From the Vehicle to Grid to the Internet of Energy: towards a smart aggregation of embedded systems

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1 Introduction

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.

In this respect electric vehicles, charging stations, distributed renewable energy production plants and other devices on the network will communicate to each other and, all together, across the utilities gateways, with The Grid and the Internets (of Things, Data, People, Media, Business, Services) for maximum efficiency and resiliency.

To face the problem of energy efficiency, Europe has defined its own strategy for developing a new generation of power grids that will address the societal and technological challenges identifying in the Smart Grid a first priority for its development and competitiveness. In this vision, future electricity markets and networks must provide all consumers with a highly reliable, flexible, accessible and cost effective power supply, fully exploiting the use of both large centralized generators and smaller distributed power sources across Europe. End users will therefore become significantly more interactive with both utilities and energy producers [1]. In this context the forthcoming Smart Grid will have a number of specific features compared with the existing energy grid [2] such as:

- Detecting and correcting incipient problems at their very early stage
- Receiving and responding broader range of information
- Having rapid recovery capability
- Adapting to changes and reconfiguring accordingly
- Embedding reliability and security concepts at the early design stage
- Providing operators advanced visualization aids

In addition the Smart Grid is the overlaying of a unified communications and control system on the existing power delivery infrastructure to provide the right information to the right entity (e.g. end use devices, transmission and distribution, system controls, customers, etc.) at the right time to take the right action.

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The main features of the Smart Grid compared with the traditional centralized grid are listed below and an illustrative example is presented in Fig. 1.

- Distributed control
- Reliable and secure communication
- Controllable transformer
- Distributed energy storage, local battery storage
- Fast fault protection, backup power management and control
- Power devices, network switch
- Efficient end use / Energy management systems
- Energy efficient smart appliances (home appliances, electric vehicles, etc.)
- Smart meters
- Wireless advanced meter infrastructure
- Demand response capabilities / Time of use pricing technology

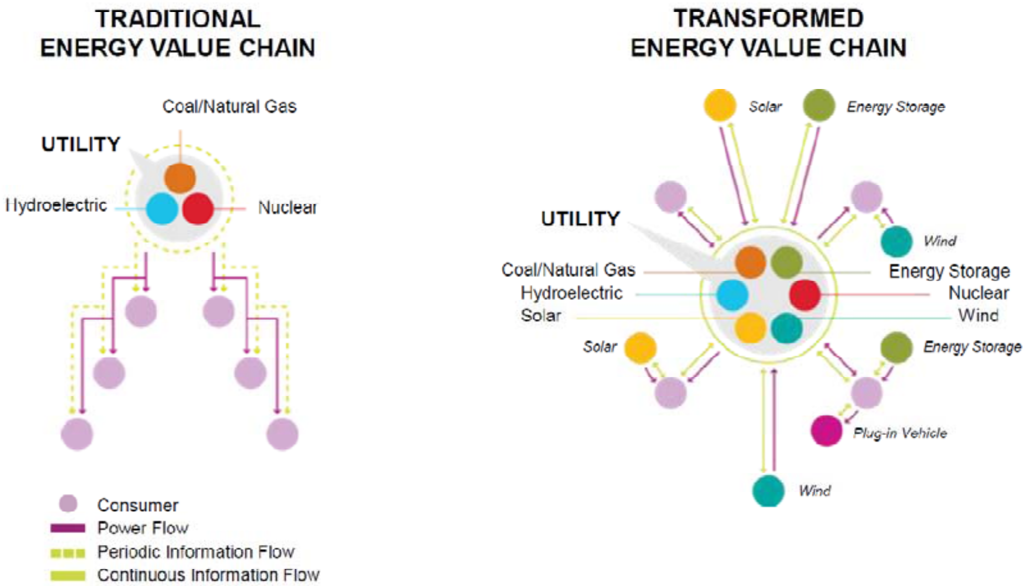

Fig. 1: Centralised vs. Smart Grid (Source: IBM)

One of the main important elements that the Smart Grid will enable is the green energy generation from and full exploitation of:

- Wind turbines
- Solar panels
- Hydroelectric power
- Generation monitoring and optimization
- Generator protection and control
- Renewable power grid interconnection

All the elements presented require a new paradigm for addressing the transmission and distribution of energy by using:

- Grid simulation, diagnostics and visualization

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- Reliability and demand forecasting
- Power system protection and fault detection
- Power restoration
- Power network control systems
- Wireless monitoring and control
- Internet data and information exchange
- Transformers and voltage management
- Energy storage systems (batteries)
- Distribution management systems
- Network management systems

Based on these assumptions the Smart Grid can be defined as a system that optimises power supply and delivery, minimizes losses, have self-healing capabilities and enables next generation energy efficiency and demand response applications. The Smart Grid entails an open standard for communications with devices - both transmission/distribution and end use devices - advanced metering infrastructure, two way communications between a power electric utility and its customers, and smart interconnections to distributed energy resources. The Smart Grid enables the market adoption and interconnection of hybrid electric vehicles (HEVs) and electric vehicles (EVs) that are plugged into electrical outlets for recharging.

The implementation will require concentrated efforts in the direction of standardising the interconnection protocols facing the compatibility issues at the earliest possible stage. Nevertheless the implementation of the Smart Grid concept will bring forward the discussion on the key differences between energy (electricity) and electronic data, transferred on the Internet identifying as a possible solution for implementing the transmission the convergence between the data packet and the energy packet and the abstraction of the data network concepts into the energy network

The main features of energy (electricity) vs. electronic data are envisioned as follows:

- Electricity is mainly generated centrally and consumed locally. Relative long distance transmission is critical and traffic control becomes important. The routing options are usually limited and the bottlenecks are more likely to appear. This will significantly improve in the case of Smart Grids.
- Electricity is not stored at a large scale, which is different compared to the Internet where data are stored and retransmitted. Storage, served as buffers, is an important stabilising factor in a complex system. The lack of storage in the electric power grid makes it vulnerable to all kinds of instabilities.
- The Internet uses a simple best effort packet delivery service coupled with programmable computers at the end points. Quality of service (QoS) is a secondary consideration. For the energy network the main priority for the service network is to satisfy the users' demand at any time. The main challenge for Internet is how to allocate the bandwidth so data packets can be delivered efficiently, while in energy networks the peak demand which can occur at any time is forecasted and monitored for scheduling the generation-transmission-distribution to meet the required demand.

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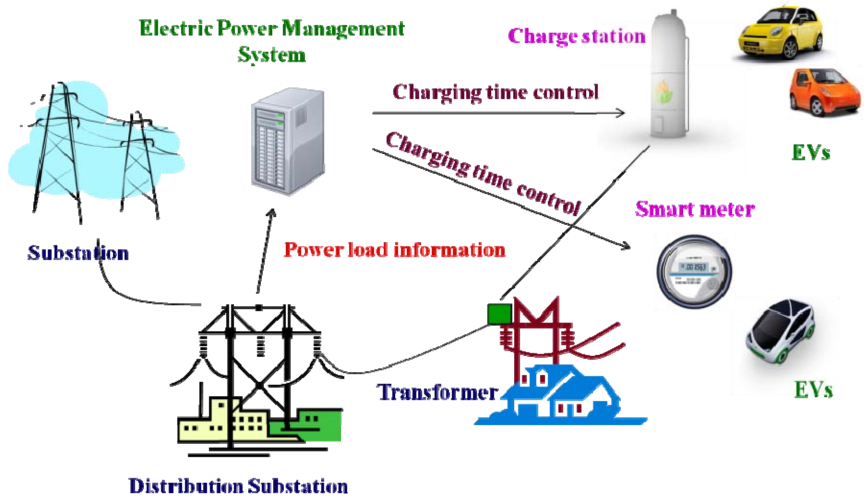

Fig. 2: Internet of Energy power distribution and communication

The ARTEMIS - Internet of Energy for Electric Mobility project's aim is to address these elements, by developing new hardware, software, embedded systems modules and algorithms to enable the predictive control by anticipating future states and demands and by intelligent decision making and energy provision schemes based on the anticipated demand.

2 Architectures

The Internet of Energy project considers demand based autonomous entities consisting of a mixture of different customers and a diversity of business models. These entities will use their influence to maintain the power consumption at the level that will keep the grid stable. The entities will maintain the necessary security at their own level and together they will assure the grid security. A certain hierarchical architecture is considered. In such architecture intelligent agents are used to monitor every load within each entity, forecasting the power consumption of each individual load including EVs charging in different places and taking predictive actions to prevent potential overloads and cascade of faults. In this concept the following elements are integrated:

- Real time control of the energy generation sources' status
- Flexible management of any kind of energy generation sources and sensors (inverters, power meters, temperature, solar meters, etc.)
- Supports for all existing protocols for the connection with both analogue and digital equipment
- Use of multi domain platforms for enabling the collection of huge data volumes while processing rapidly, easily (using common languages) and efficiently (cloud computing)
- Adoption of an open architecture to allow users to manage an unlimited number of energy generation sources' and stakeholders (vehicles, residential buildings, etc.)
- Wired and wireless transfer of data

For implementing such an architecture there is a need of a concentrated effort to develop new semiconductor technologies, sensors, microsystems components, power electronics components, communication circuits based on new communication protocols for wired and wireless data transmission, embedded systems modules for control and monitoring, interconnection to the Internet and communication with the end devices such as electric vehicles, home appliances, etc.

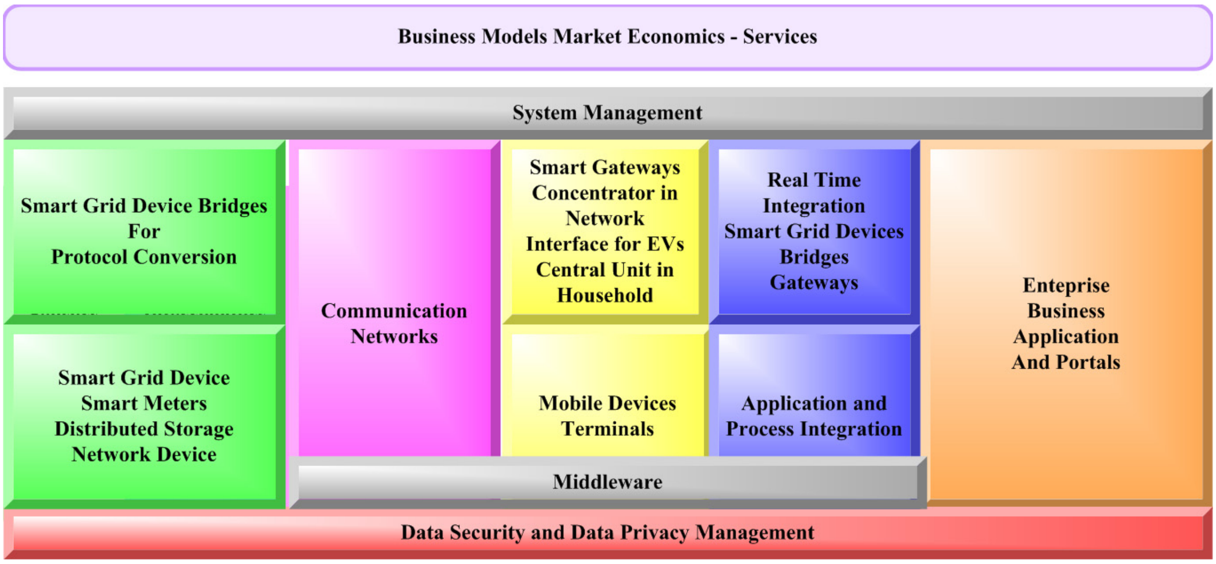

Fig. 3: Technology requirements for different stakeholders in the energy supply chain

These enabling technologies will support the functionalities of the Internet of Energy by:

- Interconnecting the load to power sharing infrastructure
- Bundling communications with energy interconnection - power - communication interface
- Enabling intelligent energy exchange
- Incorporating (optionally) energy generation and buffering
- Scale down to individual loads, e.g. EVs, residential buildings, light bulb, refrigerator, TV, etc.
- Scale up to neighbourhoods, regions, etc.
- Overlaying on the existing power network/grid
- Providing remote services via the internet energy-electronic-services
- Transferring the data via the Internet to smart controller
- Transferring the data from smart controller to individual intelligent power switch (wireless, wired, optical cable)

The electrical energy systems integrated into the Internet of Energy will be based on the technological advances in nanoelectronics, microsystems, embedded systems, communications, control, algorithms and software. From electronic components, embedded systems, computers to data centres and buildings, nanoelectronic advances in radios, processors, embedded systems, storage and networking are enabling and effective embedded sensing technologies used in operational controls. The use of microsystems and embedded system technologies in smart metering, charging and storage modules and the research needs will be presented in the next sections.

3 Smart metering

The real time knowledge of the grid situation, the price, electricity use of the electric vehicles and the charging stations availability, is vital for the implementation of energy efficient policies and the real-time awareness of the maps of the energy usage inside the grid and by individual EVs. In particular the mapping of the EVs requires detailed knowledge about the dominant patterns i.e. the battery status, the driving profile, the driving route, the energy consumption, the charging patterns at home, parking lots/charging stations, the energy exchanged through the grid, and how events (such as disrupted transmission) can impact on it.

New technologies that affect Internet of Energy concept design such as energy storage methods, enhanced smart metering, improved control, and real time monitoring, will be all dependent on the microsystem components and circuits for implementation.

The smart energy meter is one of the key technologies that will be required for implementing the Internet of Energy in particular in the electric mobility scenario. These devices must measure and aggregate cumulative energy consumption and real-time log at different scales, store the values in a digital form, communicate the measurement information using standard protocols over wired or wireless data network. Their intrinsic high-level communication capabilities will allow the utilities to remotely access the smart meters network and get a continuous up-to-date situation which can be used to manage the grid in a fast demand-response scenario.

The energy meter will also communicate with the surrounding infrastructure devices (i.e. “Internet of Things”, for example the vehicle-to-vehicle or the vehicle-to-infrastructure network) or in a vehicle-at-home scenario (i.e. cradled and therefore connected to the high-speed network), to send/get real time pricing, mission history and predictions, status of health data to/from the end user energy consumers.

Smart meters in the Internet of Energy scenario will be embedded in EVs, home appliances, charging stations and will measure many electrical parameters, such as maximum and minimum power demand, current, voltage, and power factor. They will communicate with different aggregators (from the home server to the utilities’ data farms) providing information about power outages.

The energy smart meters will be implemented as an embedded system made of a sensing unit, a microcontroller, a digital signal processing for calculation of additional electrical parameters and a communication unit that allows it to transmit and receive information, through a wired or wireless network. A typical energy smart meter is presented in Fig. 4.

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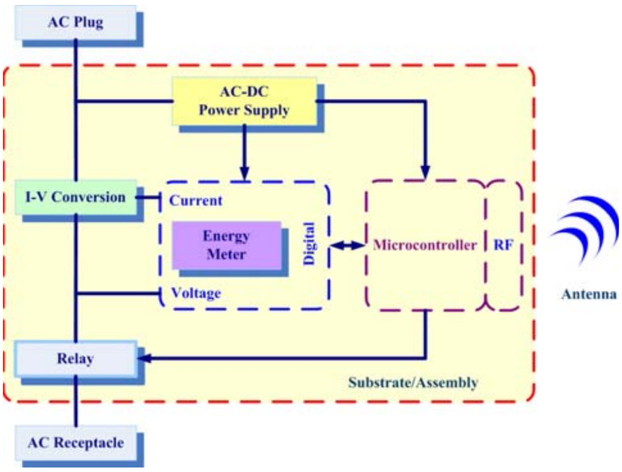

Fig. 4: A typical smart energy meter

The project addresses the development of cost efficient integrated circuits (ICs) for energy measurements including wireless communication using standard protocols to ease deployment and enable smart meters to talk to other smart device via gateways, thus enabling easier demand response and improved energy efficiency.

4 Charging Stations

The electric vehicle has a major impact on electric distribution networks and power generation infrastructure that includes new and radically different practices of applicability and use of the electric vehicle (recharging practices, urban use concept profiles).

A new generation of compact devices for specific metering of energy interchange between vehicle and infrastructure will be developed in the project. Specific protection mechanisms, load detection systems, user identification, vehicle to grid optimal communications protocol, application of new media for user friendly access to electric vehicle related information, and physical media standardization need to be included and will be addressed.

Today the way of connecting electric vehicles to the grid is to plug in the vehicle in a slow charging stand-alone charge point or just use a traditional house plug. There are first attempts to create a billing infrastructure and to use the battery for grid stabilisation. The development of a cost effective and energy efficient bi-directional power flow controller that is capable of fast charging and intelligently controls the exchange of energy between distributed storages, renewable energy sources and the grid, will be a key enabling factor and will be pursued in the IoE project.

5 Storage units

Energy storage and load balancing systems on regional, local, and building levels will become key technologies to better integrate intermittent renewable resources for

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electric vehicle charging. The utilization of the energy storage capacity of electric vehicles batteries in distributed and intermittent energy production requires new ICT solutions where the EV connectivity and software solutions play an important role and will be addressed in the project. Vehicle batteries used as micro-grid energy storage units will significantly enhance the competitiveness of local energy solutions. The project considers various storage technologies such as liquid chemistry based cells through to super capacitors and with a selection of geometries to suit the various expected operational locations; In vehicle, roadside (e.g. as a component of street furniture), at service areas, at home or at the place of work. The work is also taking into account the various charging methodologies. The storage technologies covers mainly the high energy side of the grid applications that includes energy management applications such as load levelling, peak shaving and arbitrage, where electricity storage devices are used in daily cycles and are connected to renewable energy sources and are used in conjunction to electric mobility. These devices can allow as well grid independent operation.

6 Summary and discussions

The Internet of Energy will form a distributed "Grid 2.0", linking all energy stakeholders, and having the following characteristics: two ways transport of power on the power lines provided by the smart distributed grid and information data either on the power lines or on the wired/wireless network already in place with Internet; massive energy storage and distributed generation to help balancing the disparities between supply and demand; fault tolerance and resiliency as the network of intelligent sensors throughout the grid will give us a much clearer picture of how the flow is working. This will also allow the larger participation of the consumers thanks to a bidirectional information exchange about energy use and pricing/billing/incentives finally giving the motivation to change our own behaviours to a more energy-harvesting/saving scenario. Building the Internet of Energy will be the answer to a number of the energy challenges related to electric mobility. The enablers that will make the implementation of the concept possible are the advancements in nanoelectronics, microsystems, embedded systems, communications, control, algorithms, software and Internet technology.

7 References

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