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Development of Recharge Panels for Electric Vehicles at Buzios Smart City

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Abstract

This paper presents the implementation of an electric vehicle infrastructure and the development of refuelling panels for electric cars and bicycles at "Buzios Smart City R&D Project", an initiative of Ampla a distribution company that is associated to the European Enel Group. The text describes aspects concerning the basic concept, selection criteria, measuring system, assembling, and pre-operational tests for the first few recharge panels that were installed in Buzios. The conclusions highlight several possibilities, including the data recording improvements that are crucial for the project with regards to managing electric vehicle fleets and predict their impacts on the distribution network.

Keywords: electric vehicles; recharging infrastructure; metering; smart grids; impacts on the network

1 Introduction

As of 2011, Ampla Energia e Serviços S.A. started to implement their "Smart Grid" pilot project in the city of Armação dos Búzios, in the State of Rio de Janeiro. The city was strategically chosen because of its geographic profile and renowned tourist potential, which has projected it worldwide. The initiative evolved in order to incorporate new technologies that promote sustainable, rational and efficient use of energy, to turn it into a city of the future [1]. One of the themes of the Buzios Smart City Project is the developing of recharging stations for electric vehicles a R&D effort in connection with ANEEL (the National Electrical Energy Agency), which is the context of this paper. In light of the recommendations provided in ABNT Standard NBR IEC 61851-1: 2013 – Electric Vehicles Power Recharge Systems Part 1: General Requirements as in [2], Ampla has provided one electric Palio Weekend and two REVAS i Standard for the project. These vehicles fit in the recharge model classified as "Charge Mode 1", whereas the more recent vehicles use the "Charge Mode 3", which is characterized by this pilot communication feature that supervises correct vehicle grounding and system power on/off. In addition, Ampla has acquired 42 electric bicycles for various experiences and initiatives, particularly for use by the Búzios Municipal Guard, Municipal Health Department and local inns, as the result of an agreement with the Búzios Hotel Association (AHB) and Ampla Energia e Serviços S.A.
These bicycles will also be used in the activities of the Research and Monitoring Center (CMP) built by Ampla in that city. For that purpose, two different recharge panels have been developed for the CMP by the Vehicular Propulsion Systems Laboratory - LSPV at the Rio de Janeiro State University - UERJ. One is able of simultaneously recharging two cars and the second two bicycles. These panels enable recharge data collection and they will be also used to demonstrate to CMP visitors how real time measurements can assess electric vehicles performance. Additional recharge panels should be installed in nearby sites that are relevant for vehicle performance analyses, as well

as to promote the project. This paper is intended to show the main guidelines for the localization of the recharge grid and to provide project details as the inclusion of metering in the electric vehicle recharge panels. It includes aspects related to the concept, the selection criteria, metering system characterization, assembling, and pre-operational tests of the units installed at CMP, in Búzios besides the impacts in the grid.
Since 2006 LSPV has been coordinating R&D projects in the context of ANEEL with respect to the performance of electric vehicles, especially in urban centres and the impacts of this new electric energy market. These experiences were considered as important references for the development activities described in this text and are reported in [3 - 6].

2 Development

2.1 Guidelines for Locating rhe Recharge Infrastructure

According to the Master Plan for the City of Armação dos Búzios, the municipality is divided in three macro-zones: Peninsular, Continental, and Insular. The Peninsular macro-zone is identified as the city's busiest tourist region, containing most hotels and inns as well as Buzios's main tourist attraction, which are the beaches. Because of this profile, that region of the city also concentrates most businesses and banks. The City Hall and most municipal secretariats are also located in that macro-zone. Coincidentally, Ampla's Research and Monitoring Center (CMP) is also located in the Peninsular macro-zone, including the medium voltage distribution grids responsible for the supply of energy to this region, which are supervised by the CMP. Considering the above mentioned facts, for the purposes of project visibility, the recharge stations were thought to be strategically in the peninsular macro-zone.
Fig. 1 shows a map of the peninsular macro-zone and highlights the sites proposed for recharge infrastructure installation in the city of Buzios. In Fig. 1, marker 01 identifies the CMP, in blue and yellow, indicating the existence of a panel for bicycles and a panel for cars. Markers 02 through 08 identify local inns, in blue, indicating the existence of a panel for bicycles. Green markers indicate the location of bicycle parking facilities with no recharge panel. Spots 13 and 14 are also shown on the map to correspond to the Municipal Secretariat for the Environment and Fishing and to Ampla's Commercial Agency in Buzios, which are also indicated for the installation of electric car recharge panels. The Municipal Secretariat for the Environment and Fishing was indicated by virtue of their partnership with Ampla in the Buzios EcoAmpla Awareness Project, which is intended to encourage recycling practices by exchanging recyclable waste for light bill bonuses, and is therefore an interesting place for the installation of recharge stations.

Figure1: Electric vehicle recharge infrastructure

2.2 The Concept of Recharging Structures

The recharge structures in Búzios were conceived to meet recharge needs of the electric cars provided for the project as well as to collect recharge data for the development of this research effort. Four recharge structure models were therefore conceived, two of which will prioritize research activities and the other two, which are modular, will meet both research needs and the public needs in the city of Búzios.
The research recharge structures were installed at the CMP and comprise one panel for electric cars and another one for electric bicycles, and both feature two simultaneous recharge outlets. The other two models were conceived for installation at strategic spots in the CMP supervision area, one for electric cars, with a single recharge outlet, and another one for electric bicycles with three simultaneous recharge outlets.
These recharge structure models are to be equipped with metering that enables real time data transmission for the development of research activities.

2.3 Metering System

When the project started, Ampla requested LSVP to provide an assessment of a residential smart plug utilized in another R&D project in order to study the energy consumption habits of customers. An analysis of the technical characteristics showed it was designed for an input voltage in the 100 to 240 V range, with two independent current inputs. One of them in accordance with the Brazilian standard for 10 A and the other via connectors for 50 A capacity. Besides, it had an electric meter for power, energy consumption, voltage, current and power factor. Communication with the electric meter could be performed through a software capable of generate a spreadsheet containing measurement records that also enable online visualization of the values being monitored. Fig. 2 presents a photo of the above mentioned “smart plug” during tests at LSPV.

Figure 2: Residential smart plug in tests at LSPV

Considering that the metering characteristics met the project needs, the next step was looking for a protection box for all components of the recharge panel. Thus, the residential smart plug was modified to work inside the box as a single phase meter prototype. It was resized for fixation on a bus type called DIN, maintaining the input of 50 A as per original design. Fig. 3 presents photos with the front and back view of the single phase prototype for use inside the recharge panels

Figure 3: Single phase prototype

The technical characteristics of the metering system are listed below:

Input power: 100 to 240 V
Maximum current: 10 A or 50 A
Grid frequency: 60 Hz
Measurements (average values): voltage, current, frequency, apparent and active power, power factor and energy consumption.
Accuracy: ≤ 2%
Sampling frequency: 4.096 kHz (1s)
Resolution: 16 bits
Mass memory: 2 MB
Integration interval: selectable between 5 and 15 min
Registration time: 227days@5min or 682days@15min
Local communication via USB port
Set up software compatible with Windows operating system

2.4 Protection Boxes

It was carefully analyzed the technical data issued by national and international manufacturers of protection boxes for installing electric equipments. With this information, became possible to establish a proposal subjected to the following criteria:

Component quality
Absence of difficulties for assembling
Absence of difficulties for operating
Safe use
Compliance with current standards
Internal space for installing metering components
Protection degree
Availability of spare parts
Total cost of panel and individual components
Delivery time

The winner proposal presented a high level of safety involving their recharge outlets, which rely on a mechanical interlocking system that avoids any contact with energized parts during vehicle recharge operations.
In the case of recharge panels for the electric bicycles, use of the Brazilian standard outlet was considered crucial in order to comply with current standard ABNT NBR 5410 on electrical low voltage installations. Another relevant point was the operational safety degree, called, IP 66, which means weather resistant, totally protected against dust and against direct sprays of water up to 15° from the vertical as occurs during storms. Table 1 presents a summary of the main technical features

of the above mentioned recharge panels in accordance with the site of installation and type of panel.

Table1: Characteristics of the Recharge Panels

Panel	Poles	Voltage (v)	Current (A)
Cars	2P+G	200 - 250	16
Bicycles	1P+N	250	10

Note: P – pole; G – ground; N - neutral

2.5 Assembly of Recharge Panels

Fig. 4 and Fig. 5 show, respectively, front and internal views of both panels for electric cars and electric bicycles. It is important to mention that the two panels have circuit breakers for short circuits and residual currents in accordance with the Brazilian standards.

Figure 4: Front and internal views of recharge panels for cars

Figure 5: Front and internal views of recharge panels for bicycles

3 Previous Tests

After finalizing panel assembly, pre-operational tests were run to check panel and component performance prior to definitive installation at the CMP.

3.1 Residual Current Protection

To verify the operation of residual current protection devices, the Trial Method 2 suggested in Annex H of NBR Standard 5410 Version 2008 was adopted, according to Fig. 6.

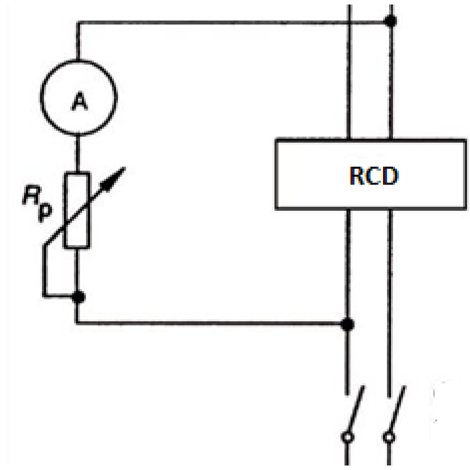


Figure 6: Scheme for verification test of the RCD (Residual Current Device Circuit Breaker)

The following resources were used for this test:

Scopemeter FLUKE, model 125/S
FLUKE i30S AC/DC Current Clamp, 5 mA - 30 A range, 0,1 mA resolution;
MINIPA voltage and current probe, ET-3880 model;
Potentiometer: 50 kΩ.

The residual current circuit breaker, type bipolar, has the following technical characteristics:: nominal current (In) of 25 A and residual current (IΔn) of 30 mA. The test voltage was 220 V (phase-phase) for the car panel and 127 V (phase-neutral) for the bicycle panel.
The tripping current (IΔ) measured by the Scopemeter 125/S was around 25 mA and it is considered satisfactory in accordance with the standards.
Fig. 7 presents two photos of recharge panels, at left for cars and at right for bicycles, during the verification tests of RCD operation, showing the metering resources and the potentiometer used to adjust the tripping current.

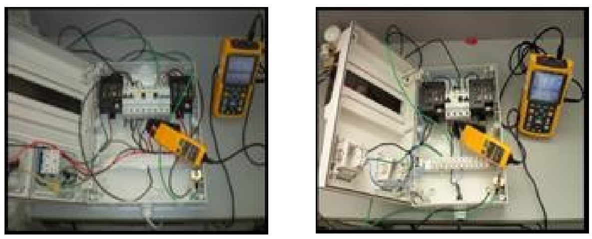


Figure 7: Residual current circuit breakers of recharge panels for cars and bicycles in test

3.2 Electric Car Panel Tests

The electric car recharge panel tests were performed on a VW Kombi converted to electric traction as shown in Fig. 8. This conversion is a partnership project between the Rio de Janeiro State University – UERJ and the Federal Center of Technological Education Celso Suckow da Fonseca - CEFET-RJ. Several experiences are conducted with this platform that actually works as a laboratory for both institutions.

Figure.8: Recharge panel for electric cars in test

The metering device in the recharge panel is capable to generate a spreadsheet indicating the energy consumption (kWh), the average power (W), the maximum and minimum active power values (W), the feed power (W) and the load current (A), recorded at 5 minute integration intervals.

3.3 Electric Bicycle Panel Tests

The tests with the electric bicycle recharge panel were conducted in the LSPV/UERJ facilities. An electric bicycle E Bike S was provided by Ampla for that purpose is shown in Fig. 9

Figure 9: Recharge panel for bicycle in test

4 Impacts on the distribution network

Experiences and tests of recharging cars and bicycles were performed at the Ampla's Research and Monitoring Center (CMP) in Buzios. The results were utilized to develop a new mathematical model to predict the impact of a group of electric vehicles connected to a distribution feeder or a transformer. Fig. 10 shows two electric bicycles simultaneously recharged in the CMP by the panel at left side.

Figure 10: Electric Bicycles Recharging in CMP

At right side is possible to see the panel for recharging electric cars. Fig. 11 shows two Nissan – Leafs, outside the CMP, being simultaneously recharged by this panel.

Fig. 11 Recharge of two Nissan Leafs at CMP

4.1 Model of Demand Curve During Electric Vehicle Recharge

A model for evaluating the demand curve during an electric vehicle recharge is presented. It was developed after the results of several tests with the panels described in this article. Tables 2 and 3 reproduce the behavior of typical conditions and results found in performed tests with an electric bicycle. Table 2 refers to the route corresponding to the discharge of the battery, previously charged by 100%. Table 3 refers to the replacement of about 22% of the battery energy.

Table 2: Route characteristics

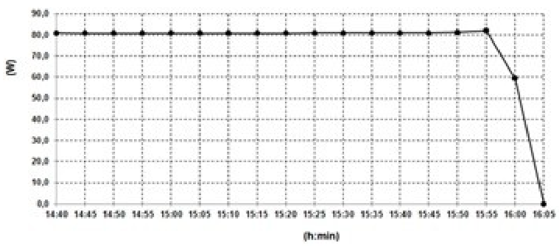
Period of Time (min)	Distance (km)	Average Speed (km/h)
12:51	4,40	20,54

Table 3: Results from the recharge test

Recharge Time (min)	Recharge Energy (Wh)	Efficiency (Wh/km)	Recharge Rate (Wh/min)
88	109,23	24,83	1,35

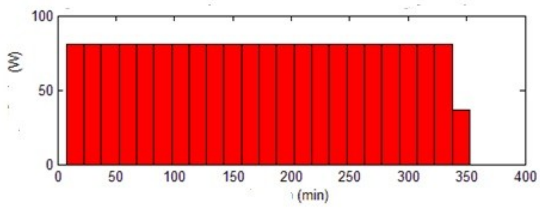
Figure 12 presents the behaviour of the average active power for every five minutes interval, during the recharge of a E Bike S. It was obtained based on the data collected by the meter installed in the charging panel.

Figure 12: Average active power during a recharge of E Bike S (W)



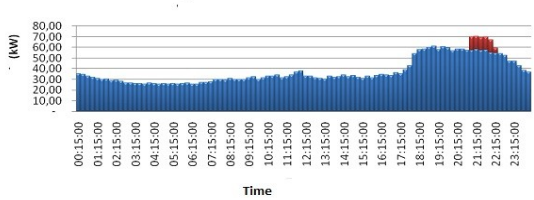
Tests with electric bicycles indicate that the effects of current and voltage throughout the charging process is finished with decay current until it is reduced to a residual value when the battery state of charge reaches 100%. The active power demand has a constant value followed by a descending in ramp shown in Figure 12. Therefore, a model for predicting the charging curve of electric vehicles was developed in this research. Indeed the recharge of electric vehicles, in general, has the same behavior in accordance with comparisons with previous studies [3]. However, it was necessary to consider the charging curve in terms of discrete variables to represent the demand of active power in time intervals corresponding to the conventional measurement of electrical systems in Brazil equal to 15 minutes. Therefore, the maximum charging time equivalent to 100% state of charge is a multiple of 15 whose maximum demand coincides with the battery charger power, in this case 80 W. The energy for recharging is associated with the capacity of the battery bank. Considering as reference the values of the consumption efficiency (Wh/km) and the recharge rate (Wh /min) in Table 3 it is possible to generate, in Fig. 13 a curve in terms of discrete values corresponding to the range of E Bike S.

Figure 13: Discrete model representation corresponding the range of E Bike S



The error in the maximum demand was 0.84% and the error in energy was 1.13%, both considered satisfactory. This modeling can be adapted to any distance travelled and corresponding recharge times. Based on these calculations developed with MATLAB, the Fig. 14 shows the daily load curve in blue of a distribution transformer of 75 kVA under the impact represented in red by 150 electric bicycles under recharging starting at 21:00 and an average previous distance equal to 15 km/day [7].

Figure 14: Simulation of the impact of recharging 150 bicycles on a 75 kVA distribution transformer



According to Fig: 14, the following results were obtained:

- Energy for recharging the bikes - 16.2 kWh
- Recharge Demand - 12.15 kW
- Maximum transformer demand - 61.2 kW (at 19:00 without considering bicycles in recharge)
- Maximum transformer demand - 70.3 kW (at 19:00 considering bicycles in recharge)

Even having started the recharge of the electric bicycles at 21:00, there is a 15% increase in maximum demand at 21:15. In a smart grid environment it is convenient, for example, that the recharge be transferred to 03:00 a.m. to avoid transformer overload. Air conditioners in Buzios determine a low inductive power factor. In fact, it would be suffice to be lower than 0.92 to overload the transformer.

4.2 Effects of the connection moment to the grid for recharging

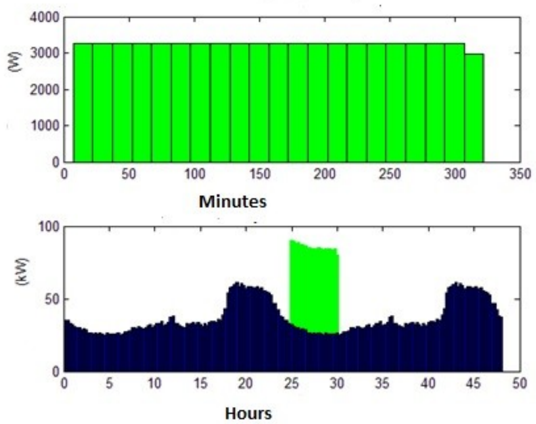
Based on the methodology presented in item 4.1 will be described the expected effects of the connection moment for charging of electric cars in the grid taking as reference the technical characteristics of an electric Palio Weekend car in accordance with Table 4.

Table 4: Electric car characteristics

Battery Voltage (V)	Battery Capacity (Ah)	Recharge Efficiency	Range (km)
253	76	0,95	100

Fig. 15 shows the representation of the electric car recharging curve in terms of discrete variables corresponding to an average distance of 74.7 km / day. Just below is also represented the typical daily demand curve for two consecutive days of the 75 kVA transformer, considered in the previous section. The superposition of 18 electric cars connected at 1:00 a.m. for recharging is represented in green. Such vehicles are simulating an electric car fleet of delivery services that are recharged at night in a deterministic process.

Figure 15: Deterministic process of electric car recharge



The simulation was performed with all the vehicles connected to the transformer at same time considered a power factor equal to 0.92, inductive. According to Fig: 15, the following results were obtained, in order to get 100% state of charge:

- Energy for recharging the electric car: 17 kWh
- Total distance traveled by the fleet - 1411.7 km
- Energy for recharging the fleet - 308 kWh
- Maximum demand - 90.5 kW (98.4 kVA)
- Maximum demand time – at 1:00 a.m.

It is important to mention that even having begun to recharge the fleet out of peak, at 1:00 a.m., still resulted in 31.2% overload in the transformer.
The most realistic situation generally corresponds to recharging performed at random with respect to the connection time for recharging. In the context of smart grids it is possible to avoid exceeding the network capacity by a demand side management supported by a simulation tool [8].
Therefore, to evaluate the recharging of 18 electric cars connected to the transformer at different times was kept the same average distance considered in the deterministic case described in Fig. 15 for comparison. The model was carried out by the Monte Carlo method with a lognormal probability density function, which is described in equations (1) and (2), utilizing MATLAB.

$$\mu = \log\left(\frac{m^2}{\sqrt{v+m^2}}\right) \quad (1)$$

$$\sigma = \sqrt{\log\left(\frac{v}{m^2+1}\right)} \quad (2)$$

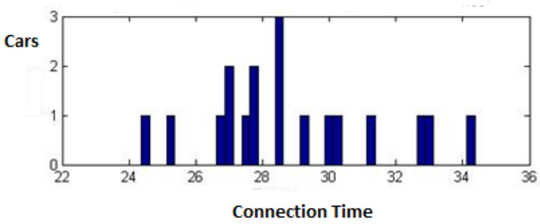
The mean and the standard deviation of the associated normal distribution is represented by the first members of the equations (1) and (2), respectively. Variables *m* and *v* are the mean and the variance of the lognormal function. Both are functions of these terms in accordance with equations (3) e (4), respectively.

$$m = e^{\left(\mu+\frac{\sigma^2}{2}\right)} \quad (3)$$

$$v = e^{(2\mu+\sigma^2)}.\left(e^{(\sigma^2)} - 1\right) \quad (4)$$

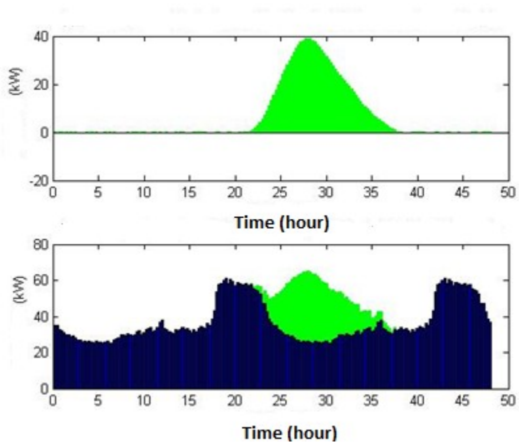
This stimulation was sorted with 2000 random trials per vehicle. Fig. 16 shows a sample of the lognormal distribution considering the connection time for recharge at random. This figure shows the number of vehicles and the corresponding connection time for recharge.

Figure 16: Sample of the lognormal distribution



The stochastic process of connection time and energy supply to recharge a group of electric vehicles is described in Fig. 17. The upper graph, in green, shows only the active power demand that feeds the electric cars. The lower graph represents the superposition of an electric car recharge on the transformer demand curve (48 hours).

Figure 17: Stochastic process of electric car recharge



The results of this simulation indicate that 3 cars start the recharge at 2:45 a.m. and it is the maximum. Of course the total energy required to recharge the fleet is the same of the deterministic process, 308 kWh, because they travel the same average distance per day. However the maximum demand occurs at 2:45 a.m. and it reaches 65.3 kW (71.0 kVA) without overload the transformer. These calculations become possible to determine the diversity factor of time to start the recharge. In the deterministic case all the vehicles start the recharge at same time. In comparison only 3 cars is the maximum number of cars in the stochastic process. Therefore the diversity factor is 0.17.

5 Conclusions

Test results with the developed recharge panels for cars and bicycles has demonstrated that they can be utilized in the Research and Monitoring Center - CMP at Búzios and for the planned recharging network.

There is an overall insight that these panels can be improved to other uses, either public or private, considering the promising prospects of electric vehicles for transportation activities. In fact, both recharge panels, for cars and bicycles, can be assembled and installed by a low cost in comparison with similar products found in the market.

After one year on operation, several recharging samples were registered by the recharge panels at CMP. It is a valuable data set for modeling the demand and consumption impacts on the network. It is desirable to add a module for remote access by internet to expedite data collection from the metering devices.

The development of recharge panels for electric vehicles and the tests performed demonstrated the feasibility to establish a new methodology to estimate impacts on the distribution networks. Usual technical data is sufficient for simulation. In this way, it was shown to be possible achieve decisive results for planning and operation of distribution networks.

The work highlights the importance of the introduction of smart grids, showing that in this environment the automation can optimize the convenient use of existing gaps in the transformer demand curves in order to meet the market penetration of electric vehicles.

It is highly desirable the introduction of public policies in Brasil to eliminate tax barriers aiming at the production, marketing and electric vehicle recharging infrastructure [9].

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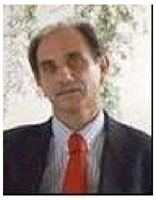

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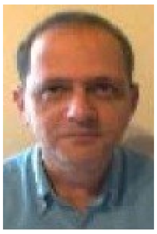

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