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Design, development, and operation of a fast charging station backed by a battery system

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Summary

Energy storage systems will play a role in the deployment of fast and ultra-fast electric vehicle charging stations by enabling locations with limited grid power availability, avoiding grid reinforcements cost, integrating local renewable energy sources, and improving grid integration. This work presents the experience in the design, development and operation of a 50 kW fast charging station backed by a 75 kWh second life battery storage system, including the development of a software tool to ease the design and techno-economic analysis processes.

Keywords: fast charger, energy storage, Second-life battery, demonstration

1 Introduction

The electromobility sector in Europe is under an exponential growth driven by the regulatory pressure and incentives to reduce greenhouse gas emissions, a broader portfolio of electric vehicles (EV) and an increasing willingness to adopt emissions free vehicles. The European Union Green Deal targets 55% emissions reduction from cars in 2030 and 0% emissions from new cars in 2035, leading to a 13 million zero and low emissions cars forecast for 2025 [1].

One of the key elements to allow this growth is the availability of public fast charging infrastructure for EVs and it is expected that 1 million charging stations will be required in 2025 [1]. However, the deployment, operation, and exploitation of EV fast and ultra-fast charging stations (FCS) face several challenges that hinder its techno-economic feasibility for certain locations:

- High power grid connection requirement. There are many appropriate locations for FCSs, where due to the very high power needed the access to the grid requires high investments related to grid extensions, secondary substation for medium voltage grid connections or grid reinforcements. Additionally, these actuations may significantly extend the deployment period of the projects.
- High operational costs. FCSs operational cost are mainly related to the electricity supply contract and more specifically to the demand charge, which is a fixed cost independent from the FCS usage and related to the contracted power. The demand charge may account the main share of the electricity bill depending on the grid tariff structure of each country and the usage ratio of the FCS.

- Low self-consumption rate of local renewable energy sources. The integration of renewable energy for self-consuming is foreseen as fundamental to reduce operational costs, however, nowadays EV public charging usage is fundamentally stochastic, specially in country with moderate EV penetration, and it has a limited real time matching with photovoltaic (PV) generation patterns. As result the self consumption ratio is low and this hinders the economic feasibility of PV installations associated to charging stations.
- High impact on the distribution grid. The massive deployment of FCSs can pose a significant stress to the distribution grid in certain locations due to a stochastic high power load.

In this context, battery energy storage systems (BESS) are a key technology [2] to enable a fast and effective charging infrastructure deployment by reducing investment and operational costs, accelerating commissioning time and mitigating the negative impact to the distribution grid. Such a solutions are being studied at a scientific level for same years now [3] [4] and several pilot FCSs backed by Li-Ion BESSs have recently come into operation.

Second life battery (SLB) concept basically consists of the repurposing of batteries that have reached their end of life (EOL) in a first application in the automotive sector for their use in a stationary application [5]. Automotive batteries face very demanding requirements in terms of energy and power density and cycling profiles, as consequence the EOL is typically considered when the remaining capacity drops below 80% of the initial capacity. However, these batteries are still suitable for a second use with less demanding requirements as for example stationary storage applications for self-consumption or to support EV charging installations [6]. The main benefits and challenges of SLB are the following:

- Lower price than new batteries, and more specifically, lower levelized cost of storage.
- Assure access to batteries in a scenario of high and growing demand mainly driven by EVs.
- Reduction of the environmental impact by the activation of circular economy processes.

Nevertheless, SLB faces several challenges:

- Regulatory uncertainty.
- Battery performance and remaining useful life for the new application.
- Great diversity of EV batteries makes difficult the standardization and systematization of repurposing and remanufacturing activities.
- Being price competitive, especially considering the cost reduction new Li-Ion batteries are having and further reduction perspectives for next years.

This work presents the experience and process for the design, development, and operation of an EV fast charging solution with a BESS based on SLB.

2 EV charging stations design tool

The design and techno-economic feasibility analysis of FCS integrating BESS and local renewable generation assets is a complex process as it depends on many interdependent factors, as: battery characteristics, charging demand, PV generation pattern, grid restrictions or energy tariffs among others. The detailed analysis of solutions with a BESS is important given that batteries are consumables whose useful life depends on many factors such as calendar, number and type of cycles and environmental conditions.

A software tool has been developed to deal with this complexity and to do the optimal sizing and techno-economic analysis of the charging solution. Its main characteristics are:

- Design and simulation of charging stations integrating different kinds of charging points, BESS, PV and grid connection.
- Probabilistic functions and a querying theory model to simulate the EV charging demand.

- Simulation of the energy flows according to the selected energy management strategy. Several energy management strategies are allowed, and new ones could be added.
- Dynamic and degradation battery models based on characterization and aging tests to estimate the behaviour of the BESS throughout the project's life.
- Calculations of techno-economic results for the project lifetime, including CAPEX, OPEX, NPV and other economic efficiency parameters.

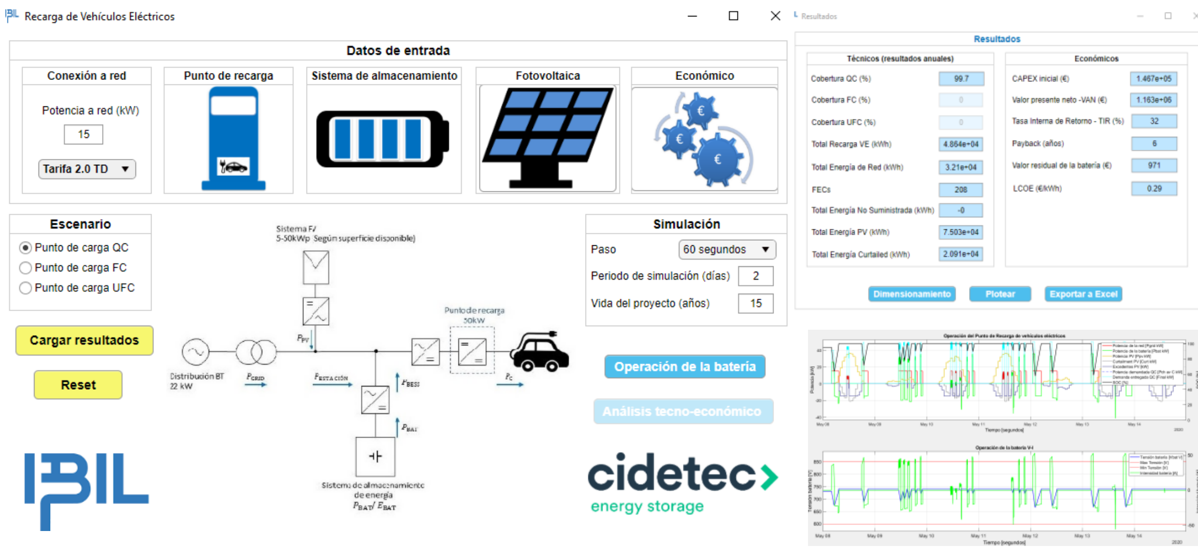

Figure 1: Graphical interface of the sizing tool for charging stations design and analysis.

3 BESS solution design and development

A fast-charging solution buffered by a BESS based on second life battery modules from Irizar e-mobility electric buses (e-bus) has been developed. As shown in Figure 2 the architecture of the solution consists of the charging terminals, a BESS connected to the AC grid through a bidirectional power inverter, the energy management systems (EMS) and the backend.

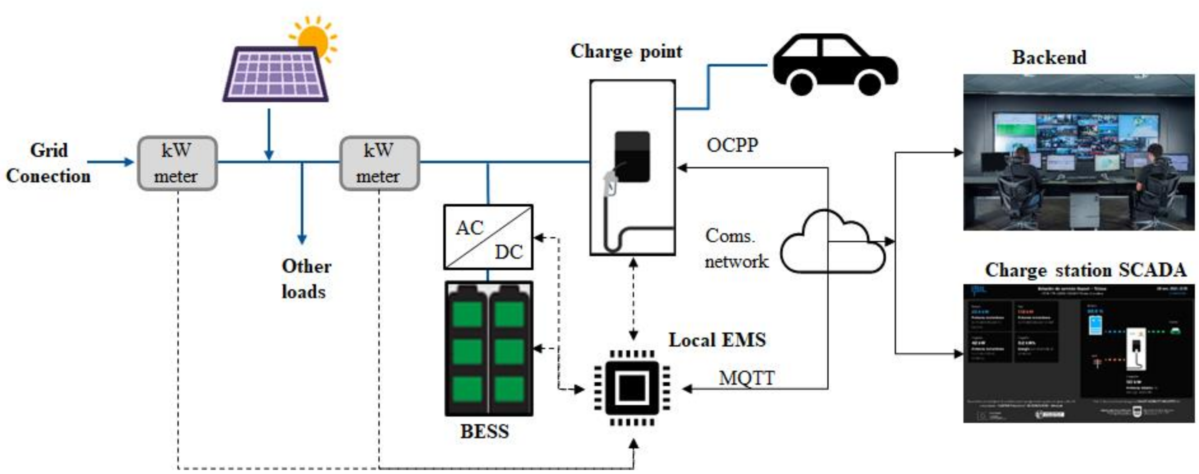

Figure 2: Adopted architecture for charge stations backed by BESS

The development of a BESS based on SLB has been chosen, considering the high stock of used batteries expected to come from electric bus (e-bus) fleets, the good fitting of these batteries with the targeted applications and the cost performance benefits of the second life concept.

There are several business and remanufacturing SLB strategies for the repurpose of automotive batteries at cell, module, or pack level. In general, e-bus batteries require less remanufacturing effort than EV's ones, as these have a more complex mechanical and thermal solutions due to their integration and location in the car. In this case the repurposing has been done at module level. Battery modules have been used without any major change and the final electrical system configuration is very similar to that of the e-bus battery pack so that the same battery management system and protection unit is used. The BESS cabinet and thermal control unit are different and have been specifically designed for the stationary application.

Several BESS sizing and configuration analysis have been made considering typical FCS configuration, minimum, maximum and typical charging sessions profile, battery modules characteristic and the bidirectional inverter characteristics. In this case the DC voltage working range of the power inverter has highly conditioned the minimum and maximum number of battery modules that can be efficiently connected in series. Finally, a 75 kWh/75 kW BESS has been designed as a basic unit that permits to form solutions connecting several units in parallel with one or more power converters. Table 1 shows the main characteristics of the BESS.

Table1: BESS solution's main characteristics

BESS solutions	
Battery chemistry	Li-Ion NMC
Battery Nominal capacity	75 kWh
Battery Charge Power	75 kW
Battery Discharge power	25 kW
Number of battery modules	16
Battery DC nominal voltage	700 V
DC Working voltage	570-796
Operational SOC	5-95%
AC grid connection voltage	400 Vac
Auxiliary power	1,5 kW
Dimensions (HxWxD)	2500x950x600 mm

An EMS for controlling the power flows of the system has been designed and developed. The charging station is connected to IBIL's backend through OCPP to allow a remote monitoring, control, and operation. The EMS holds the following functionalities:

- **Peak shaving**: this functionality controls that the power consumption from the grid never exceeds the maximum limit, which can be a fixed or a dynamic limit.
- **Price arbitrage:** this functionality aims to optimize the cost of energy by shifting BESS charge from one period to another. A self-consumption optimization functionality has also been developed for those installations that integrate local generation. These functions require to predict the EV charging demand to avoid limiting the charging service due to lack of BESS power.
- **Dynamic Load Management:** this functionality performs the EV charging load management, distributing the available power between the charging points and limiting the charging power according to the available grid, BESS and PV power.
- **Flexibility provision:** the possibility of providing services through demand side flexibility is being evaluated [7], as it would provide a new source of revenue and improve the bankability of the BESS. However, this would require demand and generation accurate forecast so that avoid conflicts between functionalities that could affect to the EV charging service, which is the main functionality of the system. Flexibility services

highly depend on the market design and regulatory framework of each country, in the case of Spain demand assets can participate in the electric system balancing services since 2021.

4 Pilot charging station with BESS

By means of the software tool and considering charging needs, location restrictions and battery solution characteristics, a pilot charge station backed by a BESS was developed in a Repsol's service station in Tolosa, Spain. In this station only 15 kW were available for additional electric loads and if additional power was needed very costly investments were required.

First, techno-economic and simulation studies were carried out to analyze possible solutions to install a 50 KW charge point with and without a BESS. The conventional solution for this location required a medium voltage grid extension, a new client's secondary substation and shifting from a low to a medium voltage grid access tariff. The alternative solution was based in the previously described 75 kWh BESS but based on electric bus new battery modules, as SLB modules were not yet available. The study was done considering the following aspects:

- 15 years project lifetime.
- Annual EV charging demand of 12 MWh.
- BESS based on new battery modules with a capital cost of 550 €/kWh.
- A grid reinforcement investment estimated in 90,000 € and a useful life of 30 years. A residual value of the 50% at the end of the studied period of 15 years.
- Grid access tariffs in force in Spain since 1 June 2021.
- Wholesale electricity price of 70 €/kWh.

Figure 3 shows a comparative study of the ownership cost without considering financial aspects. It shows those costs that vary from one solution to the other, so that the common costs, as that of the charging point, are not considered. The results show that the solution buffered by a BESS is the most suitable for Tolosa's charge station under the defined working conditions and considering that the BESS would have a 15-year useful life.

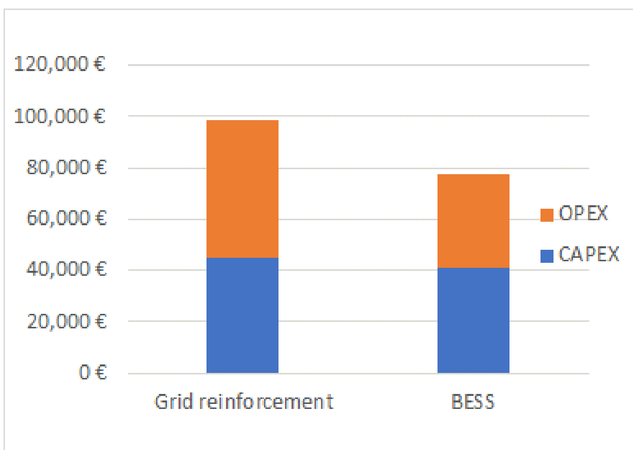

Figure 3: Comparison of cost of ownership of charging station solutions for Tolosa

By means of time series simulations the EMS strategies were analyzed and it was validated the capacity of the BESS solution for providing EV charging without curtailments. Different EV charging demand profiles were simulated, as the one in Figure 4.

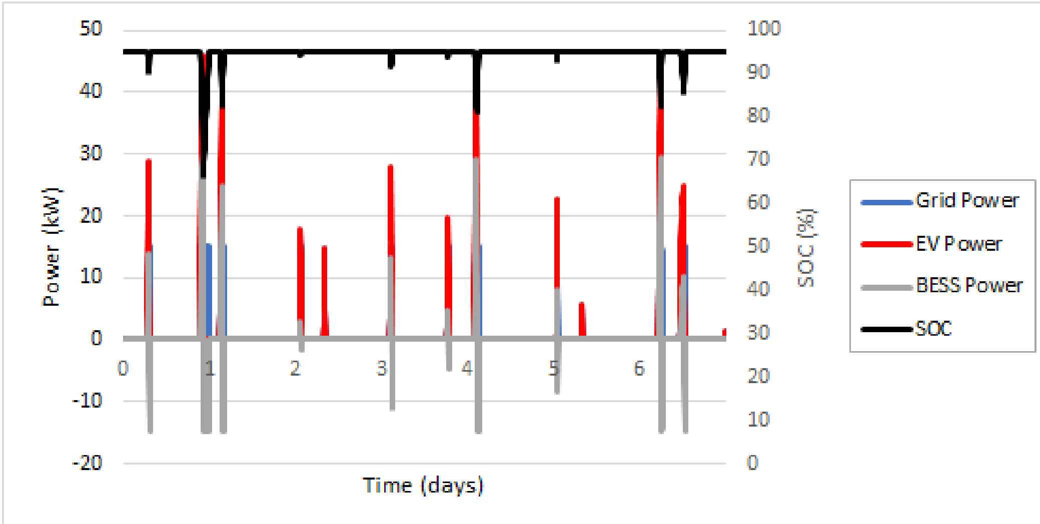

Figure 4: Simulated energy flows of the charging station

Finally, on the basis of the described studies the pilot charge station was developed with a 50 kW fast charge point from Ingeteam, a 75 kWh battery with a nominal power of 35 kW and a 15 kW grid connection.

Figure 5: (left) 75 kWh BESS during the assembly process (right) Charge point and BESS in Repsol's service station in Tolosa, Spain.

The EMS in Tolosa's charging station performs peak shaving and price arbitrage functions. Figure 6 and 7 show the power flows of the system's elements during two of the sessions. The sign criteria employed is as follows: positive for BESS discharging and negative for charging; positive for grid consumption and negative for injection. In the example of Figure 6, the two phases of the peak shaving algorithm can be appreciated: first, when the EV charge load overpasses the limit of 15 kW, the BESS starts to feed power, as shown in the figure the BESS follows the small and big variations of the EV load; second, when the EV charge stops, the BESS starts charging up to the established SOC target (91%) to be able to better buffer next charging sessions and hence maximize the EV charging service.

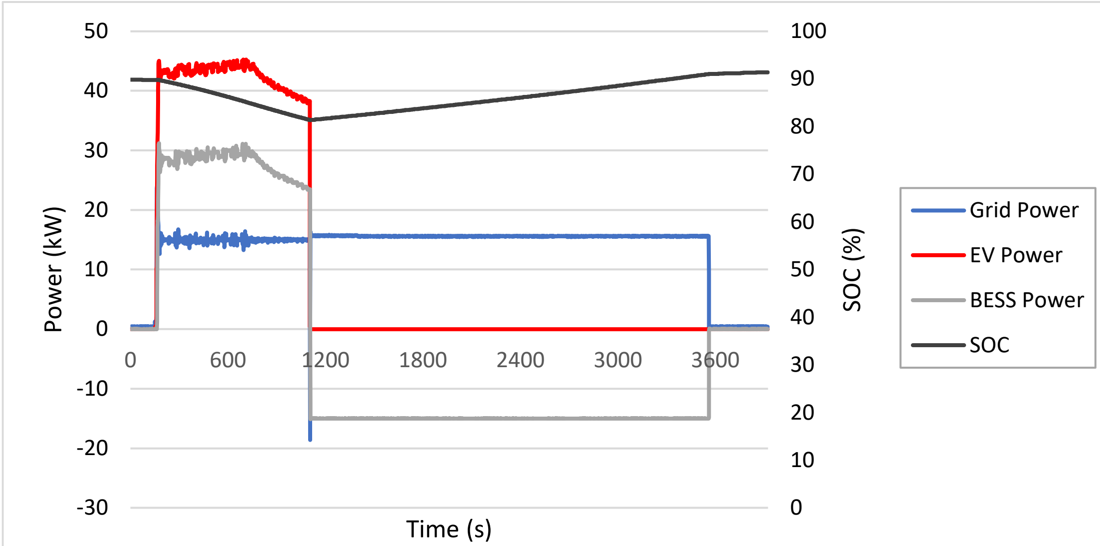

Figure 6: Example 1 of EV charging session in Repsol's charge station in Tolosa, Spain

Figure 7 shows a charging session with a different EV load profile, in this case the BESS enters into operation for a short period and after the session as the SOC does not fall below the established threshold the BESS does not need to recharge. In this case, it can also be seen that when the EV load falls below the maximum allowed grid power of 15 kW the BESS stops giving support.

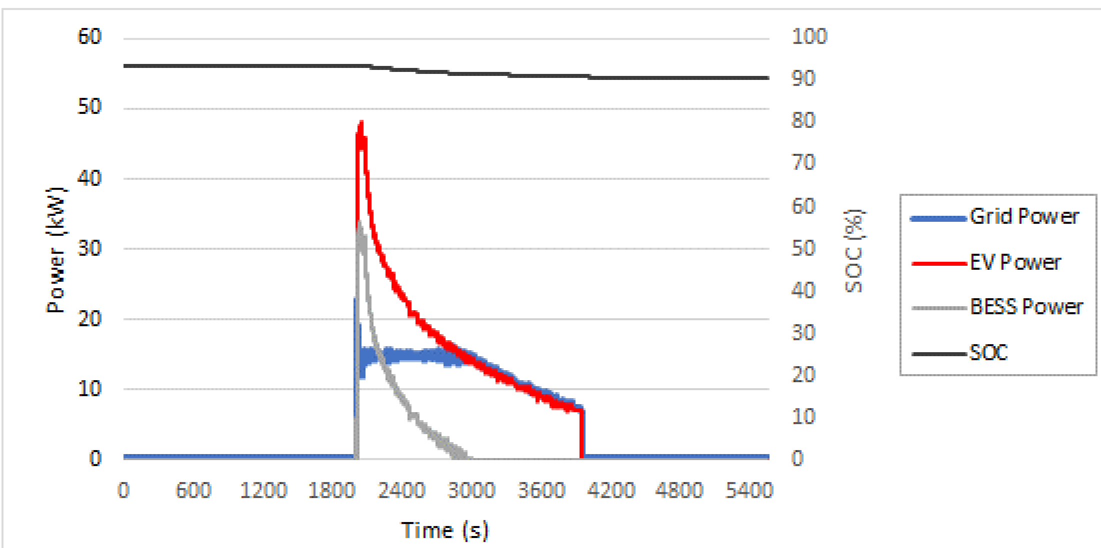

Figure 7: Example 2 of EV charging session in Repsol's charge station in Tolosa, Spain

Since the charging station entered operation hundreds of EV charging sessions have taken place, the battery has allowed fast charging in a location with limited available power. The usage of the charge station during 2021 has been moderate, below the 12 MWh annual load of the simulations. This use ratio is fully compatible with the battery capacity and the EV charge load has been fully satisfied. In these conditions the expected useful life of the battery could overpass the estimated 15 years.

It is expected that the increasing penetration of EV will also significantly increase the public charging demand during next years, also in the charge station of Tolosa. When the use of a charge station backed by a BESS increases it may happen that the battery does not have the time to recharge between two or more charge sessions, this would lead to a situation where the available charging power would be limited to that of the grid. It is fundamental to work in the business rules and client experience and communication to deal with these situations. Additionally, if the number of hours without the possibility of providing a fast EV charging grows, it would be necessary to study alternatives as increasing the battery capacity, the power exchange capacity with the grid or both.

5 Conclusions

Energy storage is a key technology to accelerate the deployment and improve the techno-economic feasibility of fast and ultra-fast charging stations for certain locations.

This work has presented a BESS solution for fast charging stations. These kinds of installations must be analysed and dimensioned case by case as there are many aspects and interdependent factors to consider, for what a software tool has been developed. The key elements are BESS based on second life batteries from electric buses and an EMS. The EMS integrates several functions as peak shaving, price arbitrage and self-consumption optimization functions, additionally, the possibility to provide flexibility services to the electric systems will be considered in the future.

A real case study of a 50 kW fast charging point with a 75 kWh/35kW BESS, located in a Repsol's service station in Tolosa, Spain, has been presented, describing the final implementation and the obtained operational results. After more than 1 year in operation it has been demonstrated that the solution is feasible, and a continuous fast charging service has been successfully provided.

The economic and commercial feasibility of fast charge stations backed by BESS will depend on several factors, as the BESS useful life, the reduction of battery cost, the wholesale energy prices, the distribution grid congestion level and the possibility to increase the system revenues through flexibility services.

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