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Energy Management of a Photovoltaic System with Hybrid Energy Storage Battery-Super capacitor

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Abstract

This paper describes a method for regulating the voltage of a DC bus of the hybrid power system pv/wind associated with storage devices. A hybrid energy storage system (HESS) that combines batteries and super capacitors (SCs) is an interesting solution. The batteries are employed to meet long-term energy requirements, while the using of SCs, to meet immediately the demand for instantaneous power. In this paper, we propose a new management strategy that manages energy flows between storage devices, by maintaining the SOC of super capacitor and the SOC of the batteries at acceptable levels and to reduce stress on batteries and improve their life cycle. the simulation results demonstrate the efficiency of the proposed energy management strategy for the sudden change in power generation and load demand.

Keywords: hybrid energy storage, solar irradiation, batteries, super capacitor.

1. Introduction

Renewable energies such as solar photovoltaics produce intermittent generation and are hard to predict with precision. The storage of energy allows, a priori, to guarantee at all times the balance between production and demand, necessary condition for the proper functioning of any electricity system. However, although the storage elements are adapted to fulfill this role, their cost being signed, it is necessary to find a compromise between conditions of use, performance and energy storage capacity. Most autonomous photovoltaic systems need an energy storage buffer to provide continuous energy to the charge when solar irradiation is inadequate. Batteries employed in renewable energy storage systems can have multiple irregular charge/discharge cycles. It can also have a negative effect on battery life and can increase project costs. To resolve this problem, researchers have proposed HESS and new energy management approaches to improve battery life. In the event of a voltage drop or complete interruption of the power supply, energy must be supplied by the energy storage devices. Conventional energy storage devices for uninterruptible power supplies are essentially based on the choice of good batteries [1]. Some loads require a high starting current for a period of time, for example, loads from the engine, air conditioner and refrigerators, where the starting current can be 6-8 times the normal operating current [2]. The energy storage applied in an autonomous photovoltaic (PV) system consists of lead batteries. Batteries are defined as high energy, low power devices, which gives low charge / discharge rates [3]. while super capacitors have a high-power capacity, but a low energy density, which gives high charge / discharge rates, which makes them very suitable for use in conjunction with electrochemical batteries [4]. The rule-based controller(RBC), the filtration based controller (FBC) and droop based control (DBC) is a together of the traditional control techniques. The precise mathematical model of the system is necessary since these control approaches are sensitive to changes in parameter values. In RBC, the pre-established rules are followed while allocating electricity for HESS. Thermostat, state machine, and power follower control methods are three categories of RBC [5]. The RBC controller is simple and easy to implement and is an effective method for real-time energy management. Nevertheless, the sensitivity to parameters variation is the disadvantage of this method. To control nonlinear and complex systems, optimization based methods have become more popular [6]. These methods can be categorized as the artificial neural network (ANN), Fuzzy logic control (FLC), evolutionary algorithms such as genetic algorithm, dynamic programming, linear programming, and model predictive control (MPC). FLC method is one of the effective methods for controlling complex systems. This control method is simple and not requires the exact mathematical model of the system. The proposed control strategy's performance is validated and confirmed using simulation tests.

2. System Description

Figure 1 depicts a stand-alone PV system consisting of a PV panel, battery, and SC. This pv power system is connected with variable load. Photovoltaic panels, batteries and super capacitors are linked to a single DC bus. To connect the PV source to the DC bus, a boost converter is employed. The role of this converter: It raises the voltage of the PV to the DC voltage and it enables the maximum amount of power to be produced by applying an MPPT (Maximum Power Point Tracking) algorithm. The supercapacitor (UC) has fast dynamics, thus can be added to smooth, fast fluctuations of the PV power and the loads in the short-term (from seconds to minutes) [5]. The UCs are connected to the DC bus through a bi-directional DC-DC converter. The batteries are defined as devices of high-energy and low-power, therefore the batteries are used to smooth the difference between the PV produced power and load demand in long-term (from minutes to hours) [6]. The batteries are connected to the DC bus through a bi-directional DC/DC converter. The SCs have opposite characteristics than the batteries. system stability can be affected by the loss of the instantaneous balance between supply and load. Therefore, an energy management algorithm is mandatory. The following sections go over the system's modelling and control.

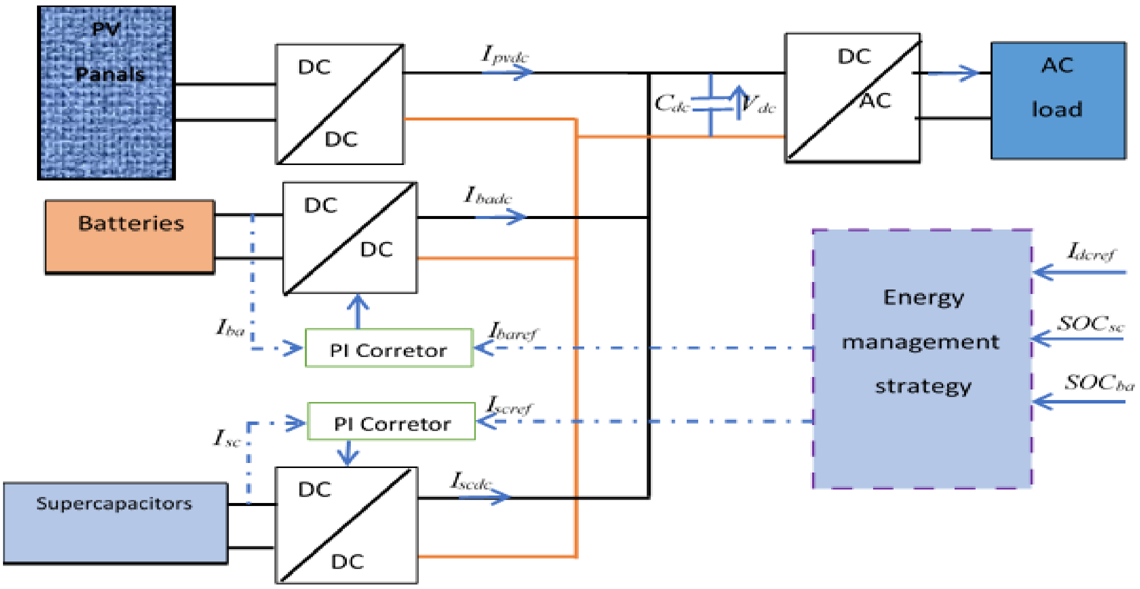

Fig.1. Photovoltaic energy storage system.

3. Modelling and Control of PV Distributed Generator

3.1 Modelling a PV generator

An equivalent circuit represents the model investigated in this study. This one consists of a single diode for the cell polarization function and two resistors (series and shunt) for the losses [7],[8]. This model is based on the technical specifications of the solar cells provided by the manufacturers (data sheets). to represent the non-linear behaviour of photovoltaic generators, various mathematical models have been developed, which results from the semiconductor junctions, which are at the base of the current Ipv of the photovoltaic cell under standard operating conditions is given by (1) according to Figure (2):

$$I_{pv} = I_{ph} - I_d - I_{Rsh} \quad (1)$$

where: Iph depict the photo-current, Id: Polarization of the PN Junction Current and Irsh: Current in the Resistor Rsh. The current expression for the solar cell is:

$$I_{pv} = I_{sc}\{1 - K_1[\exp(K_2.V_{mpv} - 1)\quad]\} \tag{2}$$

Where K1, K2 and coefficients are given as [9]: K1=0.01175 (3)

$$K_2 = \frac{K_4}{V_{co}^m} \qquad K_3 = \ln\left[\frac{I_{cc}.(1+K_1) - I_{mpp}}{K_1.I_{cc}}\right] \tag{4}$$

$$K_4 = \ln\left[\frac{(1+K_1)}{K_1}\right] \tag{5}$$

3.2 Two branches model of Super capacitor

Super capacitors are added as a storage element for its high-power devices, among the models presented in the scientific literature, the two-branch model is used in this work. Figure 2 depicts an equivalent electric circuit with two RC branches, which was proposed by Zubieta and Bonert [10].

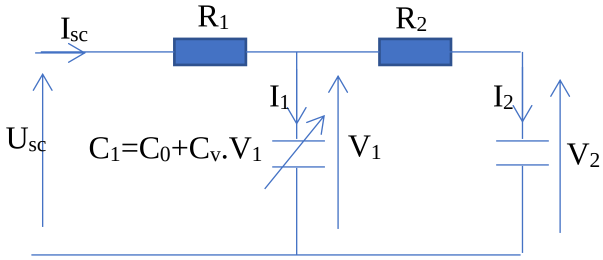

Fig.2. Supercapacitor simplified circuit

The main capacitance C_1, called differential capacitance, depends on the voltage v_1. It consists of a constant capacity C_0 (in F) and a constant parameter Cv (in F/v) and it is written as:

$$C_1 = C_0 + C_v.V_1 \tag{6}$$

The R_1C_1: fast branch determines the SC immediate behaviour during rapid charge and discharge cycles in a few seconds. The second cell R_2C_2 is the sluggish branch. It completes the first long-life cell in a few minutes and describes the internal energy distribution at the end of the charge or discharge. Neglecting the leakage current represented by the parallel resistance Rf during a rapid charge / discharge of the SC.

The following equation expresses the voltage of the equivalent circuit of the SC

$$U_{sc} = N_s Vsc = N_s.V_1 + R_1\frac{I_{sc}}{N_p} \tag{7}$$

Where U_{sc} and V_{sc} are pack voltage and elementary voltage of the super capacitors respectively. Isc and isc are pack current and elementary current of the super capacitors respectively.
Ns and Np are the number of series/ parallel branches of the SC connections. The voltage V_2 in the secondary capacity C_2 is expressed by:

$$V_2 = \frac{1}{C_2}\int i_2 dt = \frac{1}{C_2}\int \frac{1}{R_2}(V_1 - V_2)dt \tag{8}$$

The current i_1 flowing in C_1 is given by:

$$i_1 = i_{sc} - i_2 \tag{9}$$

The current i_1 is denoted also in terms of the instantaneous charge Q_1 and C_1 as:

$$i_1 = C_1\frac{dV_1}{dt} = \frac{dQ_1}{dt} = (C_0 + C_V C_1)\frac{dV_1}{dt} \tag{10}$$

where the charge Q_1 is given by:

$$Q_1 = C_0 V_1 + \frac{1}{2} C_v V_1^2 \tag{11}$$

Then voltage V_1 is defined as follows:

$$V_1 = \frac{-C_0 + \sqrt{C_0^2 + 2.C_v Q_1}}{C_v} \tag{12}$$

3.3 Battery Energy Storage

A battery energy storage system consists of series and parallel chains of batteries. There are several lead-acid battery models, and their implementation is difficult because many parameters must be considered. The RC model is used in our study. this last also known as the simple model includes E, the emf that models the no-load voltage of the battery, an internal resistance R_s and a capacitor C_{bat} modelling its internal capacitance.

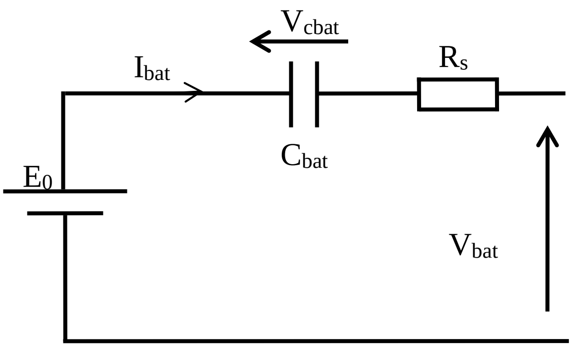

Fig.3. RC model of the battery

Thus, the expression of the voltage V_{cbat} according to the current I_{bat} is given by the following:

$$V_{bat} = E_0 - R_s I_{bat} - V_{cvat} \quad (13)$$

The battery's state of charge (SOC) is defined by the following equation:

$$SOC = 1 - \frac{Q_d}{C_{cbat}} \quad (14)$$

With: C_{bat}: the nominal capacity (Ah) of the battery;

Q_d: the amount of charge missing in relation to C_{bat}. The value of C_{bat} is given by the following expression:

$$Q_d = Q_{d0} - I_{bat}.t \quad (15)$$

$$C_{bat} = \frac{Q_d}{V} = \frac{I_{bat}.t}{V} \quad (16)$$

3.4 Battery-Supercapacitors Combination

As shown in Fig. 1, the battery and supercapacitors have been combined in parallel. The two converters DC/DC and AC/DC are supposed ideal, without losses. The DC-bus voltage Vdc is taken to 465 V. This work presents a control system that is designed to profit the rapid charge and discharge capability of the SCs in order to decrease the battery stresses due to instantaneous power demands. The goal of the combination between the battery and the SCs is to make the super-capacitors provide the power transients and to smooth the high-power demands applied to the battery during autonomous operation.

4. Control and energy management strategy of DC bus

The modern batteries have a higher energy storage density while they have a relatively slow response speed. On the other hand, super-capacitor has a low power density but a rapid response speed. Consequently, in the design of the EMS control, the super-capacitor must be responsible for the rapid exchange of transient energy while the battery must support the charging or discharging of energy in a relatively stable regime. The result is a control design as illustrated in Fig. 4. The PI corrector calculates the reference current I_{dcref} to maintain the voltage of the DC bus at the reference voltage V_{ref}.Then a low-pass filter is applied to obtain the reference current of the battery I_{baref} while the rest is used as the reference current super-capacitor I_{scref}. At all times, the sum of the reference currents, I_{scref} and I_{baref} must be equal to I_{dcref}.

$$I_{dcref} = I_{scref} + I_{baref} \quad (17)$$

The behavior of the DC bus can be modelled by the following:

$$C_{dc}\frac{dV_{dc}}{dt} = i_{pv} + i_{scdc} + i_{badc} - i_{load} \tag{18}$$

Where i_{pv}, i_{scdc}, i_{badc} and i_{load} represent the PV panels current, DC currents of super-capacitors, batteries, and the load current respectively. C_{dc} is the central capacity that will enable imposing a common DC bus voltage to all other sources, also to the load.

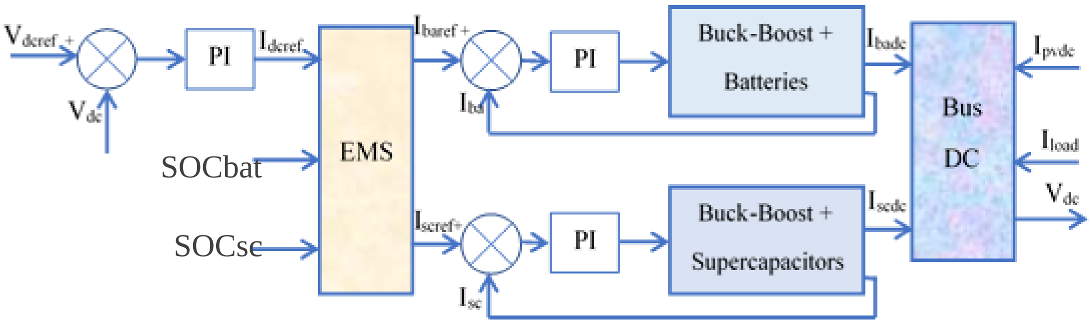

Fig.4. Block diagram of the DC bus control.

A strategy for energy management provides the static converters' reference current. I_{scref} for Super capacitors and I_{baref} for batteries. Regardless of how the load behaves or how much power is being produced by the solar generator, these currents guarantee that the DC bus voltage will remain constant. Super capacitors and Batteries are controlled by current and two PI correctors are used to calculate the duty cycle α_{sc} and α_{ba} for the bidirectional Buck-Boost converters. If a problem occurs on an element, the super capacitors and/or batteries ensure the regulation of voltage DC bus. In any time, the sum of the reference currents, I_{scref} and I_{baref} must be equal to I_{dcref}.

5. Numerical Simulation

To confirm the validity of the proposed control and energy management strategy. The proposed system (shown in Fig. 1) was simulated using the MATLAB/Simulink soft war to demonstrate how the supervisory controller will manage the system.

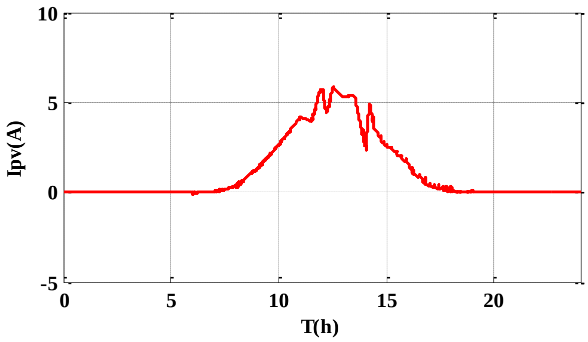

Fig.5. PV current

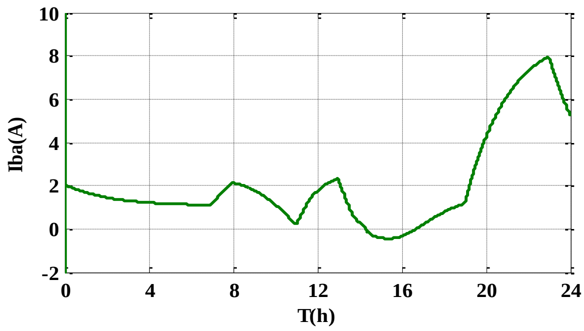

Fig.6. Batteries current

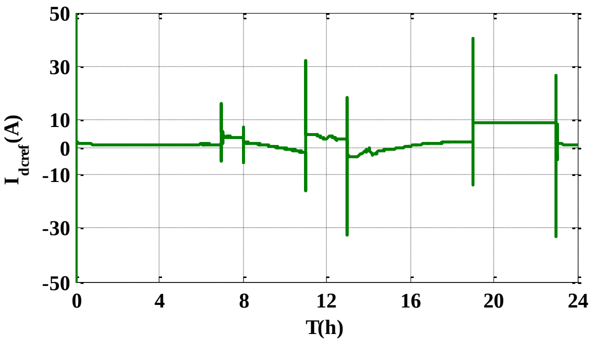

Fig.7. Idc current

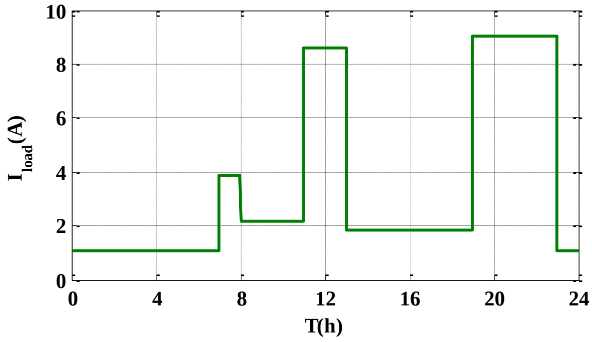

Fig.8. load current

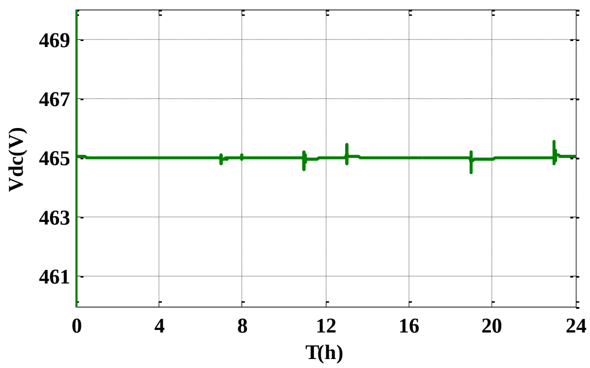

Fig.9. DC bus voltage

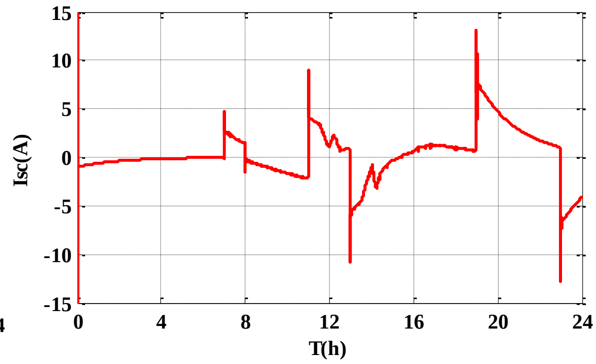

Fig.10. SCs current

This simulation was run for 24s at various solar irradiation levels; the various photovoltaic current values are shown in Fig. 5. The reference current evolution for the DC bus is shown in Fig. 7. The SCs begin to discharge when PV panels is not able to give the desired power, whence I_{dcref} and the SoC_{sc} must be more than 30%, and start to charge when the PV gives more than desired power where $I_{deref} < 0$ and the SoC se must be lower to 90%. The batteries begin to discharge when the I_{dcref}, SoCsc < 30% and the SoC_{ba} >30%. Fig.9. shows DC bus voltage (V_{dc}) with V_{dc} =465V.

6. Conclusion

The storage of photovoltaic energy using a battery-super capacitor combination is discussed in this paper. The strategy of control and regulation the DC bus voltage has been presented to demonstrate the viability of this hybrid storage system. Next, to deal with the variation of solar irradiation and/or the variation of the load, it was explained how crucial it is to use super capacitors to reduce peak power as well as high power demands. This controller gives the better an efficient energy management and ensures continuity of supply by using the methodology that involves a reversible chopper between the batteries and the DC bus and another between the SC and the DC bus to ensure stable voltage on the DC bus of 465V. Simulation results show that the proposed control and management strategy of DC bus are effective and able to supply desired power.

7. Acknowledgements

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