Joint EC/EPoSS Expert Workshop
"Smart Systems for the Full Electric Vehicle"
Brussels
25-26 June 2008

EPoSS Strategy Paper
Smart Systems for the Full Electric Vehicle
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1. Introduction

Growing concerns about public health, global warming and economic safety are calling for sustainable road transport technologies. Electric vehicles (EV), due to their zero local and potentially minor green house gas emissions, are considered the cleanest option. Of even higher concerns are the opportunities EVs provide in terms of efficiency and flexibility in the use of energy. Taking into account that in Europe 73% of all oil is consumed by transport, the introduction of EVs should be a first priority for savings of the most critical source of primary energy.

According to recent announcements of major automakers, both plug-in hybrid electric vehicles (PHEV) and small full electric vehicles will be launched into the market within 2 to 5 years from now.

Interestingly, even broad introduction of EVs should not be an issue for utility providers and grid operators: Estimating the energy consumption of an EV to be about 140Wh/km (e.g. for a mid size vehicle) and taking into account on average 10.000 km travelled per year, it can be stated that 10 million vehicles would require 14 TWh of energy which is just a small fraction of the annual electricity output of a EU member state (e.g. in Italy it would be about 4 %). The use of on–board solar cells could further reduce this percentage.

Leveraging mass use of EVs however is currently facing several weaknesses amongst which are: limited driving range, high cost and overall limited efficiency. For the most part of these issues, solutions may be found at the level of the subsystems for energy storage, electric power train, and energy management. Like demonstrated for the internal combustion engine previously, it can be expected that smart system technologies combining novel microsystems and advanced ICT solutions will be the key enabler for the required gain in performance.

This paper summarizes the findings and strategic recommendations resulting from an expert workshop on "Smart Systems for the Full Electric Vehicle" held on 25 and 26 June 2008 in Brussels. Together other accompanying documents and the slides of the presentations this paper will be accessible from the EPoSS website:

www.smart-systems-integration.org/public/electric-vehicle.

2. Joint EC/EPoSS Expert Workshop

The European Commission and the European Technology Platform on Smart Systems Integration (EPoSS) jointly organized an expert workshop "Smart Systems for the Full Electric Vehicle" that was held in Brussels on 25 and 26 June 2008. The goal was to create a comprehensive vision of the technology needs for the full electric vehicle with a particular focus on Smart Systems Technologies, and to derive strategies that may serve as a roadmap

for automakers, automotive supply industry, academia and public authorities, 60 pre-selected experts representing vehicle manufacturers, suppliers and academic research institutions from 8 different countries took part in this exclusive event.

The agenda consisted of two keynote speeches and five consecutive round table discussions each opened by a dedicated impulse speaker. In addition, experts were given the opportunity to make short statements on the role of smart systems for the topics of the respective round tables. Eventually, following in-depth discussions on the research priorities, a list of foremost general R&D needs was compiled, and possible smart systems technologies were identified and characterized for each of the workshop topics. According to these discussions, more research is needed particularly in the areas of battery management, power electronics and active control of engines and wheels. In addition, ICT solutions for the integration of electric vehicles into the power grid and range extension are considered to be of major importance in the future.

According to a statement made by Antti Peltomäki, Deputy Director General of the DG Information Society and Media, the European Commission will call for proposals on the development and design of intelligent microsystems for electric vehicles in the FP7 ICT Work Programme for 2009-2010.

The paper in hand has been set up in order to respond to this announcement with a roadmap and a set of strategic recommendations. For this, the invited experts were approached again after the workshop and asked to prioritize the lists of general R&D needs and smart systems technologies according to importance and urgency.

3. R&D Needs and Future Smart Systems

The workshop discussions were grouped around five major topics:

- Smart Systems for the Management of Accumulators,
- Advanced Vehicle to Grid Connection Systems,
- Active Control Units for Active Motors and Wheels,
- Intelligent Power Electronic Devices, and
- Smart Integration of Range Extenders.

For each of these topics, a list of five most important R&D needs was established, and rated in terms of urgency by indicating the year when related projects should start. Furthermore, sets of smart systems technologies were identified and characterized by their critical functionalities. Afterwards, these systems were assessed regarding the year of projected availability on the market and regarding the year related R&D should start if the availability requirements shall be met in time.

a) Smart Systems for the Management of Accumulators

Beyond the small energy density of the single battery cell, which today is the biggest roadblock for the EV, the integration of cells into a battery pack is an important issue particularly concerning safety, cost, manufacturability, diagnostics, maintenance, repair and recyclability. Solutions for these challenges may be found in both passive measures (e.g. packaging and thermal management) and active measures for electrical monitoring and adaptive control.

For the latter ones which are the domain of smart systems technologies, the following general R&D needs were identified and classified as most urgent (to begin in 2009): The

development of energy management system architectures and fast active switching elements as well as the establishment of evaluation and testing standards. Furthermore, in the midterm (from 2010), there will be need for solving the safety issues related to the high energy content of e.g. Li-ion batteries, and for battery recycling measures.

The experts suggested a smart system that may play a crucial role for the management of accumulators in the future: An *Advanced Battery Power/Energy Management System*.

It will be required by 2010, should integrate functionalities for the determination of the value of the battery, failure diagnosis, cell equilibration and crisis management, thus providing safety for the full life cycle of the battery including the end of life and advanced functionality such as energy/power routing and ECU communication. Foremost R&D needs to be addressed at the earliest possible instance include the development of an ageing model and measures for the protocol of aging, as well as for energy deploying circuits. Operating at the global level with a choice of accumulators this could be applied to a combination of batteries and supercapacitors, operating at the local level of single batty cells it could provide a new way of extending the battery life.

Key R&D needs are globally the development of charge and discharge algorithms, and locally the application of power electronics for monitoring and switching individual cells. Foremost R&D needs to be addressed at the earliest possible instance include the development of an ageing model and measures for the protocol of aging, as well as for energy deploying circuits. These topics are to be addressed as soon as possible.

b) Advanced Vehicle to Grid Connection Systems

The Vehicle to Grid (V2G) concept adds functionality to the basic charging and metering capabilities of a power plug by allowing bidirectional routing of energy between the battery and the (smart) grid. This way, batteries can be considered part of the grid that in peak times may be available for power regulation. A V2G system has to anticipate and be aware of the user's charging needs and the state of the net, and thus would be a smart system providing both new functionality and new business opportunities at the interface between the car and the energy supplier.

General R&D needs related to V2G systems cover mainly three areas: the development of basic control algorithms and appropriate hardware, research in user acceptance, and the development of new business models at the interface of vehicle and grid including leasing concepts for batteries and life cycle cost sharing between the EV owner and the utility. All these topics are considered being of high urgency, and thus have to be considered at the earliest possible instance.

The experts suggested two smart systems for the V2G connection: An *On-board* and an *Off-board Charging and Metering device*.

The *On-Board Charging and Metering Device* which is needed as early as 2010 will enable the integration of plug-in hybrid vehicles into the grid. It shall be equipped with navigation aids based on GPS and with wireless communication connecting the device to the computers of the grid operator. This will enable the device to identify which utility is running the nearest local power plug. In addition, the On-board Charging and Metering Device will combine metering and charging capabilities with safe and trusty operation and simple power grid awareness. R&D needs (to be addressed early on) are identified to be on charger topologies, contactless charging, increased durability and general reduction of cost, weight and size.

The *Off-Board Charging and Metering Device* will provide full V2G or Vehicle to Home (V2H) functionality and may be supported broadly by the utilities from about 2015. R&D needs refer to public acceptance, privacy protection and smart grids in general.

c) Active Control Units for Electric Motors & Wheels

Electric motors add particular performance to the vehicle, e.g. regenerative and electric braking, full torque at all vehicle speeds, and the opportunity to distribute the power between several motors if wheel motors are used. Making use of these properties requires active and adaptive control measures that take into account the driver's intentions, the state of the road and the state of charge of the battery, i.e. the full range of functions provided by smart systems technologies.

The experts agree that the most urgent general R&D needs are related to weight, torque density and cost efficiency of electric motors and to packaging. They also believe that there is a need for modelling which in the midterm may lead to architectural optimization of electric drive trains as well as to new measures for health monitoring and fault diagnosis.

A smart system that was suggested is an *Intelligent Traction Control Unit for Vehicle Dynamics*. Its functionalities include good torque controllability over a wide speed operating range, high torque density, high efficiency and low cost as well as regenerative braking, anti-lock braking/traction control, and fault diagnosis and tolerance. It is believed that such a system will be demanded by the market as optimization requirements arise after a first round of electric vehicles have been launched, i.e. from the year 2012 on. Foremost R&D needs (to be addressed starting in 2010) for such a smart system cover the investigation of robust traction control techniques, power quality and stability studies of the vehicle's electrical systems, the analysis of safety critical failure modes and the understanding of their consequences, methods and tools for health monitoring and fault diagnosis as well as measures for compliance with EMI/EMC and power train safety standards.

d) Intelligent Power Electronic Devices

Power electronic devices of importance for the electric vehicle include DC/DC converters, inverters for the main drive and the auxiliaries as well as battery chargers and vehicle to grid connectors. Development of these components faces challenges by the high currents and temperatures which they have to withstand. Intelligent solutions for such robustness issues are a particular property of smart systems.

According to the experts, most important and most urgent R&D topics include thermal management (i.e. sensing, cooling, the use of thermally stable materials like SiC), packaging technology, the development of passive components, and the voltage/current rating of semiconductor devices. Additionally, integration vs. partitioning of modules has to be considered.

Three distinct smart system technologies have been proposed at the Joint EC/EPoSS Workshop: *Power Switching Components*, *Power Electronics with Partitioned Intelligence*, and *Local Level Power/Energy Routers*.

Power Switching Components, which will be demanded by the market from about 2012 on, are characterized by their power loss at a particular frequency. Their critical functionalities include reliability and failure management properties like e.g. failure prediction, self diagnosis, shut down process, and self healing capabilities. R&D needs (to

be addressed asap) refer to materials, module development, prediction of failures, degradation conditions, advanced deterministic concepts, fault-supporting topologies, and design for test.

Power Electronics with Partitioned Intelligence, needed from about 2014, will require balancing between intelligent and deterministic algorithms and thus requires a special design.

And, the *Local Level Power-Energy Router* (to be launched in 2014) is characterized by the integration of passive and active devices which may lead to a sophisticated and costly interface. R&D requirements include, e.g. an intelligent strategy for control at local level.

e) Smart Integration of Range Extenders

The opportunity of long-haul driving, even though representing just a minor fraction of the standard drive cycle in Europe, is considered a key functionality for user acceptance of alternative drive trains. Given the range restrictions of batteries, advanced electric vehicles will be equipped with a range extender that recharges the battery if needed. Such range extenders may be a highly-efficient internal combustion engine or a fuel cell possibly assisted by solar panels. Managing the efficient use of the range extender, one has to take into account various parameters including the state of charge of the battery, the driver's intentions, the traffic situation etc. Thus it is calling for smart ICT solutions.

Most important and urgent R&D needs associated to the integration of range extenders are ICT based solutions for energy storage management and strategies for integration. In view of the two most apparent range extender technologies, R&D related to plug-in batteries and to effective internal combustion engines (taking into account exhaust standards) are required. Generally, effective use of range extenders requires information exchange on the availability of power.

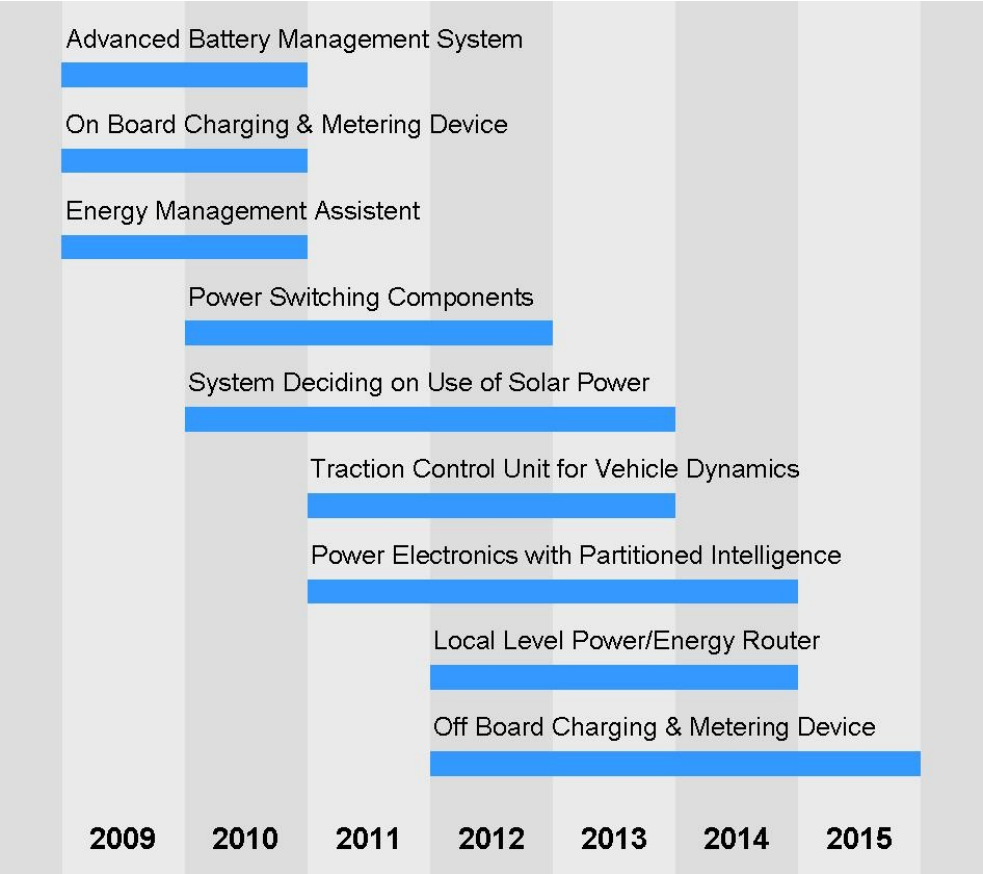
As stated by the experts, smart systems playing a role for the integration of range extenders into the EV are the *Energy Management Assistant* and an *On Board System Deciding on the Use of Solar Energy*.

The *Energy Management Assistant* aimed at minimizing energy consumption in regular use (to be needed from 2010) should have energy routing capabilities and should be aware of availability and limitations of power. Other key functionalities span a range from a HMI based trip planner (allowing e.g. the alteration of plans) to thermal control of the internal combustion engine and its after treatment devices. R&D is required particularly in the area of controller topologies, interface parameters, data management and the application of fuzzy logic. Furthermore, some research on assessment criteria (NEDC) is needed. Given the early market demand, R&D in these areas should start as soon as possible.

The *On Board System Deciding on Use of Solar Energy* is a system that will be called for as soon as solar cells can be used on board the vehicle, i.e. probably in about five years from now for the first massive commercial introduction. An interesting functionality would be a direct link of the solar cells to the grid, and in terms of life cycle considerations, it would be good to match the lifetimes of solar cells with those of the electronics. R&D is required particularly in the domain of non-planar solar cells that can be applied to the car, in the area of electronics integration and in general strategies for the use of solar power asking e.g. what to charge, the battery or the supercapacitors. Research projects on these topics should start asap.

4. Smart Systems Roadmap

Summarizing the detailed discussions on smart systems technologies enabling the full electric vehicle that were reported above, the following roadmap can be drawn. The indicated time frames span the entire R&D process starting from early research addressing the key enabling technologies to the launch of a system prototype.



5. Conclusions

Summarizing the workshop discussions, it can be stated that Smart Systems Integration is considered a crucial technological path towards electric mobility. The key functionality assigned to Smart Systems in a full electric vehicle is the adaptive and context-aware routing of (mainly electrical) energy and power. It is the major requirement that all application fields considered have in common: the management of accumulators, the interface between vehicle and power grid, the motor control, the DC/AC conversion, and the gain of driving range.

Examples of such Smart Systems for the full electric vehicle that were identified at the workshop include: cell monitoring systems for batteries and supercapacitors, charging devices for the vehicle-to-grid connection, torque control units, power switches, and energy management assistants.

According to the experts, foremost R&D needs related to Smart Systems are seen at both the subcomponents level and at the level of system integration. Regarding subcomponents for actuation, challenges are, e.g., semiconductor devices for switching with high power/temperature capabilities. Therefore, research will have to address innovative circuit technologies and the proper choice of materials like GaN and SiC. At the level of sensors, devices that determine the state of charge, health, and function of accumulators, even of each

single cell therein, will be required. Such systems may be based on local measurements of current, voltage and temperature. Regarding the diagnostic and predictive capabilities of Smart Systems, models have to be developed, e.g. for battery ageing, failure prediction, management of energy/power demand and availability, and both deterministic and intelligent algorithms have to be derived. Major system integration issues are related to thermal management of power circuits and motors, operability in harsh environments, and the circumstances of bidirectional energy flow. Advanced cooling measures, robust packaging and intelligent interfaces between the vehicle and the grid or between a choice of power sources (battery pack, supercapacitor bank, plug-in battery, ICE range extender and solar cells) and the motor will deserve particular attention. Overall R&D priorities include the reduction of cost, weight and volume, as well as the gain of safety, reliability, and electromagnetic compatibility. According to the experts, there is also need for secondary research in safety, user acceptance, privacy protection, business models, physiological compatibility and assessment criteria.

Beyond the topics discussed at the workshop, it may be expected, that Smart Systems play the role as enabling technology for other important aspects of electric mobility, too. For example, they may provide efficiency gains at the level of auxiliary functions like air conditioning or vehicle lighting. And, one could also envisage Smart Systems providing novel active safety solutions for the future road transport based on lightweight vehicles.

It can be stated that smart systems will enable basic functionalities of the electric vehicle like energy management, charging and metering, and battery monitoring and maintenance. Therefore, R&D on these topics should start as early as possible. Other functionalities like traction control and advanced power/energy management may significantly enhance the performance of electric vehicles and thus define R&D topics for the mid-term. Finally, smart systems are expected to play an enabling role for the future of advanced accumulators, power grids and range extenders, particularly for the routing of power and energy at the interfaces between those components.

6. Recommendations

From the results of the Joint EC/EPoSS Expert Workshop on “Smart Systems for the Full Electric Vehicle” the following three recommendations for R&D funding priorities can be derived:

a) FP7 ICT WP 2009/10: Call for “Smart Systems for the Full Electric Vehicle”

According to the announcement made by the Deputy Director General of DG Infso, Antti Peltomäki, at the workshop, the European Commission will call for proposals on “Smart Systems for the Electric Vehicle” within the ICT work programme 2009/10. In view of the discussions at the expert workshop it can be stated that a call with the following content would meet both the most urgent R&D needs related to the electric vehicle and the plans of the major players in the automotive and supply industries: Smart systems enabling the full electric vehicle (a) by providing aware, caring and robust means of power and energy routing between accumulator cells, battery packs, motors and grids, (b) by applying adaptive control to electric motors and wheels, and (c) by actively enhancing the safety of road transport based on batteries and lightweight vehicles. The focus shall be on technologies representing a breakthrough in efficiency, simplicity and cost reduction. There is clear potential for one IP in each of these three areas. Therefore, EPoSS suggests including the abovementioned R&D needs as a single topic to the list of application-specific smart systems within the Objective 3.9 of the ICT Work Programme 2009/10.

b) ICT WP 2009/10: CSA "Enabling Technologies for the EV"

The workshop made obvious that there is a tremendous need of coordination between the different players involved in the move towards electric vehicles. Therefore, a Coordination and Support Action aiming at identifying the needs in terms of components, infrastructure and regulations enabling and leveraging the technologies for full electric vehicles is urgently needed. It should bring together automakers, suppliers, utilities, public authorities and user organization like e.g. automobile clubs. EPoSS recommends to call for such CSA at the earliest possible instance, e.g. within the ICT work programme 2009/10.

c) PPP - EPoSS JTI activities: "Smart Systems for Sustainable Mobility"

Smart system technologies that leverage sustainable mobility by providing ICT based solutions for energy efficient, clean and safe road transport are constituting one of the pillars the EPoSS JTI is setting up. Enabling technologies for the full electric vehicle will be of major importance therein as they combine outstanding innovation potential with the opportunity to ensure global competitiveness for one of the most important branches of the European industry. Representing the major players including some of the world's top-selling suppliers and car makers, EPoSS is well set to join the European Commission in a major action for the promotion of R&D on Smart Systems for sustainable mobility. From the discussions at the workshop, it can be clearly stated that one priority of the initiative would be to create the technologies, subcomponents, infrastructures, and regulations required for the mass production and use of electric vehicles in Europe. A particular focus shall be put on technologies enabling intelligent power and energy routing at the interfaces between accumulator, motor, power grid, and range extender.

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