# Smart, Connected and Mobile: Architecting future electric mobility ecosystems.

Ovidiu Vermesan
SINTEF
Oslo, Norway
Ovidiu.Vermesan@sintef.no

Peter Hank
NXP Semiconductors
Hamburg, Germany
Peter.Hank@nxp.com

Lars-Cyril Blystad
SINTEF
Oslo, Norway
Lars-Cyril.Blystad@sintef.no

Roy Bahr
SINTEF
Oslo, Norway
Roy.Bahr@sintef.no

Reiner John
Infineon Technologies
Munich, Germany
Reiner.John@infineon.com

Alessandro Moscatelli
STMicroelectronics N.V.
Milan, Italy
Alessandro.Moscatelli@st.com

***Abstract*—This paper provides an overview on facts and trends towards the introduction of connected electric vehicle (EV) and discusses how and to what extent electric mobility will be integrated into the Internet of Energy (IoE) and Smart grid infrastructure to provide novel energy management solutions. In this context the EVs are evolving from mere transportation mediums to advanced mobile connectivity ecosystem platforms.**

***Keywords-electric vehicle; Internet of Energy; in-vehicle communication; telematics;connected vehicle***

## I. INTRODUCTION

Electric vehicles (EVs) manufacturers are increasingly embedding telematics in vehicles to monitor system failures, road/terrain and driving profiles, location information, energy management, charging station location and vehicle performance, in order to implement vehicle-to-x (V2V and V2I or V2I+I) communication. As the demand for connected electric vehicles and new lifestyles continues to rise, players in the new ecosystem - EV manufacturers, energy utilities companies, mobile network operators and service providers- have to work together to benefit from the rich customer data that is increasingly available in the "automotive" cloud. Doing so will help all constituents offer value added services that can potentially drive revenue growth, reduce costs and improve the bottom line. While in-vehicle connectivity will become ubiquitous, EV manufacturers will offer it primarily through embedded, tethered and integrated solutions that will integrate the information related to energy management and charging of EVs in different places (i.e. residential buildings, charging stations, large parking facilities, etc.) using a combination of renewable and purchased energy.

Mobile Internet is evolving towards embedded Internet and Internet of Things through enabling technologies such as machine to machine communication (M2M) creating new challenges and opportunities to the automotive industry.

There are significant business and economic motivations for mobile network operators and equipment manufacturers to invest in developing the technologies for the electric mobility ecosystem services. In this context the activities are focused on the development of new technologies that scale with the growth of EVs market, and a broad standardization effort in system interfaces, network architecture, and implementation platforms.

The business models for the different charging options differ due to the different stakeholders involved in the process. The residential charging include the houses with parking and garages where the driver plugs in the vehicle every night/day, while for multi-unit housing the property manager provides charging in the shared vehicle park. An example of sustainable electric mobility ecosystem is illustrated in Fig. 1.

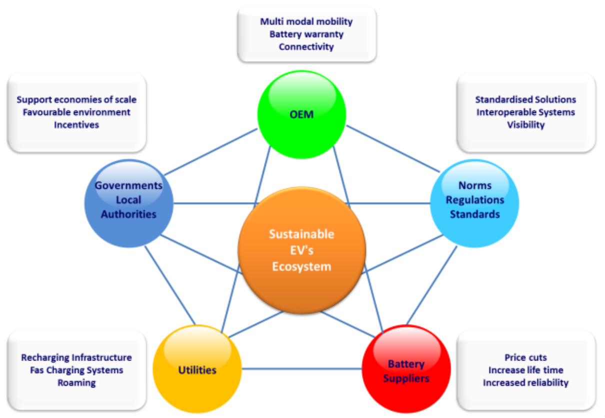


Fig. 1 Sustainable electric mobility ecosystem

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Work charging includes the situations where the employers are offering charging in their premises to their employees and for customers (i.e. for free or subsidized rates as an incentive).

Fleet charging include the professional fleet operators will charge their fleet mostly at their own premises. They might also provide ‘energy-cards’ to drivers to charge elsewhere.

Commercial charging addresses the privately owned or managed enterprise offering parking/charging to customers, most likely for free as incentive (e.g., cinemas, shopping malls, retail chains, hotels etc.).

The public charging are the areas covering the parking/charging that is accessible to the public most likely for a fee. Parking likely to be the key business, and operated by a facility manager (e.g., airports, public parks, stadiums, etc.).

Internet of Energy provides an innovative concept for power distribution, energy storage, grid monitoring and communication. This concept allows units of energy to be transferred when and where it is needed. Power consumption monitoring will be performed on all levels, from local individual devices up to national and international level. Internet of Energy will therefore provide to the consumers a highly reliable, flexible, resilient, efficient and cost effective power supply network, in particular enabling the full deployment of distributed power sources (i.e. small scaled renewable sources) in combination with large centralized generators.

One of the cutting edge capacities of the Internet of Energy will be the storage of energy for later use which is becoming a necessity for the full utilisation of the renewable sources capabilities whose output is intrinsically variable and intermittent. One way to achieve this goal is to incorporate EVs not only as energy consumers but also as energy providers and stores.

The introduction of distributed renewable energy and storage together with transportation electrification and deployment of EVs, allows traditional consumers to not only consume, but also to produce, or store energy.

The implementation of this will allow energy generation peaks to be stored in the batteries of the connected EVs for later usage, in particular during high power consumption demand periods.

A real time monitoring will be essential for both the consumer control of the process on the basis of the real-time energy price, and for the power supplier to restrict or permit to a specified device the access to the power network on the basis of the grid’s local and overall state. During a fast charge, in the timeframe of few minutes an electric vehicle can pull as much power as an entire home consumes during the whole day at full load and this need to be managed, in particular when concurrent activities are occurring.

This new concept will accommodate greater levels of demand side management; generation and storage resources on the distribution system; generation closer to the loads; and possible greater flexibility for islanding and micro grids; and considerably higher levels of intermittent generation, especially on the transmission system.

These changes will require changes to the power system capabilities, and will have a significant impact on the EVs and the "real time" connectivity between the EVs and the infrastructure/Smart Grid in order to monitor and control the reliable operation of the power system in a most economical fashion and provide an optimal energy management solution to individual EV.

In this context intelligent energy management systems will use the information available in-vehicle and on the infrastructure through connection to the Internet to optimize the energy management of the vehicle and make proper decisions about energy consumption. In this way intelligent energy management systems can help to use the energy efficiently depending on the context situation and enables vehicle drivers to plan their trips, manage their battery pack and under specific circumstances, inject electricity from their EVs to power the grid, contributing to frequency regulation and reducing their cost of ownership of the vehicle.

## II. IVEHICLE - INTERCONNECTED VEHICLE

### *A. In-vehicle Communication*

The powertrain of EVs is implemented using several electric motor topologies that form the basis for electrifying the driveline. The topologies include a single electric motor, an electric motor in each of the steering wheels, a motor for each rear wheel and one motor per wheel [1]. By 2025, OEMs will produce a wider range of drivetrain technologies in order to serve the different usage patterns and mobility behaviours.

The EVs are using the electrical energy stored in batteries or another energy storage device. While an electric vehicle's power source is not explicitly an on-board battery, EVs with motors powered by other energy sources are generally referred to by a different name: an EV powered by sunlight is a solar vehicle, an EV powered by fuel cells ($H_2$) is a FCEV and an electric vehicle powered by a gasoline/gas/diesel generator in addition to the electric motor is a form of hybrid electric vehicle (HEV).

The battery modules used today are based on Lithium Ion (Li-Ion), due to considerable improvement in the energy density values; while new energy source architectures are proposed to use several energy sources - hybrid storage systems.

Combining batteries with other storage devices, such as super capacitors allows the inclusion of power electronic converters at the storage energy level and make possible to decouple the power (acceleration, braking mode) and energy (cruise speed) functions of storage, providing lower power levels in batteries, and improve the energy management efficiency in the storage system [2].

The EVs generation 2 focuses on developing the integrated EV concept, while generation 3 will introduce the multi-functional architecture and autonomic driving features that are preparing the development of generation 4 which will introduce the value based architecture and seamless integration concepts.

The EVs generation's evolution is illustrated in Fig. 2.

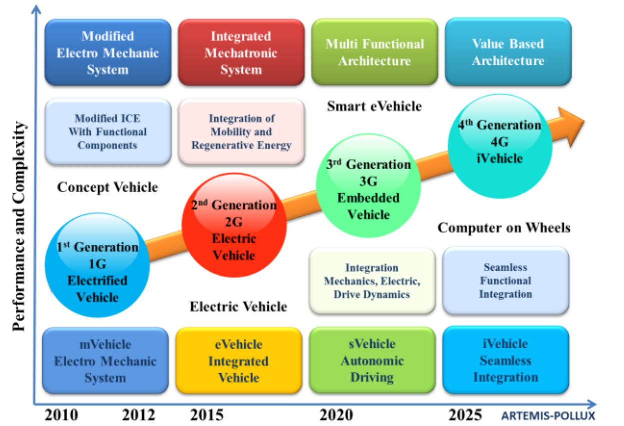


Fig. 2 Electric vehicles generations

The EV traction batteries operate in harsh environments, are submitted to wide temperature ranges, are subjected to hard loading cycles and they have to withstand shock and vibration that may lead to fast aging (loss of capacity and internal resistance increase) [3].

The main factors that affect battery performance are the following:

- State of charge (SOC);
- Battery storage capacity;
- Rate of charge/discharge;
- State of health (SOH);
- Operating temperature;
- Age.

The EV battery pack includes a battery management system (BMS), used to monitor and protect the battery and its users, and to keep it prepared to deliver (or charging) the power demanded by the energy management system (EMS).

The BMS interacts with the braking system, since large current and gradient values are affecting the proper function of the battery pack.

The system uses the recovered energy, monitor the battery SOH in real time and transmit the information via the in-vehicle communication to the vehicle controller and to the EMS. To predict the performance of batteries, different mathematical models can be used.

The EV energy management is considered at two different levels [4]:

- Local energy management that address the optimization for each subsystem, in real time. This process includes mainly the in-vehicle modules and in-vehicle communication layer;
- Global energy management, that address the optimization at system level to coordinate the power flow in each subsystem and supervising the whole system. This process includes both the in-vehicle modules and the infrastructure/Smart Grid and in-vehicle/Internet communication;

The EMS has to consider a variety of real time operating conditions determined by traffic conditions, topography, and driver characteristics. These requirements have an influence on the in vehicle network communication technologies. For next generation in-vehicle networking, the automotive industry identified Ethernet as a promising candidate besides CAN and FlexRay. Ethernet is an IEEE standard and is broadly used in consumer and industry domains. It will bring a number of changes for the design and management of in-vehicle networks and provides significant re-use of components, software, and tools.

Ethernet is intended to connect inside the vehicle high-speed communication requiring sub-systems like Advanced Driver Assistant Systems (ADAS), navigation and positioning, multimedia, and connectivity systems. For hybrid (HEVs) or electric vehicles (EVs), Ethernet will be a powerful part of the communication architecture layer that enables the link between the vehicle electronics and the Internet where the vehicle is a part of a typical Internet of Things (IoT) application. Using Ethernet for vehicle connectivity will effectively manage the huge amount of data to be transferred between the outside world and the vehicle through vehicle-to-x (V2V and V2I or V2I+I) communication systems and cloud-based services for advanced energy management solutions [4].

### B. *Vehicle to Infrastructure Communication*

The EV require efficient solutions for providing vehicle-to-infrastructure communication (V2I) and vehicle-to-vehicle communication (V2V), which are services that allow vehicles to continuously exchange information with the environment through which they pass in order to provide efficient energy management solutions for individual vehicles and users.

The batteries today are the EV component with the highest cost, weight and volume and in order to reduce their effect on the overall cost of the vehicle, novel E/E/communication architectures combined with efficient energy management solutions need to be provided in order to increase range and efficiency.

On the infrastructure side, the electricity grid, EV charge spots/stations and the communication (via wired and wireless channels and the connection to Internet) are the main elements that enable the energy supply for EVs. EVs support a variety of charging modes which range from low to high power charges using AC or DC modes. The EV charging needs can vary depending on specific conditions (i.e. range, charging time, cost, incentives, etc.) and the EV drivers may need to charge the battery up to the 80% of capacity in 10-15 minutes or in 4 hours that are less demanding for the energy system and the batteries of the vehicle.

The variety of charging modes requires different electronic and communication features both at the EV and the charge spot sides. The use of smart metering allows meeting the specific requirements of regulatory scenarios for EV charging. The ISO/ IEC61851 standard describe the charging solutions and the communication requirements. The communication interfaces include Ethernet, serial, Power Line Communication (PLC), GPRS/GSM and LTE.

One of the primary objectives of the IoE project is to develop inexpensive, reliable communication hardware which is able to transport the information across long distances in a secure way. Here, an industry-hardened variant of the PLC appears to be in many cases the technology of choice because of its filed proven ability to transport sensors information and actuators commands over existing low and medium voltage lines, without needing any new wire complex and expensive installation.

PLC is already massively adopted by major energy Utilities, such as ENEL, A2A, ACEA, ENDESA, IBERDROLA, ERDF and many others, to remotely access customer power meters and build an Advanced Metering Infrastructure (AMI). In this "Access" domain, some narrowband PLC technologies with baud rates ranging from few kbps to few hundred kbps have been widely accepted and deployed, as by the facto standards, supported and promoted by leading industrial Associations such as Meters&More and PRIME Alliances, others have been just proposed for new standards evolutions such as the IEEE P1901.2. In the Home Area Networking (HAN) domain, RF technologies like ZigBee or M-BUS, are often used for Energy Management applications, but PLC is also becoming a good complementary technology to assure 100% communication coverage over the entire building. HomePlug standards are the most used PLC technologies in HAN domain with over 65 Million devices installed to date. In HAN domain, by exploiting the broadband frequencies, HomePlug technologies may cover either Smart Energy specific applications (HomePlug GP) with baud rates of few Mbps or consumer applications like Home-Video and Internet distribution inside the house (HomePlug AV/AV2) with baud rates of some hundred Mbps. PLC is also suitable for V2G communication according to ISO/IEC 15118 [5].

The energy management system interaction with the other elements of the electric mobility ecosystem is illustrated in Fig. 3.

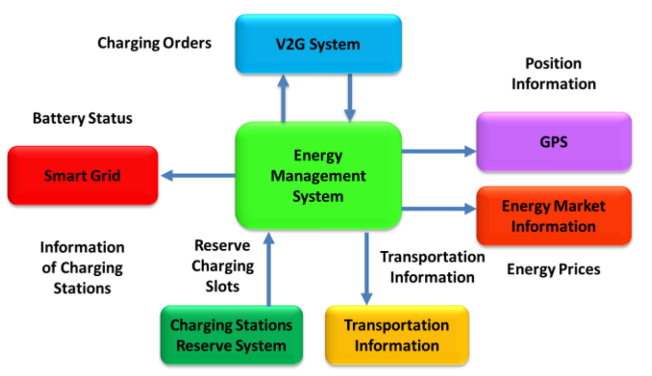


Fig. 3 Energy management system interactions

The availability of traffic information from global positioning systems (GPS), mobile phones, and geographic information systems (GIS), and the communication systems implemented in the vehicle and infrastructure make possible the calculation and predictions of the vehicle propulsion load and energy usage . This information combined with EMS using predictive control schemes have a significant influence on the powertrain design and control. EV charging infrastructure management tools include a single interface to communicate with the charging spot/station independently of the charge spot model, configuration or producer, etc. This is necessary in order to be able to integrate multivendor charging infrastructures that offer a similar web service-based interface to the infrastructure and similar Apps for mobile devices (PCs, tablets, mobile phones, etc.)

## III. Internet of Energy

The Internet of Energy (IoE) concept enables the creation of electric mobility ecosystems where the electric utilities will need to provide incentives to consumers for shifting loads (the vehicle charging is one of them) during off-peak hours. For implementing this, the consumers will need to have the possibility to program the charger to make the battery be fully charged at the scheduled time of the vehicle mission, still optimising the charging rate in order to get the lowest possible energy price. Smart battery charger will be necessary for the implementation of these features.

The IoE concept allows a common network rich in efficient energy, information technology, and communication bandwidth and a radical change in the way energy and information is generated, distributed, and consumed. The integration in a shared physical infrastructure with cables for electric power and wired and wireless connections for communication is the evolution required for electric mobility.

The information and communications systems need the electricity, and the electric power grid of the future needs the information and communications technologies.

The connection of vehicles to the Internet gives rise to a wealth of new possibilities and applications which bring new functionalities to the individuals and/or the making of transport easier and safer. At the same time creating new mobile ecosystems based on trust, security and convenience to mobile/contactless services and transportation applications will ensure security, mobility and convenience to consumer-centric transactions and services. The Internet of Energy concept is illustrated in Fig. 4.

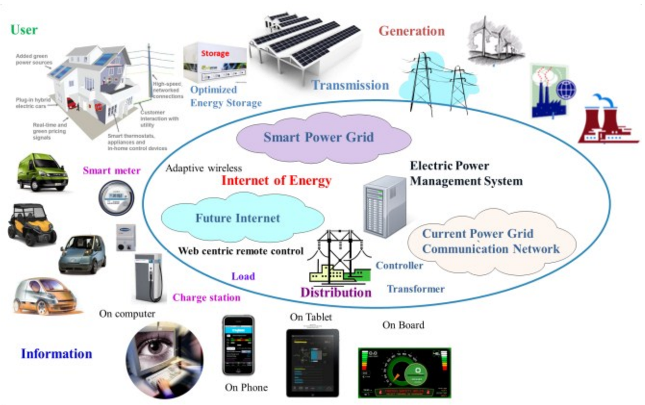


Fig. 4 Internet of Energy (IoE) concept

The implementation of a smart grid is imperative to allow the market success of the electric mobility and to overall reduce costs, increase efficiency, increase consumer awareness, and allowing the network operators to supervise the local and overall load management. The Internet of Energy concept is defined as a dynamic network infrastructure based on standard and interoperable communication protocols that interconnect the energy network with the Internet allowing units of energy (locally generated, stored, and forwarded) to be dispatched when and where it is needed. The related information/data will follow the energy flows thus implementing the necessary information exchange together with the energy transfer.

The relationship between transport, energy, and consumers will change with the introduction of EV ecosystems and new business models like electric vehicle leasing system will emerge.

The communication and information technologies are at the core of the change and the move towards mobility as a service becomes a reality with a new revenue and cost structure in mobility services, where end users pay a subscription fee that includes all ancillary costs such as insurance, maintenance, and refuelling, while the service company bears all of the upstream and downstream risks.

Internet of Energy integrates the interconnected, interoperable networks of control systems and management tools, empowered by sensors, communication pathways and information tools used to support utilities to deliver energy more efficiently. The solutions proposed are interoperable, scalable and flexible, and designed using adopted standards to enable further development of electric mobility ecosystems, services and capabilities.

Building the Internet of Energy will be the answer to a number of the energy challenges related to the implementation of the infrastructure for the electric mobility and the full deployment of the renewable energy production; while the advancements in nanoelectronics, microsystems, embedded systems, communications, control, algorithms, software and Internet technology addressed in the IoE project are the enablers that will make the implementation of the concept possible.


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