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EUROPEAN UNION

Report on the challenges OF REPLICATING batteries demonstrators

Partner Responsible

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Project funded by the Interreg Sudoe Programme through the European Regional Development Fund (ERDF)

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1. Introduction

One of the most critical aspects of the energy transition is energy storage. There is the need to produce increasingly efficient battery to support the shift from internal combustion engine cars to electric vehicles. Also, the growing deployment of renewable energies whose output power cannot be controlled, such as solar photovoltaic and wind energies, requires a boost in the grid energy storage capacity.

The challenges related to energy storage for mobile applications are very different from the ones related to stationary applications. For instance, a key aspect of electric vehicle batteries is the energy density (i.e., energy stored per cubic meter), a feature that is not so important in grid storage applications. This significant difference opens an opportunity, often named “Second life batteries”. The basic is that electric car batteries after some years of use loose capacity, and the energy density that can achieve no longer meets the requirements to fuel an electric car.

However, such batteries can still be useful for applications that do not require a very high energy density, such as grid storage applications. The purpose of this activity was precisely to test the suitability of using a repurposed electric vehicle battery to support a solar photovoltaic energy self-consumption system.

This work was carried out jointly in Lisbon and Toulouse. In both cases there is a photovoltaic generator, a battery storage, an energy consumer and an energy management system.

There are some differences, such as the different power levels, the electronic power management structures and the consumer profile. Indeed, the system set up in Lisbon includes a physical link to the power network, whereas the system in Toulouse remains a completely autonomous system. In both cases there is a photovoltaic generator, a battery storage, an energy consumer and an energy management system. Moreover, in Lisbon the batteries powered system provides energy for a room where students gather to study, and in Toulouse the energy system is used to charge an electric bicycle.

Despite this difference in size and the nature of users, the system's overall configuration, approach, student engagement and outreach to the academic community, in general, are very similar.

2. Activity Description

2.1 FCUL activity description

At the University of Lisbon, the challenge was to develop a solar photovoltaic (PV) energy self-consumption system with local storage, using a repurposed electric vehicle battery in second life.

Figure 1. Outdoor PV system

For this purpose, a **Photovoltaic (PV) system** was installed on the campus (Figure 1). The system is composed of 18 PV modules with a total installed capacity of 7 kWp. Indoors, the system is connected to the **second-life battery system** (Figure 2). The repurposed batteries were originally from a Tesla 3 vehicle. It has an energy storage capacity of 30 kWh, includes a VRM Multiplus inverter, and allows for remote control and monitoring (Figure 3). In the monitoring interface the user observes in real-time the system work, check if level of charge of the battery system and its operation mode (charging/discharging/idle). The self-consumption system supplies energy to a **studying area**, used by the students of Engineering of Energy and Environment to study either individually or in groups (Figure 4). The electric load of this area is composed by illumination, computers, and climatization.

Figure 2. Indoor battery and control system

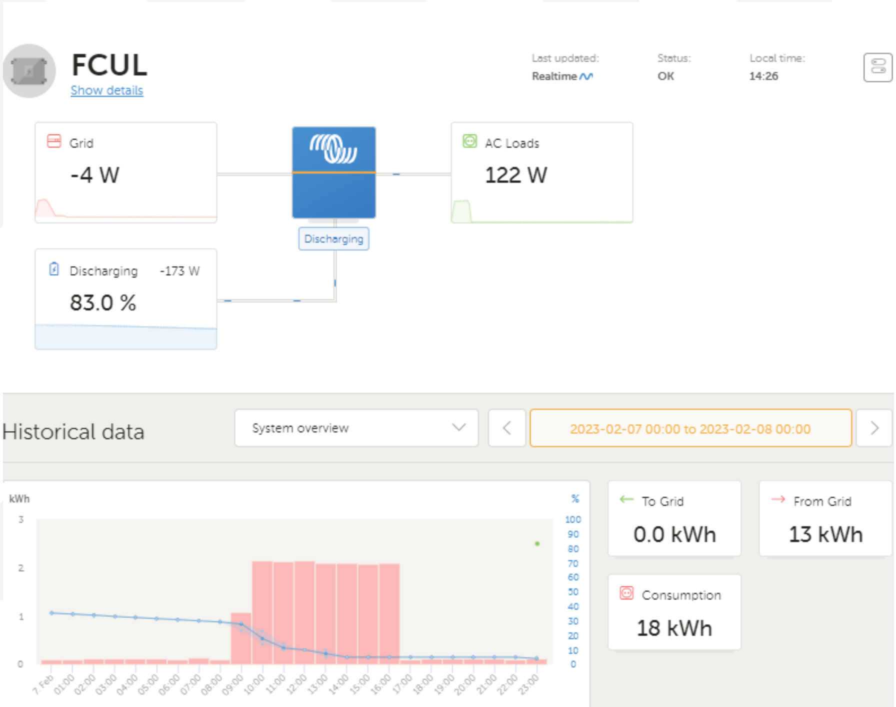

Figure 3. Real-time data visualization

Figure 4. Load: study area.

The system can operate with or without PV generation. Figures 5-7 illustrate the PV + storage system operation in different conditions, highlighting the flexibility of the system as a showcase for the self-consumption of solar energy for the academic community and visitors. In Figure 5 is presented the variation of energy consumption (kWh), and charge level of the batteries during a day without PV electric generation. It can be observed that after 13:00 the batteries charge level is below 10% and can no longer fulfil the electricity need, so the electricity is imported from the grid.

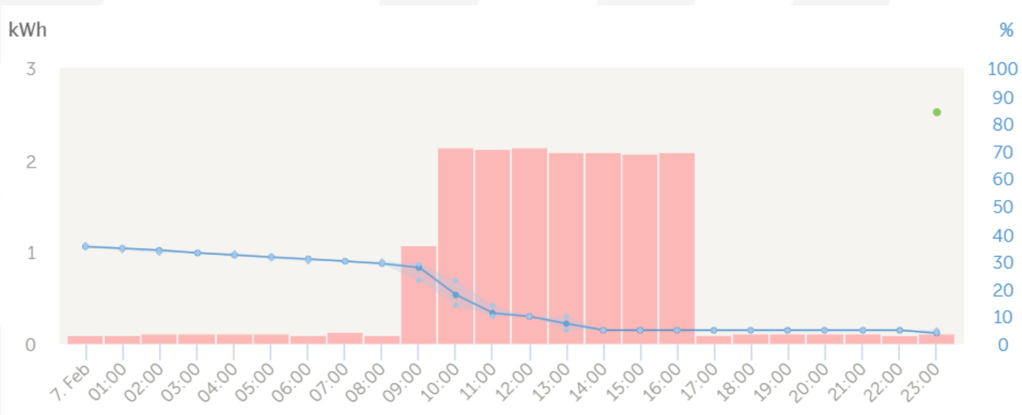

Figure 5. Operation without PV generation. The batteries are satisfying the load. Electricity from the grid is imported (after 13:00) when the state-of-charge of the batteries is no longer able to fulfil the load.

Figure 6 illustrates a situation where there is PV power generation and the electricity load are low. Consequently, the batteries will be charged by the PV modules between 9:00 and 13:00 remaining at full charge afterwards.

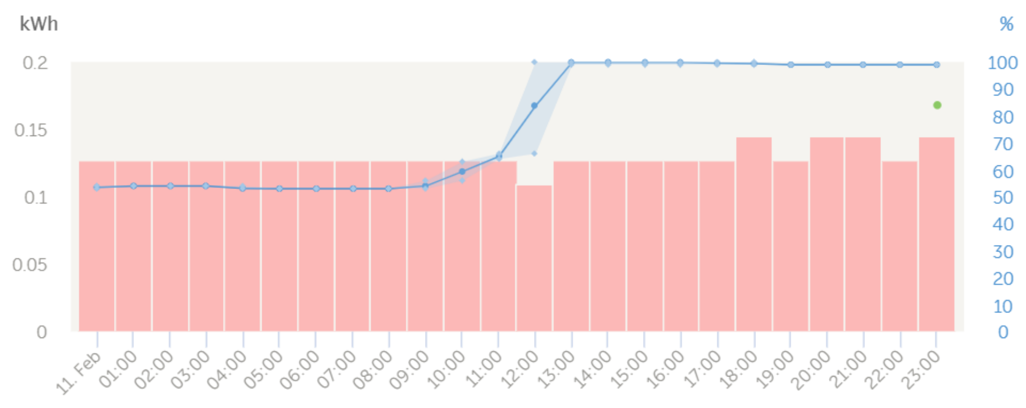

Figure 6. Operation with little load. PV generation is used to fill the batteries. When the batteries are fully charged (after 13:00), solar electricity is fed into the grid as excess generation.

In the last situation illustrated in Figure 7, there is PV generation and a significant electricity demand between 11:00 and 17:00. The system operates in self-consumption mode. The electricity generated by the PV modules charges the batteries and simultaneously feed the electricity load. After 15:00, when PV generation decreases, the electricity generation stops charging batteries, and when electricity generation ceases the energy stored in the batteries powers the load.

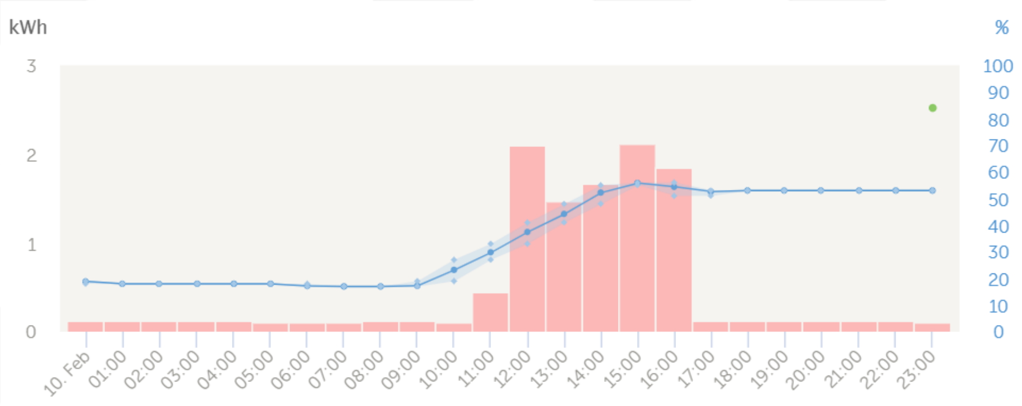

Figure 7. Operation in self-consumption mode. PV generation charges the batteries and satisfies the load. When PV generation decreases (after 15:00) it stops feeding the batteries, and stored energy helps power the load.

2.2 UT3 activity description

The schematic diagram is given in the figure below. The green arrows represent the powers (energy transfers) exchanged between the different blocks of the system. The safety devices (fuse, isolating switch, etc.) and measurement devices are not shown on it.

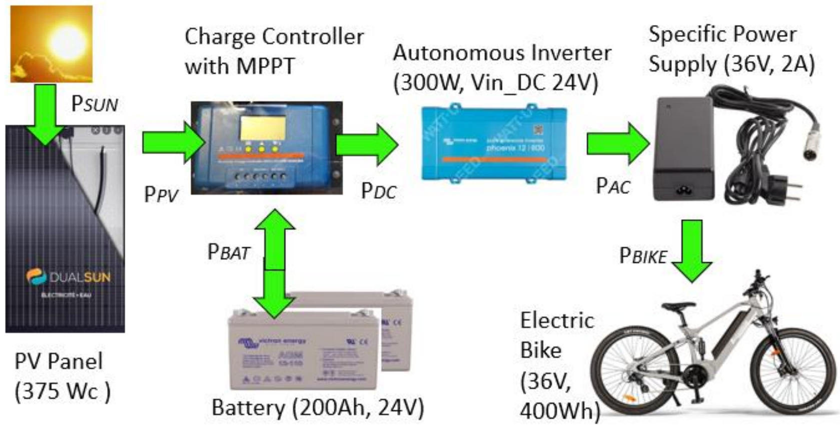

Figure 8. Eléments de l'installation

The photovoltaic panel (375Wp, 1.9m²) installed on the roof is connected through a regulator to the lead batteries (24V, 100Ah, 2.4kWh), bought new but they can easily be replaced by second hand batteries. An autonomous inverter allows the electrical power to be switched to 230V AC. The load to be powered is either an electrically assisted bicycle used daily by the room's technician for his home-work journeys, a freezer, or a specific consumption set by two active loads that can be configured.

Emphasis has been placed on measurements with:

- Displays to visualize the main electrical parameters (voltage, current, power) directly.
- Numerous sensors (pyranometer, thermometer, voltmeter, ammeter) to recover interesting data.

All the measurements are collected and stored on a computer and will be made available on a server at the University.

In parallel, the purchase of licenses for the PVsyst software allows the simulation of the entire system (production, storage and consumption).

Example of recovered measurements:

Figure 9. 7 days measurements of the solar generator voltage (blue) and battery voltage (orange).

Figure 10. Dualsun solar panels mounted on the top of the building

Figure 11. Stand-alone photovoltaic system: batteries under the table, 2 active loads are to the left of the electrical cabinet, regulator is located in the cabinet. The inverter is under the electrical cabinet. The connection of the photovoltaic panels is at the top right.

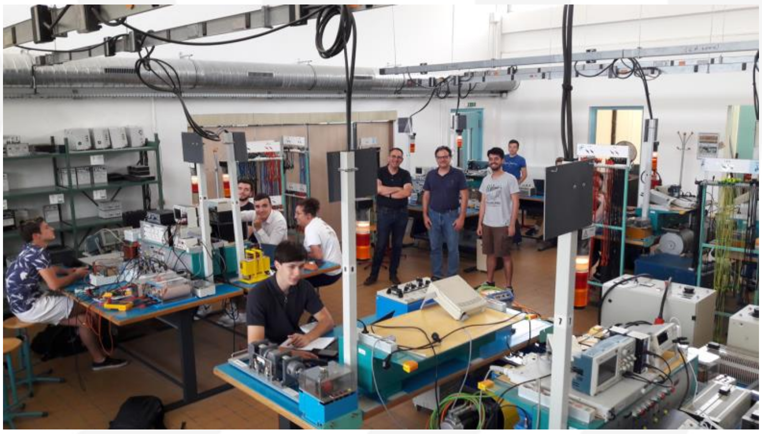

Figure 12. Power electronics room where the stand-alone photovoltaic system is installed

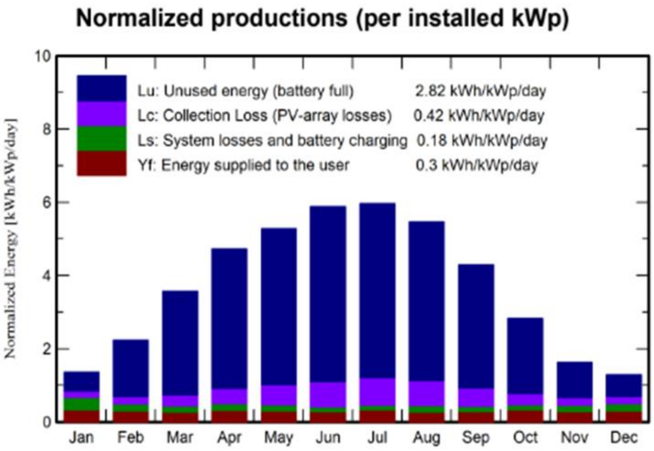

Figure 13. Example of simulation results, in this case the electric bike is charged every day without any problems.

3. User engagement

3.1 Right now

The selection of a studying area in faculty in Lisbon for the experiment has made to favour the engagement of the student community. The high-quality visualization tools included in the self-consumption system enable an effective communication, allowing the community members to follow the demonstrator tests in real time, raising awareness, interest and enthusiasm for clean energy technologies and solutions.

Similarly, in Toulouse, it has been judicious to locate the system in an experimentation room where many students are present during the semester. The students can see the daily graphs on the computer or the live measurements on the displays. In addition, having ice cream in the summer thanks to the solar-powered freezer makes the possibilities of this stand-alone system more visible.
The use of the same brand of power converter in Lisbon and Toulouse will allow the exchange of data more easily between the two university platforms.

In Toulouse, a dozen students have carried out a master's project on this system: implementation, simulation study, addition of sensors and two other students will work this summer to complete the system with wireless measurements.

Exchanges are currently taking place through direct cooperation between research professors from different universities and institutions. They will continue through the sharing of experimental data used between the partners to make students work on these data during their final year projects or during their studies. To do this, part of the experimental data will be made available to the community through the Tr@nsnet website.

3.2 In the near future

Initially, the cooperation between FCUL and UT3 involves sharing ideas on the tools and the choice of simulations to be carried out to model and characterise these systems and in particular the system's second-hand batteries. It also involves mutual help in analysing the results. In a second phase, we will be able to compare the practical results obtained in the specific contexts of each university (different voltage and power levels, different solar resources, etc.).

In Toulouse, in the very near future (6 months) this experimental site will be used as a training platform for photovoltaic energy in isolated sites. It will also be used as an experimental base, during student projects, to develop and set up a wireless and energy-autonomous instrumentation system that would double the existing measurements and would allow reflection on the measurement rates, processing at the sensor level, etc.
This reflection is particularly interesting because it is essential to recover the right parameters at the right rate without having excessive storage resources.
This living-lab offers the opportunity to carry out this reflection on very different fields (the living world with the planted filter and the electrical field)

In the longer term, in association with the research work carried out at LAAS-CNRS on batteries, this site will enable us to test battery ageing models.

In Lisbon, the second-life battery system will continue to be used in the study area, the possibility to widen the area fed by the system will be analysed, namely, to include the hall pass lights and a classroom. In order to further engage the students of the Master in Energy and Environmental Engineering, in the use and characterization of the system, internships will be proposed to work within the scope of this project.

Conclusion

In Lisbon and Toulouse, these demonstrators are well integrated into the living-lab of their respective universities. They are a showcase for the possibilities offered by photovoltaics on an autonomous site.
The main advantages of second-life batteries systems like the ones developed are:

1. Circular economy: second life for batteries which avoid considering it as a waste.
2. Increase the usability of PV energy at low prices (as the second-hand batteries are naturally cheaper than new ones)
3. Making viable an autonomous energy system.

Even if the actual capacity is lower than the capacity of new batteries is remains very interesting for cheaper energy storage and reuse.
The installed systems will be able to evolve according to the needs that will emerge (in situ tests of second-hand batteries) or that are already there (reflection on wireless measurement systems in difficult environments due to electromagnetic disturbances).
Our two systems at different power levels complement each other very well and will allow us to respond in Toulouse or Lisbon to requests for second-hand batteries over a wider range of power and energy.