Power control and Management of PV/Battery/Diesel/Water Pumping System

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***Abstract*—In this paper, a power management and control strategy is developed for a hybrid energy system that is composed of a photovoltaic generator, a battery bank and a diesel generator. It supplies a water pump system in a remote area. A power management method is designed to manage the power between the mentioned energy systems in order to obtain the desired water flow and to reduce the using of diesel generator. In order to capture the maximum power from PV generator, a fuzzy logic maximum power point tracking controller is applied. On the other hand, a boost converter is controlled by a PI controller to adapt the voltage of the battery bank to the DC bus. A PI controller is used also to regulate the water flow of the pump. The obtained simulation results show that the developed power management and control strategy has high performances. Dynamic modeling and simulation are accomplished using SIMPOWER in Matlab simulink.**

Keywords—photovoltaic generator, diesel generator,battery ,MPPT, energy management.

I. INTRODUCTION

Solar power generation is one of the most promising renewable power generation technologies due to their advantages. The most important domain of application of photovoltaic (PV) installation is the PV pumping system. Researches published in photovoltaic water pumping system were interested essentially either in optimization [1], control [1, 2], or in overall system modeling and simulation. Other researchers developed strategies in order to offer optimum energy management of PV pumping systems [3, 4, and 5]. There are several approaches for the development of management of the energy in renewable energy system, most of them emphasized on hybrid PV/battery system [6, 7]. Often the control and energy management of the PV pumping system is still a challenging field of research which is essential for improving their effectiveness.

To improve the efficiency of the PV system, the implementation of a tracker of the maximum power point is necessary. This is obtained by the inserting a power converter controlled by an MPPT algorithm between the PV generator and the load. A lot of MPPT algorithms have been developed by researches. They are perturbation and observation method P&O [3] fuzzy control method [8].In this paper we apply fuzzy logic controller.

A number of experimental AC and DC motor driven PV pumps are already in use in several parts of the word [1, 3]. A DC motor coupled with a pump is studied in this work. To regulate the flow of the pump a PI controller is used.

In this work, a new operating mode in pumping system is proposed, beside the PV generator and the battery, the diesel engine is used like another source to supply the load when the battery is empty during the night. An energy management algorithm of the overall hybrid system is proposed and is implemented using MATLAB/simpower as a programming tool. The dynamic simulations results are presented with some conclusions given about the global design.

II. MODELING OF THE PROPOSED SYSTEM

The PV/battery/diesel water pumping system considered in this work is shown in Fig.1.It consists of PV generator, battery, diesel engine and a motor pump.

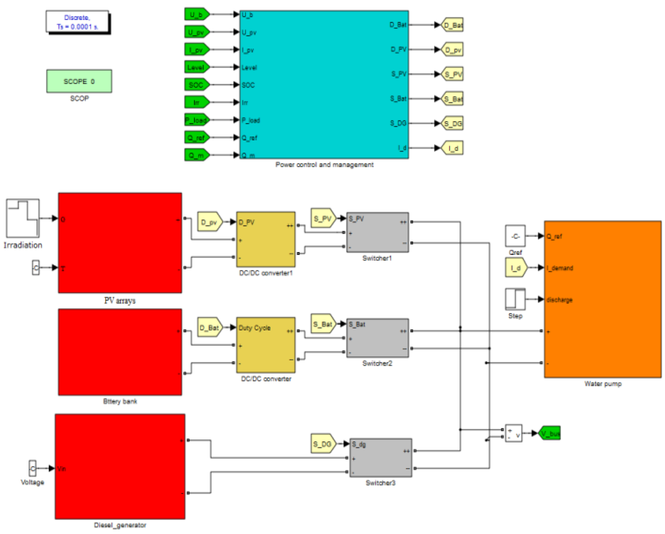

Fig.1.Structure of proposed hybrid system

A. Solar Cell Model

Photovoltaic cell is the most basic generation part in PV system. In the literature several models of the PV cell are found (one diode, two or three diodes). They differ from each other by the number of parameters involved in the calculation of the voltage and current of the PV final.

The model for a single diode is the most cited in the literature consists of a photo current source, a diode, an equivalent parallel resistor and an equivalent series resistor which can be shown in Fig.2.[9]

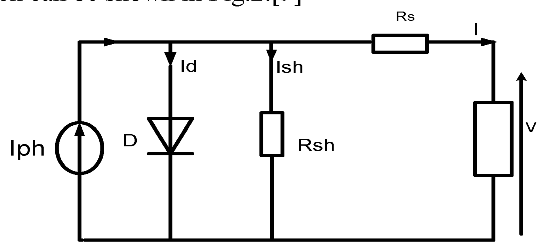

Fig.2.Equivalent circuit of solar cell

So we can mathematically express the current produced by the solar cell as:

$$\mathrm{I} = \mathrm{Ip} - \mathrm{Id} - \mathrm{Ish} \qquad (1)$$

The mathematic relationship for the current and voltage in the single diode equivalent circuit can be described as:

$$\mathrm{I} = \mathrm{Ip} - \mathrm{Is}\left(e^{\frac{q(V+R_sI)}{AkT}} - 1\right) - \frac{V + IR_s}{R_{sh}} \qquad (2)$$

V: The voltage at the terminal of the cell (in volt).
Ip: Light-generated current or photocurrent.
I_{sh}: Cell saturation of dark current.
Id: Diode current.
R_{sh}: Shunt resistance.
R_s: Series resistance.
q: The electron charge$(1.602.10^{-19}c)$.
k : Boltzman constant $(1.38.10^{-23}j/k)$
T: Absolute temperature (in Kelvin).
A: $P - N$ Junction ideality factor.
I_s: Diode saturation curent.

The parameters chosen for modeling corresponds to the PV module are listed in *Tab.1*, when have been used 5modules in parallel and 2 in series to satisfy the system sizing.

TABELE.1CARACTÉRISTICS ELECTRIC PHOTOVOLTAIC MODULE USED

Parameter	Value
Maximum power (P_{max})	$200W$
Voltage at Pmax (V_{mp})	$26.3V$
Current at Pmax (I_{mp})	$7.61A$
Open circuit voltage (V_{oc})	$32.9V$
Short-circuit current (I_{sc})	$8.21A$
Short circuit current/Temperature coefficient(K_i)	$3.18e^{-3}$
Open circuit voltage/Temperature coefficient (K_v)	-0.123
No. of cells	54

The power of PV array is varied by the variation of the voltage, MPPT strategy can make production of power in maximum point through controlled of PV array voltage, this control achieved by DC/DC converter. In this paper, we use fuzzy logic method to obtain the maximum power point illustrated below.

B. Battery Bank Model

The battery is modeled by using the generic battery model implemented in simpower system. In essence, the model established a mathematical relation among the battery voltage, the battery capacity, the output current and the dynamic of the charging and discharging process. This relationship is different depending on the type of the battery .In this case; nickel metal hybrid model is implemented.

For the battery, The DC/DC boost converter is used to regulate the voltage. The DC/DC converter adapts the low voltage of the battery $200\,V$ to the DC bus at a voltage of $500\,V$.

C. Diesel Generator

The diesel generator is a reliable source of power that can provide power whenever it is needed, the diesel generator is used when the PV power is not enough to satisfy the load demand and the state of charge of the battery bank is less than the minimum value of the energy storage. In this paper the diesel generator and its devices are assumed as a DC voltage source.

D. Motor pump Modeling

Many different varieties of pumps are used with PV-pumping system. In our case, we use the model that expresses the water flow output (Q) directly as a function of the electrical power input (P_{elec}) to the motor pump. The hydraulic power is defined as [1]:

$$Ph = \rho g h Q \qquad (3)$$

The equation of mechanical power is:

$$P_{mec} = \frac{Ph}{\eta_{mec}} \qquad (4)$$

And the electrical power:

$$P_{elec} = \frac{Pmec}{\eta_{elec}} \qquad (5)$$

To regulate the water flow in the tank a PI regulator is applied. The parameters chosen for modeling the motopump are listed in *Tab.2.*

TABLE.2 MOTOPUMP PARAMETERS

Parameter	Value
Density(ρ)	1000
Gravity((g)	$9.81\ m/s^2$
Height((h)	$12m$
Voltage(V)	$800V$
Tank volume(V)	$70\ m^3$
Nominal flow(Q_{ref})	$25m^3/h$
mechanic efficiency (η_{mec})	55%
electric efficiency(η_{elec})	85%

III. MPPT FUZZY LOGIC CONTROLLER

The proposed fuzzy logic based MPPT controller has two inputs are error (E)and change in error(DE) and one output, change in duty cycle D. The input variables are defined by:

$$Error\ E = \frac{P(k)-P(k-1)}{V(k)-V(k-1)} \quad (6)$$

$$change\ in\ Error, DE = E(k) - E(k-1) \quad (7)$$

Where $P(k)$and $V(k)$is the instant power and voltage of the boost converter. The input and output variables are converted into linguistic variables. In this case, five fuzzy subsets, NB(Negative Big), NS(NegativeSmall), EZ(Equal Zero), PB (Positive Big), PS(Positive Small) have been chosen. Member ship function used for the input variables and output variables are shown in Fig.3 (a), Fig.3 (b) and Fig.3(c).

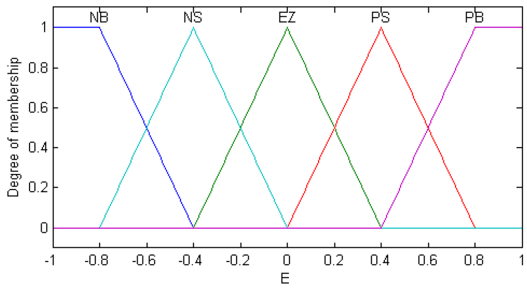

Fig.3 (a) Member Ship Function For E

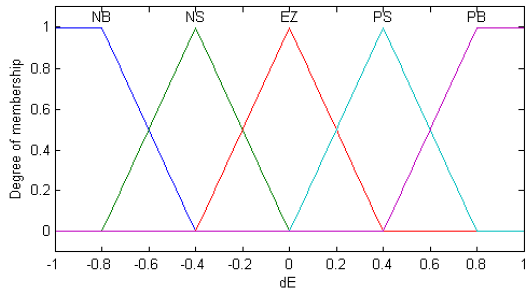

Fig.3 (b) Member Ship Function For dE

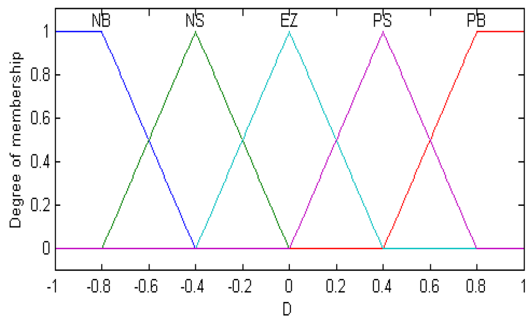

Fig. 3(c) Member Ship Function For D

A fuzzy rule base is formulated for the present application and is given in *Tab.4*. The fuzzy inference of the FLC is based on the Mamdani's method which is associated with the max-min composition. [10]

TABELE.4RULE BASE

E/DE	***NB***	***NS***	***EZ***	***PS***	***PB***
NB	*PS*	*PS*	*PB*	*PB*	*PB*
NS	*PS*	*PS*	*PS*	*PB*	*PB*
EZ	*NS*	*EZ*	*EZ*	*EZ*	*PS*
PS	*NS*	*NS*	*NS*	*NB*	*NB*
PB	*NS*	*NS*	*NB*	*NB*	*NB*

IV. THE ENERGY MANAGEMENT STRATEGY OF THE HYBRID SYSTEM

In order to decide the operating point for each component of the hybrid system, we take into account the SOC of the battery, the level of the water in the tank V, the irradiation Irr and the difference between the load power and the irradiation$E$. Then the energy required by the system is higher than that delivered by the photovoltaic arrays($E > 0.5$), the battery will supplement this lack. If the battery is empty, the lack of power will be assured by the diesel generator. When the energy required by the system is lower than that required by the photovoltaic arrays, or if the tank is full, then the energy not used by the load is stored in the battery, in this case the diesel generator is off. The developed algorithm can be described in Fig.4

I. SIMULATIONS RESULTS

Based on the above models and control methods, photovoltaic pumping system with regulation of the water level are modeled and simulated in MATLAB/simpower. To test the behavior of the system, we used an irradiance profile illustrated in Fig.5 and we keep the temperature constant at $25°C$. . The DC voltage is illustrated in Fig.6.

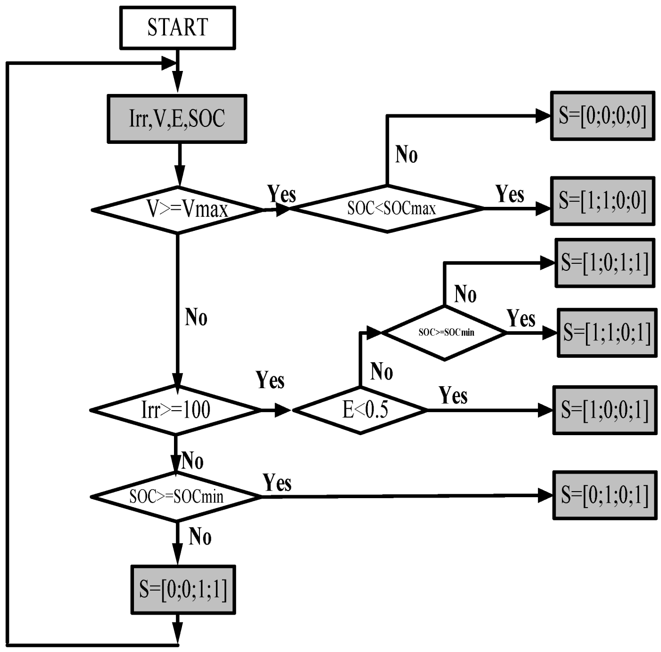

Fig.4. block diagram of the implemented energy management system

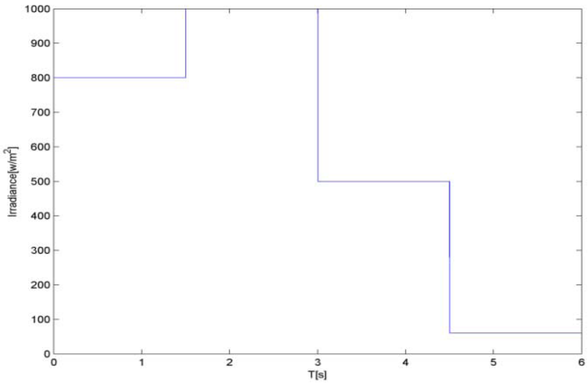

Fig.5.Solar irradiance

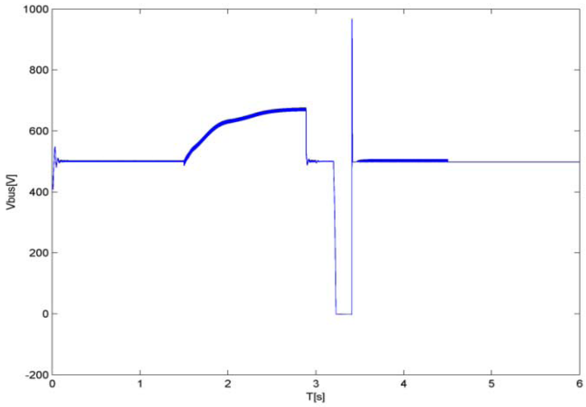

Fig.6.Bus voltage

- From $0s$ to $1.5s$:

During this period the irradiance is equal to $800w/m^2$, the PV generator produce the power according to the irradiance with MPPT mode, the tank is not full (Fig.8.), then the load is connected $S\_load = 1$ as shown in Fig.15.The difference between the load power and the pv power is higher than 0.5. In this case, the battery is in discharge mode (Fig.7.) to compensate the lack of power.

- From $1.5s$ to $2.88s$:

In this period, the Error $E < 0.5$ (Fig.12), it means that there is an excess of PV power, in this case, it's not necessary to use the battery, then the PV supplies directly the load.

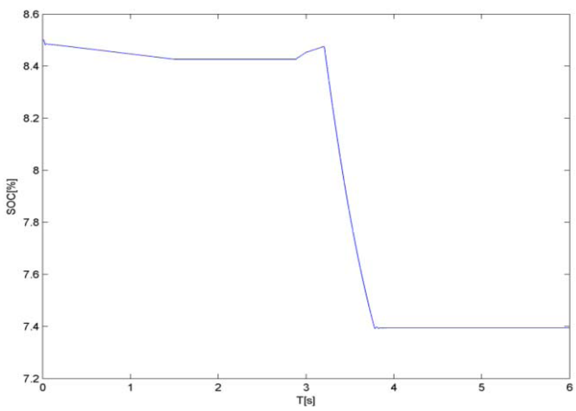

Fig.7.battery state of charge

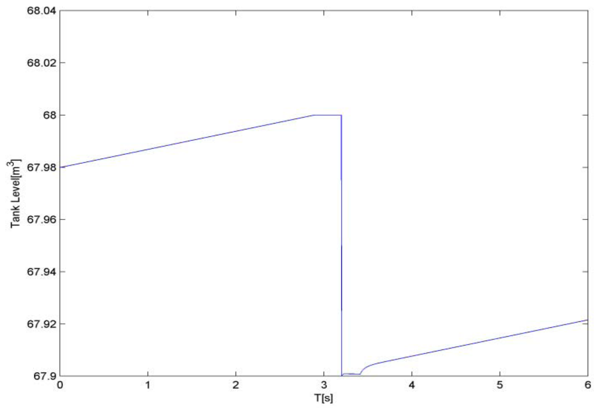

Fig.8.Tank Level

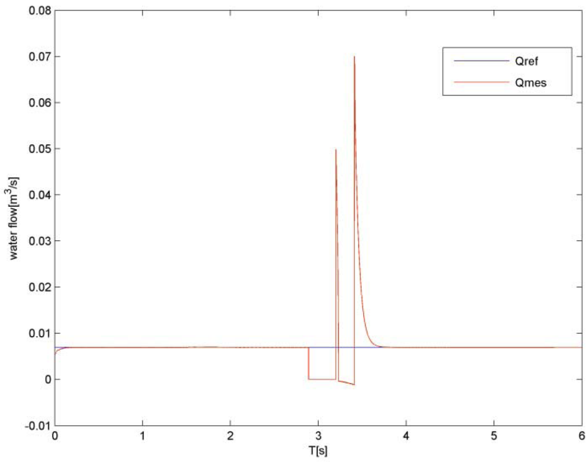

Fig.9.Reference and measured water flow

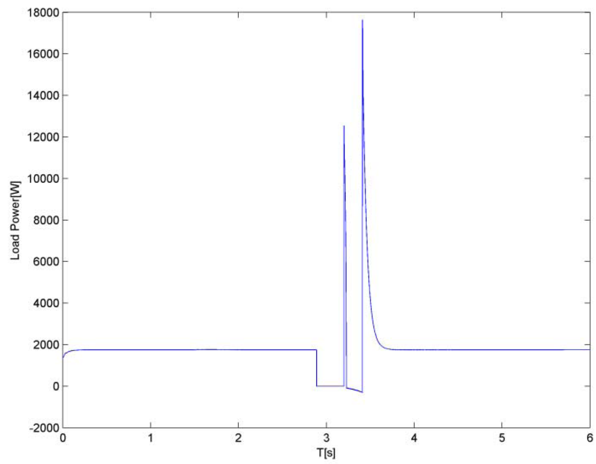

Fig.10.Load power demand

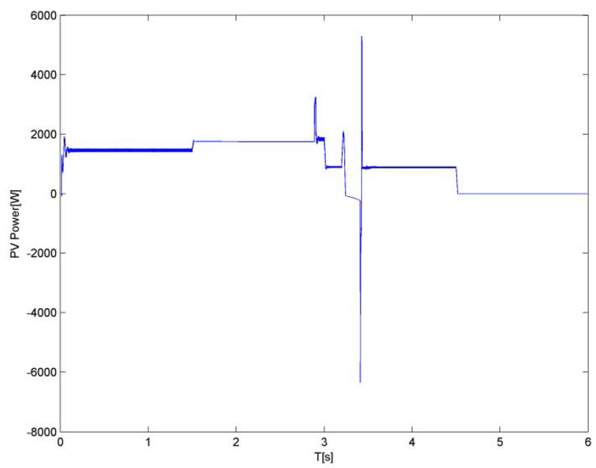

Fig.11.Photovoltaic power

- From 2.88s to 3.2s:

The battery is in charging mode, the tank is full, the load is disconnected, and the power delivered by the PV generator is used to charge the battery. In this case the diesel engine is off. After 3.2s, we carry out a discharge of the water flow, the tank level decrease, in this instance, the power delivered by the PV generator is not satisfactory to the load, this is why the battery is in discharging mode as shown in the Fig.(7).

- From 3.4 to 4.5s:

The power delivered by the PV generator is satisfactory to the load; the PV system supplies the load.

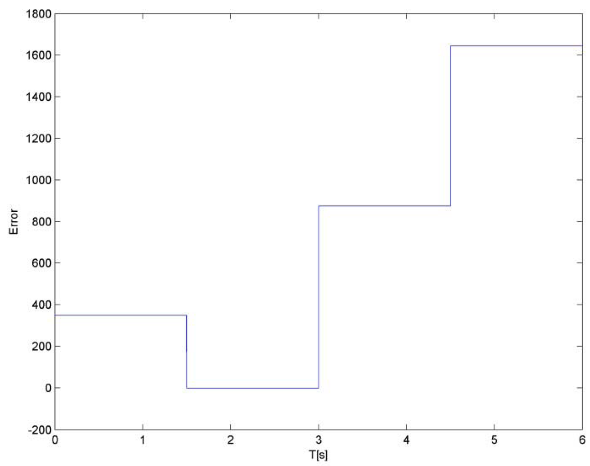

Fig.12.Load power and photovoltaic power difference

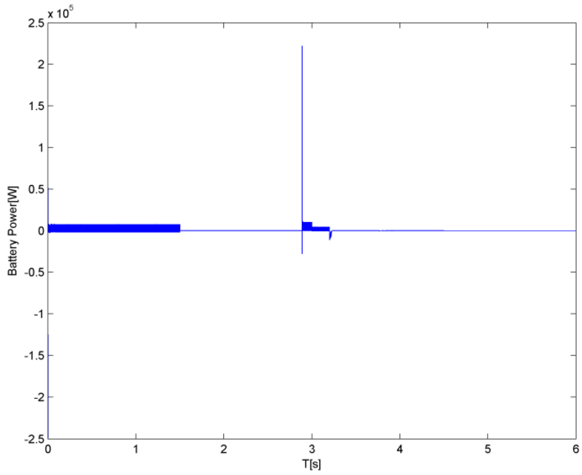

Fig.13.Battery power

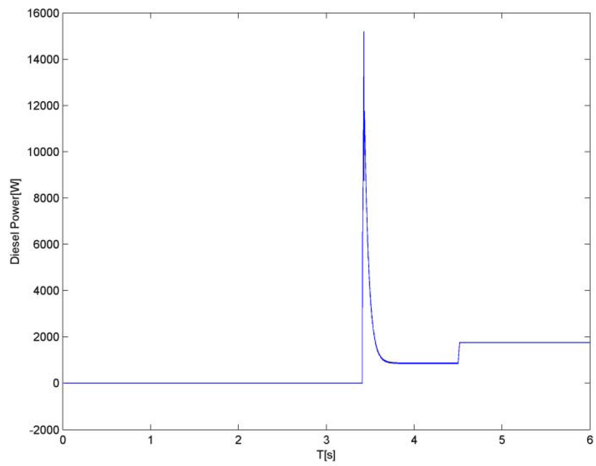

Fig.14.Diesel power

- From 4.5 to 6s:

The tank level is not in its maximum, the PV generator doesn't delivered the power demand by the load as shown the Fig .10, and Fig.11, the PV power converges to zero, the state of charge of the battery is low, in this case to satisfy the power load demand it's obligatory to use the diesel generator, the switch of the diesel engine is set to 1 (Fig.18).

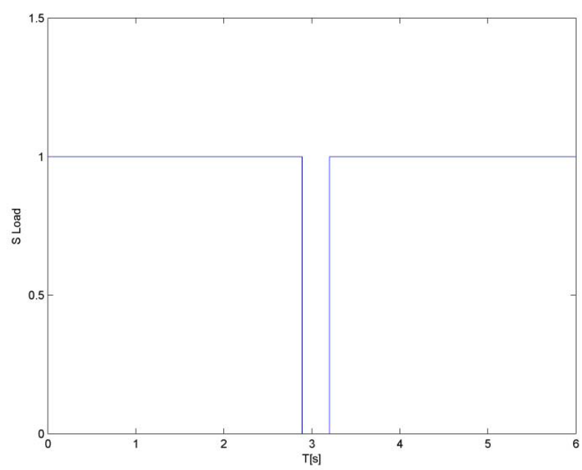

Fig.15.Load switcher variation

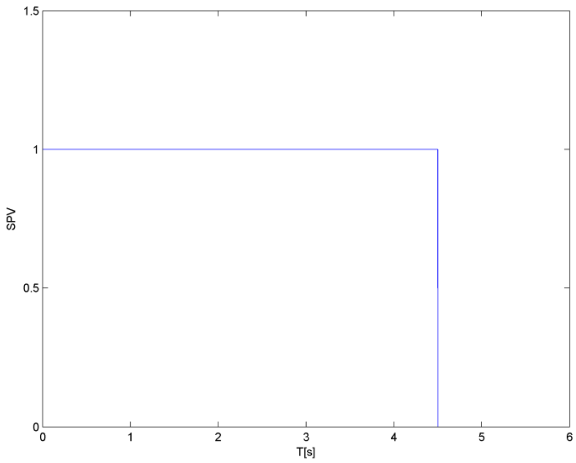

Fig.16.PV switcher variation

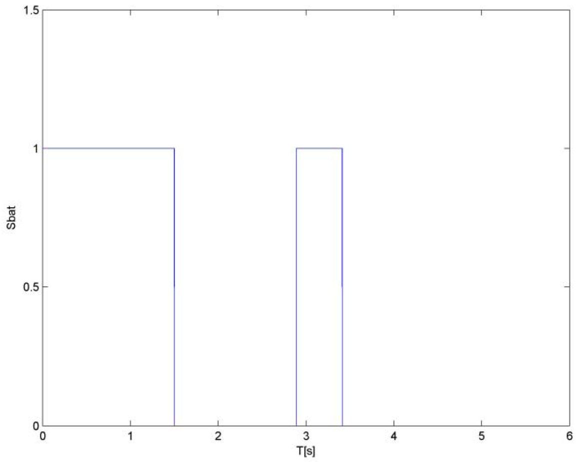

Fig.17.Battery switcher variation

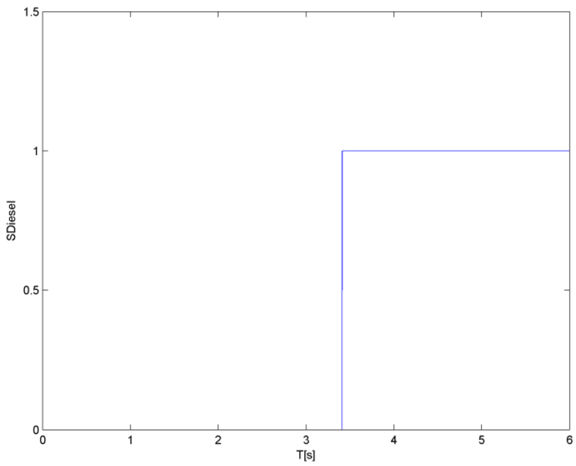

Fig.18.Diesel Switcher variation

CONCLUSION

An energy control and management algorithm devoted for pv/battery/diesel water pumping system has been presented in this article. The algorithm is based on a strategy that deals with several parameters able not only to obtain the water level but also ensure its regulation and store the excess energy in the battery when the tank is full. The simulations results show the effectiveness of this approach in terms of the energy management by the control of the different switches and the battery state of charge (SOC). A desired water flow rate is obtained and a secure tank level is maintained.

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