Hybrid High Energy Electrical Storage (HyHEELS)

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Abstract

The overall goal of HyHEELS, a project that answers directly to the Joint Call on component development and systems integration of hydrogen and fuel cells for transport and other applications (6.1.4.2.2 of the Sustainable Energy Systems and 4.1.1 of the Sustainable Surface Transport work programmes of the EC sixth framework programme) is to provide an UltraCap energy storage system for the use in hybrid- and fuel cell vehicles, which satisfies all properties necessary to make an integrative component.

Therefore, the development work comprises the optimization of the electric properties of the basic cap, its combination into scalable modules with integrated power balancing within the modules, power prediction and the communication interface with the drive train. The work program consist of two technical work packages for the development of the UltraCap modules and the UltraCap controller, and a work package concentrating on simulation & modelling as well as on testing & evaluation of the developed hardware on hybrid vehicles.

This paper will present the objectives, participants, the different Work Packages, and expected results.

Keywords: Ultra Capacitor, Parallel HEV, Series HEV, Powertrain

I. Introduction

A. Background

Since the deployment of fuel cell cars in the European fleet will constitute a process of decades (it takes more than 20 years for standard functions to reach a 90% fleet penetration) and CO_2 problems are present and demanding, the industry favours solutions with both, future potentials with innovative power trains and the possible realization of short term benefits in combination with state of the art power train technology.

In this regard it is necessary to stress the fact that automotive technology has grown to be more and more complex in the recent years by the addition of a growing number of functionalities. OEMs addressed this challenge by decreasing the production of in-house parts and by the supply of black box like system components, the integration of which still constitutes a big challenge in terms of handling complexity. This is why with HyHEELS consortium considered it to be appropriate to focus on providing an UltraCap storage function comprising all properties necessary to make it an integrative component. This is the unanimous view of both, the supplier and the OEM regarding manageable interfaces.

Therefore the HyHEELS proposal comprises the optimisation of the electric properties of the basic cap, its combination into scalable modules and an integrated power balancing within the modules. By either parallel or sequent combination of these basic modules, it will be feasible for an OEM to realise various solutions that may differ in voltage and/or capacity. For the suppliers it will thus be feasible to cover a broad market with one basic component.

However, it has to be noted that this projects also carries potential and substantial technological risks for the manufacturers of UltraCapacitors because of controversial targets, like low weight – high mechanical stability – high charging and discharging currents. High ambient temperature and extremely dynamic driving profiles cause accelerated aging processes of the cells/modules this is contrary to the life time demands of the car manufacturers.

Given the technological challenges to be mastered in the project the HyHEELS consortium has chosen to cooperate within the framework of a Specific Targeted Research Project. The consortium is of the opinion that forming a STREP provides an ideal vehicle to undertake the common research and development work.

The challenges are further detailed in the S&T objectives below.

B. *State of the art*

A passenger vehicle is one of the most widespread decentralized and non grid connected stand alone systems in our modern society. Its energy supply has to be provided internally by the vehicle itself. For decades, the drive train was powered by an internal combustion engine and the electrical energy supply of the car has been performed by a combination of a generator and a starter battery.

Future vehicles will be powered by either fuel cells in combination with an electrical machine or - in the medium term- by hydrogen powered internal combusting engines, both using pure Hydrogen. These are the most promising approaches for future transportation tasks, as Hydrogen fuel cells do not emit CO_2 provided that the Hydrogen will be generated by renewable energy.

Fuel cells for vehicles will supply energy to the drive train with the electrical machine as well as to the board net with all its loads. One major problem of the fuel cell technology is the degree of the today's technical realization. Fuels cells have still technical problems, which have to be solved. However, there are some additional system limitations. The full performance of the fuel cell will be only achieved if the fuel cell is heated up, e.g. for PEM fuel cells roughly 80 °C. Caused by this during start up phase the fuel cell is limited in power for several minutes. Therefore an additional energy storage system is needed which covers the start up phase, as a reduced function is not acceptable for the customer.

In addition, the dynamics of real load profiles often are faster than the response capability of the fuel cell requiring an energy/power buffer, unless the fuel cell is unacceptably over-dimensioned. In summary, because of these boundary conditions vehicle applications of fuel cells without an energy/power storage system of some kind are impossible.

The energy storage system will be used for restoring of vehicle kinetic energy (regenerative braking) at deceleration, as the energy conversion process of the fuel cell is not reversible. This regenerative braking saves energy and extends the range of the fuel cell vehicle. In some cases, even the size (power) of the fuel cell can be reduced if the user profile is proper and the energy storage system is powerful and strong enough.

Regenerative braking is a well know approach that offers energy savings for full hybrid vehicles (cars up to 12%, van's up to 15%, and buses up to 17%).

At present NiMH- or Li-Ion battery systems will be used for these tasks. However, these battery systems are limited in power at low operating temperatures (-30 to 0 °C). Furthermore, these battery systems can not be recharged with the same power as previously discharged with high power. At normal conditions, brake power is higher as accelerating power. Caused by this circumstances energy will be lost during regenerative braking. This results in reduced functionality of the overall fuel cell vehicle.

All of the above described power requirements may be covered by UltraCapacitors at the lowest cost, compared to battery or fuell cell.

II. HYHEELS OBJECTIVES

As already described in the section state of the art, fuel cells have some basic system limitations. These limitations should be neutralized by powerful energy storage systems. However, standard storage systems could not cover these tasks, especially at lower operating temperatures and for the required number of charge/discharge cycles.

An UltraCap provides much more power at low temperatures and accepts more power during recharge. UltraCaps could be charged and discharged with the same power, even at a temperature working range from -30 to +70 °C and exhibit a superior cycle life. Therefore, the UltraCap fulfils the most requirements on an energy storage systems used in a fuel cell electric vehicle. The only disadvantage is the limitation of the energy content compared to battery storage systems. However, during the start up phase, the fuel cell delivers some energy. As the fuel cell efficiency is roughly 50 % and caused by the fuel cell loads, the fuel cell heats up itself by losses. During this phase, the fuel cell delivers energy, however, only with less power. Therefore, the disadvantage of the reduced energy content of the UltraCap could be eliminated if the start up phase will be managed well and additional information about the UltraCap will be available.

UltraCaps are available on the market. However, there are restrictions with regard to automotive applications when looking on max. voltage and max. working temperature and packaging requirements. As the max. voltage of a single capacitor is only 2.5 V, several capacitors have to be connected in serial to a module if higher supplying voltages are required. This makes it necessary to develop an advanced UltraCap module packaging with optimized thermal behavior, weight and cost. Furthermore, caused by different self-discharge of the single capacitors, the individual voltages of the module will drifting away. Finally, the capacitor module will be mismatched in voltage. Battery systems will be usually overcharged to keep it balanced in charge and voltage. However, capacitors could not be overcharged. Therefore, special charge balancing systems were developed in the past. These charge-balancing systems exchange the energy between the single capacitors in such a manner, that all capacitors achieve equal voltages. Prototypes were already developed in former EC projects e.g. SUPERCAR. However, additional information about the UltraCap module and functions are necessary for a secure operation under automotive conditions. These are:

- capacity determination,
- Overvoltage detection/protection,
- Mismatch detection (unbalanced module),
- Power prediction,
- Maximum single voltage,
- Diagnosis of the module status (ageing, decreased capacity, increased IR),
- Communication to Super Visor.
- Low manufacturing cost, low mass production cost,
- High power density, small volume, low weight,
- Low EMI and acoustic noise, poor noise emissions,
- High reliability, high robustness, fail-safe,
- Good thermal behaviour/tolerance
- Efficient controllable regenerative braking,
- Little maintenance or maintenance free,
- Application oriented lifetime,
- Universal installation.

This information and functions are only achievable if the charge balancing system and the single capacitor voltage measurement is available. In total the following function blocs are necessary:

- Charge balancing,
- Single voltage measurement,
- Diagnosis,
- Power prediction,
- Communications interface.

These functions will be compiled by an UltraCap Controller. The development of this UltraCap Controller with all its function blocs and the definition of the electrical and mechanical interface between the Controller and the UltraCap Module is one of the advanced development targets for the STREP HyHEELS. The improved UltraCap together with the new developed UltraCap controller enables the secure and reliable function of this energy (power) storage system in combination with fuel cells in automotive applications.

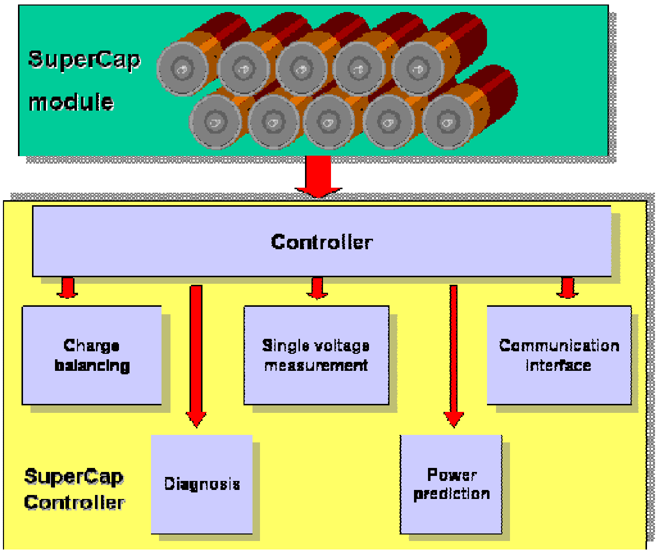

Figure 1: Modules of the UltraCap Controller

The main goals of the HyHEELS may be summarized with the expected performance which must be reached in the next years. The values are given in table 1. In other words, we have to focus on the power density which allows the weight reduction, the increased voltage which allows the serial connection number reduction and the temperature which allows to cover the full range requested by the car manufacturers.

The UltraCapacitor price targets are related to new technology and to production volume. Figure 2 gives a summary of the actual UltraCapacitor development roadmap.

Table 1: Modules of the UltraCap Controller

Year	**Volume** [ccm]	**Weight** [g]	**C** [F]	**ESR** [mOhm]	**Voltage** [Vdc]	**Power density *** [kW/kg]	**Energy density** [Wh/kg]	**Temper** [°C]	**Cycle life** [Millions]
2005 (actual data)	425	525	2600	0. 5	2.5	6	4.3	-45 +65	0.5
2007	375	475	2600	0.35	2.7	12	5.8	-45 +65	1.0
2009 (Project goals)	350	450	3000	0.3	2.85	15	7.5	-45 +70	1.5
2011	325	425	3200	0.28	3.0	19	9.4	-45 +75	2.0

*Power density = V2/4xESR/weight

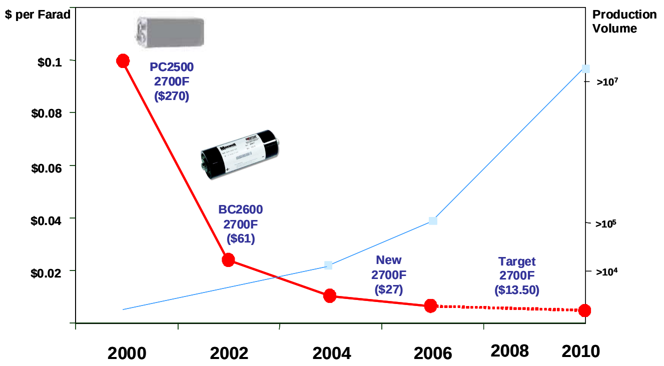

Figure 2: UltraCapacitor development roadmap

The proposal's detailed scientific and technical objectives are thus the result of a thorough analysis of the challenges in the energy supply architecture of Hydrogen fuel cell vehicles. A Hydrogen fuel cell has to be provided with power and energy during start up phase as well as during continuously operation. High power is needed for the acceleration of the vehicle and for high power auxiliary fuel cell loads like compressors. A powerful and reliable energy supply is crucial to fulfill the requirements of the future passenger cars generation, which will be powered by Hydrogen fuel cells.

Sometimes batteries are not able to supply enough power. These could be high power charge and discharge conditions as well as operating at low temperature e.g. -20 °C. UltraCaps could fill up the power gap. The approved UltraCap storage technology is available but needs to be adapted to future automotive Hydrogen applications, satisfying the demands on cost- efficiency, safety and reliability.

Aim of the proposal is the development of an improved cost efficient energy supply concept for fuel cells based on an advanced, powerful UltraCap. This will be achieved by the following development targets:

- Increasing of the max. operating voltage of UltraCaps from 2.5 V to 2.85V. High cell voltage which requires an electrochemical stability of the electrode, the electrolyte and the packaging materials.
- Cost reduction of the electrodes by new production technologies
- Cost reduction of cells and modules by industrialization
- Advanced UltraCap component electrode and packaging. All the material need to have a high electrochemical stability in order to operate the components at a higher voltage during a long time. The component packaging weight must be minimized. A special attention must be paid to the packaging tightness and to the mechanical resistance.
- Advanced UltraCap module packaging with optimised thermal behaviour, weight and cost
- Development of a UltraCap controller, including a single cell voltage measurement and a cell balancing, providing extended UltraCap information to the Fuel cell system Super Visor.

Final goal of the project is the installation of an advanced reliable and cost efficient UltraCap module, providing all necessary information, which enables the integration into the fuel cell vehicle architecture.

Installation, testing, and evaluation of several UltraCap modules will be done, besides bench testing, on existing Hybrid Vehicles like:

- Ford Transit
- Scania hybrid buses (Luxbus)
- Van Hool hybrid bus (A308H)
- Fiat Punto
- Toyota Prius

From these vehicles extensive data has been captured in the past and will be used as baseline. New data will be gathered on the above vehicles with the UltraCap modules integrated, allowing comparative analyses on the road. The mentioned hybrid vehicles are not Fuel Cell based to avoid excessive expenses, operational costs, and to overcome issues with availability. However the above mentioned test vehicles will allow to perform testing and analyzing the behaviour between the drive train, batteries, and converters.

III. PARTICIPANTS

Table 2: Overview of the participants

Participant name	Short name	Country
Siemens AG, Siemens VDO Automotive	SV	Germany
Bayerische Motoren Werke Aktiengesellschaft	BMW	Germany
Centro Richerche Fiat S.C.p.A.	CRF	Italy
Scania CV AB (publ)	SCA	Sweden
Epcos AG	EPC	Germany
Maxwell Technologies SA	MXWL	Switzerland
Flemish Institute for Technological Research	VITO	Belgium
Deutsches Zentrum fuer Luft- und Raumfahrt e.V.	DLR	Germany
Irion Management Consulting GmbH	IMC	Germany
University of Technology of Belfort-Montbeliard	UTMB	France
Warsaw University of Technology (Politechnika Warszawska)	WUT (PW)	Poland
Vrije Universiteit Brussel	VUB	Belgium

IV. WORKPACKAGES AND EXPECTED RESULTS

The work program consist of two technical work packages for the development of the UltraCap modules and the

UltraCap controller, and a work package concentrating on simulation & modelling as well as on testing & evaluation of the developed hardware.

A. *WP1 ultracap modules*

The goal is the development of an UltraCap module that is suitable for automotive applications, which can be fitted with a controller and is subsequently tested and evaluated in vehicle environment. The main obstacle for the widespread acceptance of UltraCaps is the cost issue. Another focus is the packaging and industrial manufacturing of the modules.

B. *WP2 ultracap controller*

The work is focused on the development of an advanced controller for an UltraCap module, which finally ensures the reliable operation of the module, covering the expected lifetime of over 10 years. The UltraCap Controller is necessary to satisfy the future requirements of all automotive applications.

C. *WP3 advanced research, testing & evaluation*

The goal is to confirm and validate the initial requirements by simulations and modelling. Assessment of added value of the UltraCap with possible applications together with environment impact will be reviewed. On the road testing with several types of existing hybrid vehicles equipped with newly developed UltraCap modules will deliver a validation on vehicle level.

The interdependencies of the different Work Packages are given in figure 3.

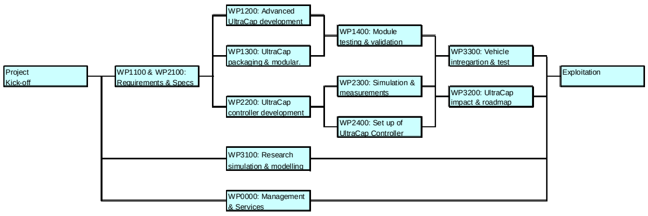

Figure3: The interdependencies of the different Work Packages

V. ACKNOWLEDGMENTS

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