Interactions of large scale EV mobility and Virtual Power Plants

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Abstract- **The complex interactions between electric mobility on a large scale with the electric distribution grid constitute a considerable challenge regarding the feasibility, the efficiency and the stability of smart electric distribution grids. On the one hand, the steadily increasing share of decentralized power generation from renewable sources entails a move away from electro-mechanical generators with huge inertia towards systems with distributed small- and medium-scale generators which are coupled to the grid via inverters. On the other hand, large-scale electric mobility which interacts with such a decentralized grid will have a huge impact on the power generation, storage potential and consumption patterns of a grid. Grid infrastructure simulations which take into account the details of these interactions and which are backed by comprehensive demonstrators may help to shed light on crucial aspects of both energy and information exchange between the traffic and the electric energy infrastructure regime. This will be highlighted by selected topics which intend to shed light on the scope and the challenges inherent in this area of simulation.**

I. Introduction

Smart Grid can be described as an upgraded electricity network enabling two-way information and power exchange between suppliers and consumers. It requires intelligent communication monitoring and management systems, which cannot be implemented without ICT. Around Smart Grid services such as Electro Mobility there will be functionalities that combine both the electricity and ICT infrastructures.

The required changes (towards Smart Grid) in the electric distribution environment bring new challenges to Distribution Network Operators (DSO). The most important technical drivers within the modernization of the distribution network are decreased number of power outages, the quality of the electricity and distribution voltage/frequency. Users have more and more voltage sensitive devices and appliances that could be damaged due to bad voltage quality.

Some parts if not most parts of the distribution network are planned for electricity transfer to one direction only. By introducing Distributed Energy Resources (DER) and electro-mobility the distribution networks system will undergo a significant reconstruction during the time change from passive to active bi-directional network. Bi-directionality raises the question of network protection into a new perspective, since not only the direction of power will change but also directions of fault currents. Also the amount of power electronics will increase for connecting DER into distribution networks which raises the question whether a "grid of inverters" will continue to operate in a stable mode with frequency as the pivotal control variable. All this will require strengthening of the distribution network, which means investments. Distribution network will become very complex needing better automation, measurements, protection and self-healing features in order to maintain or even improve the stability of voltage, current and phase, and keep harmonics and frequency within a safe range. New options like various types of islanding need to be examined as well as the methodologies about how to "reboot" a distributed grid after grid failure. All the above topics, also ensuring basic grid functionality without ICT (e. g. in case of communication failure) will be the objectives of the European Project called Internet of Energy ("IoE") [1].

To do so, the authors have chosen an approach in three steps. The first step is a generalized "IoE building" concept definition (see Fig. 1) which forms the overarching architecture of the four infrastructure demonstrators to be set up within the IoE project. Using these demonstrators, comprehensive tests shall be carried out on the performance of a specific building entity connected to a distributed "grid of inverters" mainly run by renewable energies. Special emphasis will be on the interaction between electric vehicles (EVs), their charging infrastructure and the remaining generators and consumers integrated in such an "IoE building". As within a research project it is generally infeasible to set up "village-size" demonstrators to test the interactions of a multitude of buildings, in the second step the IoE building architecture will be represented by a simulation model of such a building which will then be integrated into existing grid infrastructure models of Siemens. Using this model combination, a comparison between the present status of a distribution grid and the step beyond state-of-the-art (SoA) introduced by the IoE approach can be quantified.

The third step will be to extend the considered architecture in order to simulate the interaction of a whole fleet of electric

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vehicles with the distribution grid of a major Italian city. To do so, a vehicular mobility and communication framework, based on multiple integrated simulation components [2] [3] [4] [5] (including digital maps, charger locations, realistic vehicle mobility and energy consumption models, communication platforms) was set up and used to analyze systems' scalability and performance, emulating virtual scenarios and realizing virtual testbeds for real prototypes of IP-based service platforms' and mobile applications' benchmarking. The information gathered on tests using the IoE demonstrators, or based on Siemens EV and EV battery know-how developed in previously funded projects, are combined to simulate EV fleet dynamics and State of Charge (SOC) for a variable penetration rate of vehicles, in realistically modeled scenarios.

Adding ontology based data storage and processing [6] [7], this EV fleet is managed in such a way that each EV can seamlessly behave either according to a formalized (and reconfigurable) behavioral model, or according to the control provided by a real users-in-the-middle interacting through a smartphone with both the simulated car model and the emulated or integrated service infrastructure. This provides a unique opportunity to benchmark the systems, and validate the user's experience and acceptance, under variable scenarios and generated load assumptions, during the design phases.

II. Managing the interaction of EV and grid - the "IoE Building" Concept

The idea of the "IoE" project is to strongly interweave the use of electric vehicles with the generation and consumption of electric energy from renewable resources. An obvious prerequisite for an efficient "Internet of Energy" will be the availability of as many electric vehicles as possible for energy buffering, especially during those periods of time where there is strong demand or where energy production is far in excess of the average demand.

An example illustrates the power of such a virtual power plant. At present, the yearly amount of initially registered vehicles in the EU is about 13 million. If we assume that all these vehicles are EVs and each EV contributes with a balancing energy of 1 kWh per day, taking into account that the balancing energy of a storage power plant like Limberg II (Kaprun, Austria) is 207 GWh, the balancing energy of these 13 million EVs is equivalent to 23 Limbach II power plants – which is indeed an impressive number.

Charging via power outlet being disregarded, the interaction between EVs and the distribution grid usually takes place via chargers. Whereas simple 1-phase AC chargers are designed to just charge an electric vehicle, the 3-phase AC types for residential use and even more so the fast chargers employed in public areas are designed for bidirectional operation, i. e. they can also feed energy back into the grid, thus acting as interfaces towards EVs' batteries intended as connected buffer storages.

In order to manage the interaction between mobile (EV) and stationary buffer storage capacities and a decentralized distribution grid, the IoE project has developed a generic "IoE

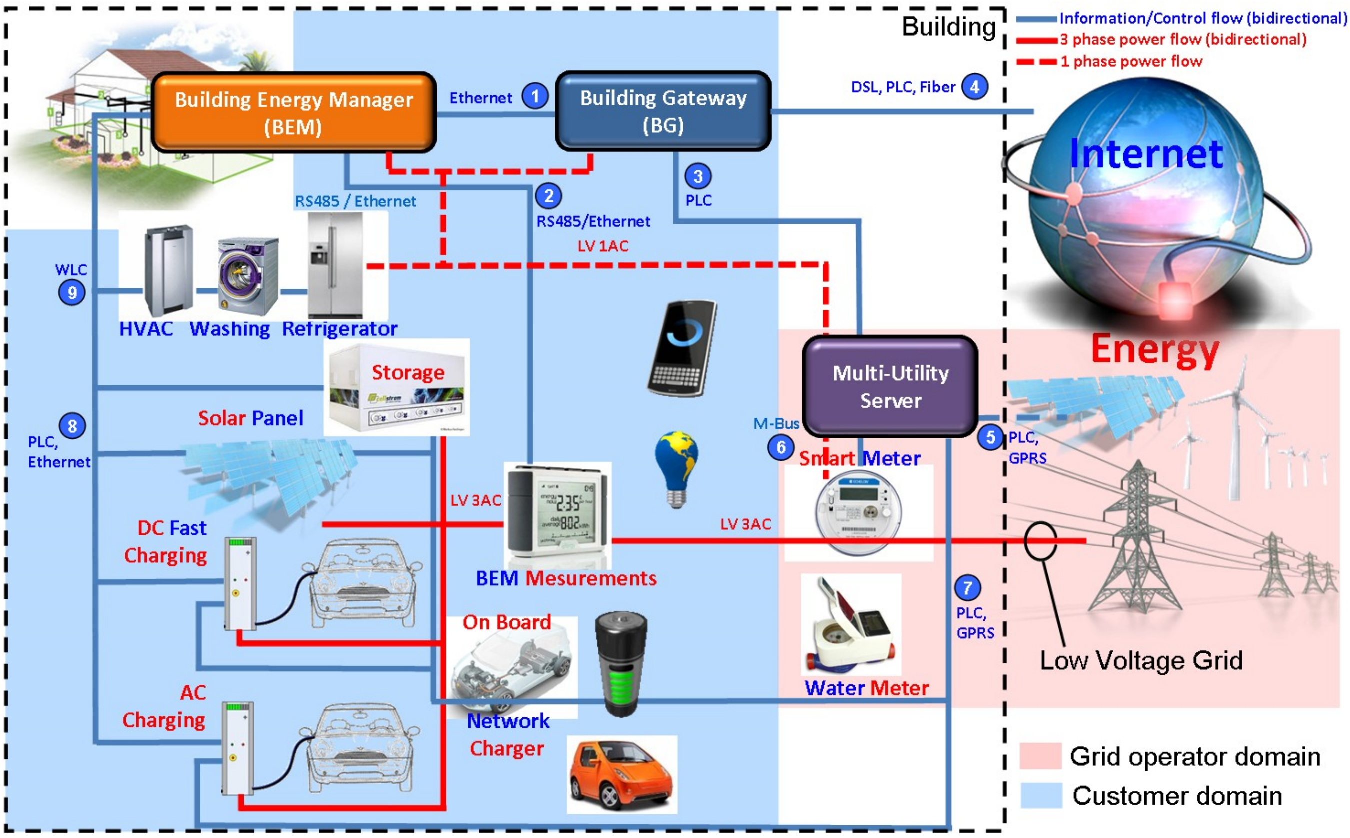

Fig. 1. Concept of the "IoE Building" as the nucleus within a decentralized distribution grid in which interaction between EV and grid takes place. The graph shows the low-voltage variant.

Building" concept which comprises all the elements of a residential or small industry / business building which contribute to generation and/or consumption of electric energy (see Fig. 1). The central authority in this concept is the "Building Energy Manager" which controls the power flow between all these elements. It represents the superset of all different components like supermarkets, EV "fuel stations", public area fast charging infrastructure, small industrial, residential buildings etc. Deriving one of the subsets from this comprehensive picture simply means "switching on and off" of IoE Building components respectively re-configuring their electric characteristics and their communication behavior (i. e. interface, protocol).

This approach has two advantages: first, it constitutes a valid representation for each one of the four building demonstrators to be realized within the IoE project. Second, it allows the easy transformation into a simulation model, which by simple re-configuration can represent a large variety of situations and infrastructures.

At present, the four demonstrators are "under construction" at four different locations in the EU. The largest one is going to be set up at the Siemens test site in Erlangen. Apart from demonstrating the feasibility of the IoE approach and providing information about how far the IoE approach goes beyond the SoA, they deliver valuable test and verification data by which the model representation of each demonstrator can be validated. In order to demonstrate also the interaction between the demonstrators by ICT, the element of price negotiation, contribution to grid stabilization as well as islanding capabilities including "reboot" after failure removal, the four demonstrators will be connected via the Internet which transfers all the necessary information by which these features can be enabled.

A very important aspect to be realized is the investigation on how the distribution of "grid codes" between power hardware components can help to reach unconditional stability of the grid even upon complete failure of communication channels.

III. From demonstrators to infrastructure

While a hardware demonstrator like the one outlined in Fig. 1 is within the scope of the Internet of Energy project, setting up the real hardware and communication infrastructure of a settlement or a complete village is not an achievable objective. Therefore, alternatives have to be identified to yield information about the behavior and performance of a multitude of "IoE Buildings". To do so, IoE will combine the "IoE Building" simulation blocks with validated and proven infrastructure simulation models of an existing village (cf. Fig. 2). As the common platform, Simulink along with the SimPower library is used to set up a combined model of an existing grid infrastructure which is to be equipped with technological approaches and solutions by IoE. Those non-standard components which are under development in the course of the IoE project and for which no predefined SimPower blocks are available will be realized as S- or C-functions.

This approach has a considerable advantage compared to

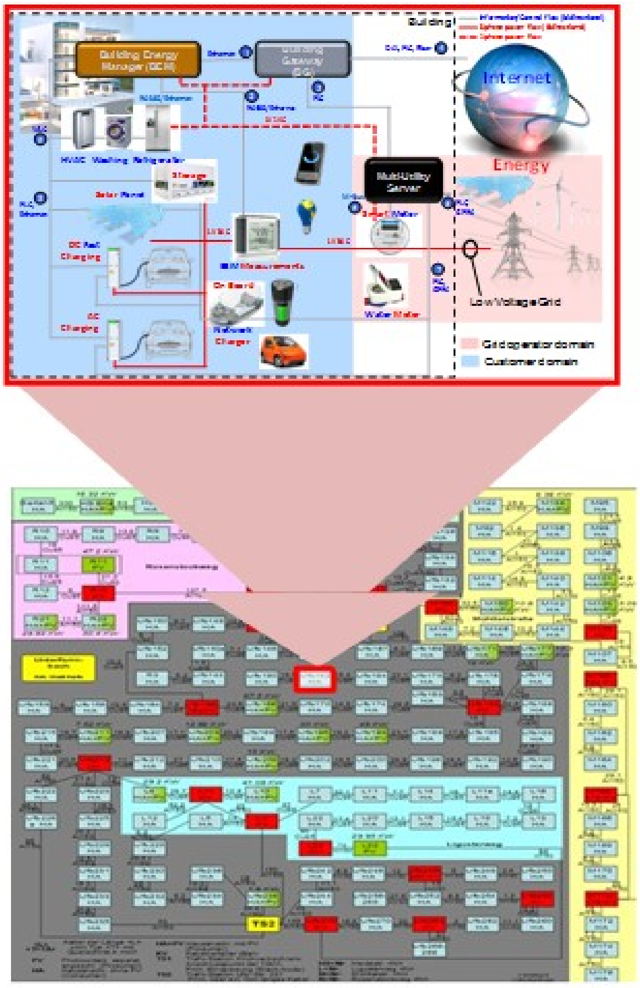

Fig. 2. Integration of the Simulink block (upper part) representing the "IoE Building" into a Simulink infrastructure model. The example shows the Unterfarrnbach infrastructure model (lower part).

building a new infrastructure model from scratch. First, the existing infrastructure model has undergone diligent testing, validation and verification using measured data of existing distribution grid infrastructures. Second, by replacing some or even all buildings by the "IoE Building", the effect of transition from the present to the IoE structure can be examined in detail. Especially the question how a "grid of inverters" affects the stability of a decentralized distribution grid can be answered in a satisfactory way. Third, proceeding in this way permits a very detailed comparison of the present with the future IoE situation, thus providing detailed information about quantitative and qualitative IoE progress beyond the state of the art.

IV. Interaction of EV fleets and city grids – the Bologna example

As the performance characteristics of fleets of electric vehicles in cities has been investigated in much detail in several other projects (e. g. "Green eMotion" [8]), this topic is not specifically covered by the IoE project. Nevertheless, to get a deeper insight into the interaction between EVs and grid, it is worth to take a closer look at a future situation when a whole fleet of EVs is on its way through a city and interacts

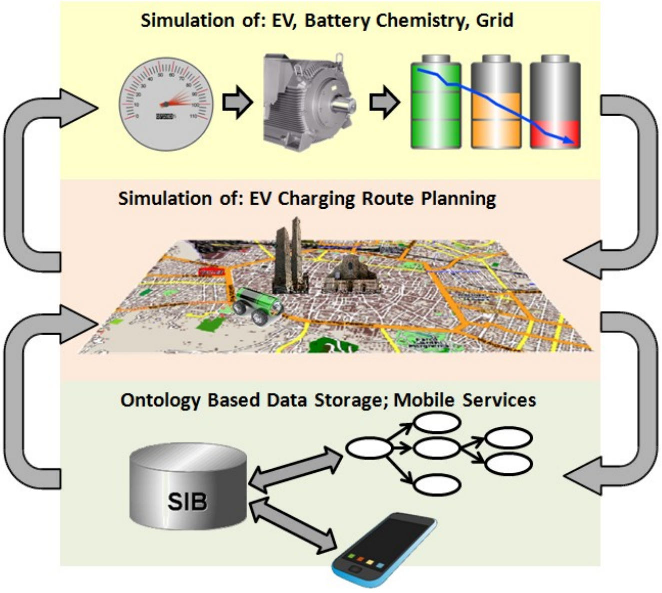

Fig. 3. graphical representation of the complete toolchain covering EV dynamics and battery behavior (top part), vehicle fleet dynamics in a street network (middle part) and ontology based data storage (bottom part).

on a large scale with the distribution grid and with novel service platforms. In the framework of the IoE project, this is done using a co-simulation framework designed at University of Bologna, and based on results achieved in [2], which involves the OpenSource simulators Omnet++ [3] [9], Sumo [4] [10] and Veins [5] [11]. This simulation tool chain is able to simulate the mobility of a multitude of vehicles through a (city) road network including traffic signs, traffic lights and other things that may have impact on the traffic flow. This is backed by realistic experimental data as the city of Bologna is equipped with a comprehensive network of sensing devices which deliver information about the traffic within the city. Initially this simulation environment was targeted at answering questions related to mobile wireless communication of EVs, data storage and processing using an ontology-based data storage and handling system and remote monitoring apps for smart devices. The IoE-specific functions to be considered were remote monitoring, information dissemination, coordination of distributed applications and IoE mobile services support. This initial scope has been widened by integrating the Siemens know-how on electric vehicles (cf. Fig. 3): EV behavior in various operating and traffic situations, weather- and season-dependent performance, EV charging operation, EV dynamics under all these boundary conditions and - among the most important aspects - the charging and discharging behavior of EV batteries under these conditions. Thus assuming a variable penetration of EVs within the simulation, information can be obtained on how a large number of EVs influences performance, stability and price structure of a power distribution grid and how battery charging/discharging cycles and lifetime are influenced by the mutual dependence of city traffic, traffic management and load balancing of public-area fast charging stations.

In addition, the realization of the simulation platform has been integrated with real service infrastructure prototypes based on ontology-based smart-space technologies [7],[8]. This allows the benchmarking of candidate service platform prototypes under variable system and load assumptions, generated by variably populated communities of EV users, and real client software entities running mobile services and applications on mobile devices. The realization and test of specific mobile applications satisfying some of the requirements of mobile EV users (like the ones reducing driving-range anxiety, reservation, route planning and assisted navigation towards charging stations, remote monitoring of charging phases) have been made possible on the simulation platform transformed into a virtual system and service emulation platform (see Fig. 3). As a result, the preliminary test of services and applications, and the tuning of resources and user's interfaces are made possible in the early design phase of the project, based on both real and virtual (that is, simulated) entities.

V. Summary and Outlook

The combination of demonstrators realized according to the definitions of the Internet of Energy (IoE) project, with realistic and validated simulation models of buildings, power distribution grids and electric vehicles' mobility in urban scenarios, permits a virtual testing of the interaction of electric vehicles with decentralized distribution grids based on renewable energies and novel service platforms. The realized framework provides experimental evidence of the potential realized by the integration of complex traffic infrastructure simulation tool chains and ontology-based data storage and processing conceived by the University of Bologna, with the Siemens EV simulation models and battery know-how. The framework will permit a thorough investigation of the interaction between EV fleets and power distribution grids, differently not easy to consider for wide and complex testbed scenarios like the city of Bologna. The perspective to obtain meaningful results is corroborated by the fact that the simulation approaches to be combined are backed by thoroughly tested infrastructure models which on their own have already proven their significance. It is expected that this analysis potential will yield a deeper insight into the mechanisms that govern the interaction between EV fleets and power distribution grids, thus helping to optimize an “Internet of Energy for Electric Mobility” towards increased stability, higher power quality, extended lifetime of its components and improved price structure. Nonetheless, the adoption of the realized framework as an emulation platform will allow the preliminary test of overlaying service platforms, control functions and mobile applications realized under variable assumptions in the early design phases.

Acknowledgments:

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References

[1] Artemis project “Internet of Energy for Electric Mobility - IoE”: http://www.artemis-ioe.eu/

[2] L.Bononi, M.Di Felice, G.D'Angelo, M.Bracuto, L.Donatiello "MoVES: a framework for Parallel and Distributed Simulation of Wireless Vehicular Ad Hoc Networks", Elsevier's Computer Networks, Special issue on "Emerging Wireless Networks: Performance Modeling and Analysis", Vol. 52, No. 1, 01/2008, pp. 155-179, ISSN: 1389-1286

[3] A. Varga and R. Hornig. "An overview of the OMNeT++ simulation environment" in proceedings of the First International ICST Conference on Simulation Tools and Techniques for Communications Networks and Systems, pages 1–10, 2008.

[4] M. Behrisch, L. Bieker, J. Erdmann, and D. Krajzewicz. "SUMO - Simulation of Urban MObility: An Overview", In SIMUL 2011 The Third International Conference on Advances in System Simulation, pages 63–68, 2011.

[5] Christoph Sommer and Falko Dressler, "Progressing Toward Realistic Mobility Models in VANET Simulations," IEEE Communications Magazine, vol. 46 (11), pp. 132-137, November 2008

[6] E. Ovaska, T. Salmon Cinotti, A. Toninelli. (2012). The Design Principles and Practices of Interoperable Smart Spaces. In Advanced Design Approaches to Emerging Software Systems: Principles, Methodology and Tools. (pages 18-47), IGI Global, 2012, Hershey – U.S.A.

[7] F. Morandi, L. Roffia, A. D’Elia, F. Vergari, T. Salmon Cinotti. (2012). RedSib: a Smart-M3 Semantic Information Broker Implementation, Proceedings of the 12th Conference of Open Innovations Association FRUCT, Oulu, Finland, Nov. 5-9, 2012, (pp. 86-98)

[8] FP7 project “Green eMotion”: http://www.greenemotion-project.eu/

[9] Omnet++: http://www.omnetpp.org/

[10] Simulation of Urban MObility (Sumo): http://sumo.sourceforge.net/

[11] Veins: http://veins.car2x.org/