Semiconductor technologies for smart mobility management.

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

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

Martin Schulz
Infineon Technologies
Warstein, Germany
Martin.Schulz@infineon.com

Kai Kriegel
Siemens AG
Munich, Germany
Kai.Kriegel@siemens.com

***Abstract*—This paper provides an overview of the latest developments in the development of semiconductor devices for implementation of electronic modules for EVs and HEVs and the implementation of charging stations and the interface with the smart grid infrastructure. The design choices are influenced by the power level of the different applications.**

Keywords-electric vehicle; Internet of Energy; semiconductor technologies; MOS; IGBT;

I. Introduction

The next generation electric vehicles (EVs) will be more energy efficient. The advancements will be mainly due to the developments in power electronics and distributed embedded control systems with the focus of very low energy consumption. Power semiconductors together with high efficiency lightweight motors are critical key devices for electric and hybrid vehicle technology.

Power electronics itself has changed rapidly during the last ten years and the number of applications has been increasing, mainly due to the developments of the semiconductor devices and the microprocessor technology. The key technology for these developments is nanoelectronics. The breakdown voltage and/or current carrying capability, the temperature range of the components, are continuously increasing and materials new developments on silicon, silicon carbide (SiC), and gallium nitride (GaN) will increase power density and power capabilities of the devices and circuits for specific applications.

In EVs and HEVs applications, power MOSFETs are generally used for systems with less than 100 V DC and IGBTs (Insulated Gate Bipolar Transistors) are used in systems requiring voltages exceeding 200 V DC. In addition in some applications ranging from around 100 to 200 V DC, MOSFETS are still used for low power applications and IGBTs are used for high current applications. Bipolar Darlington power transistors, MOS-Controlled Thyristors (MCTs), and thyristors are not used in automotive applications.

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The trends in the IGBT module on increasing their power capacity greatly help to contribute to system downsizing. The optimum combination of the new silicon and new package technologies results the most economical solution for each module ratings.

SiC unipolar devices (MOSFETs) have a potential to replace bipolar IGBT devices in various application fields, including automotive power electronics and very high voltage systems; however wafer- and device processing costs need to be reduced.

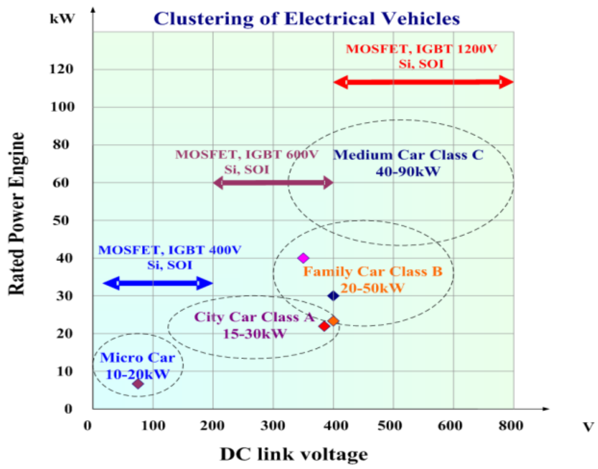

Fig. 1 EV Classes vs. Semiconductor technologies

Future EVs and HEVs will fulfill the requirements of urban and suburban traffic, which differ depending on the vehicle type and size.

The market segments in which electrical mobility will first have significant market shares will range at the beginning from micro/personal vehicles (Class μ: 10-20kW) up to small personal/family vehicles (Class A: 15-30kW) and later to family vehicles (Class B: 25-50kW). Intermediate vehicle segments and high class vehicles segments will require further developments in storage systems thus being expected to come on the market late 2020-2025 [1].

Clustering the EV power and DC link classes vs. semiconductor technologies used to implement the power modules is illustrated in Fig. 1.

Increased demand in lifetime is an on-going trend especially in applications like electric mobility or renewable energies. For these applications the demand in power density is increasing as well, leading to contradicting effects. As higher power densities lead to increased temperature levels, higher temperatures result in higher stress levels thus threatening to reduce the lifetime. Though new developments in power electronic components target to increase the lifetime, thermal management becomes more important to fully exploit the benefits from these modern devices.

Breakthrough technology in electric vehicles brings advancements that provide customers with personal transportation choices never before available.

II. In-Vehicle Semiconductor Technologies

A. *In-vehicle Modules*

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 [2]. By 2025, OEMs will produce a wider range of drivetrain technologies in order to serve the different usage patterns and mobility behaviours.

Electric vehicle architectures drive demand for automotive power semiconductors. Powertrain semiconductor bill of materials of EV/HEV is approximately 2 times higher than the semiconductor content in the internal combustion engine (ICE) vehicles. In general the need on additional power semiconductors area is driven basically from the current density of the high power applications: Higher voltages in the powertrain will reduce these costs for the semiconductor areas in the application.

The main EV functional modules are illustrated in Fig. 2.

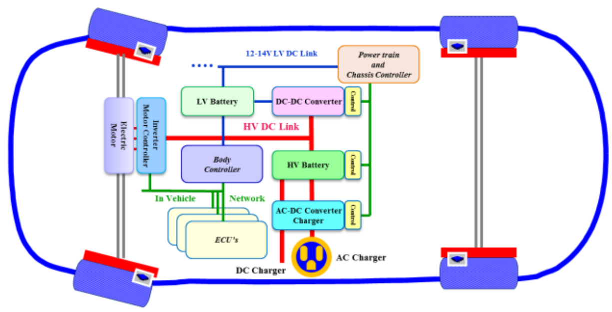

Fig. 2 Electric vehicles main modules

The architecture of the EVs and HEV´s aggregate devices, power modules, processing units, embedded systems, algorithms, mechatronic modules and mechanical parts in five main functional domains:

- Energy (batteries, super capacitors, range extender, grid connection)
- Propulsion (power converters and motor-generators)
- Power and signal distribution (wiring, harnesses and intra vehicle communication)
- Chassis (steering, brake, suspensions and correlated functions)
- Body and board control (HMI, vehicle entertainment, navigation, vehicle to vehicle (V2V and vehicle to infrastructure (V2I) communication)

The development of power electronics technologies, devices, circuits and modules for these functional domains can be clustered in four design areas:

- Power conversion - AC-DC, DC-DC, high power modules
- Power and energy management - Smart battery management, super capacitors, alternative energy sources and e-grid integration
- Power distribution network - Power switches, high current sensors and safety fail mode switches
- Smart dynamic monitoring - Information systems and feedback loops based on Si Sensors.

The electric/electronic system of a vehicle supplies power and enables the flow of information between components and control units.

B. *Charging Infrastructure Modules*

The EV charging systems contain modules that are located on board the EV and off board equipment infrastructure modules. These modules have to adopt the existing power supply infrastructure to provide energy to the vehicle, regardless of the transfer technology. The challenge today is defining a globally agreed implementation of existing infrastructure charging stations and on board chargers. One of the difficulties is the variety of energy distribution systems with different voltages and safety concepts around the world.

The sustainable electrification of individual transport requires standards in charging infrastructure and vehicles. In addition to standard components, charging stations also have operator-specific characteristics, which can depend on the operator's location or business models.

Characterisation of the charging systems are represented by different charging modes

- DC charging (mode 4 - conductive fast and quick charging). DC charging allows almost unlimited power and is the favourite concept for quick charging implementation. The specifications of the off board power source are challenging, especially if it is not dedicated to a certain EV type.
- Wireless charging using an inductive coupler. An inductive coupling is a kind of a high frequency transformer. Therefore there are possibilities to adopt different battery voltages in some discrete steps. The limitation comes from the operating point. At low

power rates efficiency decreases, which makes the system inadequate to top up batteries.

- Mains AC conductive charging. Direct connection to mains provides the freedom to the vehicle design and is restricted to a certain power level. The on board charging equipment is cost sensitive and there is a low initial effort to develop infrastructure. Technical enhancements are necessary to provide a practical and competitive charging facility.
- High power AC charging. Powerful AC sources (three phases) could also be used to charge a traction battery via the traction inverter. The voltage adaption is achieved by an off board mains transformer.

III. Charging Stations and Internet of Energy Senmiconductor Technologies

The Internet of Energy (IoE) concept is built as a robust, accessible and programmable platform that creates new applications and services that create the possibility of moving to renewable energy sources as fast as is feasible and cost effective.

This allows creating services either using the wired or wireless devices with access to Internet by managing key areas like demand response, modelling/simulation, energy efficiency and conservation, usage monitoring, real time pricing, etc.

The IoE addresses the system control, solid state devices to make the enabling technologies for the smart grid available to store and distribute energy produced from solar panels, wind turbines, batteries from the EVs, fuel cells and other energy sources.

To ensure compact design and low electric power loss, the Internet of Energy concept connected to the Electric Mobility necessitates the availability of bidirectional inverters with very high energy densities, excellent efficiency and state-of-the-art thermal management.

Charging an electric vehicle (EV) equipped with a 400 volt technology and a battery capacity of 20 kWh in a time interval of 200 minutes (roughly 3 hours) entails a power rating of about 7 kW – roughly equivalent to an electric oven at full operation. Beyond that, the capability of bidirectional operation is prerequisite to transfer electric energy from the battery of the EV into the distribution grid. The higher the rated power of the charging device the faster is the charging process.

Drive inverters might additionally be used as charging devices. Even more so, it is required that the inverter includes a filter function in order to improve the power quality and cope with locally varying grid codes. A further beneficial feature is the grid stabilization capability. Thousands of EVs can support the grid in a decentralized grid topology [3].

To charge a full electric vehicle within a timeframe of 20 minutes an inverter with a power rating of about 60 - 100 kW is required and a current rating of about 230 Amps becomes necessary. Even more than in the case of the bidirectional chargers, breakthrough concepts have to be developed for unprecedented power density, low-loss architecture and outstanding thermal management in order to minimize the efforts for cooling, losses and cost.

Novel semiconductor technologies on the basis of Silicon and Silicon Carbide (SiC) components are investigated and tested in order to fulfil the highly challenging requirements.

The development of new distributed sources requires the connection to the grid so the excess electricity generated can be stored to be drawn down later.

With this development there is a reduced demand for electricity from a central site that can slow the growth in these plants that today mostly rely on fossil fuels. There is the opportunity to use the excess power generated from these distributed renewable sources later via storage on site or by feeding it back into the grid and with the proper interconnections, there is an opportunity to reduce or eliminate blackouts and brownouts on the massive scale.

The components of the Internet of Energy concept include:

- A layered architecture.
- Advanced energy efficient power modules.
- Smart metering miniaturised embedded systems that store detailed data on energy usage and transmit and receive information, acting as the communications gateway with the edge devices like electric vehicles, residential buildings or home appliances, etc.
- Communications network and communication protocol operating in parallel with the electricity grid that distributes data between all elements of the new intelligent grid.
- Advanced utility sensors and control systems deployed in wires and substations of the distribution and transmission data network.
- Software and embedded software to control the communication process, to present, interpret, analyse and react to the amount of data that is consequently flowing through the system.
- Integration.

The Internet of Energy framework is illustrated in Fig. 4.

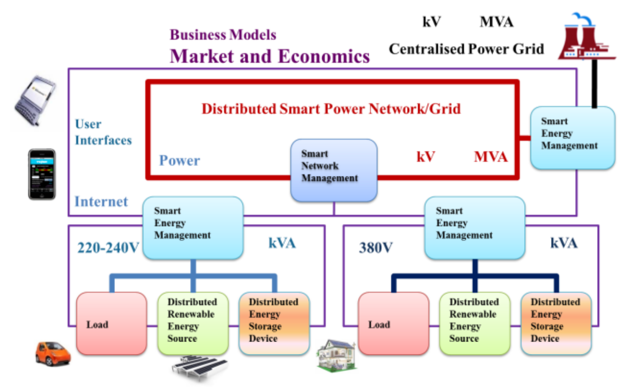

Fig. 4 Internet of Energy framework

Internet of Energy provides an intelligent, collaborative network that links energy producers/sources, with operators and utilities, and ultimately with energy consumers both big and small.

These energy distributed network links the key energy stakeholders, while providing a secure means of knowing where and how much energy is needed at all times.

The IoE concept requires the emergence of standard interfaces and the physical infrastructure to support a way of distributing power and information, requiring a broad range of intelligent devices.

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