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Technical note

Priority load control algorithm for optimal energy management in stand-alone photovoltaic systems

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ABSTRACT

In stand-alone PV System facilities no grid connection exists, therefore the solar generator and battery bank have to be carefully sized in order to supply the energy demand for a given period of time. Batteries are considered as a weak component of the system, comprising an important part of the total cost and are usually replaced one or two times during PV system lifetime. A priority load control algorithm has been developed in order to gain an optimal energy management over system loads and the battery storage, and therefore provides a better energy management efficiency and guarantee the energy supply for critical loads. This will increase the reliability of the system and the end-user satisfaction. This article describes a stand-alone PV system model used for the development of a priority load control algorithm and explains and implements the algorithm. The results of several test scenario simulations are shown and discussed.

1. Introduction

Electricity generation based on renewable sources has become an important topic today, driven by the increase of costs of fossil fuels and the concern about reducing CO_2 emissions to mitigate climate change. Photovoltaic (PV) solar energy is one of the most promising alternative energy sources, and thanks to a drop in prices in recent years, it is becoming economically and technical feasible even for domestic use [1,2]. However, Solar PV systems are relative expensive, especially on stand-alone PV (SAPV) systems which need an energy storage besides other PV system components.

In SAPV facilities no grid connection exists, the system is designed to supply enough energy to satisfy the energy demand for a given period of time. To accomplish that purpose, we have to carefully size the solar generator and the battery bank. Batteries are considered as one weak component of the system [3], comprising an important part of the total cost [4]. Optimal control over system loads and the battery storage can be employed to improve the payback period, to get a better energy management efficiency and reduce the size of PV system [5,6]. This task can be achieved using priority load control. Furthermore, with this type of control, the energy for critical loads can be guaranteed, given reliability to PV system.

About priority load control, different approaches have been taken so far. Groumpos et al. [7] and Khouzam and Khouzam [8] developed a load management strategy in SAPV system where the loads were classified into four general categories depending on their priority (convenient, essential, critical, and emergency). A variable priority was given to the battery bank dependent on the state of charge (SOC). The problem is mathematically formulated taking into account the priorities, and the optimal solution is obtained through dynamic programming techniques.

Groumpos and Papegeorgiou [6] proposed an optimal load management strategy based on three general load classification: the first category is the operational classification, which divides the load depending of voltage source: DC or AC. The second category is the system classification, which consists in classifying the load as uncontrollable, controllable or semi-controllable. The third category is the priority classification, which uses four priority levels: useful, essential, critical, and emergency load. In this method they use the controllable load to adjust the general load curve, in order to reduce the battery bank size. This improves the total life-cycle cost of the system, protects the battery bank and the priority of the loads is observed. Venayagamoorthy and Welch [9,10], worked on an energy dispatcher, which uses neural networks and fuzzy logic. The objectives are to optimize the energy supply, prioritizing

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Nomenclature

ΔT	temperature difference between battery temperature and 25 C
η_B	battery Faraday efficiency (V)
η_{inv}	inverter efficiency
τ	time constant for battery gassing process (h)
SOC	battery state of charge
SOC_{min}	battery bank minimum state of charge
a_1	logic signal from priority control algorithm
a_2	logic signal from load schedule
C	battery capacity (Ah)
C_{10}	battery nominal capacity at 10 h discharge rate (Ah)
e	electron charge (1.602×10^{-19}C)
E_B	battery bank available energy (Wh)
E_{ij}	energy required by load j of priority i in a specific period of time (Wh)
E_{pv}	PV module array output energy (Wh)
E_{ucL}	energy required for uncontrollable loads (Wh)
I	PV cell current (A)
I_0	solar cell dark current (A)
I_B	battery current (A)
I_G	PV generator current (A)
I_L	solar cell photogenerated current (A)
I_{10}	current needed to discharge a battery bank in 10 h (A)
I_{AC}	inverter AC current (A)
I_{DC}	inverter DC current (A)
I_{SCG}	PV generator short circuit current (A)
I_{SC}	PV cell short-circuit current (A)
k	Boltzmann's constant 1.381×10^{-23} J K^{-1}
K_1	constant value for V_{MPP} calculation
LLP	loss of load probability
m	ideality factor of PV cell ($1 \leq m \leq 2$)
N_S	number of PV modules in series
P_{ij}	average power required by a load j of priority i in a specific period of time (W)
Q	battery charge store at each Δt (Ah)
Q_{sc}	amount of current entering a battery when gassing begins (Ah)
R_B	weighted value associated with the battery bank operation
R_P	solar cell shunt resistance (Ω)
R_S	solar cell series resistance (Ω)
R_{ij}	weighted value associated with operating load j of priority i
r_{ij}	priority unit value associated with load j of priority $r = i$
R_L	load resistance (Ω)
R_{SG}	PV generator series resistance (Ω)
T	absolute temperature (K)
V	PV cell voltage (V)
V_B	battery voltage (V)
V_g	battery gassing voltage (V)
V_{AC}	inverter AC voltage (V)
V_{DC}	inverter DC voltage (V)
V_{fc}	battery final charge voltage (V)
V_G	PV generator voltage (V)
V_{mpp}	maximum power point voltage (V)
V_{OCG}	PV generator open circuit voltage (V)
V_{OC}	PV open-circuit voltage (V)
X_B	proportion of Δt to charge the battery bank
X_{ij}	proportion of Δt to operate load j of priority i

the critical loads and trying to keep the batteries state of charge as high as possible.

Predictive load management has also been developed. For example, Lujano-Rojas et al. [11] takes load parameters to predict load working time: the earliest hour at which a load must start its operation, the latest hour at which it must end its operation, the duration of the operation, the possible hour at which a load will start its operation, the power required, and the period of management. Therefore, the load management consists of making forecasts of the renewable energy source and using these predictions, it is possible to set the hour at which the appliance will start its operation for minimizing the energy supplied by the controllable power sources (like battery bank, diesel generator, or both).

Some of the previously cited works can only discern one priority level (priority or non-priority) [9,10]. Others, capable of handling multiple priority levels, have less precision in the energy estimation for PB-acid batteries [7,8].

Taking in account the previous review, we proposed a priority load control algorithm based on Khouzam and Khouzam's work [8]. We preferred to use a non-predictive approach because it would be a simpler system for a field implementation. Our approach includes an improvement on the energy estimation because battery available energy is calculated based on specific Pb-acid battery parameters equations, providing a better performance of the algorithm. Non-controllable loads are included in the algorithm, which extends it to be used in mixed scenarios with controllable and non-controllable loads.

This paper is organized as follows: in Section 2, we provide a description of the SAPV facility that provides our experimental data. In Section 3, we explain the all SAPV system modelling. In Section 4,we carefully detail the priority load control algorithm. We illustrate the operations of the priority load control algorithm through different cases studies in Section 5, and show the results on Section 6. In the final section, we draw the conclusions of the paper.

2. Stand-alone photovoltaic facility description and experimental dataset

The experimental data (irradiance, ambient temperature) and the components modelled on this paper, are part of a SAPV system located at the University of Murcia, Espinardo Campus. This facility started to operate on March 2003, and its purpose is to feed part of the lighting system of the Animal Service Laboratory. This lighting system is a constant load over 24 h and the energy required to work is 13.776 kWh per day [12].

A monitoring system was installed on 2007 to measure and record meteorological data (global and diffuse horizontal radiation, global tilted radiation and cell and ambient temperatures) and electrical variables (DC generated current and voltage, and DC & AC consumed voltage and current). The sample time of monitoring system is 5 min, and all the data that is measured is stored in a data base. A web-site has also been developed to present the behaviour of the facility and the research projects carried on using the system as an experimental test bench. The web allows the public to follow its performance on-line [13].

3. System modelling

A complete SAPV system model has been implemented on Matlab/Simulink software. Each component has been modelled in a different block as shown on Fig. 1, and the description is made in the following subsections.

3.1. PV generator model

The implemented PV generator model is based on the one proposed by Eduardo Lorenzo et al. [14]. This model is created from the equivalent circuit of a solar cell:

$$I = I_L - I_0\left(\exp\frac{e(V+IR_S)}{mkT} - 1\right) - \frac{V+IR_S}{R_P} \quad (1)$$

where I_L, I_0 R_S, and R_P are the photogenerated current, dark current, series resistance, and shunt resistance respectively. The factor m represent the ideality factor, k is the Boltzmann's constant, T is absolute temperature expressed in Kelvins and e is the electron charge.

In order to use this model, we need to include parameters characterizing the electrical behaviour of the cells, obtained under standard measuring conditions, the incident solar radiation and the ambient temperature of the location. For the whole system calculations, some assumptions have been considered which allow us to use commercial PV module parameters in the model with a negligible variation on the output accuracy:

a) The effect of parallel resistance and voltage drops in the conductors connecting the cells is negligible.
b) The photogenerated current I_L and the short-circuit current I_{SC} are equal.
c) All the cells of the generator are identical and function under the same conditions of illumination and temperature.
d) $\exp((V+IR_S)/V_t) \gg 1$ under all working conditions.

Considering assumptions a), b), and c), equation (1) can be written:

$$I = I_{SC} - I_0 \exp\left(\frac{V+IR_S}{V_t}\right) \quad (2)$$

where $V_t = mkT/e$. With $I = 0$, leads to the following expression for the open-circuit voltage:

$$V_{OC} = V_t \ln\left(\frac{I_{SC}}{I_0}\right) \quad (3)$$

hence:

$$I_0 = I_{SC} \exp\left(-\frac{V_{OC}}{V_t}\right) \quad (4)$$

$$I = I_{SC}\left[1 - \exp\left(\frac{V - V_{OC} + IR_S}{V_t}\right)\right] \quad (5)$$

This expression can be inconvenient to use in the sense that I is an implicit variable. However, for voltages close to maximum-power point, a reasonably accurate solution can be obtained by setting $I = I_{SC}$ in the second term.

The result is equation (6), in which we are now considering the whole generator [14]:

$$I_G = I_{SCG}\left[(1 - \exp\left(\frac{V_G - V_{OCG} + I_{SCG}R_{SG}}{N_S V_t}\right)\right] \quad (6)$$

where I_G is PV generator current I_{SCG}, is PV generator short circuit current V_G, is PV Generator voltage V_{OCG}, is PV Generator open circuit voltage R_{SG}, is PV Generator series resistance and N_S number of PV modules in series.

To validate the model, we measured experimental power data from Murcia SAPV facility described before and compared them with the output of the model. The simulation took into account solar radiation and temperature data measured at the experimental facility.

3.2. MPPT model

In a PV system without Maximum Power Point Tracker (MPPT), battery bank voltage defines the operation point of the PV modules, and therefore, even if the system has been designed with the optimum size and configuration, the solar energy production is affected by the battery operation regime (charging, discharging) and SOC. Consequently all system behaviour is linked to batteries behaviour. The importance of the MPPT model presented in this article is to decouple PV generator and battery bank, providing a MPPT voltage to the PV generator. It allows us to analyze how the proposed priority load control affects the performance of the PV system.

A review on different MPPT algorithms can be seen in Ref. [15]. We take the concept of the "Open-circuit voltage photovoltaic generator method" and implement it in our PV system model.

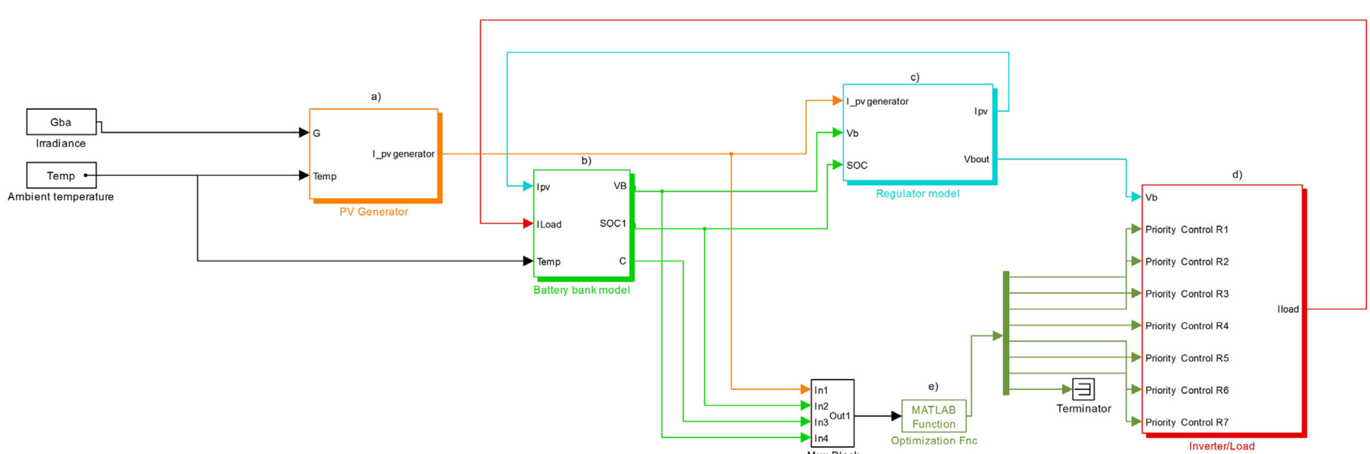

Fig. 1. Complete system model on Simulink comprising the following blocks: a) PV Generator, b) Battery bank Model, c) Regulator model, d) Inverter & Load models, e) Priority load control algorithm block.

The idea of the method is based on the fact that the PV generator MPP voltage depends linearly on the open circuit voltage of the generator.

$$V_{mpp} = K_1 V_{OCG} \tag{7}$$

where K_1 is a constant depending on the material and with values from 0.73 to 0.80 for a polycrystalline module. We chose $K_1 = 0.76$.

This is easily implemented on the PV generator model, substituting the value of V_G on the equation (6), for $K_1 V_{OCG}$.

3.3. Battery bank model

Battery models are difficult to develop, and different approaches can be made: models from chemical reactions, from DC equivalent circuit, from AC equivalent circuit or Functionality models [16].This particular model was based on Copettis work proposed for a Pb-Acid battery [14].

Three primary empirical equations are presented; the use of one or another depends on the operating procedure and regime: Discharge eq. (8), Charge eq. (9), or Overcharge eq. (10):

Discharge:

$$V_B(V) = [2.085 - 0.12(1 - \mathrm{SOC})] - \frac{I_B}{C_{10}}\left(\frac{4}{1 + I_B^{1.3}} + \frac{0.27}{\mathrm{SOC}^{1.2}} + 0.02\right)(1 - 0.007\Delta T) \tag{8}$$

where V_B is the battery voltage C_{10}, is the battery nominal capacity at 10 h discharge rate, and I_B is the battery current. SOC is the battery state of charge and $\Delta T =$ temperature (C)−25.

Charge:

$$V_B(V) = [2 + 0.16\mathrm{SOC})] - \frac{I_B}{C_{10}}\left(\frac{6}{1 + I_B^{0.86}} + \frac{0.48}{(1 - \mathrm{SOC})^{1.2}} + 0.036\right)(1 - 0.025\Delta T) \tag{9}$$

Overcharge:

$$V_B(V) = V_g + \left(V_{fc} - V_g\right)\left[1 - \exp\left(\frac{Q_{sc} - 0.95C}{I_B \tau_{sc}}\right)\right] \tag{10}$$

where V_g is the battery gassing voltage V_{fc}, is the battery final charge voltage, and Q_{sc} is the amount of current entering a battery when gassing begins. τ is a time constant of the process.

There are another equations which are important to the model:

$$\mathrm{SOC} = Q/C \tag{11}$$

where $Q = \eta_B I_B \Delta t$, is the amount of current stored by the battery at a given time. Variable C is the battery capacity corresponding to the working conditions at that moment, calculated from the expression:

$$C = \frac{1.67C_{10}}{1 + 0.67\left[\frac{I_B}{I_{10}}\right]}(1 + 0.005\Delta T) \tag{12}$$

where I_{10} is the current needed to discharge the battery bank in 10 h, and η_B is the Faraday efficiency depending on SOC, calculated from the equation:

$$\eta_b = 1 - \exp\left[\frac{20.73(\mathrm{SOC} - 1)}{\frac{I_B}{I_{10}} + 0.55}\right] \tag{13}$$

The equations (11)–(13) are also used in the Priority load control algorithm, explained in section 4.

3.4. Regulator model

In this case, the regulator only has two functionalities: one is to protect the batteries from overdischarge by disconnecting the battery bank from the load when the discharge limit is reached. The reconnection is made when the batteries recover a specified amount of charge.

The algorithm for the overdischarge protection is ruled by the following state machine behaviour, presented in Fig. 2a.

The other duty of the regulator is to protect the batteries from overcharge. In this case, the battery bank is disconnected from PV generator when the batteries reach the 100% of the state of charge. The reconnection occurs when the batteries are below a pre-configured state of charge, which in our case is 90%. This behaviour is presented in Fig. 2b.

3.5. Inverter model

The inverter is a DC/AC converter, who takes DC voltages of the battery bank and turns it into AC 230 V output. For this model, it is enough to consider the output as a constant voltage equivalent to the RMS of the AC signal. Also, it is necessary to take into account the inverter efficiency, and the energy conservation. Basic protections were not considered. This approach is based on Guasch's work [16].

In order to calculate the DC current extracted from the batteries by the AC load, equation (14) has been used:

$$I_{DC} = \frac{I_{AC} V_{AC}}{\eta_{inv} V_{DC}} \tag{14}$$

where I_{DC} is DC current I_{AC}, is AC current V_{AC}. and V_{DC} correspond to AC and DC voltage respectively η_{inv} is the inverter efficiency.

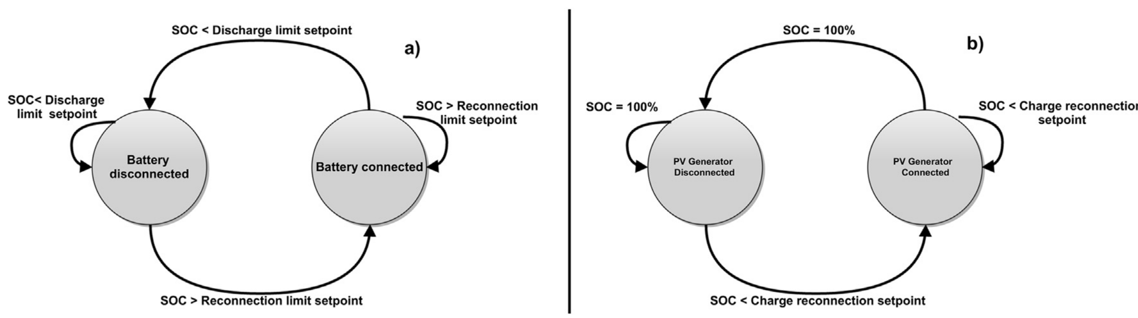

Fig. 2. Regulator model: a) State machine for battery overdischarge protection, b) State machine for battery overcharge protection.

3.6. Load model

For the load model, a simple resistor model has been used. Its behaviour is ruled by Ohm's law:

$$I_{AC} = \frac{V_{AC}}{R_L}(a_1 * a_2) \tag{15}$$

where R_L is the load resistance. Logic signals a_1 and a_2 are the enabling signals from the Priority load control algorithm and the load schedule respectively. Load is switched ON and OFF according to the output of the algorithm described below and the profile defined by the load schedule.

4. Priority load control algorithm

The purpose of priority load control algorithms is to provide energy to the highest priority loads at the expense of the less critical loads. Management of these loads in an optimal way will allow us to reduce de Loss of Load Probability (LLP) of critical loads, protect the battery bank and overall, to minimize the total life-cycle cost of the system.

The algorithm presented in this article is based on Groumpous and Khouzam & Khouzam work [7,8]. The loads are classified according their priority in 4 categories: convenient, essential, critical and emergency, which is the highest one. The battery bank priority is variable, depending of the state of charge. Table 1 summarizes the load type and its assigned priority.

The solution to the addressed problem is based on the maximization of a weighted objective function that depends on the load priorities and it is subject to the availability of energy supply.

The mathematical expression is represented as a Linear Programming problem, and it looks like this:

$$\text{maximize} \quad \left(\sum_{i=1}^{n} \sum_{j=1}^{m_i} R_{ij} X_{ij} + R_B X_B \right) \tag{16}$$

Subject to:

$$\sum_{i=1}^{n} \sum_{j=1}^{m_i} P_{ij} X_{ij} \Delta t + P_B X_B \Delta t + E_{ucL} < E_{pv} + E_B \eta_B (SOC - SOC_{min}) \tag{17a}$$

$$0 \le X_{ij} \le 1, \quad \text{for all } i,j \tag{17b}$$

$$0 \le X_B \le 1 \tag{17c}$$

where:

$$R_{ij} = r_{ij} P_{ij} \Delta t \tag{18}$$

$$R_B = r_B E_B (1 - SOC) \tag{19}$$

Table 1
Loads classification and priorities.

Load type	Priority (r)
Convenient	$r = 1$
Essential	$r = 2$
Critical	$r = 3$
Emergency	$r = 4$
Battery	Variable $r_B = 5(1-SOC)$

$$r_B = 5(1 - SOC) \tag{20}$$

$$P_B = \frac{C_a V_B}{\Delta t} \tag{21}$$

$$E_B = C_a V_B \tag{22}$$

Battery parameters SOC C_a, and η_B, are calculated with equations (11)–(13) respectively, for each time step. It makes an improvement of the energy estimation available of the SAPV system. It also included to the mathematical model the variable E_{ucL}, which corresponds to the energy of Non-controllable loads. This allows the algorithm to be used in mixed scenarios with controllable and non-controllable loads.

The expected results are values of X_{ij} for each load that corresponds to normalized values between 0 and 1. They indicated the percentage of the time in current time step that the load will be connected. For example $X_{21} = 0.75$, means the load number "1" with priority "essential" or $r = 2$, has a value of 0.75. If the system is working at 10 min sampling frequency it means that this load will capable to be connected during 75% of the time step (7 min and 30 s). For the next time step, the algorithm will recalculate this values taking into account the new energy status of the system.

For solar PV energy estimation, we assume that the PV energy measured in present time step will not change significantly over the next point, because a 5 min sampling frequency is used for the cases presented in this paper.

5. Simulations and test scenario description

In order to test the algorithm, two SAPV system scenarios have been used: Scenario A, the SAPV system has a 3.4 kW_p solar array, battery bank has a 1680 Ah capacity and the initial SOC is 0.9. Seven loads of 77.79 W are connected, with a constant consumption profile. Scenario B is a SAPV system with a 1.7 kW_p solar array. The battery bank has a 1000 Ah capacity and the initial SOC = 0.9. Seven loads of 77.79 W are connected, with a variable consumption profile that is similar in shape (time profile) to a typical household consumption profile [17,18].

Both load profiles are shown in Fig. 3.

To evaluate the functionality of the priority load control algorithm, a No Control case is also implemented. Also, a SOC based control case is used for comparison. In this latter case, we assign priority levels: For Priority 1, above SOC = 0.8 it is necessary to connect the load. Priority 2, above to SOC = 0.6, Priority 3 above to SOC = 0.4, and Priority 4 above to SOC = 0.2, which is the limit of deep discharge.

The simulations are performed over 275 days, using 5 min sample rate, for which experimental measurements of irradiance and temperature are used as input parameters. It is also assumed that all loads are controllable ($E_{ucL} = 0$).

6. Results and discussion

The results of the simulation are presented in Figs. 4 and 5. We also use the LLP value to quantify the effectiveness of the algorithms to preserve the priority loads connected. LLP allow us to quantify the reliability of energy supply, defined as the ratio between the estimated energy deficit and the energy demand over the total operation time of the installation [19]. A low LLP means a low probability to the load be disconnected.

In Fig. 4, we have simulated Scenario A over 275 days. The evolution of the SOC is shown over time for the controlled cases and No Control case.

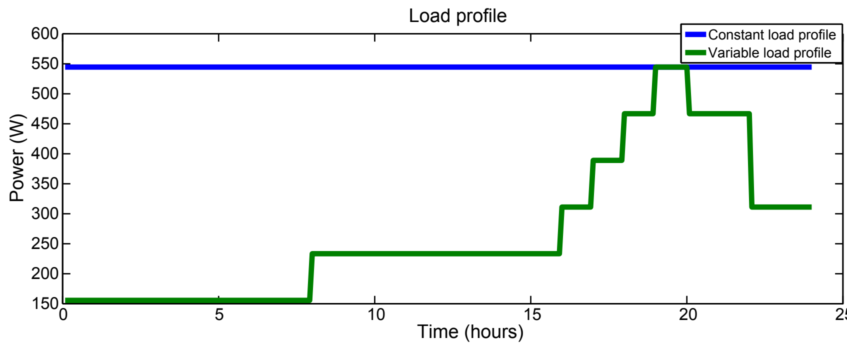

Fig. 3. Daily load profile of the SAPV. The blue line represents the constant load profile. The green line represents the variable profile. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

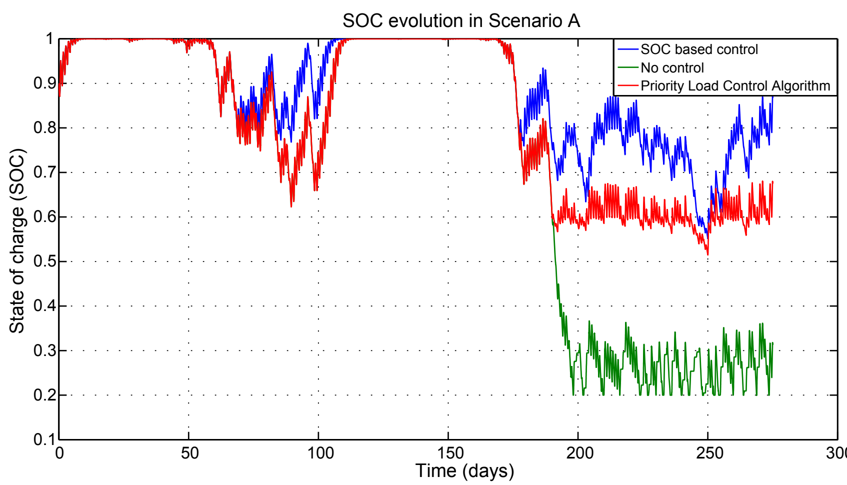

Fig. 4. SOC evolution for Scenario A (constant load profile). The blue line represents the SOC behaviour of SOC based control algorithm, the green line represents the No Control case and the red line corresponds to the results using the proposed priority load control algorithm. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The control algorithms clearly achieve the goal, maintaining the power over the priority loads, which can be seen numerically on Table 2, expressed as LLP values. Also, a higher state of charge on the battery bank is maintained, as is shown on Fig. 4.

The No Control case discharges the batteries, and all loads were cut-out for a significant period of time. For the controlled cases, the two algorithms work similarly, SOC control based case maintain the higher SOC, but further penalize the low-priority loads as can be observed in Table 2, presenting worst LLP values for the lower priority loads.

In Scenario B, Fig. 5 shows the same behaviour: the two controlled cases works very similarly, and the No Control case runs

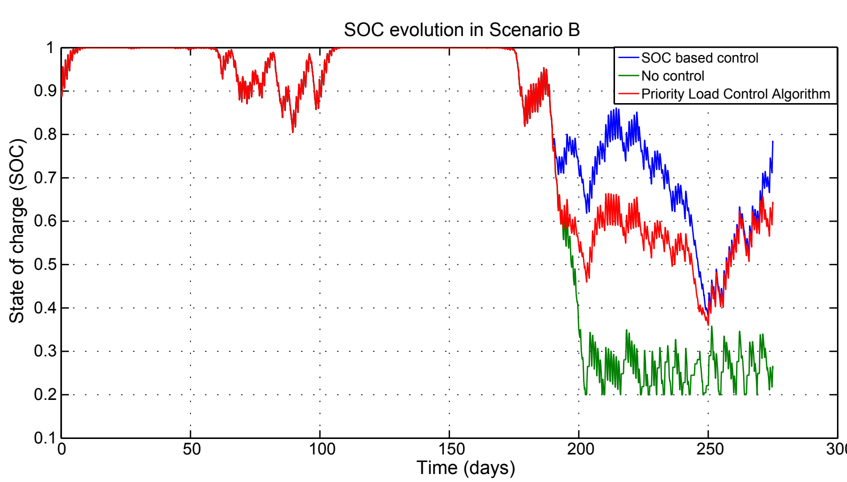

Fig. 5. SOC evolution for Scenario B (variable load profile). The blue line represents the SOC behaviour of SOC based control algorithm, the green line represents the No Control case and the red line corresponds to Priority Load Control Algorithm. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
LLP table for each load and control algorithms in Scenario A. The loads have been labelled with letters (A to G), the priority (r) are defined as the categories shown on Table 1.

Load	A, $r=1$	B, $r=1$	C, $r=1$	D, $r=2$	E, $r=2$	F, $r=3$	G, $r=4$
Priority load control algorithm	0.1588	0.1591	0.1593	0.1579	0.1581	0	0
SOC based control	0.2700	0.2700	0.2700	0.0166	0.0166	0	0
No control	0.1077	0.1077	0.1077	0.1077	0.1077	0.1077	0.1077

out the battery. Comparing Figs. 4 and 5, we can say that the behaviour of these control algorithms is independent of the load profile. This is explained because the algorithms make the calculations for one time step at once. In other words, the algorithms only take into account the current status of the system at the current calculation time step. No previous or future status of the system influences the connection of the loads at each time step, and therefore the overall shape of the energy demand is not having a strong impact on the performance of the algorithms.

In Table 3 LLP, we can see that the goal of preserving the priority loads has been reached.

Overall, the Priority Load Control algorithm shows a better behaviour and achieves best compromise between a higher SOC of the battery bank and the availability of the load. The improvement in calculation of batteries SOC, efficiency and capacity depending on their operating regime, allows the algorithm to be more precise and therefore delivers a better performance.

7. Conclusions

A priority load control algorithm was developed based on Khouzam and Khouzam work [8]. An improvement in energy estimation and batteries SOC, efficiency and capacity calculation was implemented and its behaviour is shown through different simulation scenarios, using a complete SAPV system model.

For scenario A, priority load control algorithm kept an LLP=0 for loads with priorities “emergency” and “critical” type. Loads with “essential” type priority have LLP = 0.1581 and LLP = 0.1579. The rest of the loads, which have a “convenient” type priority, have a LLP = 0.1593, LLP = 0.1591 and LLP = 0.1588. SOC time evolution can be seen in Fig. 4.

For scenario B, we got similar results, Priority load control algorithm kept LLP = 0 for the load with “emergency” type priority and LLP = 0.0051 for the load with “critical” type priority. Loads with “essential” type priority have LLP = 0.1544 and LLP = 0.1547. The rest of the loads, which have “convenient” type priority, have a LLP = 0.2651, LLP = 0.27 and LLP = 0.25.43. SOC time evolution can be seen in Fig. 5.

Comparing this results with No Control case and SOC based control case shown on Tables 2 and 3, and the SOC evolution shown on Figs. 4 and 5, it is demonstrated that the algorithm has a better performance and provides a better compromise between SOC of battery bank and the load availability.

Table 3
LLP table for each load and control algorithms in Scenario B. The loads have been labelled with letters (A to G), the priority (r) correspond to categories defined on Table 1.

Load	A, $r=1$	B, $r=1$	C, $r=1$	D, $r=2$	E, $r=2$	F, $r=3$	G, $r=4$
Priority load control algorithm	0.2543	0.2700	0.2651	0.1547	0.1544	0.0051	0
SOC based control	0.2779	0.2905	0.2860	0.0949	0.0976	0.0045	0
No control	0.0921	0.1004	0.1028	0.1039	0.0999	0.0953	0.0953

The goal of preserving the priority loads connected it is also achieve, even if there is an energy deficit. This reliability was showed through calculating the LLP for each load and will contribute to increase the end-user satisfaction with the service provided by the SAPV system.

The applications of algorithms derived from this work can be implemented on other scenarios, such as autonomous vehicles and grid-connected solar systems, for self-consumption.

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