# Supervision Strategy of a Hybrid System PV with Storage for Injection to the Electrical Network

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**Abstract.** In photovoltaic system (PVS) hybrid, battery are often used for energy storage in order to ensure a permanent operation. Our system consists of solar panels, a boost converter which serves as an interface between the PVS and the load, and a buck-boost converter between the battery and the load. To ensure proper operation of the system, the DC bus voltage must be maintained constant. The batteries are sensitive to overcharging and deep discharge phenomena and more PVS have a low conversion efficiency. Faced with these problems the objective of this study is to maintain constant voltage bus, optimize performance of the PVS and to control the battery state of charge and discharge. The control strategy is a combination of MPPT (Maximum Power Point Tracking) control based on artificial neural networks (ANN) and an algorithm against the battery charge state. Simulation results show that the bus voltage is hold constant with the PI and PID correctors. There is also an improvement in conversion efficiency and control of the state of battery charge.

**Keywords:** ANN · Battery · Boost converter · Buck-boost convert · PVS

## 1 Introduction

The environmental protection became a very important point, since the solution is to have a cheap source of energy, sustainable and low-polluting. In recent decades utmost importance is given to photovoltaic systems to meet the global energy challenge. Photovoltaic systems are no longer limited to stand-alone systems but also contribute to increase the electricity generation facilities through PVS connected to the electrical distribution network. But the major problem of these systems is their low conversion efficiencies around 10–23% [1] and the


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intermittent nature of their source. Faced with these problems photovoltaic modules must operate at their Maximum Power Point (MPP), hence the need to use commands MPPT [2] to improve performance. On the other hand to provide continuous access of energy, storage systems such as batteries are a solution. These are sensitive to overcharge and deep discharge phenomena [3]. These have a significant impact on battery lifetime. It is then necessary to associate a control system to ensure their protection. Faced with these various problems a methods have been developed to optimize the PVS conversion efficiency and control the state of charge of the battery. Traditional methods such as constant current or constant voltage have been proposed in the literature. In [4] a PI-type controller is used to maintain a constant current and the charging voltage to a variation in climatic conditions. The system consists of two converters (Boost and Buck). A MPPT control based on fuzzy logic is used to optimize the conversion efficiency and in our stady we use artificiel neuron network ANN to improuve the efficience. Simulation results show that the classical PI controller maintains the current and the voltage out of the Buck constant to charge the batteries. This objectif is achieved with the PID controller that maintains current and output voltage of the converter constant in Buck [5] and we note the good performance of the MPPT control based on logic compared to the conventional commands types P&O and INC. Other researches focus on the control of the battery charge state to improve their lives. In [6] the approach is to control the deep charge and discharge phenomena by storing energy needs at night and the same approach is used in [7]. In [8,9] experimental implementation of a device for controling the state of charge (SOC) of a standalone PV system are presented. A control strategy for a multi-source system (Panels, Wind, battery and generator) has been developed [10]. However, the system must be equipped with a charge or discharge regulator to maintien the voltage constant and we note the good performance of a series regulator [11]. Other works deal with to the regulation of the DC voltage of the system. The latter is strongly influenced by the voltage of the PVS, the battery charge and load. This is achieved in [12] where a comparative study of a PID controller and fuzzy logic (FL) is done and there is a good performance of the FL command to maintien constant the current and voltage of the charge battery. A comparative study of a PI controller and a controller based on the predictive method for regulating the DC bus of a hybrid system is presented [13]. Autors study the regulation of the DC voltage and the control of the SOC but no one uses the ANN to improuvement the performance of the PVS and control the SOC of the battery. The main goal in this paper is to maintain constant the voltage bus and to study the implementation of an intelligent control for controlling the battery charge. As a contribution we firstly kept bus voltage constant with a PID controller that improves response time and oscillations and also developed an algorithm that improve the efficiency of PVS by ANN and simultaneously control the state of charge of the battery.

## 2 Presentation of a Hybrid System

Hybrid systems combine two or more complementary renewable sources such as wind and solar or several renewable and conventional sources such as solar and diesel generator. In our case we use PVS and batteries to feed a dc load. When PVS production is sufficient and the state of charge of the batteries is below than the minimum admissible. In this case, the PVS supplies feed the load and charge the battery through a bidirectionnel converter. The hybrid system studied in this work is used to feed a continuous load at a constant voltage. It consists of solar panels that convert light energy into electrical energy and storage battery that feed the load during the low sunlight hours. A power electronic converters are used as interface between the panels and the load and between the batteries and charge (Fig. 1). The addition of a storage battery increases flexibility in system control and enhances the overall availability of the system.

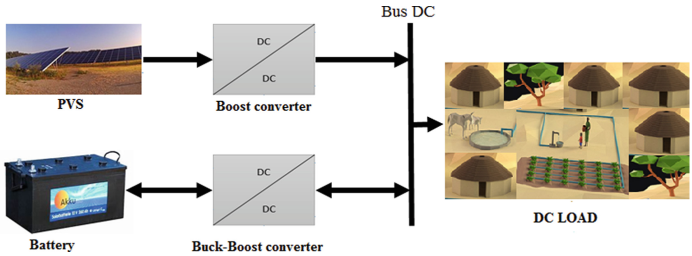


**Fig. 1.** Structure of a hybrid system.

### 2.1 Modeling Panel

In the literature several models have been developed to describe the behavior of a photovoltaic cell. The standard model consists [14,15] of a current source associated with a diode and two resistors modeling the losses. The electrical circuit representing the electrical model of the cell is given in Fig. 2. The mathematical equation linking the current $I_{PV}$ and the voltage $V_{PV}$ of the cell is given by Eq. 1 and represents the mathematical model of the cell.

$$I_{pv} = [I_{cc}\frac{G}{G_0} + k_t(T - T_r)] - I_D - \frac{V_{pv} + R_s I_{pv}}{R_{sh}} \quad (1)$$

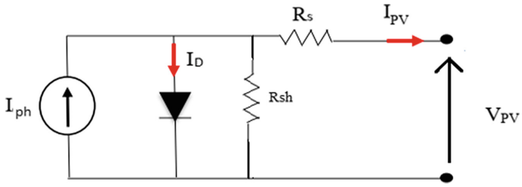


**Fig. 2.** Electric model of a solar cell.

$I_{cc}$ is the short-circuit photo current under standard conditions;

$G_0$ et $T_r$ are the reference illuminance and temperature, respectively;

$k_t = 23.10^{-3} A$ is the short-circuit photo current temperature coefficient. The current and the voltage at the terminal of a cell are low, so we associate multiple cells to obtain sufficient current and voltage to our systems.

### 2.2 Model of the Battery

Several models have been developed in the literature among which there is the simple electric model [3,16,17] or RC (Résistor Capacitor) model that are used. It consists of a fem $E_0$ representing the load voltage of the battery, a capacitor $C$ modeling the internal capacity of the battery and an internal resistance $R_b$. The mathematical equations describing the mathematical model of the battery are its state of charge (SOC) and its charging $V_{chb}$ and discharging voltage $V_{dchb}$ [18]. To protect the battery, it is essential to maintain its state of charge (SOC) between a maximum allowable state $Soc_{max}$ and a minimum state $Soc_{min}$ which must not be exceeded. The Eqs. 2, 3, 4 and 5 give the mathematical model of the battery.

$$Soc(\%) = 100(1 - \frac{I_{bat}}{C_{bat}} t) \tag{2}$$

$$V_{chb} = [2 + 0.16 Soc] + \frac{I_{bat}}{C_{bat}} (\frac{6}{1 + I_{bat}^{0.86}} + \frac{0.48}{(1 - Soc)^{1.2}} + 0.36)[1 + 0.0025 \Delta t] \tag{3}$$

$$V_{dchb} = [2.085 - 2.12(1 - Soc)] + \frac{I_{bat}}{C_{bat}} (\frac{4}{1 + I_{bat}^{1.3}} + \frac{0.27}{(1 - Soc)^{1.5}} + 0.02)[1 - 0.007 \Delta t] \tag{4}$$

$$C_{bat}(Ah) = \frac{P_{load} t}{DOD(\%) V_{bat}} \tag{5}$$

$C_{bat}$ is the battery capacity in Ah which is a function of the power of the load, the charging time $t$, DOD (Depth Of Discharge) and the battery voltage $V_{bat}$ [19].

## 3 Description and System Control Approach

### 3.1 Control Unidirectional Converter

Boost converter is used as an interface between the PVS and the charge and the objective of the control of this converter is to maximize the power output. Several MPPT control techniques have been developed in the literature and in the case of our study we will use an MPPT control based on artificial neural networks for continued maximum power point. We develop a flowchart to implement the ANN controler. The ANN are parallel connected processors where each calculates the single output based on the information it receives. To implement an intelligent command, it is necessary to get a database which is used as learning. In our study we chose the InC to generate this database by varying the profile of sunshine and temperature. The architecture of the neural control consists of an input layer of two (02) neurons corresponding to the current and voltage of the PVS, a hidden layer of fifteen (15) neurons and output layer of one (01) neuron corresponding to the durty cycle. Figure 3 shows the algorithm of the neural control used and from the current and voltage of the panels it provide a duty ratio for controlling the converter.

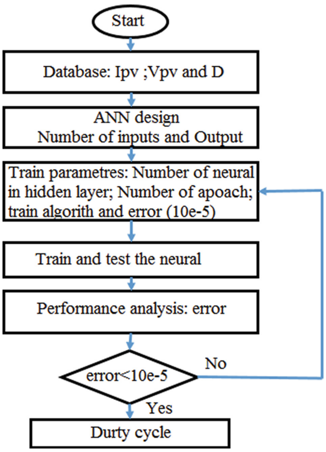


**Fig. 3.** Algorithm neuronal MPPT control.

## 3.2 Bidirectional Converter Model

The buck-boost converter Fig. 4 plays a crucial role in hybrid systems; it allows to charge and discharge the storage unit and maintain the constant DC bus. The operating principle of this converter is based on two modes. When K2 is closed K3 is open, it operates in the boost mode and the output voltage is greater than the intput voltage. When K3 is open and K2 closed, it operates in the buck mode and the output voltage is lower than the input voltage. Equation 6 gives the mathematical model this converter [20,21].

$$\begin{cases} \frac{di_L}{dt} = \frac{V_b}{L_{bb}} - (1-d)\frac{V_{dc}}{L_{bb}} \\ \frac{dv_{dc}}{dt} = (1-d)\frac{I_L}{C_{bb}} - \frac{V_{dc}}{RC_{bb}} \end{cases} \tag{6}$$

Where $V_b$, $C_{bb}$, $L_{bb}$ and d are the voltage of the battery, the output capacitor of the converter, the inductance of the converter and the duty cycle, respectively.

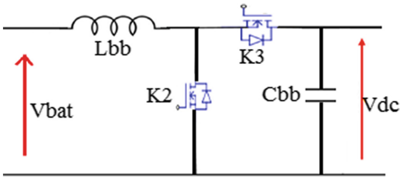


**Fig. 4.** Electrical model of a buck-boost converter.

### 3.3 Regulation of the DC Bus

The DC bus voltage depends on the power produced by PVS, the charging and discharging current of the battery and the load power [22]. To maintain it constant, generally two control loops of voltage and current are used (Fig. 5). The error between the reference voltage and the DC bus voltage is feed to a corrector and the output provides a reference current $I_{ref}$ which is compared with the current of the battery and the error produced is sent to a second corrector which its output is used to control the converter mode in charging or discharging. So when the error between the reference voltage and the the DC voltage is negative the control loop provides a negative reference current and corresponds to the battery charge. If it is positive, it generates positive reference current and corresponds to the battery discharges. Therefore, we will use the PI and PID controller to regulate the voltage and current whose transfer function is given respectively by the following Eqs. 7 and 8.

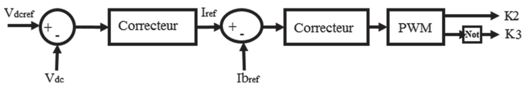


**Fig. 5.** Control loop of the voltage and current.

$$C_{PI}(p) = k_p + \frac{k_i}{p} \tag{7}$$

$$C_{PID}(p) = k_p + \frac{k_i}{p} + K_i p \tag{8}$$

From Eq. 6 the functions are found for each control loop.

$$\frac{v_{dc}(p)}{i_L(p)} = \frac{RI_L L_{bb} p + RV_{dc}(1-D)}{RV_{dc}C_{bb}p + V_{dc} + (1-D)I_L R} \tag{9}$$

$$\frac{i_L(p)}{d(p)} = \frac{RV_{dc}C_{bb}p + V_{dc} + (1-D)I_L R}{RL_{bb}C_{bb}p^2 + L_{bb} + R(1-D)^2} \tag{10}$$

In order to find the parameters of these correctors based on the phase mage method and gain where a system is stable, if the phase margin and gain are successively included between 45° and 60° and of 10 and 15 dB [23,24], we used values presented below (Table 1).

**Table 1.** Correcteur and parametres size.

| Corrector | PI | | PID | | |
|---|---|---|---|---|---|
| Parametres | $k_p$ | $k_i(s^{-1})$ | $k_p$ | $k_i(s^{-1})$ | $k_d(s)$ |
| Valus | 0.5 | 125 | 0.9 | 92.456 | $1.510^{-2}$ |

The main object if of this section is to maintain the voltage bus constant which is influenced by changes in the power of the PVS and the battery.

### 3.4 Control Strategy of the Hybrid System

The main object if is to develop an algorithm (Fig. 6) which can track the maximum power point (MMP) of the PVS and control the charging and discharging of the battery. This control strategy is the combination of a MPPT based on the ANN and a strategy of suppervion in order to protect the battery to the overcharge and deep discharge. This algorithm can be divided into four modes:

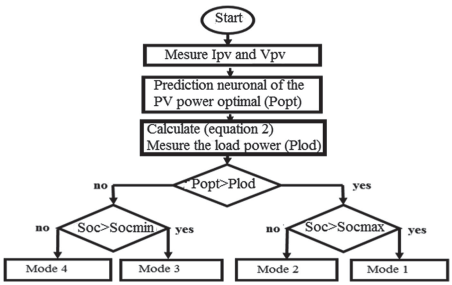


**Fig. 6.** System Control Algorithm.

**Mode 1**: when the power of the photovoltaic system is greater than the power of the load and the battery charge state is greater than equal to the maximum state of charge (85%), (S1 and S2) switch are **ON** and S3 is **OFF** to disconnect the battery and protect it to the overload.

**Mode 2**: when the power of the PVS is greater than the load power and the state of charge is less than the maximum state of charge, (S1, S2 and S3) switch are **ON** and the PVS feed the load and charges the batteries.

**Mode 3**: When the power of the PVS is less than the load power and the state of charge is greater than the maximum state of charge, S1, S2 and S3 are **ON** and the load is feed by the PVS and the battery.

**Mode 4**: when the power of the PVS is less than that of the load and the state of charge is less than the minimum state of charge (20%), switch S1 and S2 are **ON** and S3 is **OFF** to disconnect the battery in order to protect it against the deep discharge. Figure 7 shows the structure of the hybrid system with the approach of the command.

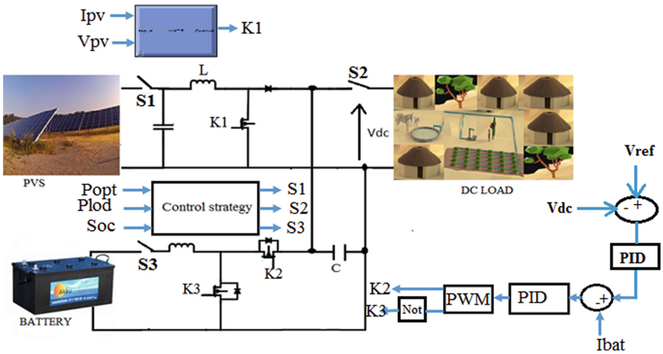


**Fig. 7.** Structure of our system stady.

## 4 Simulation Results and Discussion

The simulation is performed under the environment of Matlab/Simulink and the system consists of a PVS Twenty-seven (27) type of panel 1STH-220-P of (03) strings of (09) modules, an acid type battery set powering a DC load. The equations to design the converters elements are obtained from references [3].

Table 2 provides system parameters and the sizing results (Fig. 8).

**Table 2.** System and simulation Settings.

| Power(W) | $I_{sc}$(A) | $V_{oc}(V)$ | $C_1(F)$ | $C(F)$ | $C_b(Ah)$ |
|---|---|---|---|---|---|
| 218.871 | 7.97 | 36.6 | $150\ 10^{-6}$ | $22\ 10^{-6}$ | 50 |

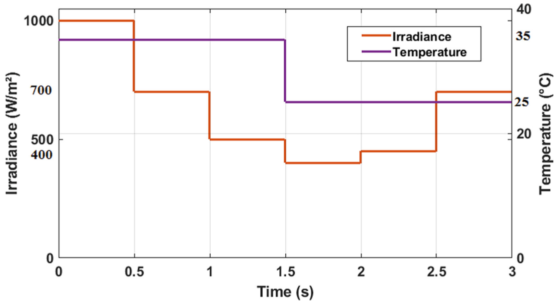


**Fig. 8.** Irradiance $(W/m^2)$ and temperature$(C)$.

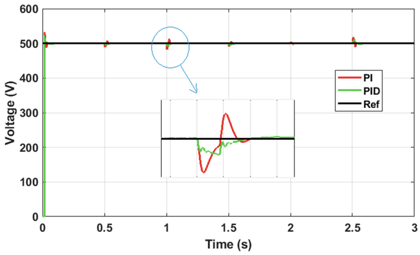


**Fig. 9.** DC bus voltage and the reference.

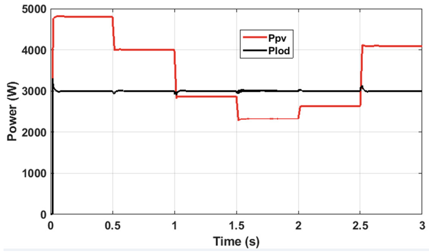


**Fig. 10.** Power PVS and load.

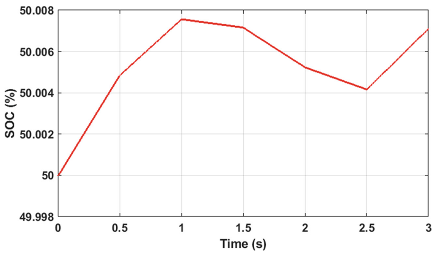


**Fig. 11.** State of charge of the battery.

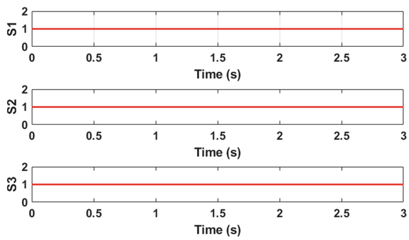


**Fig. 12.** Switchs commutation.

The objective of this study is firstly to maintain constant voltage DC bus and in the other hand to control the battery charge state and improve their lifetime. The Bus DC voltage is influenced by the variation of the voltage of PVS, the charging and discharging current of the battery and the variation of the load. For optimal operation of the system, the load supply voltage must be kept constant. A comparative study of PI and PID controller to maintain constant DC bus voltage is done. Figure 9 shows that the voltage is kept constant with the two correctors. The comparative study shows that the PID controller is better than PI in terms of response time and reduces overshoots (Table 3). The main object of this comparative study is to choose the correector who has fast speed convergence and low oscillations. That's why we choose the

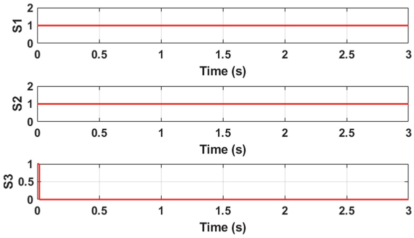


**Fig. 13.** Switchs commmutation.

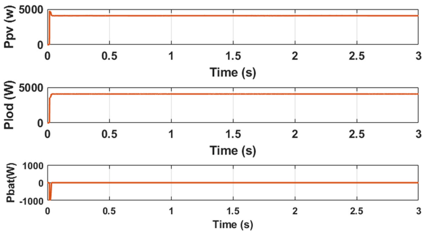


**Fig. 14.** Power variation.

**Table 3.** Comparative stydy.

| Corrector | Reponse time (ms) | Overshoots (%) |
|---|---|---|
| PI | 100 | 44 |
| PID | 60 | 20 |

PID correcteur to maintain constant the DC bus. In Fig. 10, we see that boost converter output power under standard conditions (1000 $W/m^2$ and 25 °C) corresponds to the power of the PVS proving yield optimization with neuronal MPPT control. The current and the voltage of the PVS neuronal command, provides a duty cycle for optimum operation of the boost converter. Figure 11 shows the battery state of charge and it is on mode charge when the power of the PVS is greater than the load power [0 to 1 s]. On mode discharge when the PVS power is less than the load power [1 to 2.5 s]. Figure 12 show the switchs commutation, the battery is connected. And when the power of PVS is greater than the load power, the battery state of charge reaches the maximum or minimum state of charge, S3 is turned off (Fig. 13) to protect battery to the overcharge or deep discharge. Figure 14 shows that the battery is disconnected. The load is powered continuously and the battery charge state is controlled.

## 5 Conclusion

The objective of this study is to disign a new control strategy and power management for a hybrid stand-alone PV/battery feeding a DC load. The bus voltage, kept constant is influenced by the variation of the voltage of PVS and batteries and we note a good performance of PID controller compared to a PI. The developed control strategy combining MPPT control based on ANN and battery charging state control algorithm improves the PVS conversion efficiency and contributes to the protection of the batteries against the phenomena overcharge and deep discharge. We have considered to validate our control strategy by doing a real-life implementation with all the other factors that can impact the performance of the system.

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