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Impacts of SCs on battery lifetime in HESS on DC Microgrids in BiPV

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Abstract

In this paper we present the first results of the work that we started few month ago in order to demonstrate the advantage of using Hybrid Energy Storage System (HESS) with batteries and Super Capacitors (SCs) in Low Voltage DC Micro-Grid (LVDC-MG) in residential application. To achieve this goal we study the impacts of the quantity of SCs on the battery lifetime, the HESS cost and the losses energy (energy that can't be store). This analysis has been done on the LVDC MG developed in LAAS-CNRS in ADREAM Building Integrated PhotoVoltaic (BiPV). The HESS is made by two types of Energy Storage System (ESS), SCs and OPzV lead acid batteries. The power profiles used for simulation are 1 year's data PV production and light consumption from one of the floor of the BiPV.

Keywords: LVDC MG, ESS, hybrid topology, Super Capacitor, lead acid battery, PV application, buildings

1. Introduction

To tackle the issue of reducing ecological footprint, we have to drastically change the way of how we are satisfying electrical demand in buildings (residential, commercial, industrial). Thus, buildings are responsible on much of 60% of global electrical consumption [1] and at the same time, they can be an electrical energy resource (ZEB, BiPV). But, the unforeseeable nature of the PV sources requires integrating ESSs to avoid the perturbation on the main grid. The aim of this work is to analyze the HESS interest with SCs on storage system lifetime and cost-efficiency, in buildings. This paper presents the first step of this study with the models and complete simulation tools developed on Matlab®. In the following section, we present the LVDC-MG topology, and then we explain the simulation process. Finally we discuss the preliminary results based on real PV production and light consumption power profiles recorded in ADREAM BiPV [2].

2. LVDC MG description

The LVDC-MG developed in LAAS-CNRS is descripted in [3]. Its global architecture is presented in Fig. 1. The HESS unity is made up of two elements connected in parallel on the DC bus.

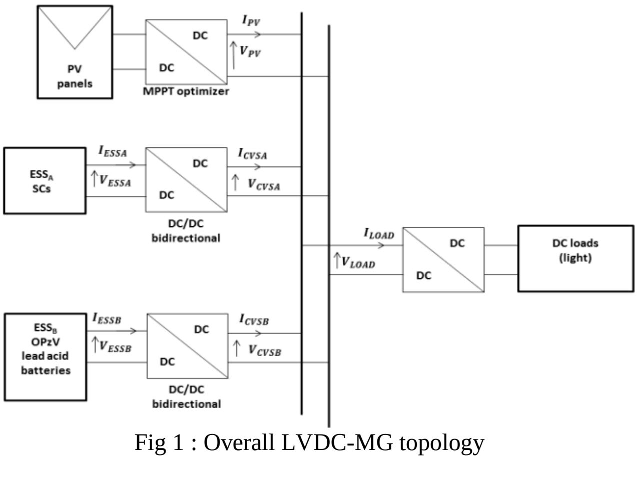

Fig 1 : Overall LVDC-MG topology

ESS A and B are respectively composed by SCs (165 F) and OPzV lead acid batteries (250Ah@C10) elements. They are associated in n_S series and n_P parallel elements to adapt the voltage and increase the total energy available. We choose to combine these two technologies because they have different characteristics and lead acid batteries are the most mature and cheaper electrochemical storage technology [4]. Association with SCs reputed for the high number of cycle that they can support, allow avoiding micro cycle in the batteries. In this way, we developed an energy management algorithm, derived from "DC bus signaling" control, which gives priority to SCs charge and discharge [3].

3. Simulation Algorithm

To achieve a better lifetime and limit constraints on the battery pack we restrict SoC range between 50% and 90%. Moreover, the C-rate is limited to 0.1C (25A) in charging and discharging mode. In a first approach, we used the common static model of batteries given by Eq. 1.

$$\begin{aligned} V_{ESSB}(t) = a_{ESSB} * SoC(t-1) + b_{ESSB} - R_{ESSB} \\ * \Delta I_{ESSB}(t-1) + V_{ESSB}(t-1) \end{aligned} \qquad \text{Eq. 1}$$

We used two different parameters set for charging and discharging modes. They have been identified from experimental tests made thank to a battery cycler BioLogic BCS-815. We validated the voltage model with different current profiles, in our operating conditions, and obtain relative error lower than 6%. SCs are represented by a capacitor C_{SC} in series with a resistor R_{SC} (R_{SC} value is taken in the datasheet). The SC voltage equation is given by Eq. 2.

$$\begin{aligned} V_{ESSA}(t) = \frac{1}{C_{sc}} * I_{ESSA}(t-1) * \Delta t - R_{ESSA} \\ * \Delta I_{ESSA}(t-1) + V_{ESSA}(t-1) \end{aligned} \qquad \text{Eq. 2}$$

Lastly, we added in simulation the converter efficiency model (η) of the DC/DC converters developed in LAAS-CNRS. The efficiency depends on ESS_i voltage and ESS_i

power (Eq. 3), where i is A or B ESS and f_k is a second order polynomial function.

$$\eta(P_{ESSi}(t), V_{ESSi}(t)) = f_1(V_{ESSi}(t)) * exp^{f_2(V_{ESSi}(t)) * P_{ESSi}(t)} + f_3(V_{ESSi}(t)) * exp^{f_4(V_{ESSi}(t)) * P_{ESSi}(t)} \qquad \text{Eq. 3}$$

The parameters of the efficiency equation are identified from several automatized tests in buck and boost modes thanks to an automatize test bench. We simulate the operation of the HESS in Matlab® environment following the algorithm presented in the flow char diagram Fig 2. The inputs signal $P_{BALANCE}(t)$ is the difference between PV production $P_{PV}(t)$ and light building consumption $P_{LOAD}(t)$. In our work we used a 1 year dataset of power profiles with a sample period of 1min from our BiPV database.

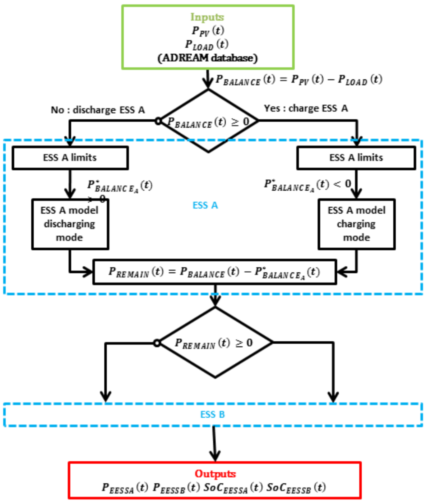

Fig. 2 : Flow chart diagram of HEES

4. Criterion

We analyzed the results according to the leveled cost LCOE HESS calculated as explain below. The time horizon choose for the study is 20 years, considering that correspond to the SCs lifetime [5]. The LCOE formula is given in Eq.4.

$$LCOE = \sum LCOE_i = \sum \frac{\sum_{t=0}^{T=20} \frac{Cost_i}{(1+r)^t}}{E_{dis\_i} * \frac{1-(1-r)^{-T}}{r}} \qquad \text{Eq. 4}$$

With r is the discount rate equal to 7%, E_{dis_i} is the energy discharging during one year in €/kWh and $Cost_i$ is the global cost including investment cost and operating cost in euros. We choose worst case values coefficient from [5]-[6] in €/kWh and we calculate the $Cost_i$ depending on battery lifetime for each year of the simulation time horizon. L_A is fixed to 20 years and the battery's lifetime L_B is calculated using a rainflow counting method based on [7]. For estimated the lifetime in year we have to calculated CD, the cumulative damage made to the batteries at the end of the one year simulation (Eq. 5).

$$L_B = \frac{1}{CD} = \frac{1}{\sum \frac{n_{cycle(DoD_k)}}{N_{CF}(DoD_k)}} \qquad \text{Eq. 5}$$

This method allows us to estimated L_B taking into account all the battery's cycle (n_{cycle}), with different DoD_k according to the number of cycle to failure (N_{CF}) given by the manufacturer. In order to analyze the interest of SCs in residential applications we compute simulation for different values of SCs in a given constant global quantity of storage energy available. Fig. 3 presents our first results.

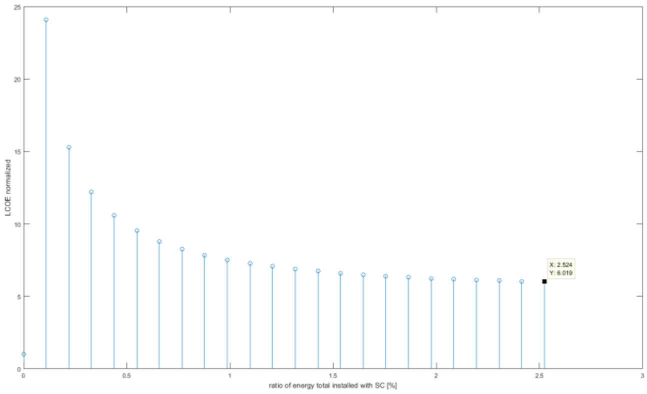

Fig 3: HESS LCOE for different values of SCs

We can see that the configuration with 2.5% of the total energy storage installed is made with SCs is six time more expansive that configuration with OPzV lead acid batteries only, and the LCOE seems converged to this values.

5. Conclusion and Future works

To conclude, our first results about impact of SCs in an HESS in LVDC-MG show that SCs allows improving battery lifetime but not enough to accelerating the depreciation. However to achieve this study it would be interesting to add additional cost included in the HESS Life Cycle Analysis. We have also to do the same analysis with different ESSs technology and load profiles (DC loads as computers…). Furthermore, we can complete this work by adding studies about impacts of ageing estimation methods or using others criteria like GHG emissions for example.

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