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Smart Microgrid and Urban Planning for Better Electromobility

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***Abstract*—Greenhouse gas emissions, produced by transport sector, have spurred the rapid growth of the electromobility. Nevertheless, this new form of mobility requires installing recharging infrastructures for electric vehicles (EVs) in urban areas, both self-service and not. This paper aims at: a) presenting an innovative energy system, and b) at highlighting the issues for its implementation in an urban area. The proposed energy system consists of three components: an intelligent charging station for electric vehicles (iCS_EVs), a heterogeneous fleet of electric vehicles (EVs), and a building with a connection to the iCS_EVs. This paper focuses on requirements and feasibility of iCS_EVs best fitting urban areas. This energy system is embedded into the urban space in which is installed through multiple physical and logical interactions. The iCS_EVs is based on a smart microgrid optimizing the power flows in accordance with the requirements of the public power grid. This microgrid contains photovoltaic sources and takes into account the following strategies: vehicle to grid, vehicle to building, and iCS_EVs to building (energy generated by the iCS_EVs and not used by the EVs directly feeds the building). Therefore, the innovative energy system offers new services that can be synergistic with the urban electromobility.**

Keywords—electromobility; microgrid; renewable energy; electric vehicles; urban planning.

I. INTRODUCTION

Electric vehicles (EVs) represent an important step towards the transition to low-carbon urban mobility [1]. Nevertheless, recharging EVs increases the energy consumption in real time. Due to the high current required, and depending on when and where the EVs are connected, the charging stations cause problems and constraints for the power grid [2]. The indirect pollution created by charging stations depends on the energy mix of electricity production allowing peak consumption, *i.e.* the spinning reserve composed mainly of fossil fuel-based power plants. In order to respond to EVs recharging, this spinning reserve should be expanded. Moreover, with regard to users, their preference to recharge the EVs is usually at the appropriate time rather than out of peak periods [3]. Thus, starting from a certain total power demand, representing the recharge of EVs during the day period, the power grid could be strongly affected [4].

On the other hand, the energy transition encourages the growth of renewable energy sources. However, the increase of the decentralized energy production reveals a growing complexity for the power grid operators involving more quality and reliability to regulate electricity flows and fewer imbalances between electricity production and demand [4]. To overcome this issue, the production of decentralized renewable energy should allow self-consumption and therefore a lower constraint for the power grid. Therefore, the concept of smart microgrid, based on renewable energy sources, storage, and connection to the public grid, aims at participating to the ancillary services [5]. Smart microgrids are reliable and effective options for increasing the penetration of renewable energy in urban areas (small scale power) while minimizing the end-user energy cost [6]-[9].

Facing to the smart grid emergence and the predictable growth of the EVs charging stations, one of the solutions is the local electrical microgrid integrated into the charging stations [2], [6]-[8]. Within this context, on the basis of photovoltaic (PV) sources, the charging stations microgrid based work in producer-consumer mode while respecting the requirements of the public grid, and focusing primarily on self-consumption.

The electromobility poses today many technical, economic, and social challenges to overcome, and creates new needs translated into products, accessories, and services [1]. In France, in 2010, the so-called *Grenelle* 2 law entrusts the competence of deploying the open public charging infrastructures to the city council. The public authorities, able to carry out these voluntarist initiatives, have begun to lay down standards and prescriptions for the installation of EVs charging stations in order to support the Municipalities in this new responsibility. These standards contain technical requirements concerning the power grid connection and the charging stations characteristics. The economic aspects refer mainly to EVs fleet sizing, operating costs, economic equilibrium between the network of charging stations and the service pricing. As for the legal themes, they set out to develop all the rules and standards relating both to the design of the charging terminal and to the use of the public space.

This paper aims at presenting an innovative energy system, which proposes new services associated with the urban electromobility, highlighting the issues for its implementation in an urban space. The section II presents the energy system that consists of: an intelligent charging station for electric vehicles (iCS_EVs), a heterogeneous fleet of electric vehicles (EVs), and a building with a connection to the iCS_EVs. As the iCS_EVs is embedded into the urban space where it is installed, multiple physical and logical interactions exist. The section III shows the interactions between iCS_EVs and the urban space. The requirements and feasibility conditions of iCS_EVs for urban areas as well as the innovative contributions of the iCS_EVs project to the progress of the current works presented in the state of the art are given in section IV. Finally, conclusions and further works are presented in section V.

II. INTELLIGENT CHARGING STATION FOR ELECTRIC VEHICLES

The innovative energy system is defined as a set of objects, an iCS_EVs, a heterogeneous fleet of EVs, and a building having a connection to the iCS_EVs. The goal is to provide iCS_EVs in urban areas while facilitating interactions between iCS_EVs, the power grid, surrounding building and users of EVs and building. EV is defined as a vehicle whose propulsion is ensured exclusively by one or more electric motors. There are two categories of EVs: a) four-wheels vehicles (*e.g.* cars, buses, trucks), and b) two- and mono-wheels vehicles (*e.g.* motorcycles, scooters, assisted bicycles, scooters, gyropods, autonomous mono-wheels, etc.). This study focuses on small-scale EVs that make a heterogeneous fleet of cars and vehicles for individual urban mobility.

The iCS_EVs is based on a smart microgrid [2] that optimizes the power flows in accordance with the requirements of the public power grid [6]. This microgrid contains PV sources, electrochemical storage, supercapacitors, and connection to the public grid. One of the solutions can be the microgrid integrated in the car parking where PV panels are installed on sun-shading roofs as shown in Fig. 1.

This energy system is able to manage optimized power flows and takes into account the following strategies:

- Vehicle to Grid (V2G), discharge of EVs batteries into the public grid;
- Vehicle to Building (V2B), discharge of EVs batteries into building;
- iCS_EVs to Building (i2B), electrical supply of building by iCS_EVs.

The V2G strategy allows the peaks of consumption to be smoothed at the power grid level, while V2B leads to the securing of the building supply during an electrical cut-off. The i2B strategy means that energy generated by the iCS_EVs and not used by the EVs directly feeds the building. Currently, there is a lack of maturity for these strategies. The literature mainly focuses on the topology of the bidirectional interface and its control when switching to V2G or V2B mode [10]. For the V2G mode there are specific studies in Germany [11], Spain [12], Denmark [13], and Brazil [14]. Regarding France, there is no applied research concerning V2G/V2B modes.

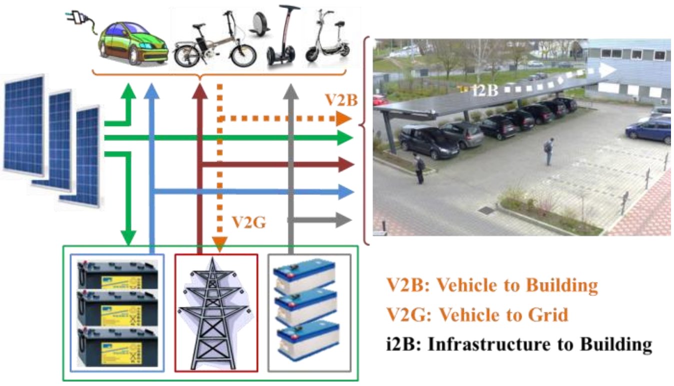


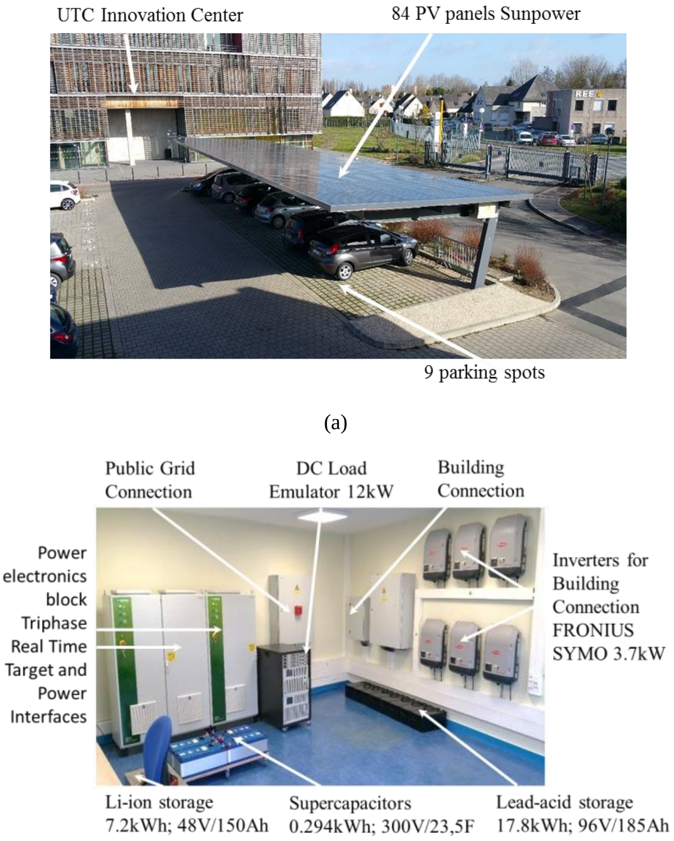
Figure 1. iCS_EVs of Université de Technologie de Compiègne.

Concerning the communication between the EVs and the charging station, some studies analyze the security modes to protect the users' data [15]; other studies are interested in the methods of identification of the EVs connected to the terminals [16], or in the performance of the wireless connection for the V2G mode [17].

Nowadays PV integrated car parking shades exist, but inject the total produced energy into the public grid and the V2G mode is used to compensate for the intermittent nature of PV energy [18]. The control algorithms are not optimized and only take into account the state of charge of the EVs batteries. Moreover, there is not a technical-economic optimization algorithm; constraints related to the use of the power grid are not taken into account and interfacing with the end-user is not provided. However, several works deal with the possibility of using the V2G mode to participate in ancillary services [19]. Often, within the limit of the possible discharge threshold, EV is seen as a conventional energy reservoir for setting the frequency. Some publications are focused on the generation of reactive power [20]; furthermore, the use of EVs connected to charging stations is related to the whole city or larger areas [21] and less often to a specific urban neighbourhood or defined local urban area. The main objective of planning the EVs' use on large areas is to improve the energy efficiency and safety in the power grid. Thus, scenarios, taking into account a varying number of EVs using the V2G mode, with different constraints, are simulated and allow a statistical analysis.

To sum up, several aspects concerning the V2G and V2B strategies are already well developed. However, in the absence of a proposal of a smart microgrid dedicated to the EVs recharging, the i2B strategy is not proposed. Furthermore, the systemic aspect of such an innovative energy system, implanted in an urban space and defined as a set of objects, *i.e.* iCS_EVs, EVs and a nearby building, or the interaction of the system with end-users and its environment is not currently in the literature. Therefore, new services at the urban level are not proposed. Moreover, most of the concepts and tools are validated through simulation and not thanks to experimentation.

The AVENUES laboratory of Université de Technologie de Compiègne (UTC) built a technological platform called STELLA, Smart Transport and Energy Living Lab.



(a)

(b)

Figure 2. Technological platform STELLA: (a) PV panels covering 9 parking spots; (b) storages and power electronics.

STELLA is a microgrid demonstrator dedicated to EVs recharging and powering a building. This demonstrator, shown in Fig. 2, is based on PV panels covering 9 parking spots of the UTC Innovation Center, electrochemical storage, supercapacitors, power electronics, power grid and building connections. This platform, funded by the European Union (FEDER fund) under the CPER grant, is operational since December 2016 and unique in France at the academic level.

The proposed smart microgrid is car parking integrated, with PV panels installed on sun-shading roofs as shown in Fig. 1(a). This PV array consists of 84 panels type Sunpower SPR X21-345 (28.9 kW nominal). In Fig. 1(b) are illustrated the main components of the microgrid. Electrochemical storage is composed by a set of lead-acid batteries in series (96V/185Ah) and a set of Li-Ion batteries (48V/150Ah) associated with the appropriated batteries management system. Supercapacitors (300V/23.5F) are added for their high power density characteristic which allows releasing a great power rapidly. The public grid connection permits the bidirectional power flow exchange. A DC load may be also emulated by programmable DC electronic load (12kW) which thermally dissipates the power it receives. The real-time target controller is designed and conceived by TRIPHASE.

III. URBAN SPACE AND CHARGING STATION IMPLANTATION

The iCS_EVs is embedded into the urban space in which is installed; therefore, multiple physical and logical interactions exist. This is why the iCS_EVs implantation is a complex task related to urban planning requiring the simultaneous integration of different parameters:

- technical and technological parameters: connection to the power grid, renewable energies integration, adaptability of the charging terminal to different types of EVs;
- legal and regulatory parameters: rules for the stations implantation on the roads, road occupancy agreements and signs, modes of consumption;
- physical parameters: dimensions and spaces adapted (or adaptable) to the location of the station;
- usage parameters: localization according to the needs of the population to ensure the proper positioning of the service.

On the localization of standardized stations of self-service vehicles, it is found that each project is a complex task. The public and the private managers of these services deal with projects where there are *a priori* few studies and no explanations of the process used to select the points of the localization and their integration in the existing street network.

Moreover, EVs used for the assisted soft modes (*e.g.* e-bicycles, e-scooters, e-mono-wheels, etc.), are little considered in urban planning [22]. However, in high density cities, this typology of EV needs to be taken into account, since their massive use could have both a significant impact on demand of electric power and on the traditional organization of pedestrian flows [23]. Eventually, the concerned facilities as sidewalks and roads can be subjected to a change in their use, implying new rules of sharing among users.

Regarding the implantation of the self-service EVs stations, two main points need to be considered:

- the charging terminals are designed only to supply the EVs. Thus, the design of iCS_EVs able to meet the needs of EVs, including assisted mobility, are something original;
- the issues of the integration and the location of the recharging stations in urban areas are not discussed yet; literature shows a lack of a generalized method to install recharging stations in urban areas while feedbacks about operational tests are available.

Finally, on the issue of urban space and iCS_EVs, the literature focuses mainly on the technical and normative problems of EVs charging terminals. There is very seldom reference to their integration in urban space, and when this is the case, the aim is rather to ensure the profitability of the service and the regulation of the public space use. However, decision makers need a support tool for urban development in order to integrate the specific needs of EVs with the target of a large-scale use.

IV. REQUIREMENTS AND FEASIBILITY CONDITIONS FOR IMPLANTATION IN URBAN AREAS

In urban areas, the following issues must be addressed simultaneously: shared energy, renewable energy, design and sizing of the energy system, availability of the power grid, territorial diagnosis, iCS_EVs optimization, urban planning and programming, electromobility, digital interfaces (data exchange), adapted tools for technical, social, legal and/or economic regulation, societal impact, and regulation. For implantation of iCS_EVs in urban areas, the main issues to be considered are presented below.

A. *Urban scale*

How can the implantation of iCS_EVs be carried out and its urban services can be selected according to the urban morphology and density, the transport demand, poles of attraction, the intermodal hubs, the socio-demographic characteristics, the solar irradiation potential, the power grid and other equipment? [24]

At urban scale, the main idea is to define an ecosystemic method for assessing the capacity of an urban space to host the iCS_EVs implantation and, consequently, the creation of an adequate tool to assess the urban space capacity. The research then focuses on spatial analysis, which should allow finding the optimal location for installing the system according to both a long-term vision and the urban programming, which should integrate such issue upstream. The main idea is to design a tool supporting decision-making processes of local and regional authorities, of construction and public works companies as well as of for other actors involved in electromobility.

Depending on the characteristics of the selected streets, different types of iCS_EVs implantation will be analyzed. The layout may be different, depending on EV types, pavement widths, dimensions and continuity of sidewalks, approximation of facades of buildings, number of crossings, the solar irradiation potential, the power grid local capacity, etc. The minimum characteristics typology has to be defined in order to ensure the replicability of the proposed tool.

B. *Infrastructure scale*

What are the possible typologies of iCS_EVs installation on the public space in terms of capacity of the power grid and regulation? What are the characteristics, constraints and adjustments to be made concerning the iCS_EVs to accommodate the electromobility? [25]

A detailed urban analysis will lead to a method and a tool for the iCS_EVs sizing according to the strategic locations. This dimensioning concerns the number of optimal recharging places, the type of places and charging stations (in relation to the type of EV) and the necessary microgrid (definition of the local energy mix and dimensioning of the sources). Other data that should be included in the sizing are: the average EVs rotation rates in charge, recharging times, parking times, power requirements, ergonomics parking spaces / recharging, capacity of the public grid, potential of the photovoltaic production, characterization of the building supposed to be connected to the iCS_EVs, etc.

C. *Associated urban services*

What is the best integration of iCS_EVs into the urban space in relation to the valorization of new associated uses like V2G, V2B, i2B, and the EVs recharge? What energy flexibility, what pooling of resources, and what functional and / or technical mix have to be designed at building, campus or neighborhood level? Depending on the urban morphodynamics of the city, what real services could EVs batteries provide to both the built environment and the power grid to which they are connected? [26]

Concerning the associated urban services, by adopting an ecosystem approach, the microgrid and its interface of connection and real time communication with the smart grid, the surrounding building, and the end-user have to be designed. In addition, a technical-economic regulation tool will be proposed for the dynamic optimization of energy costs, both for the EVs end-user and for the building stakeholder, taking into account the availability and the vulnerability of the power grid. This tool will ensure the control and the management of optimized power flows according to the V2G, V2B and i2B strategies and in accordance with the end-users criteria.

Thus, it is required to develop an appropriated interface which multilayer and multiscale design provides flexibility with respect to the necessary algorithms. With response times range from days to less than a second, this interface will aim at an optimal energy management as well as communication with the end-users. The human-machine interface has to take into account the end-user options as predefined operating mode, or real-time adjustments, or other specific criteria.

D. *Societal impact*

What potential integration into user habits [27], what social practices can be imagined? [28] What type of company can see a benefit in terms of economy and / or image?

Concerning the societal impact, the main idea is based on how users take ownership of the service; therefore, follow-up of real practices should be put in place in order to observe them. Thus, a tool that will allow access to services (user interface/services), monitoring of practices (observe how the service is used), as well as a direct link to communication via the charging terminal (which shall offer to users real-time information) needs to be characterized by technical and functional specifications.

E. *Research position*

The resulting research positioning is based on the systemic and dynamic approach and focuses on human and societal stakes. Smart microgrid and urban planning for better electromobility require, on the one hand, proper tools and methodologies, and, on the other hand, test sites in which experimenting the tools. The scientific objective is to aggregate models related to transport, urban planning and energy (Fig. 3) using an interdisciplinary framework leading to a technical-economic-environmental evaluation methodology for iCS_EVs.

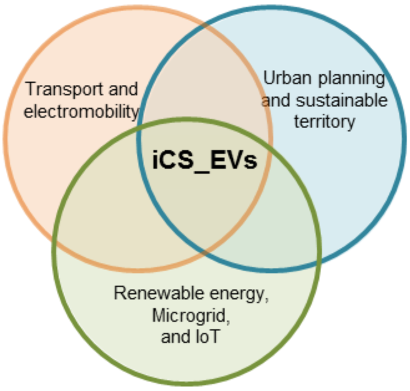


Figure 3. Interdisciplinary approach for urban electromobility.

The resulting technological objectives are:

- designing intelligent energy management strategies suited to the urban morphodynamics and local PV energy production capacity;
- developing models for the definition and characterization of electromobility demand;
- modeling the electromobility patterns of cities within the context of new technologies and information to end-users;
- providing support and tools to territorial stakeholders to promote the emergence of iCS_EVs.

Scientific issues, associated with technical-methodological and societal ones, have been identified:

- scientific issue: real-time optimization of power flows and control of interfaces within iCS_EVs;
- technical-methodologic issue: identification and parameterization of concomitant factors for electromobility, transport demand and urban morphodynamics;
- societal issue: assessment of the societal impact of iCS_EVs and the acceptability of the proposed solutions.

The following fields summarize the innovative contributions of the iCS_EVs project to the progress of the current works presented in the state of the art.

- *Energy system.* An innovative energy system, implemented in an urban space and defined as a grouping of objects, i.e. iCS_EVs, EVs and a nearby building, will be developed using a systemic approach. The systemic aspect will ensure the compatibility and interoperability of the proposed tools and methodologies. The interaction of the system with the end-user and his environment is proposed thanks to the new urban services (V2G, V2B and i2B);
- *Renewable energy.* Facing to the smart grid emergence and the growing need for EVs charging stations, the local and PV-based microgrid will allow increasing renewable energy production while participating to electrical system ancillary services.
- *Electromobility.* The massive use of EVs for individual urban mobility can become a real challenge for cities with high density. This is why iCS_EVs will take into account not only the recharging of electric cars but also EVs for individual urban mobility, *e.g.* bicycles, scooters, mono-wheel, etc., which are little considered during urban development. Therefore, hybrid and / or specific iCS_EVs will be proposed. A second innovative contribution concerns the ecosystemic method of implantation and dimensioning of iCS_EVs on urban roads.
- *Urban services.* Several aspects concerning energy management strategies V2G and V2B are already proposed and well developed theoretically. However, in the absence of a proposal of the smart microgrid dedicated to the EVs recharge, the i2B strategy is not yet proposed in the literature. The i2B strategy, according to which the energy produced by the iCS_EVs and not used by the EVs directly feeds a nearby building, is essential in urban areas for a better integration of renewable energies.
- *Urban planning.* Implantation of iCS_EVs requires the simultaneous integration of multidisciplinary, multicriteria, and multi-scale parameters: technical, legal and regulatory, morpho-dynamic, and social. The proposed work focuses on the development of integrative tools and methodologies to help urban actors to carry out iCS_EVs implementation projects.
- *Spatial analysis and territorial decision support*. The optimization of the iCS_EVS implantation implies a fine spatial analysis of the host territory. The choice of the implantation being the result of the crossing of several parameters, e.g. urban morphology, socio demography, radiative potential, etc., a multicriteria analysis will help the final choice of implantation sites.
- *Social Acceptability.* The systemic aspect of the project includes social modeling in order to measure the societal impact and acceptability rate according to the typologies of iCS_EVs that will be proposed.
- *Experiment.* Most of the concepts and tools proposed will be validated by experimental tests thanks to the technological platform STELLA. The energy management strategies V2G, V2B and i2B will be analyzed according to the experimental tests and technical prescriptions will be proposed.

V. CONCLUSIONS

The proposed iCS_EVs and the associated services represent an incremental innovation in relation to a range of existing PV integrated car parking shade, which produces clean energy, but in passive mode without ancillary services, rarely consumed locally, or rarely in interaction with the end-users and its environment.

Then, by applying an iCS_EVs to a real urban space, confronting the needs of the urban stakeholders, as well as the technological test of the proposed technical regulation, an interdisciplinary project is proposed by AVENUES UTC and

SYSTRA Urban/rail public transport civil engineering. Different scenarios will be considered to define the technical-economic-environmental evaluation methodology for iCS_EVs.

The tools and methodology will be designed taking into account the need for replicability in different urban spaces. To achieve the goal of this project, an interdisciplinary and intersectoral group has been established from the research teams of AVENUES UTC and SYSTRA R&D engineers.

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