# High Density Power Electronics for Fuel Cell – and Internal Combustion Engine – Hybrid Electric Vehicle Powertrains HOPE

## Project Summary

According to the "Joint Call on component development and system integration of hydrogen and fuel cells for transportation and other applications" the main aim is to develop generic technology and modular systems – built up from components that can be manufactured in essentially similar configurations, but with different qualities, to meet the specific performance, lifetime and cost requirements of the different applications (e.g. FC stacks, Membrane Electrode Assemblies, batteries, **power electronics**)".

The project **HOPE is addressing for power electronics**. It is based on previous EU research projects like the recently finished FP5 HIMRATE (high-temperature power modules), FP5 PROCURE (high-temperature passive components), and MEDEA+ HOTCAR (high-temperature control electronics) and other EU and national research projects. The general objectives of HOPE are: Cost reduction; meet reliability requirements; reduction of volume and weight. This is a necessity to bring the FC- and ICE-hybrid vehicles to success. WP1 defines specifications common to OEM's for FC- and ICE-hybrid vehicle drive systems; Identification of common key parameters (power, voltage, size) that allows consequent standardization; developing a scalability matrix for power electronic building blocks PEBBs.

The power ranges will be much higher than those of e.g. HIMRATE and will go beyond 100 kW electric power. WP2 works out one reference mission profile which will be taken as the basis for the very extensive reliability tests planned. WP3 is investigating key technologies for PEBBs in every respect: materials, components (active Si- and SiC switches, passive devices, sensors), new solders and alternative joinings, cooling, and EMI shielding. In WP4 two PEBBs will be developed: IML (power mechatronics module), which is based on a leadframe technology; and SiC-PEBB inverter (silicon carbide semiconductor JFET devices instead of Si devices). WP5 develops a control unit for high-temperature control electronics for the SiC-PEBBs. Finally WP6 works on integrating the new technologies invented in HOPE into powertrain systems and carries out a benchmark tests. All the results achieved in HOPE will be discussed intensively with the proposed Integrated Project HYSYS where the integration work will take place.

There is a voluntary agreement between the European Commission and car manufacturers that has set a target in terms of average emissions from new passenger cars of 140g of $CO_2$ per km in 2008/2009. The overall target is to reduce fuel consumption because it correlates with CO2 emission. The ultimate solution is the fuel cell (FC) which does need hydrogen only. But FC cars will not be in larger scale series production before 2015. In the meantime ICE-hybrid cars will emerge like the Toyota Prius and the Ford Escape.

There is a need for different power ratings because of the great variety of cars and their grade of electrification. If one assumes that there would be for every car manufacturer and every car model an individual power electronics, it is obvious that this would lead to high cost. Therefore, a standardization is highly needed that is based on "power electronics building blocks (PEBB)" with a certain rated power, shape and terminal geometry. Those PEBBs will be then a mass product which can be manufactured at a reasonable low price.

The project HOPE focuses on power electronics which is needed to supply an E-motor with the corresponding currents and to convert different voltage levels (Fig. 1).

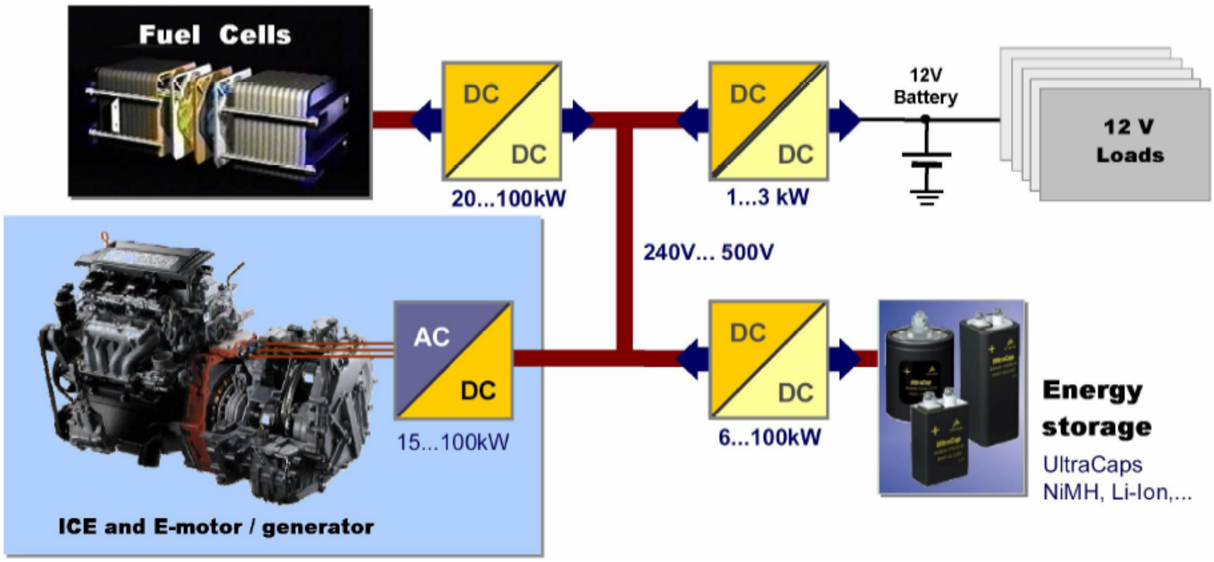

Fig. 1. Block diagram for FC- and ICE- hybrid electric vehicle powertrain.

A necessary multifunctional power electronics converter transforms an electrical energy produced by generator connected to the shaft of the ICE. The electrical energy is stored in an electrochemical batteries and supercapacitors. Simultaneously part of the generated power is used to supply of the on-board low voltage devices. The car breaking energy is transformed into electrical form and is stored in a battery, instead to be dissipated on the break block as a heat. The energy recovery increases significantly an efficiency of the whole system, especially during so called “city cycle”. On other hand, rapid requirement of the additional power (e.g. during car acceleration) can be covered from electrical storages. The electrical power in a hybrid systems is fed or taken from the electrical machine connected with a shaft of ICE. Therefore, the electrical machine becomes a generator or a motor supporting the ICE dependently on the necessity. Thanks to this solution the ICE is designed on the average power instead the maximum power. Application of the smaller and lighter ICE provides the materials and energy needed to its production are saved, but mainly again a fuel economy is increased.

The main requirements of the designed power electronics converter concerns a reduction of the cost, volume, weight as well as the operational reliability of the device. A costs reduction is evident succession of the device standardization, mass production and modular construction for many types of vehicles. A size limitation of the power electronics is mainly connected with smaller expenditures of device cooling. An application of the modern high temperature semiconductors elements (based on the silicon carbide SiC junctions operated in temperature range up to 275$^{o}$C), as well as new construction of the cooling system is a needed solution. A temperature difference between junction and ambient is significantly higher in case of SiC than for the classical silicon junctions, that requires much less expenditures on cooling. A higher temperature operation provides the power converter can by much more effectively exploited, mainly by increasing of the switching frequency of the semiconductor elements, that involves reduction of the passive filters size and costs (especially inductors). Increasing of the switching frequency requires apply of the EMI filters, that is also considered in the HOPE project. Also there is necessary to design a new concepts of the high temperature current sensors. As the device will be integrated, all of the components will be placed near the SiC junctions, and will be thermally stressed, therefore all of them must be thermally resistive. There are planed in the HOPE project, a few tests of the final device and verification of its operational reliability.

**A description of the problems for participants from ISEP in HOPE project**

A participants from Institute of Control and Industrial Electronics are employed to design a concept of high temperature current sensor system (workpackage WP3) and cooperation in range of sensor integration (workpackage WP4). As the temperature range of the current sensors based on the Hall effect (prod. LEM, HONEYWELL, ALLEGROMICRO) amounts max. 125$^{o}$C, they are not to be able to operate in integrated power electronics device based on the SiC elements. Therefore, other physical phenomena (giant magnetoresistance, giant magnetostriction, Faraday's effect, piezoelectric effect and other) are considered to be applied in design of high temperature current sensor. Except the Hall sensor replacing element, the possibility and necessity of high temperature low signal electronics application, needed in a compensatory method, should be considered. A compensatory method is necessary if characteristic of new sensing element is nonlinear. The higher switching frequency of the converter implicates that, the operational band of current sensor must be higher in comparison to classical current sensors with Hall element.

Selection of the technologies, materials and elements to construction of the high temperature current sensor as well as the project of the sensor and current measurement system are the tasks for participants from Warsaw University of Technology. An investigations will be made in wide range temperature change, not observed up to now in power electronics devices. Expected maximum range of temperature amounts 275$^{o}$C and are 150$^{o}$C higher than in classical power converters. Essential problem of this part of HOPE project is to be close to this temperature as its possible. It needs adequate methodology and infrastructure, which will be implemented during an investigation of the current sensor

WUT team includes:

***Prof. Wlodzimierz Koczara*** (MSc, PhD, DSc) - Team leader.
Born in Warszawa, Poland 1942. Graduated 1966 by Warsaw University of Technology (WUT). PhD in 1973, DSc in 1978. Since 1981 till present time he is head of Division of Electrical Drives WUT. Since 1981 till 1986 head of Institute of Control and Industrial Electronics. His main specialties are power electronics and drives, power electronics adjustable speed generation systems, power conditioning. Since 1997 he is member of Executive Council of European Power Electronics and Drive Association. Prof. W. Koczara has international academic experience as visiting professor: Nottingham Trent University, Le Havre University, De Monfort University (Leicester) and Pretoria University, and his international industrial experience as designer/leader of new power electronic generation systems: VOLTAMPERE – South Africa and NEWAGE-AVKSEG – UK. Author of 3 text books. Author and co-author of more than 80 papers and more than 50 patents. Supervised 11 PhD and currently he supervises next 14 PhD students. Member of EPE.
***Prof. Jozef Lastowecki*** (MSc, PhD, DSc)
Born in 1938, Poland. Graduated by Warsaw University of Technology in 1963. PhD in 1970, DSc in 2002. He is specialist on control devices for power electronics systems and electromagnetics. His DSc. thesis, published in 2002 is entitled: *Current Sensors for Feedback Application in Power Electronics Converters*. Research in current sensors used for power electronics converters, carried in his division, are awarded by successful habilitation (DSc) of Prof. Jozef Lastowiecki and by 2 Polish patents and 1 pending patent. He is an author of 2 text books and more than of papers and patents. Member of IEEE.
***Mr Grzegorz Iwanski*** (MSc, PhD)
Born in 1977, Kielce, Poland. Graduated by Warsaw University of Technology in 2003. PhD in 2005. He is specialists on power electronics and variable speed power generation. Author of 20 papers presented on National, International and World Conferences. Moreover, author of 2 papers published in Polish Journal "Electrotechnical Review" of Polish Institution of Electrical Engineers.
***Mr Filip Grecki*** (MSc)
Born in 1981 Gdansk, Poland. Graduated by Warsaw University of Technology in 2005. Currently he is a PhD student since March 2006. His PhD study is directly connected with HOPE project and concerns a current sensor for high temperature applications.

List of Participants

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