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Short Communication

Analysis and evaluation of battery-supercapacitor hybrid energy storage system for photovoltaic installation

Zineb Cabrane *, *Mohammed Ouassaid*, *Mohamed Maaroufi*

Department of Electrical Engineering, Mohammadia School of Engineers (EMI), Mohammed V University, Rabat, Morocco

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ABSTRACT

Standalone operation of a photovoltaic generating system under fluctuating solar irradiance and variable load conditions necessitates a storage energy unit. The energy storage system by using battery–supercapacitor combination is an interesting solution. However, batteries have a high energy storage ratio but are limited in the power. In the other hand, supercapacitors can provide high levels of power while they have a much lower energy storage ratio. Moreover, the SC can act as a buffer against large magnitudes and rapid fluctuations in power. In this paper, supercapacitors are used to reduce stresses on batteries and improve their life cycle. In this context, the performance of the RMS current gain in battery, the gain in energy losses, the total energy efficiency and the elimination rate of surge load power are explored, in different operating state conditions. These parameters are also investigated versus the SCs cost. All tests are carried with different number of parallel supercapacitors and the filter constant.

Introduction

The renewable energy systems and particularly the photovoltaic systems have developed rapidly. However, the photovoltaic energy source is being increasingly recognized as a cost effective power source and a clean renewable energy vector [1]. The photovoltaic panels exhibit a strong nonlinear electrical characteristic. Also, the variable operating conditions can be associated with the weather change [2].

Hence, the variable nature of solar irradiance and fluctuating load profiles make the operation of photovoltaic power systems a challenge, particularly when they operate in standalone mode. However, the integration of an energy storage system into a power system based on a photovoltaic energy provides an opportunity for better responses of voltage and current, especially during solar irradiance fluctuations and load demand variations [3,4]. The typical energy storage applied in standalone photovoltaic system is lead acid batteries. Batteries have high energy density, but suffer from a low power density, slow dynamic response and giving low charge/discharge rates [5]. They offer a much higher ratio of energy storage to weight than can a supercapacitor; while on the

* *Corresponding author.*
E-mail addresses: zinebcabrane@gmail.com (Z. Cabrane), ouassaid@emi.ac.ma (M. Ouassaid), maaroufi@emi.ac.ma (M. Maaroufi).

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other hand, supercapacitors can supply much higher currents than batteries [6].

Supercapacitor has short charging/discharging time and a long cycle life. It is easy to maintain them. They have an high power density [7]. Moreover, the combination of battery and supercapacitor has complementary qualities and provides an excellent solution that can cover a wide range of power and energy requirements [8]. As a result, enhancement of power quality using batteries and supercapacitors is actively pursued in the field of renewable energy [9,10] and it was demonstrated that this combination has lower battery costs, a general increase in battery life and higher overall system efficiency [11]. This combination was developed successfully in many applications like pure battery-powered electric vehicle [12], hybrid electric vehicle [13] and uninterruptible power supply [14].

This study presents a hybrid design approach by using a combination of SCs and batteries for the photovoltaic energy storage. However, an energy management strategy combining a control of bus voltage and energy management of storage devices is proposed and the control scheme is presented. The aim is the reduction in battery stresses by the use of SCs. We investigate the impact of the number of parallel SCs and the filter constant on the gain in battery RMS current, the gain in energy losses, the elimination rate and the energy efficiency of surge load power in different operating state conditions. Thereby, the influence of these parameters on the optimal SCs-battery combination versus the supercapacitors cost is investigated.

This paper is arranged as follows: After introduction presented in Section Introduction, the system description and modeling are given in Section System description and modeling. The control and management of DC bus are addressed in Section Performance analysis of the SCs-battery combination. Section Simulation results and validation elaborates the performance analysis of the SCs-battery combination. The obtained results are available in Section Conclusion. Concluding remarks are given in the last section.

System description and modeling

The photovoltaic generator produces a variable energy that is influenced by the change of solar irradiance and cell temperature [15]. This generator is connected to the boost converter that allows to boosting the voltage of the PV generator to reach the DC bus voltage. Maximum power point tracking (MPPT) is implemented to identify the maximum power operating point; subsequently the PV panel is set to operate at that particular operating voltage for maximum power extraction, through the use of a control algorithm.

Hybrid batteries/supercapacitors energy storage system configuration

The combination of battery and supercapacitor can provide an excellent match that can cover a wide range of power and energy requirements in renewable energy systems, especially in photovoltaic power systems. As a result, several types of configuration can be found. The four most used topologies of the hydride Energy Storage System HESS are presented in the following.

The basic passive parallel hybrid configuration is shown in Fig. 1 [16], the supercapacitor and batteries are directly connected in parallel to the load. Due to the direct connection, the SC essentially operates as a low pass filter. The main advantage is the ease implementation and no complicated control devices needed. The disadvantage of this configuration is that the power sharing between the battery and SCs is uncontrolled and dictated only by the parasitic elements also the DC bus voltage is unregulated and varies depending on the battery voltage range, which impacts the load design.

Fig. 2 shows the schematic of the hybrid energy storage system configuration by using a bidirectional buck-boost converter to interface the SC, the voltage of the SC can be used in a wider range. This configuration has one controlled power sources. However, the bidirectional converter needs to be oversized in order to handle the power of the SC. In addition, the nominal voltage of the SC bank can be lower. The battery is connected directly to the DC bus; as a result, the DC bus voltage cannot be varied [17].

The SC/battery configuration is shown in Fig. 3. In this configuration the voltage of the battery can be maintained lower or higher than the SC voltage. The SC is connected to the DC bus directly working as a low pass filter. But the battery power is uncontrollable. The control strategy applied to this topology allows the DC link voltage to vary within a range so that the SC energy can be more effectively used [18].

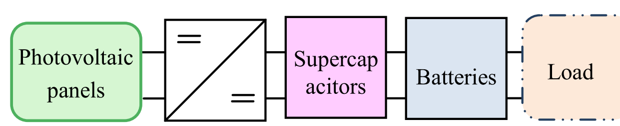

Fig. 1 – Basic passive parallel hybrid configuration.

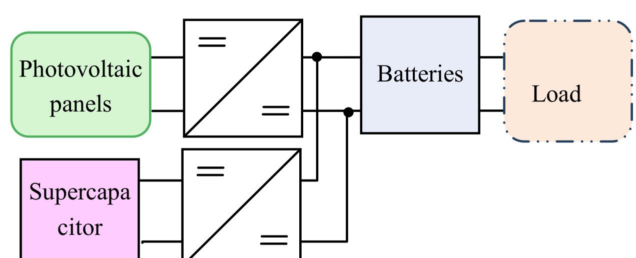

Fig. 2 – Supercapacitor/battery parallel configuration.

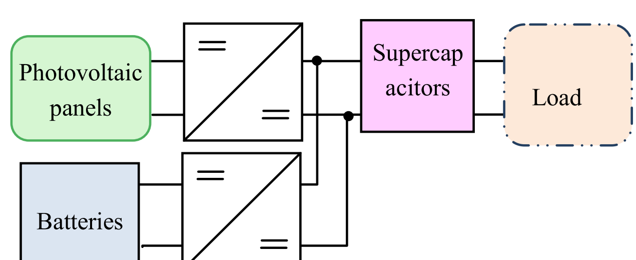

Fig. 3 – Battery/supercapacitor parallel configuration.