Battery Energy Storage System (BESS) development for peak shaving of an Electric Vehicle Supply Equipment (EVSE)

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Abstract. The Electric Vehicle (EV) has become as one of the most promising solutions to solve the problems of the current mobility model: high consumption of final energy, great generation of pollutants and huge dependence of foreign fossil fuels. Despite of its benefits, the spread of the Electric Vehicle Supply Equipments (EVSE) involves some problems that can affect to the electric system: power quality deterioration in the electric grid and the increase of electric demand. These problems are more pronounced if EV fast charge systems are used in weak grids.

This paper proposes and justifies the use of Battery Energy Storage Systems (BESS) to solve the problems of the DC fast charging EVSEs. CIRCE has developed and constructed a test bench to evaluate the use of a BESS that supplies part of the energy consumption of a DC fast charging EVSE with a limited power connection to the electric grid. As it can be seen in the paper, real tests have been developed to prove that a BESS can provide the necessary energy to the DC fast charging EVSE for peak shaving and reducing the power of the connection to the electric grid.

Key words

BESS, Peak shaving, Smartgrid, EVSE, Electric Vehicle (EV), Load levelling.

1. Introduction

The need to displace fossil energy sources to renewable sources that allow a future stable supply of energy needed to maintain the current society activity is one of the great challenges of this century.

For this purpose, currently it is difficult to think about an only renewable source able to supply to the global energy consumed an adequate Energy Return On Investment (EROI). Due to this fact, many authors propose as a solution a solar, wind and hydro energy mix, having the hydraulic energy a lower impact on global energy production [1, 2]. This substitution of the current energy model will inevitably lead to almost complete electrification of society [1].

Then, within this scenario, the electric vehicle (EV) is proposed as one of the most promising solutions for the transport sector in Spain and the rest of the developed countries [3 and 4]. However, nowadays in Spain, the transport sector suffers from some major problems [5]: this sector consumes the 38% of the final energy in the country, is responsible for a great part of the CO_2 emitted to the atmosphere (25,4% of the total) and depends on a great way of fossil fuels, which added to the growing prices of petroleum, has a negative impact in whole Spanish economy.

Although the EV presents obvious advantages, this new mobility technology also generates problems arising from its high electric energy demand that can generate a big impact in the electric system. This impact is directly associated to two facts: power quality deterioration in the grid to which the EV and the necessary charging infrastructure are connected, and the increase of electricity demand, mainly when using fast chargers. These problems can be more pronounced in weak grids [6].

Several solutions are proposed to avoid or reduce the impact of the high demand of EVs and fast chargers in the electric grid, like the load management [7], power electronics configurations of the chargers with low power quality impact [8, 9 and 10] or the integration of the EV charger in smartgrids with electric energy generation and storage systems [11]. The Spanish Government also states that the electric vehicle charge manager can use electric energy generation and storage technologies to reduce the impact of the EV in the electric system [12].

Taking into account this scenario, CIRCE has developed a test bench to evaluate the use of electric energy storage systems to reduce the grid impact of the high demand of a DC fast charging EVSE. This paper shows the results of the developed tests and justifies the use of storage systems to reduce the impact of the EV on the grid.

2. Description of the CIRCE Test Bench

The CIRCE Test Bench is composed of hardware and software components, as shown in Fig. 1. These components are listed and described below.

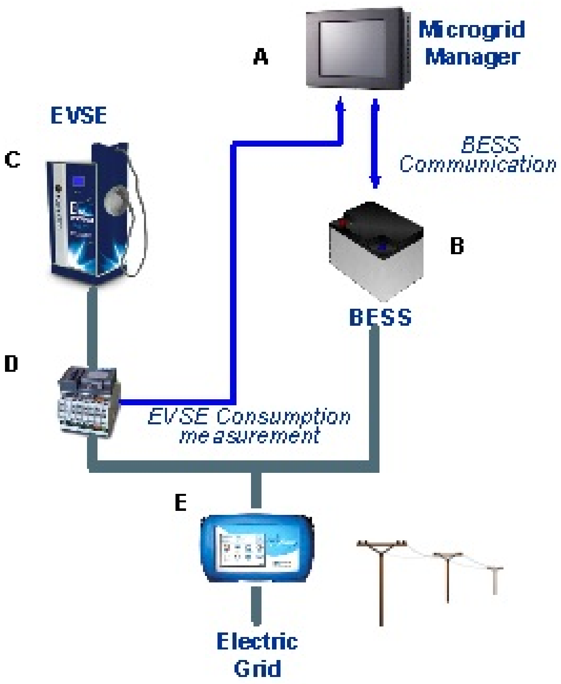

Fig. 1. CIRCE Test Bench scheme

A. Microgrid manager

The microgrid manager is a system that controls the energy flow of the electric microgrid and is communicated with the EVSE and BESS power meter with this purpose. This component uses the EVSE power value to calculate the operational command to be sent to the BESS and also receives information about the power consumed or supplied from the BESS and the state of charge of the batteries. The communications and power calculations are performed at a frequency of 1 time per second.

The user can choose an automatic or manual operation mode. In the automatic mode, the user selects the power consumption limits of the EVSE and the BESS for battery charging, as well as the state of charge to be obtained using the BESS. In the manual mode, the user controls directly the BESS, having the possibility of deactivating the automatic load levelling management system or charging or discharging the battery for specific purposes.

B. BESS

This system supplies the power needed for the load levelling management. The BESS topology is presented in Fig. 2.

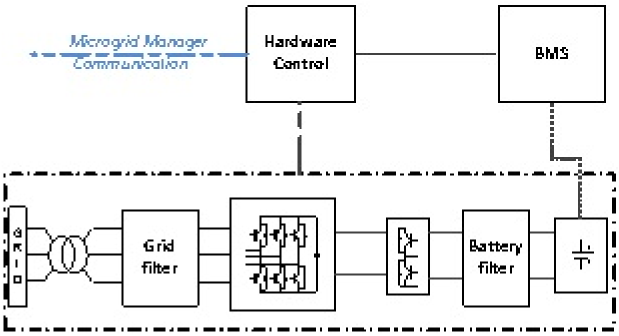

Fig. 2. BESS topology

The system presents the following characteristics:

- Four-quadrant grid-synchronized inverter operation.
- A DC/DC converter to charge/discharge the battery.
- A nominal power of 20kVA.
- A Li-ion battery pack with Battery Management System (BMS), which is 74Ah capacity and a nominal voltage of 650V.
- Possibility of being connected to the microgrid manager using RS-232 or RS-485.

Fig. 3. BESS hardware control

Fig. 4. BESS Lithium batteries

C. EVSE

This is the system that provides energy to the batteries of the EV in the mode (current and voltage) requested by it. The EVSE used in the tests performed by CIRCE is a fast charging EVSE (mode 4 EVSE according to IEC 61851-1:2010) operating under CHAdeMO protocol, whose main characteristics are:

- Rated voltage (input): 400 V_{AC}
- Maximum input power: 54 kW
- Output power: 50 kW
- Output voltage: 20 – 500 V_{DC}
- Maximum output current: 125 A_{DC}
- CE mark, according to applicable standards

D. EVSE power measurement device

A PQube AC Monitor device is connected to the three phase EVSE output to measure the active power of the EV charge consumption. It is connected to the microgrid manager via Ethernet communication.

E. Grid power monitoring instrument

A Power Xplorer grid analyser is used, being connected downstream of the coupling point of EVSE and BESS to measure the power demanded by the electric network. It has not relevance for the load levelling control and is used to check the correct microgrid operation.

3. Test description

The objective of the tests is the real demonstration of the operation of a Battery Energy Storage System (BESS) used to reduce the peak demand of a 50kW EVSE. It is supposed that an EV charging station that has a connection to the electric grid with a limited power of 30 kW and the BESS supplies the energy needed to perform a charge at 50 kW. For this purpose, an electric vehicle is charged from 21% to 80% of its total capacity.

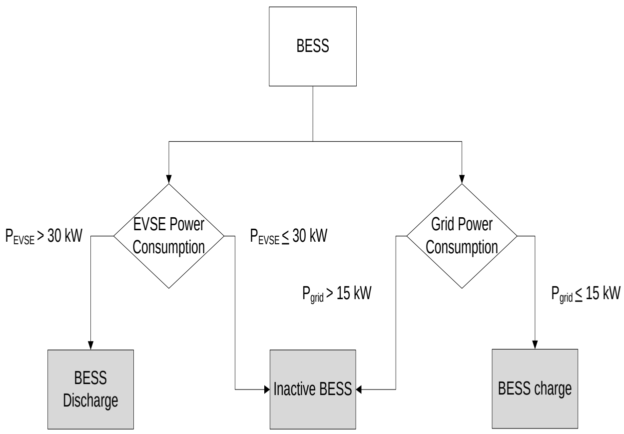

Fig. 5. BESS operation mode

When the EV charger power demand goes down to 30kW, the BESS stops supplying power. After a few minutes, the grid consumption is lower than 15kW, and the BESS starts to charge again the battery, which will depend on the state of charge.

The initial state of charge of the battery is 73% and the microgrid manager is configured to reach the 75%. At that moment, the charging process will be finished.

4.Test results and analysis

The whole test is performed carrying out the procedure described in the previous section, connecting all the microgrid devices. A logging of the EVSE and BESS power is carried out every second by the microgrid manager and other one of the grid power downstream of the coupling point of these subsystems using the power monitoring instrument. The grid power measured is composed by BESS and EVSE power, in addition to the constant consumption of the metering devices and the lamp connected to the grid (lower than 1 kW). These curves overlapped are represented in Fig. **7**.

A. Graph Analysis

The automatic operation mode is connected at second 40. As the battery state of charge is 73% and it has been established a state of charge of 75%, the microgrid manager sends a battery charging command variable to the BESS with a 15 kW limit.

100 seconds later, the charge of the EV is performed. An overcharge period of 5 seconds in the electric network can be observed due to: the measurement frequency of the power consumed by the EVSE, the 1 second delay of the microgrid manager, the BESS 1 second time response and the battery state of charge at the beginning of the EV charge. This last fact implies the increase of the overcharge time with respect to a starting point in an idle state of the BESS. In the oscilloscope screen shown in Fig. 6, the BESS grid currents transitions (green and pink coloured), can be seen, as well as the DC bus at this point, where both command variable change per second and BESS response time are represented.

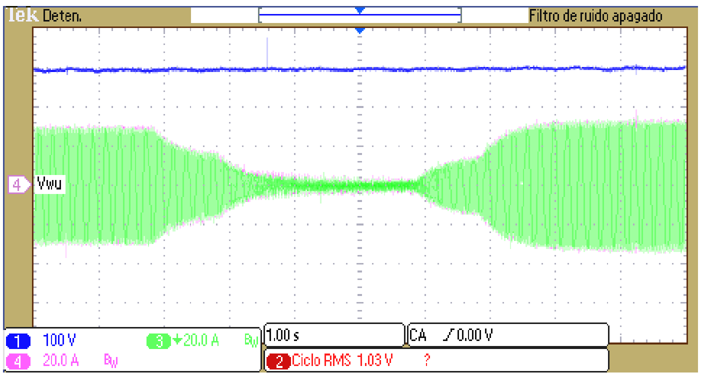

Fig. 6. BESS grid current and Vdc voltage transitions at the beginning of the electric vehicle charge

At this point, the electric network consumption is constant at 30 kW until the EVSE consumption is lower than that value, being present a small disturbance at the second 200, due to the abrupt power consumption decrease of the EVSE.

Once the EVSE consumption is lower than the power established by the user, the BESS receives a zero command value, stopping the commutation two minutes later.

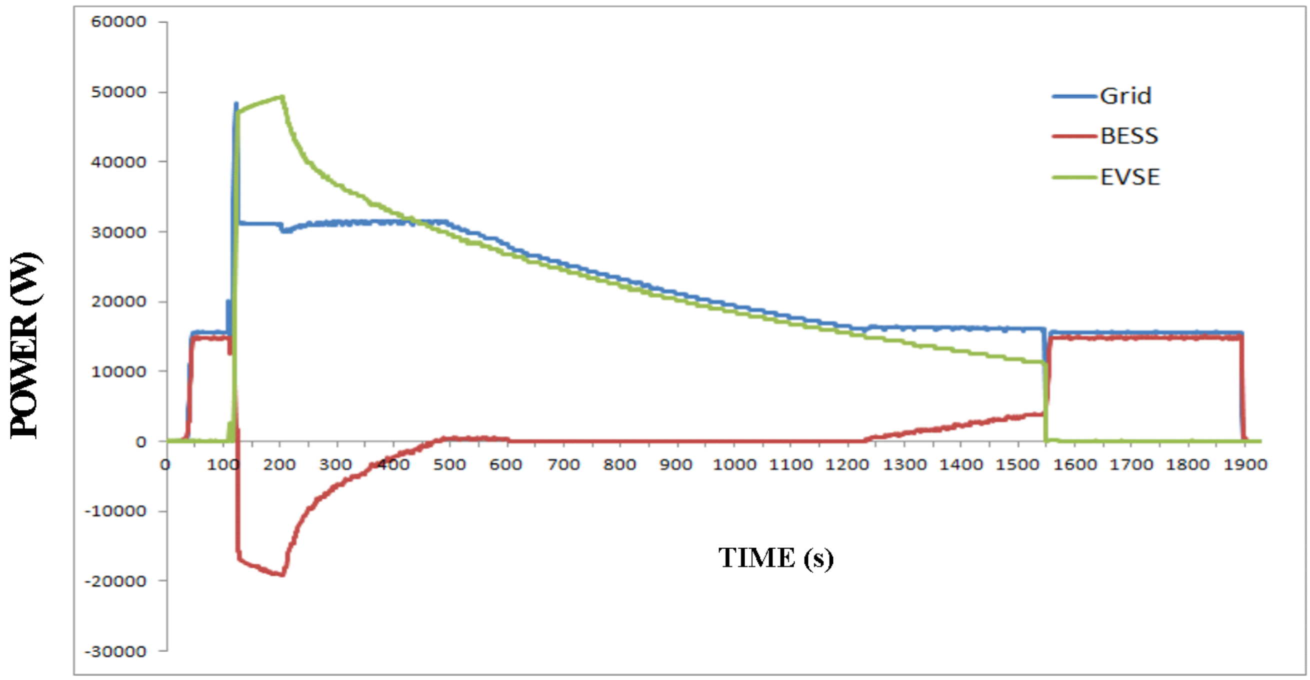

Fig. 7. Grid, BESS and EVSE power during the electric vehicle charge

When the EVSE consumption is lower than the 15 kW limit established by the user, the microgrid manager sends the left power command to the BESS, which commutes again and the grid consumption is stabilized at the value set.

Once the EV has reached the established state of charge of 80%, the EVSE finishes the EV charge. At this moment, the grid consumption is lower and is increased later due to the battery charge carried out by the BESS. When the SOC of the BESS batteries is at 75%, established by the user, the system operation stops and the test is finished.

A. BESS waveform output

The waveform of the BESS output current is represented in Fig. 8. The grid current THD of the BESS output, measured using a Power Xplorer electric grid analyser, is lower than 1%, within the limits given by IEC 61000-3-12:2011 standard.

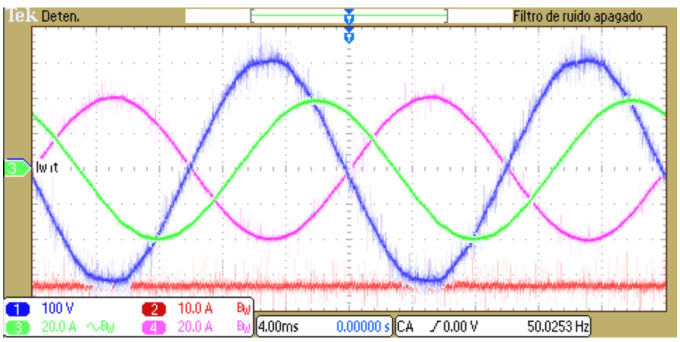

Fig. 8. BESS grid current, grid voltage and battery current

5. Conclusion

In this paper, a BESS developed by CIRCE for peak shaving, load levelling and variability of renewable energy in a smartgrid has been tested using as a load the charge of an electric vehicle with an EVSE.

During the test, it has been checked that the operation of the system can balance the EVSE demand at the defined values, with the exception of the start of the EV charging process, in which the abrupt charge demand implies momentary electric network saturation due to the delay existing in the whole microgrid manager. To avoid these saturations, it would be necessary to increase the control frequency of the microgrid, or integrate both systems in DC. In this case, it would not be necessary to implement communication systems which increase the latency, or introduce complex metering devices with low response time, being only necessary the monitoring of the microgrid DC voltage.

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