Sustainable Electric Mobility Analysis in the Savona Campus of the University of Genoa

Morris Brenna, Federica Foiadelli, Michela Longo*
Department of Energy
Politecnico di Milano
Via La Masa, 34 Milano -Italy
*e-mail: michela.longo@polimi.it

Stefano Bracco**, Federico Delfino
Department of Naval, Electrical, Electronic and Telecommunication Engineering – DITEN
Savona Campus - University of Genoa
Via All'Opera Pia 11a, 16145 Genova - Italy
** e-mail: stefano.bracco@unige.it

***Abstract*— Today, the concept of Smart Grid is very often strictly related to Electric Vehicles (EVs) infrastructures. EVs have not gas emissions, they have silent driving and much higher efficiency than internal combustion engine vehicles and, in particular, they are fundamental for the world's sustainable mobility. In fact, many industries and universities have decided to replace their corporate fleet with green vehicles. The aim of this work is to present the Smart Grid project at the Savona Campus of the Genoa University, with particular attention on the use of the EVs. The scope of this work is to evaluate the different habits of charging the vehicles and to study new scenarios to take advantage of the full potentiality of smart mobility.**

Keywords—Smart microgrid, electric vehicles, data analysis

I. Introduction

In Europe, as reported in [1], the transport sector is responsible for around a quarter of greenhouse gas emissions and road transport alone contributes to about one-fifth of the EU's total emissions of carbon dioxide. The environmental problems related to the use of fossil fuels in transport such as greenhouse gas emissions and air pollution are notable [1]. These issues are the major motivation for the growing interest in electrification of mobility. In recent years, there have been important efforts to study the effects of strategies to reduce on-road traffic emissions and the consequent effects of these emissions on air quality.

In the aforementioned framework, emissions can be reduced by the use of alternative clean fuels such as hydrogen, biofuels, natural gas, liquefied petroleum gas, and electricity. As a consequence, electric vehicles (EVs) are more and more assuming an important role in the transport sector [1-4] even if, as evidenced in [1], due to their current limits in their battery capacity and driving range, they are today considered to be best suited to urban and suburban driving.

As reported in [2], electrification of road transport generally can refer to vehicles of many kinds including bikes, scooters, passenger cars, delivery vans and vehicles for public transport. In [2] the benefits and challenges of EVs are outlined in terms of primary energy savings, reduction of emissions and security of energy supply. In [5] the authors introduce guidelines for the local promotion of electric mobility in an area of central Italy and possibly to extend the methodology to other regions, highlighting the importance of investments in charging infrastructures.

As evidenced by Tushar et al in [6], the use of EVs as electricity storage and of renewable energy sources as distributed generators makes smart microgrids more reliable, stable, and cost-effective. As assessed by Hu et al. in [7], EVs are regarded as an important source of balancing for the intermittent renewable energy resources. In [8] EVs are seen as an environment-friendly alternative to vehicles with internal combustion engines, but the authors also emphasize how uncoordinated charging of EVs can cause a severe stress on the power grid.

Kara et al. in [3] estimate the benefits of EV smart charging for different stakeholders, whereas in [9] the authors propose a novel optimal charging scheduling strategy for different types of EVs, based on both transport system information, such as road length, vehicle velocity and waiting time, and grid system information, such as load deviation and node voltage. As assessed by Mukherjee et al. in [8], research activities are mainly focused on unidirectional or bidirectional charging modes scheduled using centralized or decentralized strategies, which depend on different factors also related to mobility aspects.

In [7] a review and classification of methods for smart charging of EVs is presented, focusing on different control strategies. A survey of the latest research on EVs is also reported by Mwasilu et al. in [10], with a particular attention to their interaction with smart grids. In [11] the authors draw some considerations about the electric car industry, whereas in [12] some technical solutions and design approach of charging stations are proposed.

The topic of this study is to present the Smart Grid project of the Savona University Campus, with particular attention on the use of the EVs. In particular, this work is focused on the evaluation of the different habits for the vehicles charging and on the study of new scenarios that take advantage from the full potentiality of the smart mobility.

The paper is structured as follows. In Section II the smart hardware and software of the Savona Campus "Smart Polygeneration Microgrid" (SPM) is presented. Then, in

978-1-5090-2320-2/16/$31.00 ©2016 IEEE

Section III, the two electric vehicles (Renault Twizy and Renault Fluence Z.E.) owned by the University of Genoa are analyzed referring to their energy consumptions, in order to carry out some considerations on the habits of charging. Finally, Section IV summarizes the paper and draws conclusions.

II. Smart Polygeneration Microgrid

The Savona University Campus is located in an old military complex, refurbished fifteen years ago, about 2 km far from the Savona city center, as visible in Fig. 1. The Campus hosts some facilities of the University of Genoa (classrooms, offices and laboratories), some small medium enterprises and research centers on sustainable energy, protection of the environment, simulation of engineering processes and health.

Fig. 1. The location of the Savona University Campus

Since February 2014 the Smart Polygeneration Microgrid (called SPM) is in operation at the Campus [13-16]. The SPM derives from a special project funded by the Italian Ministry for Education, University and Research (MIUR); it consists in an innovative test-bed facility aiming at locally producing thermal and electrical energy in order to reduce the annual energy bill of the Campus without increasing the primary energy consumption and CO_2 emission.

The scheme reported in Fig. 2 describes the architecture of the SPM. From the electrical point of view, the SPM is a three phase low voltage smart microgrid, connected to the external medium voltage distribution grid and fed by the following power plants: a photovoltaic (PV) system, three cogeneration microturbines (Capstone C30 and C65 models), three concentrating solar systems (CSP) and electrical storage (ES) batteries (lithium and sodium-nickel chloride). Moreover, in the SPM there are two electric vehicle charging stations, each one equipped with two plugs (Type 1 and Type 2).

With regard to the thermal system, the buildings of the Campus are heated by a small district heating network where the hot water is produced by the thermal power plants (the three cogeneration microturbines C30 and C65 and the two boilers B1 and B2). On the other hand, domestic hot water (DHW) is produced by electric heaters (EH), apart from the student new residences where it is provided by solar thermal (ST) panels and concentrating solar systems. As far as the building conditioning during summer is concerned, all buildings are equipped with traditional electric heat pumps (HP) while the library is cooled by an absorption chiller that uses as thermal input the waste heat discharged by one of the three cogeneration microturbines.

In Fig. 3 the connection of the different power plants to the main switchboards (Q01, Q02, Q03, Q04) of the SPM is shown. Moreover, it is important to highlight that the Energy Management System (EMS) of the SPM uses different inputs (costs and revenues functions, forecast of electric and thermal energy demands, operative constraints relative to the performance of the plants, and the forecast of the renewable production by resorting to weather services and historical records) to compute an optimal scheduling for the dispatchable sources (microturbines and boilers) and the storage systems; the goal of optimization procedure is the minimization of daily operation costs.

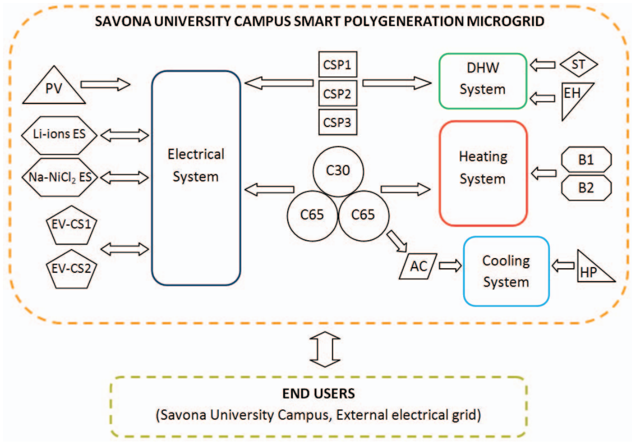


Fig. 2. The structure of the Smart Polygeneration Microgrid at the Savona University Campus

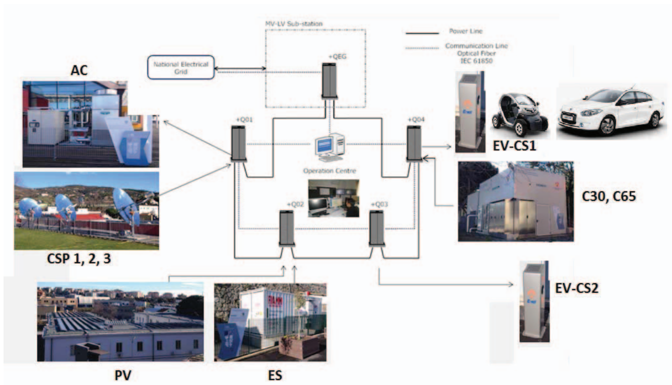


Fig. 3. The SPM grid topology

III. ELECTRIC MOBILITY ANALYSIS

In the present paper, experimental data relative to the two EVs charging stations (indicated by EV-CS1 and EV-CS2 in Fig. 3) of the SPM are reported and analyzed in detail. Furthermore, experimental data of a third charging station located in the University headquarters in Genoa are also considered, since all the three stations are monitored from the control room of the SPM, by means of the connection to the Siemens ECAR Operation Centre [17]. Moreover, the EV-CS1 and EV-CS2 charging stations are also monitored by the SCADA system of the SPM, in terms of power, current and voltage values.

The aforementioned three charging stations provide electricity to the following full electric vehicles owned by the University of Genoa: a Renault Fluence Z.E. and a Renault Twizy [18]. In Table I the standard features of the mentioned vehicles are reported, such as the battery capacity, energy consumption, driving range and maximum speed.

TABLE I. CHARACTERISTICS OF ELECTRIC VEHICLES

Type of Vehicle	*Battery Capacity [kWh]*	*Driving range [km]*	*Energy average consumption [Wh/km]*	*Maximum Speed [km/h]*
Renault Fluence Z.E.	22	185	146	135
Renault Twizy	6.1	80	87	80

The data analysis period is one year. Moreover, it is very important to consider that as a function of the day and the hour in which EVs are recharged, there are three different time slots (F1, F2 and F3), each one characterized by different prices of electricity withdrawn from the public distribution grid. Table II describes this classification.

TABLE II. DIFFERENT TIME SLOTS

Day	Hours 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23 24
Monday	F3	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3
Tuesday	F3	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3
Wednesday	F3	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3
Thursday	F3	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3
Friday	F3	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3
Saturday	F3	F3	F3	F3	F3	F3	F3	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F3
Sunday	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3

Observing the values reported in Table II, it is possible to hypothesize that during the time slot F1 (characterized by a higher price of the electricity withdrawn from the public grid) it is convenient to charge EVs by means of the electricity produced by the SPM (in particular by the photovoltaic plant, whose production attains higher values typically during F1 period). On the other hand, in nighttime time slots EVs are expected to be charged by withdrawing electricity from the public grid or from the storage systems of the SPM, since in those hours the renewable production is null, as well as that of cogeneration microturbines.

The data collected on the recharges of the EVs have been processed using Minitab software [19] in order to evaluate the charged energy, the recharge time and the time slot used; they have been characterized using the box plot graph as shown in Fig. 4.

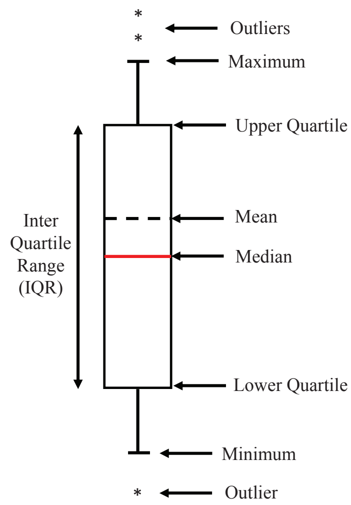


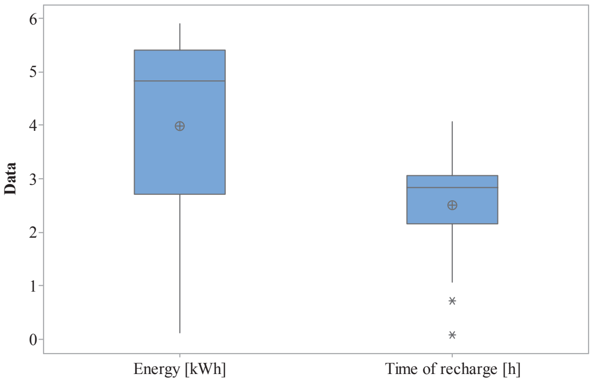
Fig. 4. Box plot for the data representation.

This approach is useful to calculate the average charged energy, the most probable variation range and the maximum and the minimum values that can occur. In particular, this study permits to understand the habits of the EV users. The outlier data have been also represented and considered in the statistical analysis.

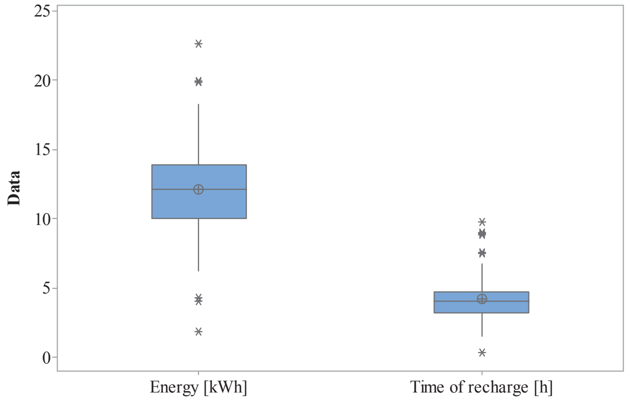
Figure 5 shows the energy drawn for each charge and the charging time for the charging stations located in Savona Campus (Fig. 5a) and Genoa University (Fig. 5b) headquarters. It has been possible to observe that, in general, the Renault Twizy is recharged in Savona whereas the Renault Fluence Z.E is usually recharged at the Genoa University headquarters. In fact, the recharges made in Savona campus are characterized by lower energy (4 kWh on average) and shorter time (2.5 h on average) than in Genoa (12 kWh and 4 h respectively), that are compatible with the two different type of vehicles (table I).

Another aspect that has emerged from the data analysis is the different habits for the vehicles recharge. Indeed, for the Savona Campus charging station the chosen time slot is F1, usually in the morning, instead in Genoa the preferred time slot is F2, especially from 6 p.m. to 11 p.m. In particular, at the Savona Campus the EVs are charged when the SPM electrical production from renewable sources is higher, whereas in Genoa the EVs are charged in the evening, when offices are closed and, consequently, there is not any necessity to use the EVs.

Starting from this preliminary analysis, it has been possible to observe that the use of EVs has been done considering the real needs of the end-users (i.e. professors, researchers and administrative staff), as they were gasoline or diesel powered vehicles. Therefore, the possibility to operate EVs as electrical storage systems, following a Vehicle-to-grid (V2G) strategy [20-21], has not been yet exploited mainly due to the fact that at present the installed charging stations and the EVs are not compatible with V2G [22-24].



(a)



(b)

Fig. 5. Box plots for the data representation respectively for the Savona Campus (a) and the Genoa University headquarters (b)

To conclude, two typical charging conditions for the Renault Twizy are reported in Fig. 6 and in Fig. 7. In particular, Fig. 6 shows a situation in which the EV was charged from 60% of state-of-charge to 100%, whereas in Fig. 7 a complete recharge is reported (from the minimum state of charge to 100%).

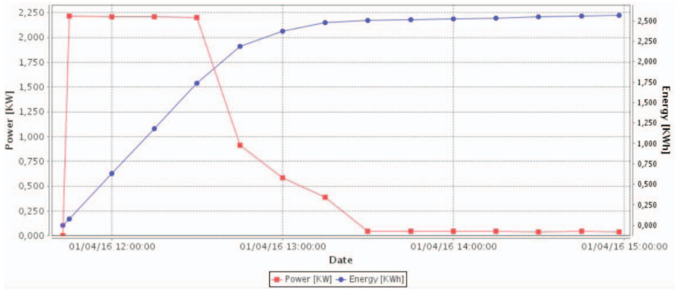


Fig. 6. Twizy charging from 60% to 100% of state-of-charge

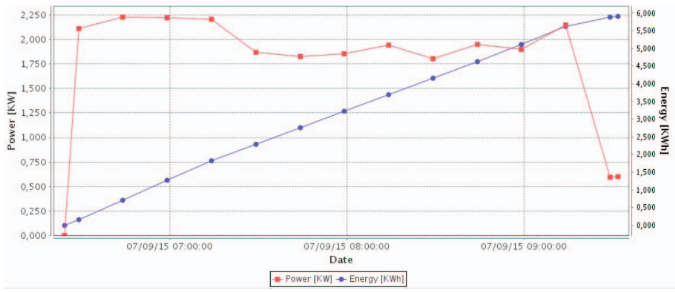


Fig. 7. Twizy charging from minimum to 100% of state-of-charge

As it is possible to note, the last period of the charging process, from 80% to 100%, is done at a reduced power rate in order not to damage the batteries and to protect them against overvoltages and overcharge.

IV. Conclusion

In this paper, the Smart Grid project of the Savona University Campus has been presented, with a focus on the use of the EVs integrated with Renewable Energy Sources (RES). In particular, the attention has been paid on the analysis of the different habits of the electric vehicles recharge and on the study of new scenarios that could exploit the benefits of the smart mobility concept.

The obtained results showed that currently the users in the recharging process do not consider the need of the electric grid, e.g. the availability of renewable source, but they tend to keep the same habits with the traditional vehicles.

In order to exploit the future vehicle-to-grid opportunities given by the electric vehicles, it will be necessary to introduce new actions that are able to shift the charging process in function of the needs of the network compatibly with the availability of the vehicles.

At present, the research activity is focused on some road tests on the Renault Twizy performed in the Savona city.

In the future, the adoption of the V2G option at the Savona Campus could be considered in order to foster challenging research activities on electric mobility, as well as to further optimize the Campus energy consumptions.

REFERENCES

[1] D'Appolonia SpA/Ramboll/TM Leuven, "Clean Transport - Support to the Member States for the implementation of the Directive on the deployment of alternative fuels infrastructure. Good practice examples," January 2016.

[2] ERTRAC/EPoSS/SmartGrids, European Roadmap, "Electrification of Road Transport," 2nd Edition, 2012 (Available at: http://www.ertrac.org/uploads/documentsearch/id31/electrification_roadmap_june2012_62.pdf).

[3] E.C. Kara, J.S. Macdonald, D. Black, M. Bérges, G. Hug, and S. Kiliccote, "Estimating the benefits of electric vehicle smart charging at non-residential locations: A data-driven approach," Applied Energy, vol. 155, pp. 515-525, October 2015.

[4] M. Majidpour, C. Qiu, P. Chu, H.R. Pota, and R. Gadh, "Forecasting the EV charging load based on customer profile or station measurement?," Applied Energy, vol. 163, pp. 134-141, February 2016.

[5] G. Comodi, F. Caresana, D. Salvi, L. Pelagalli, and M. Lorenzetti, "Local promotion of electric mobility in cities: guidelines and real application case in Italy," Energy, vol. 95, pp. 494-503, January 2016.

[6] M.H.K. Tushar, C. Assi, M. Maier, and M.F. Uddin, "Smart microgrids: optimal joint scheduling for electric vehicles and home appliances," IEEE Transactions on Smart Grid, vol. 5, no. 1, pp. 239-250, January 2014.

[7] J. Hu, H. Morais, T. Sousa, and M. Lind, "Electric vehicle fleet management in smart grids: A review of services, optimization and control aspects," Renewable and Sustainable Energy Reviews, vol. 56, pp. 1207-1226, April 2016.

[8] J.C. Mukherjee, and A. Gupta, "A review of charge scheduling of electric vehicles in smart grid," IEEE Systems Journal, vol. 9, issue 4, pp. 1541-1553, December 2015.

[9] Y. Luo, T. Zhu, S. Wan, S. Zhang, and K. Li, "Optimal charging scheduling for large-scale EV (electric vehicle) deployment based on the interaction of the smart-grid and intelligent-transport systems," Energy, vol. 97, pp. 359-368, February 2016.

[10] F. Mwasilu, J.J. Justo, E.K. Kim, T.D. Do, and J.W. Jung, "Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration," Renewable and Sustainable Energy Reviews, vol. 34, pp. 501-516, June 2014.

[11] O. Marcincin, and Z. Medvec, "Concept of charging stations for electric cars," In Proc. of the 2014 15th International Scientific Conference on Electric Power Engineering (EPE), Brno, Czech Republic, May 12-14, 2014.

[12] I. Grdic, V. Kirincic, and S. Skok, "The development of charging stations for electric vehicles: A solution or a problem?," In Proc. of the 36th International Convention on Information & Communication Technology Electronics & Microelectronics (MIPRO), Opatija, Croatia, May 20-24, 2013.

[13] S. Bracco, F. Delfino, F. Pampararo, M. Robba, and M. Rossi, "A dynamic optimization-based architecture for polygeneration microgrids with tri-generation, renewables, storage systems and electrical vehicles," Energy Conversion and Management, vol. 96, pp. 511-520, May 2015.

[14] S. Bracco, F. Delfino, F. Pampararo, M. Robba, and M. Rossi, "Planning and management of sustainable microgrids: The test-bed facilities at the University of Genoa," In Proc. of IEEE Africon Conference (Article number 6757862), Pointe-Aux-Piments, Mauritius, September 9-12, 2013.

[15] L. Barillari, A. Bonfiglio, S. Bracco, M. Brignone, F. Delfino, F. Pampararo, R. Procopio, M. Robba, and M. Rossi, "An optimization algorithm for the operation planning of the University of Genoa smart polygeneration microgrid," In Proc. of IREP Symposium: Bulk Power System Dynamics and Control - IX Optimization, Security and Control of the Emerging Power Grid, Rethymno, Greece, August 25-30, 2013.

[16] S. Bracco, F. Delfino, F. Pampararo, M. Robba, and M. Rossi, "A pilot facility for analysis and simulation of smart microgrids feeding smart buildings," Renewable and Sustainable Energy Reviews, vol. 58, pp. 1247-1255, May 2016.

[17] https://oc.electromobility.siemens.it

[18] http://www.renault.fr

[19] https://www.minitab.com

[20] http://www.ev-charging-infrastructure.com/

[21] M.A. Lopez, S. Martin, J.A. Aguado, and S. de la Torre, "V2G strategies for congestion management in microgrids with high penetration of electric vehicles," Electric Power Systems Research, vol. 104, pp. 28-34, 2013.

[22] M.C. Falvo, F. Foiadelli, "Preliminary analysis for the design of an energy-efficient and environmental sustainable integrated mobility system", IEEE PES General Meeting, 25-29 July 2010, Minneapolis, MN.

[23] M. Brenna, A. Dolara, F. Foiadelli, S. Leva, M. Longo, "Urban scale photovoltaic charging stations for electric vehicles", IEEE Transactions on Sustainable Energy, vol. 5, Issue: 4, pp. 1234 - 1241, 2014.

[24] M. Brenna, F. Foiadelli, M. Longo, "The exploitation of vehicle-to-grid function for power quality improvement in a smart grid", IEEE Transactions on Intelligent Transportation Systems, vol. 15, Issue: 5, pp. 2169 – 2177, 2014.