at high frequency (200 kHz is a typical value in this case) to reduce the size of all the electromagnetic components, such as the capacitors, inductors and the transformer. The circuit diagram for such a 1 kW converter is shown in → 3, where it can be seen that it consists of the cascade of an EMI filter, active switching integrated power electronics converter (IPEM), electromagnetic passive components forming the passive integrated power electronics module (passive IPEM) and an output filter, as shown in the partitioning of → 1.



→ 2. Schematic representation of a distributed power system for supplying information processing systems as loads.

→ 3 also illustrates the sub-module that resulted from applying the developed planar integrated technology, as well as the efficiency increase obtained from this integration. The active IPEM is integrated by using a technology named Embedded Power, as developed at the Center.

The integration of the EMI filter is illustrated in → 4. Note how many discrete passive electromagnetic functions are integrated into this one module, achieving a huge reduction in the number of interconnections that has to be made in assembling the system. The filtering characteristics of these integrated filters are also superior to filters assembled from discrete components. As shown in → 5, the passive electromagnetic functions are successfully integrated into the passive IPEM.[6, 7] Note again the integration of seven inductive functions, the transformer function and the blocking capacitor into one component, reducing the number of interconnections dramatically, as well as reducing the profile and increasing the power density, as indicated by the table in the figure. The figure also illustrates the essential stacking nature of the planar technology developed, enabling effective mass production. However, the nature of these structures (filter IPEMs and passive IPEMs) lead to many electromagnetically coupled layers, leading to involved electrical transmission structure/ transmission line modelling to enable accurate design.[9]

The comparison of the integrated converter to a discretely constructed counterpart with the same ratings in → 5 illustrates the improvements clearly. It is furthermore important that the superior performance version uses technology adapted to mass production.

The thermo-mechanical challenges

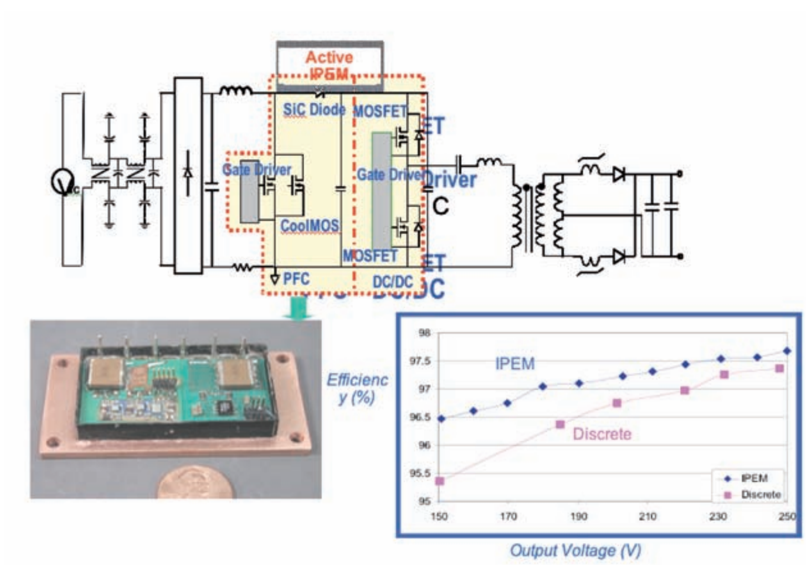
As in all engineering solutions, however, the reduction of the number of system interconnections in the developed integration technology comes at a price. Reference to the examples in → 3 to 5 immediately indicates the large interfaces involved in the integration technology. The required electromagnetic energy handling capacity of these systems, coupled with the maximum electromagnetic energy density in the materials involved, dictates the minimum volume of electromagnetically active material that must be used.

→ PTO

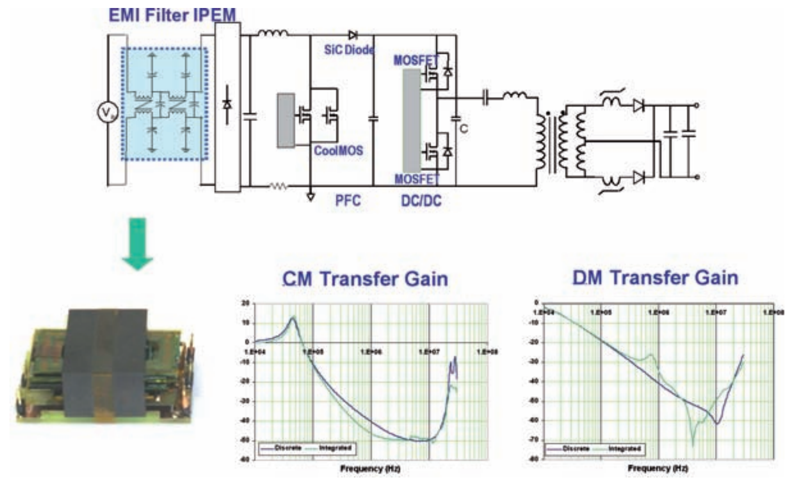
The application requirements dictate the extremely low profiles, so that this leads to the planar technology developed. This consequently translates to large surface areas that have to be coupled electromagnetically and thermally to each other. The materials constituting the technology are on the other hand dictated by the electromagnetic characteristics, i.e. metals, semiconductors, ceramics, and polymers. It will be immediately obvious that these materials have widely divergent thermal and thermo-mechanical characteristics. A fundamental barrier to the technology for power processing is its thermal limitation. In order to achieve power densities as high as possible, the module will be operated at the maximum feasible temperature. These high operating temperatures (in excess of 100°C) and the large temperature variations, coupled with the appreciable differences in coefficients of thermal expansion (CTE), drive the eventual failure of this kind of integrated modules and is also being intensively researched by the Center.

Conclusion

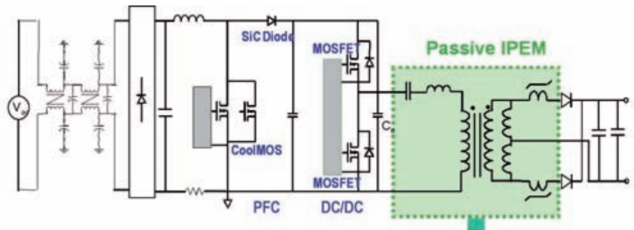
The work that is involved with developing a new integration technology for electronic power processors is vast in extent. The technology has to be researched in terms of materials, processes, electromagnetic functions, thermal characteristics and thermo-mechanical behaviour of the interfaces involved. It is believed that the programme described has led to a viable integration technology that can lead to the necessary paradigm shift envisaged for future powering of information processing systems.



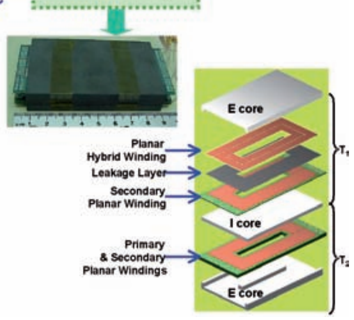
→ 3. *Circuit diagram of a front-end converter (FC) of a distributed power system (DPS), highlighting the part to be integrated and showing the actual 1kW integrated active power electronics module (active IPEM). Note the improved power efficiency.*[5, 8]



→ 4. *Circuit diagram of FC, highlighting the electromagnetic interference (EMI) filter to be integrated (EMI filter IPEM), the actual integrated module and the superior characteristics.*[5, 8]



Parameter	*Discrete*	*Passive IPEM*
Power (kVA)	1.0	1.0
F_s (kHz)	45	45
$L_{m1,2}$ (uH)	45	45
L_s (uH)	2	1.8
C (uF)	2.3	2.5
No. of Components	7	1
No. of Terminals	17	5
Total Profile (mm)	42	16
Total Volume (cm³)	168	82
Power Density (W/in³)	97	200



→ 5. *Circuit diagram of FC, highlighting the electromagnetic power passives to be integrated (passive IPEM), showing the actual module and its internal construction. Note the improved characteristics in the table.*[6, 7]

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