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Energy Management for Stand Alone PV System

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Abstract

One of the crucial elements for mastering the performance of a Stand Alone PV System (SAPVS) is the control and management of the energy storage. We focus in this article on the energy control and management algorithm which is a part of a tool we have elaborated and which is devoted for simulation and performance evaluation of SAPVS.
For a given energy demand and power PV generator, the algorithm proceeds to several tests on parameters as SOC, I_{PV}, I_L in order to take the best decision for balancing the mismatch between the available energy produced by the source and the power required by the load. As example, the energetic behavior of a PV system applied in a local rural electrification is analyzed through the charge and discharge of the battery and the parameters SOC, I_{PV}, I_L, I_B for a typical day in winter and unfavorable day. We show that the elaborated algorithm allows us to avoid any shortage energy for the case treated.

Keywords: Stand Alone PV System, Energy Storage, Energy Management, System Performance.

Nomenclature

C Battery capacity, AH
I_B Charge and discharge current battery, A
I_L Load current, A
I_{PV} PV array current, A
P_{PV} PV array power (W)
P_{NU} PV array power non used (W)
R_I Internal resistance of the battery, Ω
$S_{\min}$ Minimum value of the battery State of Charge
S_{Max} Maximum value of the battery State of Charge
SOC Battery State of Charge
SOC_0 Battery State of Charge at initial time
$SOC(n)$ Battery State of Charge at hour n
T_{amb} Ambient temperature, °C
V_B Battery voltage, V
V_R Open circuit voltage, V

1. Introduction

Climate change and oil shortage have prompted the ever-growing awareness about the need to use non pollutant energy. This favorable economic background conducted to an impressive growth rates of the photovoltaic industry in the last decade and it is expected to continue in the upcoming years. In this context, the number of PV installations increases year after year but without noting a significant decrease in the PV system cost.
As the initial cost is high, the users need to be ensured that the PV system installed will be reliable and energetically efficient. To reach this goal, we have elaborated a helpful tool for the design and analysis, devoted as a first step, for SAPVS [1].
After having briefly described this tool, we will focus, in this article, on the energy storage and management of the PV system. We present an energy management strategy devoted for a Stand Alone PV systems based on a hierarchically structured control algorithm. The control strategy proposed to limit the charge/discharge batteries current is based on the test of the SOC, I_{PV}, I_L, I_d. This algorithm has been designed with the aim of optimizing the energy efficiency and, at the same time, avoiding irregular working conditions that could reduce the life expectancy of the components.

2. Presentation of the SAPVS tool

The beginning of a system design is the preliminary studies where the needs and the requirements of the user are expressed. In the case of a SAPVS, we must know mainly the electrical power that the system must supply and its autonomy in case of lack of sunshine in other words the battery capacity. These data allow good sizing of the system in order to be efficient, reliable but without neglecting its cost.
After the sizing step, it will be useful, before the realization of the system, to proceed with the system simulation for the evaluation of its performances in order to bring any needed correction.

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We have elaborated this code to be used as a tool for the design of SAPVS and also for the follow up of the already installed systems.

2.1Architecture of the simulation program

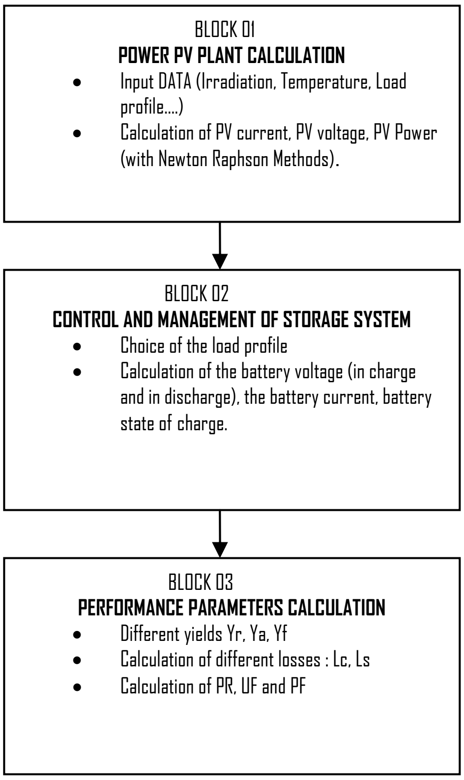

Figure 1. Synoptic of the SAPVS simulation program

The elaborated SAPVS simulation program is based on three main blocks (figure 1). The first block uses the Newton Raphson method to calculate the power PV field taking into account the global irradiation and the ambient temperature. The second block is devoted to the management and control of storage system based on an algorithm which will be presented in this article. The third block calculates the yields Y_A, Y_R, Y_F and the losses L_C and L_S for deducing the factors P_R, U_F and P_F used to evaluate the SAS performances. The results are presented as tables, graphs and histograms.

3. Control and Management strategy for the storage system

In SAPVS systems, a storage system is a solution for balancing the mismatch between the available energy by the source and the power required by the load. Both the power flows into and out of the storage device have to be designed accurately and controlled according to a global energy management strategy.

Control power flows can be easily obtained by interconnecting storage device (battery bank) and generation sources (PV plant) by means of algorithm which is implemented on a power converter. Control algorithm with a hierarchical structure has to adapt controlling actions in order to satisfy many constraints and critical conditions (low state of charge, over voltages, over currents...) with an assigned priority order[2].

3.1Storage system model

In most cases, the storage system is composed of several batteries. The common battery used is made of lead acid. Its charge is modelized by [3] - [5]:

$$V_B = V_R + \frac{I_B}{C}\left\{\frac{0.189}{1.142 - SOC} + R_I\right\} \quad (1)$$

Where

V_b : battery voltage, (V), I_B : current battery (A), C : battery capacity (A.H), V_R : open circuit voltage (V), SOC : State of Charge of the battery at given time.
R_I : Battery internal resistance (Ω) .

$$SOC = SOC_0 \pm \frac{I_B.\Delta t}{C_{nb}} \quad (2)$$

SOC_0 : Battery State of Charge at initial time, Δt : time of charge or discharge (s).

When the voltage of each element is over 2.28V we add the following term:

$$(SOC - 0.9)\log\left\{\frac{300\ I_B}{C} + 1\right\} \quad (3)$$

Where,

$$V_R = 2.094\ \{1 - 0.001\ (T_{amb} - 25)\} \quad (4)$$

T_{amb} : Ambient temperature (°C)

$$R_I = 0.15\ \{1 - 0.02(T_{amb} - 25)\} \quad (5)$$

The battery discharge model is given by:

$$V_B = V_R - \frac{I_B}{C}\left\{\frac{0.189}{SOC} + R_I\right\} \quad (6)$$

3.2Control Strategy

to the load and the excess current will be used to charge the battery $(I_B = I_{PV} - I_L)$.

b- $SOC > S_{min}$ and $I_{PV} < I_L$

As I_{PV} is lower than I_L , the PV array cannot feed the load so we disconnect the PV array from the load and the latter is supplied only by the battery (battery discharge).

Case 2: $SOC < S_{min}$

In this case the battery is discharged and can't supply the load, so the load is disconnected and we proceed immediately to the recharge of the battery by the PV array.

4. Control and Management strategy applied to a practical Stand Alone PV system.

The example treated in this article concerns a small PV field devoted to rural electrification for a group of six houses, located at Tamanrasset (south of Algeria), whose daily energy needs is about 2 KWh (figure3). We present in the following the simulation results obtained with the control algorithm and we analyze by the means of the battery the energy behavior of this Stand Alone PV station.

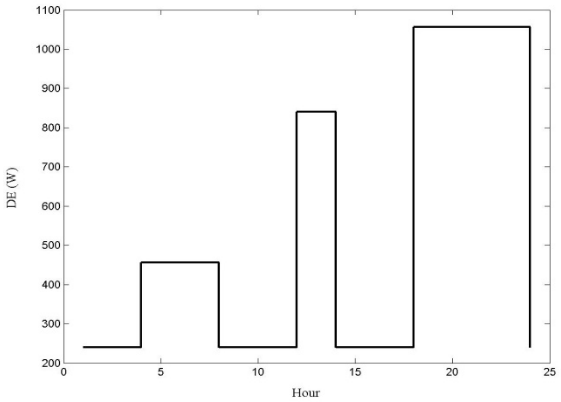

Figure 3. Daily village consumption.

4.1Description of the example treated

From the technical prescription manual and taking into account the meteorological data for the selected site and the autonomy requirements of the system (four days), we have sized the system by using PVSST 1.0 software developed by our team [6]. The results obtained conducted us to the following configuration:

- A PV field of 3.33KWp power installed must be composed by 24 branches in parallel. Each of them has 4 modules (36Wp) connected in series to have a voltage output of 48V.
- A set of 24 batteries elements of 2V connected in series having a nominal capacity of 1250Ah,

4.2Analysis of the energy management of the SAPVS studied by means of the battery behavior.

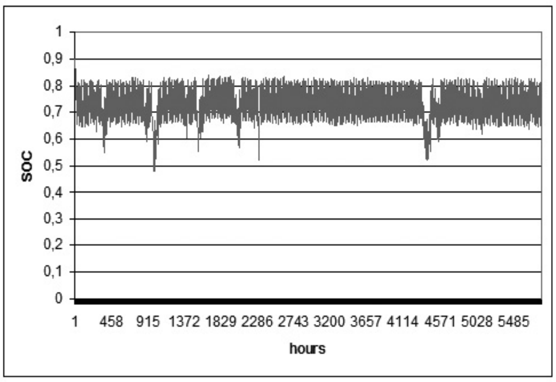

Figure 4. State of charge of a battery during a year

The battery is a key element in the SAPVS. It imposes the voltage for the whole system. The figure 4 represents the plot of the SOC of a battery on a period of one year for the energy needs profile given in figure 3. We notice that the SOC is comprised between 0.65 and 0.82. However, there are few days where the SOC is weak but it doesn't reach in any case the threshold value 0.2 of the battery. Its minimum value is of the order of 0.48. The low peaks of the SOC correspond to winter days where the irradiation is the lowest of the year. As shown on figure 5.

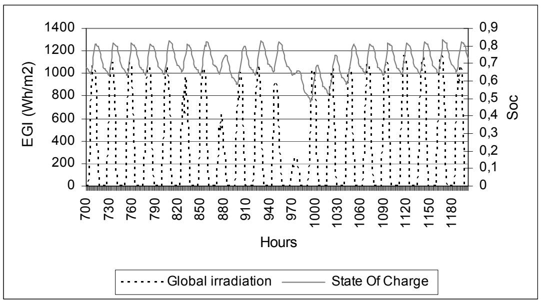

Figure 5. Variation of the battery SOC and the irradiation for the most unfavorable days of the year.

We can understand the energy management of the PV system by means of the battery charge and discharge for a given day. To show how our control algorithm is dealing with optimal manner, depending on the energy available, we analyse in the following the evolution of the system during the day successively for the case of '*a typical day*' and for the case of '*unfavourable*' day

4.2.1Case of typical day in winter

Figure 6 shows clearly that the PV system, while working, passes through several steps which depend on meteorological conditions, the currents I_{PV}, I_B, I_L and the SOC. That can be traduced by:

Region A: 0H – 7H

In this period of time there is an absence of irradiation that means $I_{PV} = 0$. The load is fed by the discharge of the battery which leads to the decrease of the SOC.

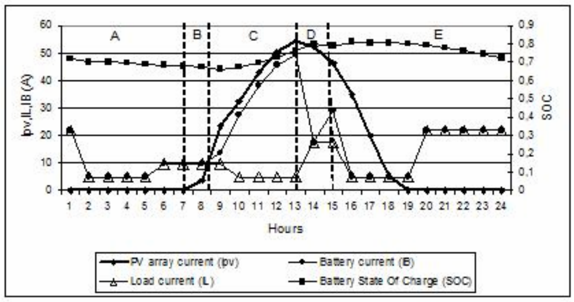

Figure 6. Variation of the battery SOC, I_{PV}, I_B and I_L for a typical day in winter.

Region B: 7H – 8H

In the beginning of the day, at the same time I_{PV} increases but I_{PV} is lower than I_L. The battery continues to discharge in the load $(I_B = I_L)$.

Zone C: 8H – 13H

In this zone $I_{PV} > I_L$. The load id fed by the PV current array I_{PV} while the battery is charging with a current $I_B = I_{PV} - I_L$.

Region D: 13H – 15H

As $I_{PV} > I_L$, while the $SOC < S_{Max}$ the battery continues to charge. When the $SOC > S_{Max}$, the PV array is disconnected from the battery and the battery begins to discharge in the load, $I_L = I_B$.

Region E: 15H – 21H

As soon as $SOC < S_{Max}$, the battery begins to charge again. We notice that the beginning of the region E matches with the day phase where the irradiation and consequently I_{PV} decreases. The battery is then discharging.

4.2.2 Case of the day whose SOC is the lowest of the year.

The figure 7 represents the evolution of the system in the case of the day where the SOC is the lowest of the year.

Region A: This zone concerns the day before and the beginning of the day on focus. We notice in this region that I_{PV} is very low, that means that the irradiation received by the PV array is absent or very low. In these conditions, as long as $(I_{PV} < I_L)$, The PV generator is disconnected from the load and the latter is supplied by the battery, whose discharge provoke the decrease of the SOC.

Region B:

This range time corresponds to the beginning of the day of interest. The irradiation begins to rise $(I_{PV} > 0)$ but is insufficient to feed the load $(I_{PV} < I_L)$, the PV array still being disconnected and the battery supplying the load with $(I_L = I_B)$. The battery continues to discharge and the SOC reaches its lowest value of the year (0.48).

Region C:

In this zone the irradiation has reached such a good level which allowed I_{PV} to increase and exceed I_L while the $SOC < S_{Max}$. In this case the PV array is able to supply the load and charge the battery with $(I_B = I_{PV} - I_L)$.

From the figure 6 and 7, we notice that the system doesn't show any situation of lack of energy, that means that the sizing of the PV system has been done correctly and the strategy adopted in the elaborated control and management algorithm seems to be efficient.

In order to characterize the operation of PV system, the Performance Ratio PR has been introduced. PR indicates how the energy produced by the PV system is used. The greater is PR the better the energy produced by the system is used. On the figure 8 we can see the ranges of the values taken by PR during one year for the SAPVS used for rural electrification. For the case treated, it appears clearly that for about 60% of the year PR is in the range (0.5-0.6) and that is in conformity with the figures recommended by the IEA for a SAPVS applied for rural electrification. A PR lower than 0.5 represents only 5% of all the cases.

5. Conclusion

An energy control and management algorithm devoted for Stand Alone PV System has been presented in this article. The algorithm is based on a strategy which deals with several parameters as the SOC, I_{PV}, I_L and I_B. We have shown, trough the presented example of rural electrification how the energy control and management algorithm deals with different situations for balancing the mismatch between the available energy produced by the source and the power required by the load requiring for certain cases the energy accumulated in the battery bank. This algorithm aims to optimize the use of the energy available from the PV generator and the battery while extending the lifetime of the latter and making the overall system more reliable and cost effective.

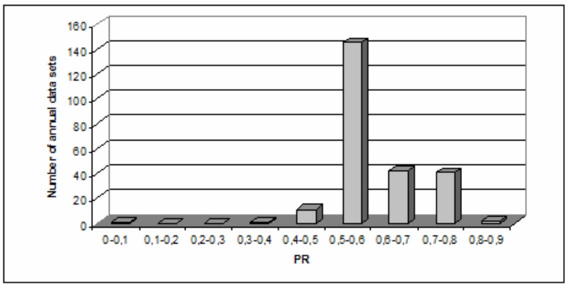

Figure 8. Range of values taken by P_R for one year in the case of SAPVS used in the example treated.

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