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An Integrated Tool to Monitor Renewable Energy Flows and Optimize the Recharge of a Fleet of Plug-in Electric Vehicles in the Campus of the University of Salento: Preliminary Results

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Abstract: A tool has been developed to integrate electric vehicles into a general systems for the energy management and optimization of energy from renewable sources in the Campus of the University of Salento. The tool is designed to monitor the status of plug-in vehicles and recharging station and manage the recharging on the basis of the prediction of power from the photovoltaic roofs and usage of electricity in three buildings used by the Department of engineering. The tool will allow the surplus of electricity from photovoltaic to be used for the recharge of the plug-in vehicles. In the present investigation, the benefits in terms of CO_2 and costs of the scheduled recharge with respect to free recharge are evaluated on the basis of the preliminary data acquired in the first stage of the experimental campaign.

Keywords: Electric and solar vehicles, Renewable energy, Information processing and decision support

1. INTRODUCTION

Several papers in literature address the possibility of using plug-in Electric vehicles as storage solutions to fully take advantage of renewable energy sources (RES) by shaping the load demand curve (Tomic et al. 2007, Andersen et al. 2009). For this purpose, EVs need to be equipped with vehicle to grid (V2G) communication systems (Lund et al. 2008).The management of the EV charging can be studied as an optimization problem where the objective is to maximize the usage of energy coming from renewable sources, or equivalently, to minimize the environmental impact in terms of CO_2 emission. However, there are some constraints to be taken into account: battery capacity, maximum charging/discharging power, state of charge at arrival time, desired state of charge at departure, user preferences (priority charge, eco-friendly charge, economic charge) and amount of power available from the grid or from RES.

The aim of the present investigation is to improve the energy efficiency of a multi-building facility (the University campus) that includes renewable energy plants and monitored buildings. The University of Salento have developed two prototypes of plug-in vehicles that can move in the campus only and used as a storage system. An electric vehicle (a Smart ED) has been also tested at the University of Salento for a period of 6 months between May and November 2013. Actually, the present investigation integrates the outcomes of two research projects: PRIME and BEAMS (7th Framework Program).

The research project named ‘‘PRIME - Progetto di Ricarica Intelligente per la Mobilità Elettrica’’ is funded by MATTM (Ministero dell’Ambiente e della Tutela del Territorio e del Mare, Italy) and involves several industrial and academic partners. The goal of the project is to collect experimental data of mobility demand, fuel consumption and vehicle performance from a fleet of Smart ED sold to about 100 users in three different Italian cities and two plug-in electric vehicles at the University of Salento. The projects also studies the behavior of customers, analyzes the impacts of charging stations for electric vehicles on the stability of the electric grid and estimates the reduction of pollutant and greenhouse emissions. Finally, technical standards and economic incentives to promote the diffusion of electric vehicles in Italy are identified and suggested.

The goal of BEAMS (Building Energy Advanced Management Systems) is the improvement of energy efficiency in public buildings, by an integrated control of heterogeneous sources (e.g. electric vehicles and photovoltaic installations) and loads, (e.g. public lighting, ventilation, air conditioning). In order to achieve this goal the OGEMA architecture (Open Gateway Energy Management Alliance) is used (http://www.ogema.org). OGEMA has been further extended and adapted to the requirements of more complex scenarios. In addition, a Facility Management Environment (FAME), has been developed to coordinate control strategies to increase energy efficiency across the entire campus. At the moment the FAME system is applied only to a part of the campus.

2. THE MONITORING AND SCHEDULING TOOL

A tool has been implemented for the real time monitoring as well as the optimization of the EV charging/discharging process and the forecast of the energy storage capacity within the University campus (see Fig. 1). The tool includes the following modules:

1) A short-term forecast module that predicts the production of electric energy from photovoltaic modules
2) A short-term forecast module for the request of power from the buildings according to historic data;
3) A status monitor for each plug-in vehicle including the level of SOC and the position (in motion, in parking, in recharging) and for the charging station. Historic data about electricity consumption acquired on board are also acquired via V2G devices and stored to predict the actual range of the vehicle. Information about the past recharges is also available from the charging station.
4) A module for the management of the charge according to the status of the vehicles and the surplus of energy produced by the photovoltaic system;
5) A model for the calculation of emission of CO_2 from a plug-in vehicle with a well-to-wheel approaches.

A module to evaluate the economic advantage of using the surplus of energy from PV to recharge the vehicles instead of selling the energy to the grid will be added as further development.

2.1 The monitoring infrastructure

The campus of the University of Salento includes several buildings and parking area covered with photovoltaic panels. The present investigation focuses on three buildings used by the Department of Engineering for Innovation: "Corpo O", "Corpo Y" and "La Stecca".The first floor of the "Corpo O" has been chosen for the installation of KNX (Konnex) devices (see Fig. 2). The floor of "has been divided into two portions, one equipped with monitoring and controlling devices while the other one is just monitored. In this way, it is possible to compare the power consumption of the fan coils, the lighting and the sockets with and without the control devices. The two sections of offices are symmetric respect to a central plane, the lighting and air conditioning systems are exactly the same, in terms of brands, size and power. The use of the offices by the staff is quite similar. Lights are turned-on manually while the turning on of air-conditioning system is timed.

The photovoltaic modules are mounted on a metallic structure with an area of about 4892 m^2. The nominal power is 960 kWp, given by two subfields (353.3 and 606.7 kWp). The PV modules are oriented to South-East with a tilting angle of 3° and 15° respectively. The DC/AC conversion system is composed by three inverters. The temperature of the PV module and the ambient temperature are measured by PT100 temperature sensors. Solar irradiance sensors are also linked to the data acquisition system. The monitored data are saved in a PLC Siemens for the post-processing (Congedo et al. 2013).

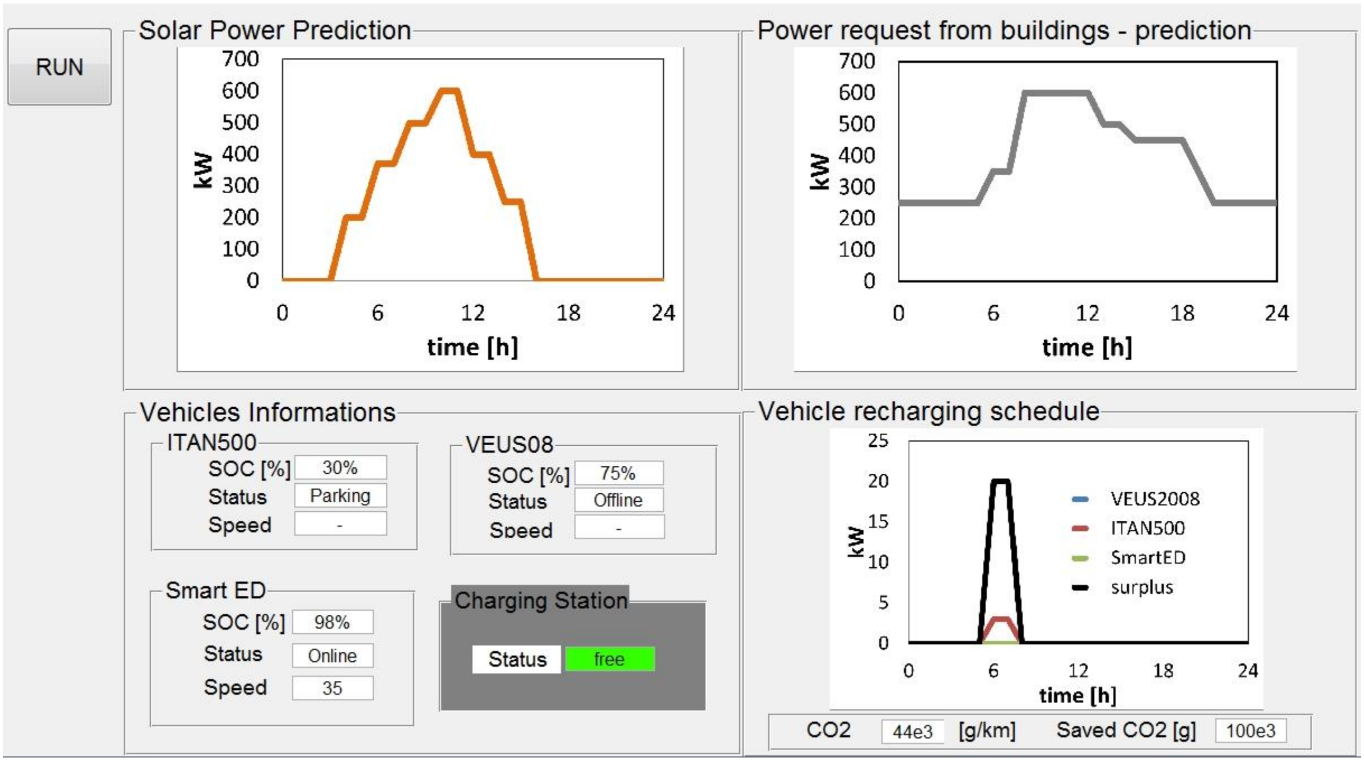

Fig. 1. Snapshot of the monitoring and scheduling tool

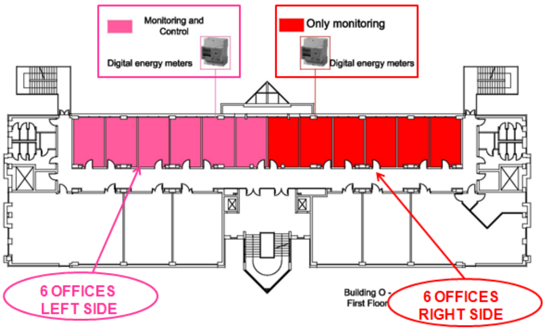

Fig. 2. Monitoring and control of building "corpo O"

The fleet of plug-in vehicles of the University of Salento includes a solar electric vehicle (VEUS2008) and a gasoline hybrid electric vehicle (ITAN500) designed at the University of Salento. A Smart ED has been also included in the first stage of the experimental campaign. The plug-in vehicles are equipped with an on board system for acquisition, filtering and storing of data about electric current to/from the battery and the electric motors (an example is shown in Table 1). The acquisition and transmission system is based on Arduino, a programmable prototyping platform. More details can be found in Donateo et al. (2014).

The data acquired on board are; battery current and voltage, auxiliaries status and current. The instantaneous speed of the vehicle is obtained by a GPS system. These data are gathered by Arduino and sent, through wireless interface, to the central server where the management platform is run.

Table 1. Example of records of electric consumption measured on the Smart ED

ID	Avg Speed [km/h]	Lenght [km]	Aux. status (AC/Radio)	Elect. Cons. [kWh/km]
1	28.89	2.0	OFF/ON	0.221
2	34.55	8.8	OFF/OFF	0.221
3	35.34	11.5	OFF/OFF	0.169
4	28.88	4.1	ON/OFF	0.254
5	14.72	7.0	OFF/OFF	0.167
6	18.33	7.1	ON/OFF	0.223
7	29.27	4.2	ON/ON	0.191
8	71.52	13.5	OFF/OFF	0.226
9	61.56	6.8	ON/ON	0.195
10	22.83	9.6	ON/ON	0.189

The plug-in vehicles are recharged through *Enel Distribuzione* recharging infrastructure consisting of Charging Stations (CS) connected to a central system (Clearing House). These are the main features of the recharging infrastructure:

- Access to recharging procedure through RFID ID card;
- GPRS communication enabled towards the Clearing House;
- Identification and authorization to charge from Clearing House;
- Remote control of the recharging process;
- User interface to support customer on recharging procedure and status (kWh for recharge);
- Power line communication between EV and CS enabled;
- Data acquisition and transmission of every single charge procedure;
- CS remote monitoring and availability check.

The solution is embedded with revenue-grade smart-metering, ready for integration into the upcoming smart grid.

An example of record the recharging events at the recharging station installed in the campus is shown in Table 2.

Table 2. Record of the recharging events (example)

VEHICLE	recharging date and initial time	recharging time	kWh
VEUS	02/11/12 10:46:32	4 h, 53 ', 28 "	2,403
VEUS	05/11/12 08:15:31	8 h, 48 ', 53 "	4,323
VEUS	20/05/13 08:15:09	0 h, 19 ', 30 "	0,100
SMART ED	14/06/13 08:13:44	1 h, 15 ', 35 "	3,777
SMART ED	24/06/13 09:54:43	1 h, 31 ', 27 "	5,517
SMART ED	02/07/13 07:39:38	2 h, 14 ', 50 "	7,385

2.2 The forecasting module

The forecast module of OGEMA uses PV power forecasts provided in form of txt files. The files contain the absolute power output for a certain PV plant with given rated power with 15 minute time resolution. Each predicted value has a time stamp indicating the date and time. The service is offered for installation sites in Europe and uses weather forecasts from different European meteorological services. Normally, this forecast information can be obtained within 6 hours after satellite data has been provided. The following information are offered by forecast service providers:

- Precise forecast by the hour up to 72 hours ahead (3 options: 6 hrs, 24 hrs, 72 hrs ahead);
- 15 minute exact actual feed-in quantities and extrapolation ;
- Spatial resolution of the forecasts;
- State-of-the-art algorithm;
- Consideration of fog and snow cover.

A high accuracy is guaranteed by international weather services, satellite based radiation measurements and regional measuring networks of solar power plants. Data are delivered via web service or email.

In the BEAMS project, the power feed-in forecast information in txt files is intended to be provided by a partner of the project via email. As long as this is not yet available, a simulated 24 hour forecast is taken into account in order to check the forecasting functionality.

In the same way, a forecast of electric consumption from the buildings is obtained with the use of historic data.

If the forecast power generated from the PVs is higher than the forecast power consumed in the buildings, a surplus of energy does exists. In this case, the system schedule the recharging of the vehicles according to their availability and status of SOC (see Fig. 1).

2.3 Scheduling module

To schedule the recharge of the vehicles, the following parameters are needed:

- Status of the charging stations (availability);
- Specification of the vehicles (battery capacity, maximum charging power, connection and disconnection times)
- Status of each vehicle (availability, charging status, State of Charge).

Using this information OGEMA performs a scheduling of recharges with a linear programming solver.

Fig. 1 illustrates an example of successful management of a partial recharge of vehicle ITAN500 based on forecast of PV production and buildings power request.

The PV forecast model uses static and dynamic parameters. The main dynamic variables are the measured meteorological data: solar irradiance and ambient temperature (DeGiorgi et al. 2014).. The power P of the PV system is calculated as:

$$P = \eta_{inv} \cdot A \cdot P_{module} \cdot 0.99 \quad (1)$$

where η_{inv} is the inverter efficiency and 0.99 is a loss factor for the losses on the electric line.

The area A [m²] of the PV array is given by:

$$A = \frac{P_{nominal}}{\eta_{inv}\,\eta_{module} \cdot 1000\,\frac{W}{m^2} \cdot 0.99} \quad (2)$$

where $P_{nominal}$ is the nominal peak power and η_{module} is the module efficiency. The factor 1000 W/m² is the global irradiation at standard test conditions (STC). The individual power P_{mod} [W/m²] for a PV module with assumed size of 1 m² is calculated as:

$$P_{mod} = \eta_{mod} \cdot irr \cdot \left(1 - \propto \left(T - Tout + k \cdot \frac{irr}{1000\,\frac{W}{m^2}}\right)\right) \quad (3)$$

where *irr* is the current solar irradiance, α is the PV temperature coefficient, *T* is the current outside temperature and *k* is the heating factor, (30 °C for rooftop mounting without ventilation). *Tout* the outside temperature at STC (25 °C).

3. SAVED EMISSIONS OF CO_2

Scheduling the recharge of the vehicles when there is a surplus of electricity from photovoltaic allows a saving of emissions of CO_2 that is evaluated according to two reference values:

1. Well-to-wheel emissions of CO_2 of the electric vehicle when recharged from the grid;
2. Well-to-wheel emissions of CO_2 of a gasoline vehicle (Smart ForTwo) over the same driving conditions and auxiliaries status.

The WTW emissions of CO_2 from the conventional vehicle can be calculated as:

$$CO_{2,CV} = FC \cdot CF_{WTT} \cdot CO_2 g \quad (4)$$

Where:

FC is fuel consumption in g/km.

CO_2g is the amount of CO_2 produced from the combustion of a gram of gasoline. The complete combustion of 1 liter of gasoline produces 2.4 kg of CO_2. Assuming a density of 700 kg/m^3, 1 g of gasoline produces 3.42 g of CO_2.

CF_{WTT} is correction factor that takes into account production and distribution of gasoline. Sullivan et al. (2004) suggests a correction factor of 1.162 for gasoline cars.

The overall emissions of an electric vehicle can be calculated as:

$$CO_{2,BEV} = EC \cdot CO_2 e \cdot CF_G \cdot CF_R \quad (5)$$

Where:

EC is the electric consumption measured in kWh/km.

CO_2e is the emission factor of the national electric system. A report from the International Energy Agency,(2011) indicates for Italy an average emission of 386 g of CO_2 per kWh of electric energy. This values takes into account the amount of energy acquired from foreign countries and produced mainly from nuclear.

CF_G is a correction factor that takes into account the losses of energy in the national grid. According the Terna report for years 2011 and 2012 (2013), the losses on the electric grid are about 7% of the total energy production (CF_G=1.07). The need of absorbing energy to cool down the batteries determines a difference between the nominal energy measured on the recharging station and the actual energy stored in the batteries. Specific tests have been performed in Donateo et al. (2004) to measure the losses of energy during the recharging phase due to the cooling of the batteries. Based on the results of the tests, a correction factor CF_R= 1.1 has been considered.

Using literature data about different vehicles configuration and engine typology, Mellios et al. (2011) developed the following correlation for the fuel consumption of gasoline vehicles to be used in traffic models:

$$FC = FE \cdot be \cdot 0.000278 \cdot [m \cdot (g \cdot r_0 + 1.05 bea) + \\ + (v/3.6) \cdot m \cdot g \cdot r_1 + (v/3.6)^2 \cdot 0.6 \cdot c_d \cdot A] \quad (6)$$

Where *bea* has the measure of an acceleration and depends on both average speed (*v*), engine typology (diesel or gasoline) and vehicle specification (automobile or light duty):

$$bea = 0.45 - 0.007\,v + 0.000028\,v^2 \quad (7)$$

and *be* is the brake specific fuel consumption which depends on vehicle specification and driving conditions (average speed). For a gasoline car:

$$be = 1339 \cdot v^{-0.305} \quad (8)$$

In (3), FE is an engine efficiency improvement factor that decreases from Euro6 (0.98) to Euro 0 (1.40), *g* is the gravitational acceleration, *m* the vehicle mass in kg, c_d the drag coefficient, *A* the frontal area in m^2, r_0 and r_1 are rolling friction coefficients.

According to Baumgart et al. (2010), the use of air conditioning determines an increasing of fuel consumption varying from 0.323 to 1.505 in the month of July depending on the type of cycle (urban, extra urban and highway). Consequently, the fuel consumption calculated with (3) can be corrected with an overconsumption OC according to the values of Table 3.

$$FC = FE \cdot be \cdot 0.000278 \cdot [m \cdot (g \cdot r_0 + 1.05\,bea) + (v/3.6) \cdot m \cdot g \cdot r_1 + (v/3.6)^2 \cdot 0.6 \cdot c_d \cdot A] + OC \quad (9)$$

Table 3. Overconsumption of the Gasoline Smart due to air conditioning

speed range	driving cycle	OC [g/km]
<25km/h	urban	10.5
25-45km/h	mixed	7.0
>45km/h	Extra-urban	3.5

Table 4. Tuning values for electric consumption with and without air conditioning

	correlation 1	correlation 2
test	ac_OFF + Freuers and Reuss(2013)	ac_ON
k1	3.41E-04	4.17E-04
k2	0.414	0.548
k3	6.88E-03	7.94E-03
k4	6.67E-05	3.31E-05

To develop a similar correlation for electric vehicles, the authors took into account the results of their experimental investigation (Donateo et al. 2014) and the data of Freuer and Reuss (2013) on the same vehicle (Smart ED). The correlation was expressed in terms of electric consumption four tuning variables k1, k2, k3 and k4 were considered:

$$EC = k_1 \cdot [m \cdot (g \cdot r_0 + 1.05\,bea) + (v/3.6) \cdot m \cdot g \cdot r_1 + (v/3.6)^2 \cdot 0.6 \cdot c_d \cdot A] \quad (10)$$

With:

$$bea = k_2 - k_3 \cdot v + k_4 \cdot v^2 \quad (11)$$

The values of the tuning variables that minimize the square mean error between the predicted consumption and the experimental data are reported in **Error! Reference source not found.**. More details about the investigation on electric and plug-in vehicles can be found in Donateo et al. (2013) and (2014).

4. PRELIMINARY RESULTS

The scheduling of the recharge has not been extensively applied. Therefore, the results available at the moment are limited to the monitoring of the system (buildings, vehicles, recharging station and PV panels) between July 2nd 2013 and October 4th 2013. The outcomes of the monitoring process are shown in Table 5.

Table 5. Preliminary results of the monitoring system

July 2th - October 4th			
vehicles	electric consumption	kWh	122.6
	total distance	km	346.5
	recorded electric consumption	kWh	67.0
	avg electric consumption	kWh/km	0.2
	eq. gasoline consumption	kg	15.8
infrastructure	measured consumption “Corpo O” (1/ 4 of floor)	kWh	5323
	estimated consumption of the three buildings	kWh	229954
	electricity produced by PVs (1MW)	kWh	524414
	overall surplus	kWh	294460
CO_2 (WTW)	gasoline	kg	62.9
	electric vehicle (from grid)	kg	30.4
	electric vehicle (from surplus of renewable energy)	kg	0

The consumption of electric energy has been measured on ¼ of first floor of “Corpo O” and is equal to 5323kWh. This value was multiplied by 12 to take into account the whole building and by 3 to extend to the other two buildings. Moreover, a correction factor of 1.2 was considered to take into account the presence of research laboratories that are assumed to consume more than offices and classrooms. Complete data about the three buildings will be available in the development of the project. The photovoltaic panels produced an average power of 1kW and generated about 524MWh. In this period of time, the Smart ED was the only electric vehicle available for acquisition and transmission of data to the system and also the only vehicle to be recharged from the station. The limited use of the electric vehicles in this first stage of the experimentation determines a very low value of the electric energy measured at the recharging station compared with the energy produced by the PV panels.

Moreover, electric consumption recorded on board of the vehicle is significantly less the electric consumption measured at the station since some of the trips of the Smart ED were performed before installing the monitoring device. Finally, about 10% of the nominal energy measured on the recharging station is not stored in the battery because of the losses due to the battery cooling system as described before. Using the data of Table 1 and the procedure for the calculation of CO_2 emissions in the previous paragraph, it is possible to state that by recharging the vehicle with the surplus of energy the saved CO_2 is 62.9 kg with respect to the gasoline Smart and 30.4kg with respect to the electric vehicle recharged from the grid.

A complete economic analysis of the whole system is not yet available. However, a simple calculation has been performed to obtain the economic advantage of recharging the vehicle with self-production of energy from PV. The results are shown in Table 6 and consists in a gain of €59,45 for the 122.6kWh measured at the recharging station.

Table 6. Economic analysis

Electricity from the grid			
	Unit cost	kWh	total
Cost	0.20€/kWh	122.6	€24.52
Electricity from self-production			
Benefit	0.285€/kWh	122.6	€34.94
		Balance	€59.45

5. CONCLUSIONS

A tool has been developed to integrate electric vehicles moving in the Campus at the University of Salento into a general systems for the energy management and optimization of energy from photovoltaic roofs. The results of the first stage of the application of the tool is reported in the paper with a calculation of the saving of CO_2 and money that is obtained with a smart scheduling of the recharge of plug-in vehicles in the University Campus.

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