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Supercapacitor in battery charges of photovoltaic panel: analysis of the technical feasibility

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Abstract

The power generation from photovoltaic sources is variable and may contain unhoped fluctuations, which can be relieved by using energy storage systems. However, there is a technical contradiction in extracting the maximum power from a photovoltaic panel and the charge cycle of a battery. To overcome this problem, this paper presents an improvement consisting in a collaborative association of lithium ion batteries and supercapacitors showing the technical feasibility in a photovoltaic system.
The structure of the energy conversion system was developed and was set up the converter's configuration, design and operation simulation. The power management of full system implementation was simulated and the results are presented. The proposed system development and it technical analysis was carried out for both situations, with and without the use of supercapacitor. It was concluded that the supercapacitor in the photovoltaic systems bring better charging conditions, resulting in shorter charging times and better system performances.

Keywords: battery charger; digital control; photovoltaic panel; supercapacitor

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1. Introduction

The energy from the cells can either be used directly or can be used to recharge batteries, which in turn can power some consuming application [1]. A necessity for the storage system arises to limit the effect of the variation of the solar conditions along the environmental day conditions [2]. However, the cost of batteries and their limited lifetime are serious disadvantages [3] [4]. In addition, there is a technical contradiction in extracting the maximum power from a photovoltaic panel and the charge cycle of a lithium ion battery. To contain that problem, in this work we propose an association of batteries and supercapacitors in a collaborative operation.

To get the point of maximum power generation from a photovoltaic (PV) panel, under frequent variations in solar irradiance and temperature, it is necessary to perform the MPPT - Maximum Power Point Tracking of the PV panel [5] [6]. However, there is a problem in extracting the maximum power point from a PV panel, as shown in Fig. 1 (a), with the charge time curve of a lithium ion battery, as shown in Fig. 1 (b). This problem comes up because to follow the charging of a battery it is necessary to go through two stages, one of constant current and another of constant voltage, which do not match to the voltage and current output from PV panel operating in MPPT.

Even using only converters this problem persists because photovoltaic generation may contain unhoped fluctuations, while battery charging cannot have fluctuations. Therefore, the MPPT of the PV panel is not possible without consideration of generated energy waste, if there isn´t an intermediate step of energy storage.

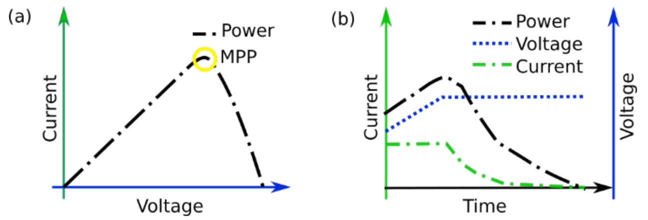

Fig. 1. (a) PV panel power curve (b) Battery charge curve.

The problem was analyzed in this study with an intermediate step of fast energy storage, provided by the use of a supercapacitor [7]. The idea of using a supercapacitor is to supply the power needed to charge the battery when the PV panel does not produce all the necessary power, or to absorb the excess of panel generation.

2. Methodology description

The proposed design involves the use of supercapacitor in a *Li-ion* battery charger, using the solar energy from the PV panel, called in this paper as the Solar Battery Charger with Supercapacitor (SBCS).

The diagram of this type of charger is shown in Fig. 2, where the systems of control (SC), which control the direct current converters (CCC), are represented in order to achieve the main objective of charging the battery. These control systems are coordinated by the power manager (PM), which reads the signals of generated power, current and voltage levels in the system, in order to continuously charge the battery even if there isn´t enough solar radiation.

According to the diagram of Fig. 2, the PV panel converts the energy needed to charge the battery. We can see in Fig. 2, the CCC1 is the direct current converter that performs the tracing of the maximum power point of the PV panel. The CCC2 bidirectional converter has the function of keeping energy in the supercapacitor when the photovoltaic panel generates excess energy and can´t be received by the battery. In addition, the CCC2 can manage power from supercapacitor to charge the battery when the PV panel does not generate enough, in way of maximizing the generated energy from PV panel. So, the supercapacitor performs the function of intermediate energy storage, a kind of energy buffer function.

The CCC3 converter has the objective of charging correctly the battery according to its manufacturer's description, following optimum charging curves [8].

That combination of a supercapacitor and a battery to form an energy storage system reduces the stress on the battery caused by the high discharge currents, resulting in an increase in the life of the batteries [9].

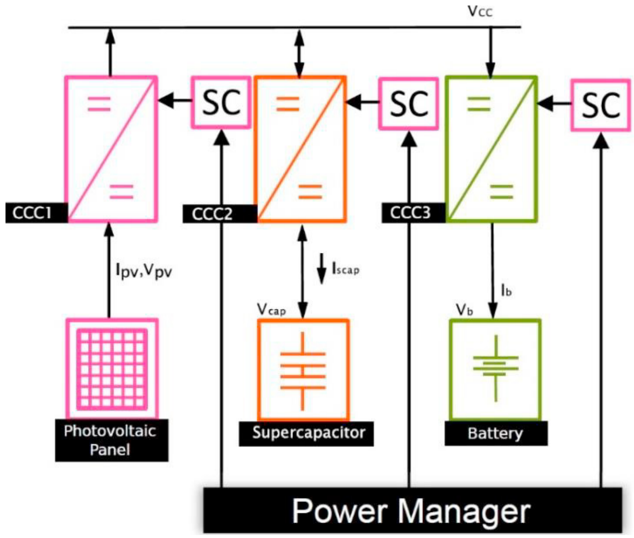

Fig. 2. SBCS proposed design.

The basic operation of this system is based on four main states: *i)* charge only the battery, *ii)* charge the battery and discharge the supercapacitor, *iii)* charge the battery and supercapacitor and *iv)* charge only the supercapacitor. For these operation states, the MPPT function can be at on or off state, according to the current operation conditions.

The supercapacitor discharges when the power generated by the PV panel is below the minimum required by the battery, P_{bmin}, helping to charge the battery. The supercapacitor is charged when the power generated by the panel is greater than P_{bmin}, taking advantage of the surplus energy generated. This happens because the MPPT function is running along with these steps, so the supercapacitor is charging and discharging.

One concern about charging a typical *Li-ion* battery is to avoid an overvoltage. Because this is important, the battery voltage must be constantly monitored [9]. Finally, when the battery current reaches the floating current, I_{bmin}, means the battery has fully charged, then the charger is turned off [10], as seen in Fig. 2.

It was implemented the SBCS circuit with the appropriate devices and operational components data [10] [11] [12] and the *Psim* electronic simulation software was used to analyses the work-flow.

3. Results and discussion

3.1. Case study 1 – Time from 0 to 120 seconds

From the SBCS performed simulation was obtained the operational quantities results and the output signals:

Nomenclature

SOC	battery charge state
I_b	battery current
V_b	battery voltage
V_{scap}	supercapacitor voltage
V_{CC}	voltage CC
P_{pv}	power generated by the PV panel
MPPT	control on/off of de MPPT algorithm
C_b	on/off battery control
$I_{scap\ ref}$	reference current in supercapacitor

For simulation time from 0 to 120 seconds, we can see in charts from Fig. 3 the results variation and, for the same time simulation, we can see in Fig. 4 the output signals of the PM.

The MPPT implemented function was target, the maximum power point was reached for the system, as seen in the first chart in Fig. 3, where the P_{pv} curve overlaid the $P_{pv\ max}$. Another important issue is the battery current and voltage regulation by the CCC3 also reaching its objectives within a margin of tolerance, keeping whenever possible the SOC of the battery in constant growth, as seen in the third chart in Fig. 3. Transients in the current I_b and I_{scap}, are in the second chart, during the moment when the supercapacitor is charging and when it is discharging are justified by the fact that the CCC2 converter is changing their mode of operation in these transitions and the current in the inductor of CCC2 does not follow that exchange instantaneously.

One of the most important results was the energy transfer from the supercapacitor to the battery when there was no power available from the PV panel, keeping the battery charge stable even when the supercapacitor is charged above 3 V, as seen in the fourth chart. It was also possible to verify that the battery through the two stages of charge, the first of constant current and the second of constant voltage, as shown in the fifth chart.

In Fig. 4 we can see that system operated in state of charging the battery and supercapacitor, during the periods in which $P_{pv} > P_{bmin}$. It also operated in state of charging the battery and discharging the supercapacitor, when $P_{pv} < P_{bmin}$. With this, the system alternated between two states in most of time, maintaining the battery charge, that is, C_b being at zero, as seen in Fig. 4.

Another verified characteristic is that the voltage regulation, V_{CC}, does not need to be between 25 to 30 V as specified during the design of the converters, but only with values above the battery voltage, V_b, as seen on the fifth chart in Fig. 4. To perform this voltage regulation, was used the current that goes to the supercapacitor or the one supplied by it.

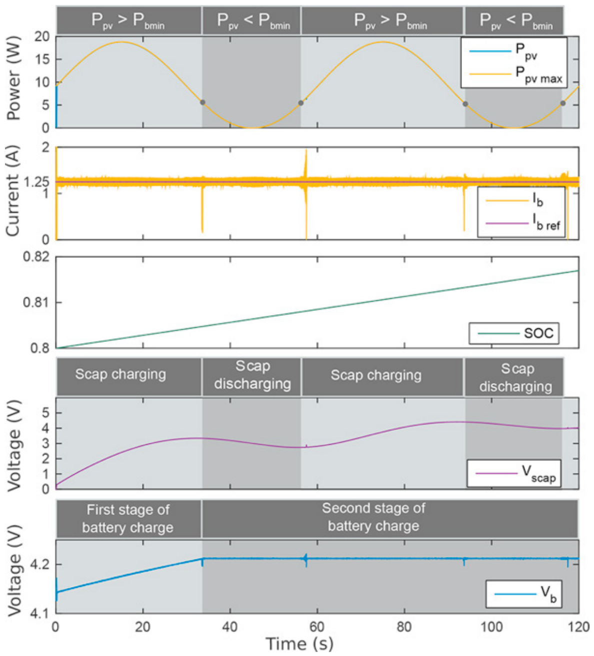

Fig. 3. SBCS variables curves from case study 1.

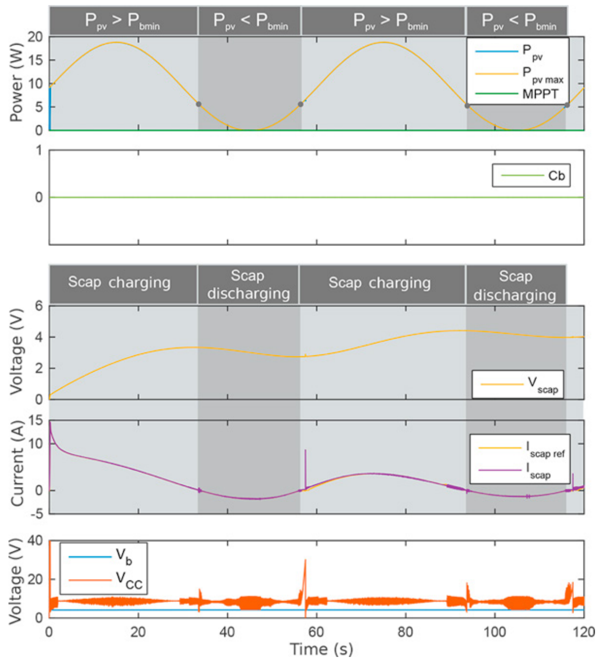

Fig. 4. SBCS variables curves from study case 1.

3.2. Case study 2 – Time from 0 to 300 seconds

Another simulation was carried out with a slower variation of the solar irradiation, a system simulation from 0 to 300 seconds. The results are shown in Fig. 5. It was observed that SBCS works better for less abrupt variations of the solar irradiation, means, the charging of the battery is done in a smoother way, without abrupt variations in the battery current, I_b. Given that solar irradiation over a one-day period varies at small rates [13], so SBCS reaches the battery charging requirements satisfactorily. The SBCS was obtained better performance in transitions of charging and discharging of the supercapacitor, approximately in time 175 seconds and 280 seconds in the Fig. 5.

For this case study we make a comparison between using or not the supercapacitor. As a result, the charging time increased, in addition to the wasted energy, since there is excess of generation. All difference between the energy generated by the PV panel and the energy consumed by the battery would be wasted, since there would be no place to store it without the supercapacitor.

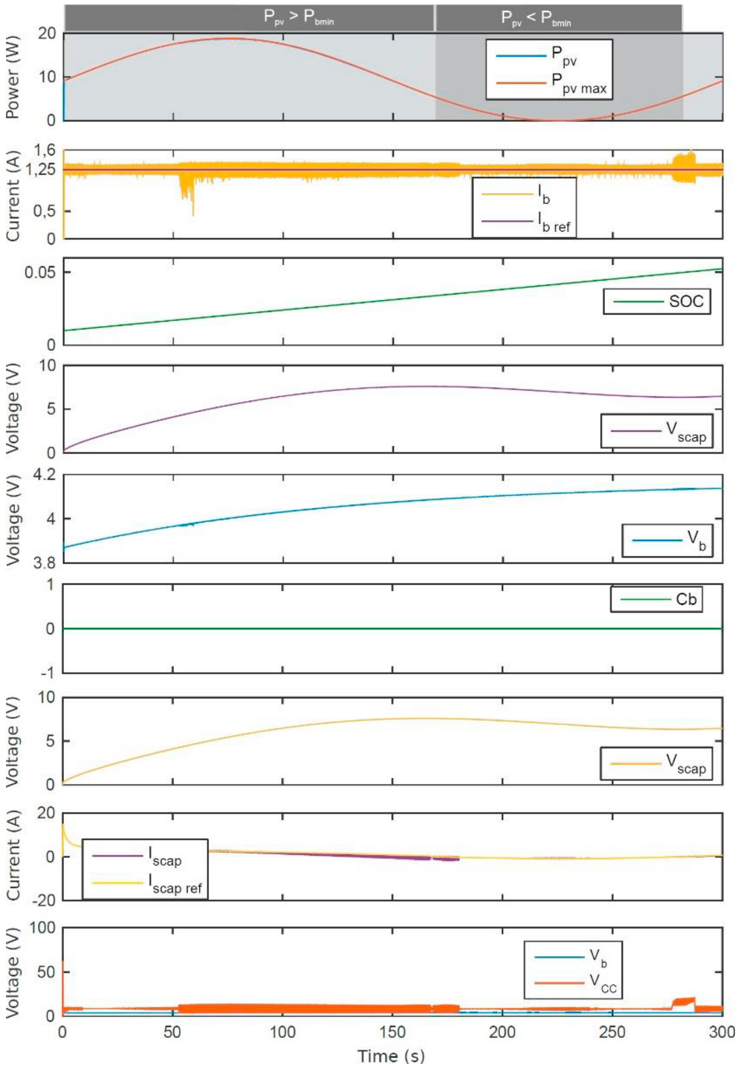

Fig. 5. SBCS variables curves from case study 2.

Another point still analyzed is in the period which the power generated by the panel is less than the minimum for the battery charge, $P_{pv} < P_{bmim}$, when there aren´t enough power to charge the battery, so the current I_b goes to zero, so the battery would take longer to charge. For this case study with supercapacitor, the battery has loaded up to just over 5% of its total charge. In case of simulation without the supercapacitor, the battery charged up to about 3,6%.

In the case study with supercapacitor, for finishing the first step of battery charging where the current is constant and goes until the battery reaches 65%, it will take approximately 65 minutes. Considering the system without the supercapacitor, at the same 300 seconds, the battery charged about 3,6%, reaching to 65%, will take about 90 minutes. We can say that the system without supercapacitor takes about 38,46 % longer to charge the battery. These analyzes were performed observing that, in this case, the relation between the time in which $P_{pv} > P_{bmin}$, time T_b, and the total simulation time T_t, the relation T_b/T_t, was of 0,623.

4. Conclusion

In this work a photovoltaic battery charging system with supercapacitor was presented. The simulations were performed using the *Psim* software to check for the technical feasibility in the use of supercapacitors in photovoltaic battery chargers. The simulation results carried out to control supercapacitor charge and discharge and for the extraction maximum power of the photovoltaic panel were verified. Battery charge was carried out continuously even for brief zero photovoltaic generation and the supercapacitor operated properly as an energy buffer.

We observed that system worked properly for the frequent variations of the solar irradiation, keeping the objective of charging the battery continuously, even under adverse weather conditions. When submitted to a time of some minutes without any solar irradiation, supercapacitor was able to maintain the battery charge.

We conclude for the effectiveness of the MPPT photovoltaic panel, the rapid response of the control system, the adequate storage capacity and the quick delivery of supercapacitor energy.

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