Enhancing with EV Charging Station Functions a Residential RES based Network

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Abstract: The emergence of Electric Vehicles is creating a possible congestion of the electric grid. The switch in transportation, especially in cities (future Smart Cities are considered) is asking for the utilization of Renewable Energy Sources, RES, to decrease pollution. To address these two demands the paper proposes a solution based on a Residential Charging station architecture for Urban Electric Vehicles. The theoretical structure is presented and then the practical solution, as Smart Residential MicroGrid based on RES, is shown. In order to make an implementation more economically and technically affordable and be able to address in the very near future the growing need of EV Charging stations, the presented solution starts from the existing equipment used in millions of homes, mainly for solar energy.

1 INTRODUCTION: EV EVOLUTION

The world is undergoing a transition from internal combustion engines cars to electric vehicles, EVs. Increased pollution, especially CO2 emissions and, to some extent, the fossil fuel sources depletion pushed governments and car manufacturer to promote EVs. Therefore, since 2013 EV global sales increased by 400% (www.navigantresearch.com, 2016).

This change is only the beginning. Due to governments' incentives and policies, such as zero-emission regulations, decrease of production costs with the scale effect consequences and arise public interest, the global EV market is increasing rapidly. According to IEA, (IEA, 2011):

"Assessments of country targets, original equipment manufacturer (OEM) announcements and scenarios .... **the electric car stock will range between 9 million and 20 million by 2020 and between 40 million and 70 million by 2025."**

The increase in EV number will subject the electric grid to a great strain. Transportation consumes (uses) about 33 % of the total energy production in EU and about 30 % at world level (Fig.1), (Eurostat, 2017; EEA).

From this 33 %, more than half (as can be seen from Fig. 2) is consumed by cars. That means about 17-18 % from all energy is consumed by cars, which is oil based. To make the change and replace this amount of fossil fuel based energy to electricity, moreover, the useful one (letting aside the losses in the production and distribution) is an enormous task.

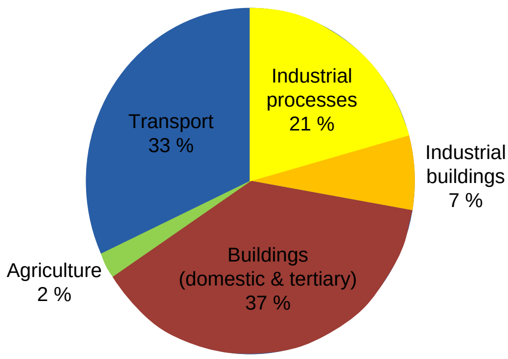

Figure 1: Eurostat 2017 Consumption of energy.

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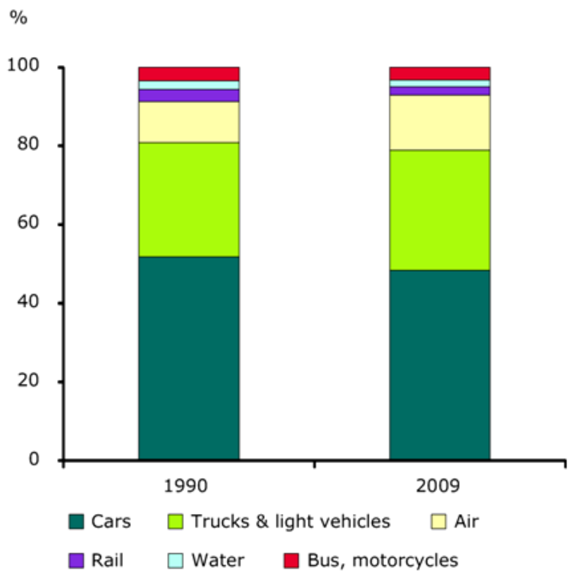

Figure 2: Transportation share (www.eea.europa.eu).

The scientific community, industry and state entities know that and in consequence many steps were already taken toward developing and implementing Charging Stations for EVs.

But EVs introduction will have a positive effect on the pollution and energy economy only if the charging energy will come from Renewable Energy Sources, RES.

Only the direct integration of RES with EV charging infrastructure ensures a way to effectively decrease the emission related to EVs, meet charging demand, and reduce the dependence on the power grid (IEA, 2011; Traube, 2013; Birnie, 2009; Roy, 2014; Saber, 2011). Also the total efficiency of the EV is improved considerable if the electric energy is produced locally using RES (Marinescu, 2017).

The literature presents results of research, (Bhatti, 2016; Traube, 2012; Sujitha, 2017; Shareef, 2016) and industrial solutions (which can be also found online) based on Photovoltaic, PV, (Solar energy conversion) and considering dedicated conversion power plants (NPTS Report, 2000)

Considering the Smart Cities Development Context, the research proposed in this paper is oriented toward Residential Charging Station using RES (the most spread and available Solar and Wind) connected in an IT driven (controlled) network.

2 THE URBAN RESIDENTIAL CONTEXT

2.1 The Sources

In urban areas there is a lot of room available for PV installation like homes and enterprises roofs, parking roofs, etc. Published researches are showing a great progress in obtaining cost-effective transparent PV cells to replace windows or to cover facades. Also, the already existing bifacial PV modules are generating additional electricity from the light reflected by the environment to the backside placed PV cells of the modules.

In a report, Fraunhofer Institute considers that „*A typical application for bifacial solar modules would be a tilted system on a light-coloured flat roof*" (Graichen, 2015). In cities, the authors of this paper are taking into consideration the PV and small wind turbines as RES being able to supply with electric energy the residential loads including the EVs. We are considering also small wind generators placed in residential generating facilities. Distributed Wind term defines a single or small number of wind turbines serving an on-site load.

The small wind turbines can be from 0.2 kW to several kW, more precisely 3 kW, according to DWEA. The Distributed Wind Energy Association (DWEA) represents the industry that manufactures, sells, finances, installs, and supports distributed wind energy systems. DWEA estimates that in 2030 there will be 23.7 million homes and buildings suitable for Distributed Wind and that together represent a potential for 1,100 GW of generating capacity in USA (DWEA, 2015). Very appealing small wind turbines solutions, suitable for buildings, able to decrease the tower height, reduce noise and vibrations and increase efficiency are presented in (WWEA, 2015).

Even if the produced energy is not enough, there is a considerable electric energy potential to be created by these RES in a Smart City. Through these means, the RES is producing energy near the consumer, so the transport lines are not overcharged. These Distributed RES (DRES), systems provide generation near the point of use on utility distribution networks. DRES systems, as the one proposed in this paper, do not require new or reinforced transmission lines.

Adding to the involved electronic converters enhanced functions, DRES can improve the quality of the utility service by providing voltage support, harmonic compensation, PF compensation and frequency support during faults or transients (Munteanu, 2018).

In addition the proposed solution in this paper is exchanging energy with the network to assist it. For example, the residential RES based energy system can inject energy in the grid in case of need (contributing to peak shaving) and absorb energy from the grid during the night, when the consumption is low and base power capacity plants are forced to reduce the production with negative consequences in efficiency and pollution level.

Developing a communication system between the grid and the residential power stations based on economic relationships, letting the results to be known by people, the customers are educated to consider their energy consumption carefully.

Our solution, considering both solar and wind resources, is exploiting the complementarities between these RES, especially useful due to their compensatory seasonal variation, for decreasing the size of the storage devices and consequently optimizing costs.

The above considerations are backed by the forecasted evolution of prices for the considered RES equipments. For example in (Graichen, 2015) the PV energy cost is estimated to decrease from 9c/kWh in 2014 to 4-6 c/kWh in 2025 and 2-4 c/kWh in 2050, a conservative estimation where the variation limits take into account the local conditions.

For small wind turbines, WT, in (DWEA, 2015), the cost of a kWh is previewed to drop from 28 c/kWh in 2014 to 11 c/kWh in 2030. For those interested in the next power range, for 4-15 kW installed power; the costs are 20 c in 2014 and 6.5 c/kWh for 2030. But such cases are not very encountered. Even if the wind power range would be smaller, the wind energy has a higher capacity factor, about double: 12-18% for PV and up to 40 % for WT. That means, in average, that a 4 kW PV will produce the same energy as a 2 kW WT per year.

Also a shift in policies which encouraged RES until now would work in favour of wind. Some of the policies that have been instrumental in growing the solar market have had as a consequence the slowdown in growth of the distributed wind market. As solar module prices have dropped in recent years, many of these imbalanced solar programs have been scaled back and an emerging effect is the reversal of the trend in favour of wind, (DWEA, 2015):"In Japan, the FIT (Feed in Tariff) program now pays distributed wind up to 20 kW over twice the rate of solar PV "to encourage technology diversity".

2.2 The Urban Electric Vehicles

It is important to consider the type of the EV. The future urban transportation system will imply some changes in today's cars structure. In crowded cities, where it is already difficult to find parking places, will enjoy the spread of many types of vehicles with 2, 3, 4 seats or small busses (about 8 seats). This is because a great advantage of the EV driving system is that variable places number vehicles can have about the same efficiency. Th**is** is also coming from the reduction of the size and masses, adapting the solution to the needs. Looking at Fig. 3, it is obvious that such variety of EVs will better ensure the transportation needs. The variety of EVs, with reduced number of seats, will occupy less parking spaces, contributing to the decongestion of the future Smart Cities.

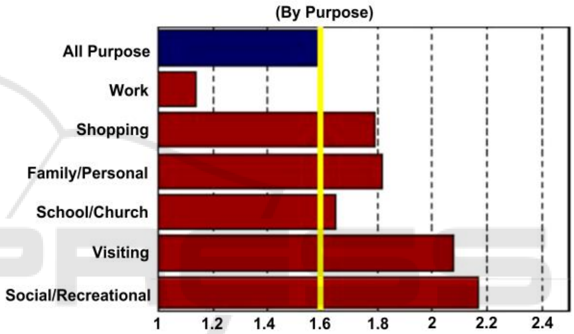

Figure 3: Number of travellers in a car by activity purpose (NPTS Report, 2000).

Even automated driven Electric vehicles will ensure an optimization of the transportation. Many studies are developed related to EVs progress. For example on (www.navigantresearch.com) the interested people can find many studies, such us: **a) Electric Mobility in Smart Cities:** E-Buses, E-Bikes, E-Scooters, PEVs in Shared Mobility Services (2016); **b) Light Electric Vehicles:** Low Speed/Neighbourhood EVs, Electric Motorcycles, and Electric Scooters (2017). The studies titles are giving a good image on the future EVs in Smart Cities. To these lists of EVs we would like to add three wheel EVs as an option for EVs supposed to transport 3 people or less and some luggage in a daily travel in a town. A very interesting research result is presented in Table 1.

Table 1: The frequency of the daily journey length for cars, average (%) (JRC Report, 2013).

Country	Below 1 km	1<5 km	5<10 km	10<25 km	25<50 km	50<100 km	100 + km	Average trip length (km)
Cyprus								10.4
Geramny (MiD)	26.2	35.3	15.1	14.5	5.5	2	1.4	11.5
Italy (ISFORT)		42.8	21.2	24.7	7.6	2.5	1.2	12.2
Latvia	4.7	51.5	26	11.4	5.5	50 km+1.3		8.7
Sweden	14.6	36	15.2	17.1	8.6	3.7	2.6	15.8
Switzerland	39.6	32.9	11.6	9.9	3.5	1.9	0.7	7.2

As one can see 93% of daily journeys by car have less than 37 km and the most frequent ones are less than 10 km! In fact the trip length average value is around 10 km (variations depend from country to country).

From the above data one can conclude how frequently an EV require recharging, considering the battery capacity, or, in another important way of technically considering things, how often is the car at home to facilitate recharging.

3 RESIDENTIAL CHARGING STATION STRUCTURE

In a previous paper, (Marinescu, 2017), is proposed the following structure of a residential smart Micro grid, MG, with EV charging station capabilities, based on RES (Fig. 4).

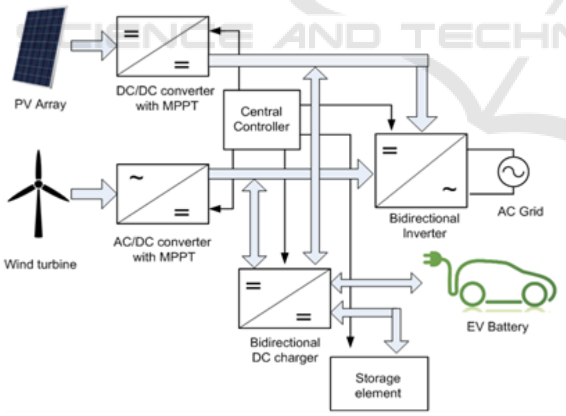

Figure 4: RES based EV charging station diagram.

Detailed description of the theoretical and technical reasons behind the structure components selection can be finding in the mentioned paper.

While developing our research and reaching to the implementation stage, some other important reasons surfaced. The most important one was to offer the already existing Home Renewable Energy Systems the possibility to add EV Charging capability. That is because there are already millions of home MGs based on RES into operation.

Another important issue was to use the existing electronic converters and associated equipments dedicated to Solar and Wind RES. This is because there are already on the market highly efficient converters, with a remarkable flexibility of use and at affordable prices. As the market introduction of hundreds of millions of EVs in the next 7 to 15 years is foreseen, the proposed solution will allow supply this new fleet in a clean and sustainable way.

After this last part of the study, the real implemented diagram resulted is presented in Fig. 5. In order to study and implement optimal EV charging solutions, a smart MG platform designed to act as a EV charging station, too, based on RESs has been developed at the R&D Institute of *Transilvania* University of Brasov, Romania.

A schematic diagram of the developed MG is presented in Fig. 5 and illustrations of the system's main components are included in Fig. 6. The MG is supplied by an 8 kW PV power plant along with a 2 kW wind turbine emulated by means of a laboratory test-bench, while a 48V Li-ion stationary battery interfaced with the MG by a 6kW inverter provides around 20 kWh storage capacity. As shown in Fig. 5, the single-phase MG, having a rated voltage and frequency of 230V and 50Hz respectively, includes an EV charging port designed for AC Level 1 and Level 2 charging modes.

The MG is connected to the utility grid and the power bi-directional exchange is monitored by a smart meter. Moreover, in case of grid malfunctions, the MG can be programmed to switch into island mode, continuing supplying the loads from the local sources and from battery. During this state the MG voltage is controlled by the battery inverter. The charging and discharging processes of the Li-ion battery pack are coordinated by a battery management unit (BMU) providing information regarding the battery operation to the interfacing inverter by means of a CAN bus. The battery Capacity choice was very important and the selection was made considering the discussion from Section 2.2. The selection of the battery inverter was made in such a way as to enable the highest charging current possible for a single-phase grid.

As Fig. 5 shows, the main MG components are interlinked through a local communication network based on wired and wireless technologies, while the transferred data is collected and processed by an MG central controller (hereafter called MG manager) with the main purpose of managing the energy in the system for an optimal EV charging planning.

During operation, based on data collected from the system (e.g. available RESs, available power, battery state of charge, EV charging status) and from outside by means of various web services (e.g. weather forecast, energy prices and requests for booking of the EV charging station from customers through the web application) the MG manager running specific optimization algorithms will decide the energy balance within the MG and the power exchange with the grid.

The development of control algorithms for optimal energy management is undergoing and they will be integrated in the software designed for the MG manager shown in Fig. 5. The MG will report power statistics from the Web system every 10 or 15 minutes (depending on the available meteorological forecasts), it will use charging demand forecast from Web system to start energy storing earlier, etc.

The MG manager will also ensure the connectivity with the web application for the reservation of the charging station by EV users. The

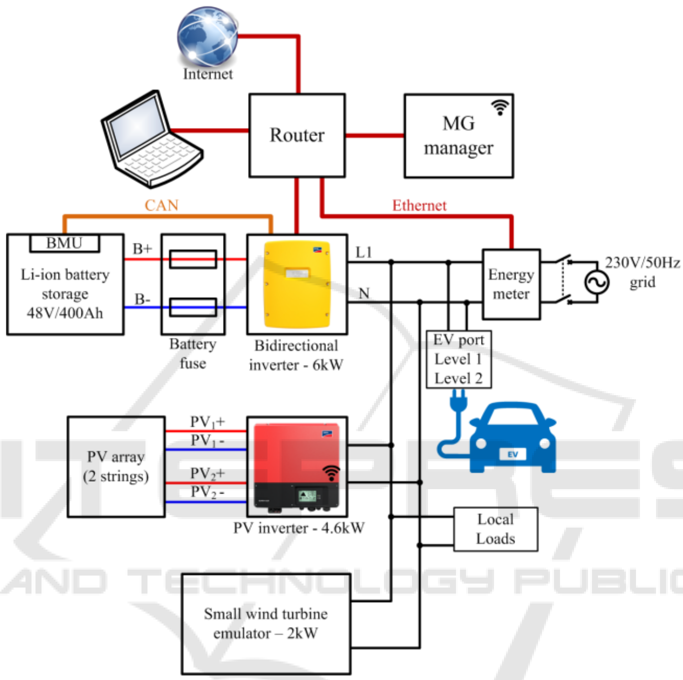

Figure 5: Diagram of the smart Residential MG designed as an EV charging station.

Figure 6: Illustration of the smart Residential MG acting as an EV charging station.

web application structure is presented in Fig. 7.

As a result, the MG manager allows for remote communication over the Internet with a Web platform designed for enhancing collaboration experience between EV drivers and EV charging stations (the one described in the current paper).

Web platform has user friendly interface for registering and managing owned charging stations, provides various useful reports and allows unmanned machine-to-machine communication between charging hardware and hosted software.

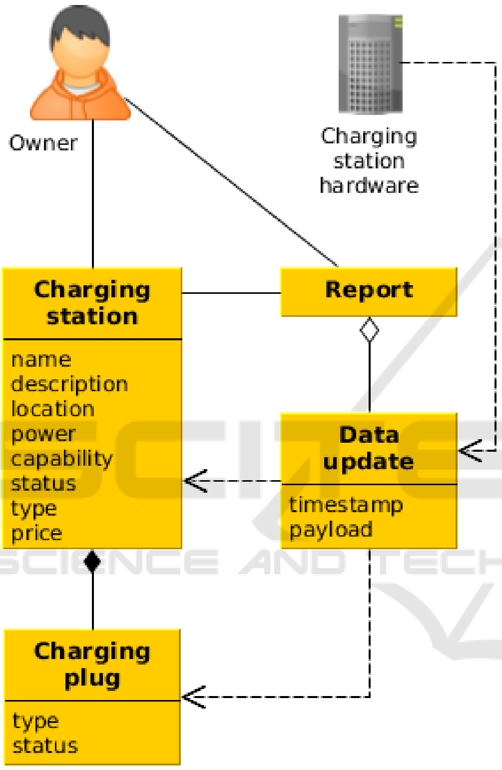

Figure 7: Web System domain structure.

Charging station owner is represented by authenticated user with rights to register new charging stations (power user role). Charging station concept in essence is geographical location with name and other relevant attributes, like electrical power, capability, energy source type and charging price. In addition it has status indicator for better management by the owner.

Charging station hardware is treated as external unmanned party which pushes updates about its state via provided API. Payload of data updates is decoded and used for updating information of charging station and its plugs. In addition data updates are aggregated into report which provides valuable information for charging station owner about its facilities (e.g. usage patterns).

Moreover reservation of charging posts is available on an established time horizon (of 24 hours in our case). When reservations are made this information allows MG manager to decide the best economical use of the energy resources for the considered time horizon ahead.

Web platform for review and testing is publicly available at https://smart-grids.science.itf.llu.lv/.

4 CONCLUSIONS

In this paper, the impact of emerging EV-based transportation in the future Smart Cities has been evaluated. Enhancing the already existing millions residential RES Microgrids with an EV Charging function will help the utility grid, by offering to exploit Distributing RES to avoid overcharging. Therefore, the paper presented and analysed a solution for an EV Charging Station starting from a RES based home power station. The solution is implemented with technologically mature components, such as photovoltaic-based and wind based systems. The selection of the main required components is discussed and justified.

Future developments in transforming multiple Microgrids in Smart ones are ongoing. Different scenarios will be simulated and considered in the MG control. As one can see following the Fig. 5 and Fig. 6, the proposed structure was implemented with some power reserves. Future research will establish the optimal power values for the components taking into account the local weather conditions for different sites and the network energy economical price values (which reflect the network congestion).

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