Increase Efficiency of Photovoltaic Pumping System Based BLDC Motor Using Fuzzy Logic MPPT Control

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Abstract: - The aim of this paper is presentation of an approach for modeling , control and optimization of a photovoltaic pumping system which contains a PV generator , DC-DC boost converter, MPPT controller, DC-AC inverter and a BLDC motor. We use an intelligent control method for searching the maximum power point (MPP). This method uses a fuzzy logic controller applied to a drive a DC–DC converter to an optimal operating point using PV panel's measured variables. The PWM signals are generated by the interaction of the motor speed closed-loop system and the current hysteresis. The motor reference current is compared with the motor speed feedback signal. The considered model has been implemented in Matlab /simulink environment. The results show the effectiveness of the proposed method under variation irradiation ,in order to increase the performance of the water pumping system.

Key-Words: - *Pumping system, photovoltaic, MPPT, BLDC, Fuzzy logic, Optimization*

1 Introduction

Solar energy is the most important, most effective and least expensive over other renewable energy source.

Solar energy conversion can be achieved using either by thermal or photovoltaic effects. Many applications can use such renewable source of energy such as: water pumping, air conditioning, light sources electric vehicles, refrigeration systems. Standalone photovoltaic (PV) systems [1] are widely used in military and space applications, [1,2].

The evolution of life has been possible thanks to the presence of water. Using photovoltaic generators to operate the water pumps is now a technology in development that is characterized by gradual decrease in cost. Since the first installation of photovoltaic pumping system in the late seventies, these systems provide human domestic needs, livestock and irrigation water in rural areas, and have gained considerable acceptance in terms of reliability and performance and today they are considered to be the most significant applications of photovoltaic energy conversion.

With development of technology many algorithm based artificial intelligence like genetic algorithm[33] and fuzzy logic [34] , fuzzy logic is an intelligent control method that has been used recently for improving the efficiency of PV installations by giving the maximum power point tracking (MPPT) algorithm the ability to track effectively the maximum power point of a photovoltaic system under variable irradiation conditions.

In this paper, an intelligent control technique using fuzzy logic control is associated to an MPPT controller in order to improve energy conversion efficiency of a PV standalone water pumping system

2 DESIGN OF PUMPING SYSTEM

The following figure describes elements constituting the water pumping system figure 1.

2.1 PV array

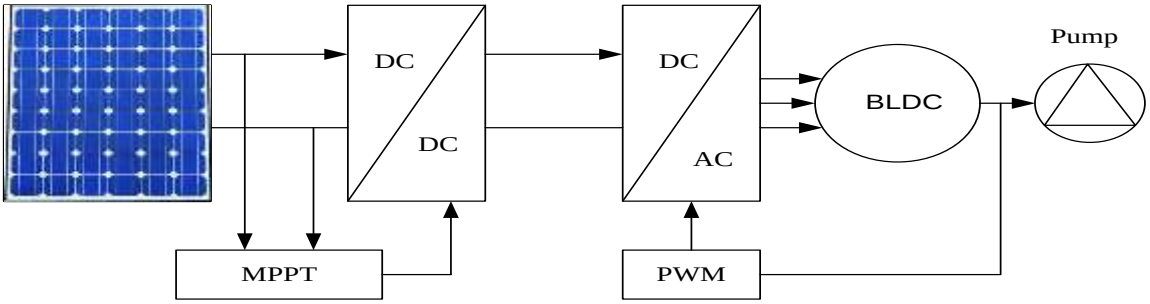

Fig. 1 Block diagram of the BLDC water pumping system

This is the most important element since it provides the electric power needed from the water pumping system; we chose the PV panel Kyocera 200 GT [3].

2.1.1 Characteristic of PV module under uniform insolation

For modeling of PV generator, the cited mode in [4,5] is used, it's based on diode equivalent circuit of PV cell figure 2 , the aim of modeling is characterization of used PV module and knowledge of maximum operating point of this module in different conditions climate such as solar irradiation daily and temperature.

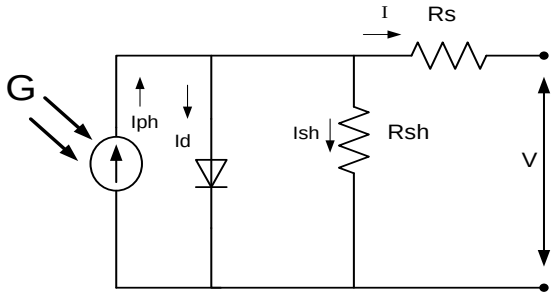

Fig. 2 Block of equivalent circuit of PV cell

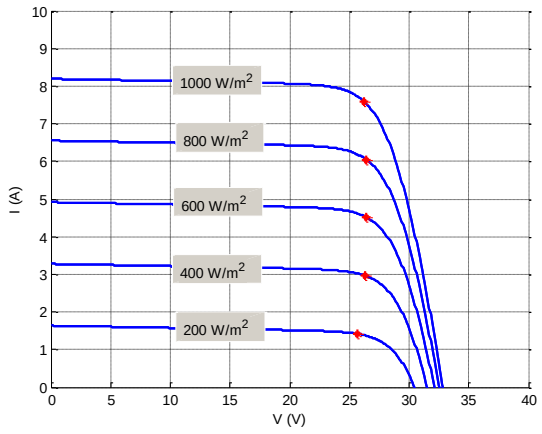

Fig. 3 Current VS Voltage Characteristic (T=25°c)

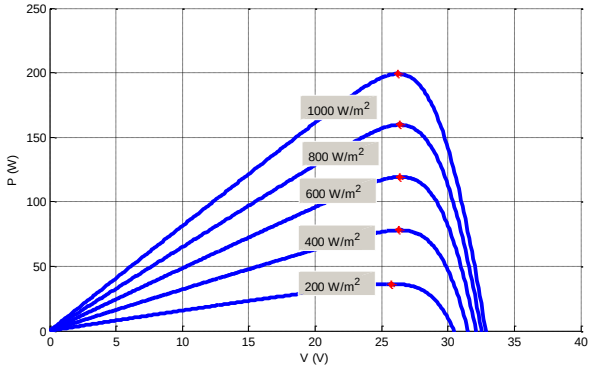

Fig. 4 Power VS Voltage Characteristic curve (T=25°c)

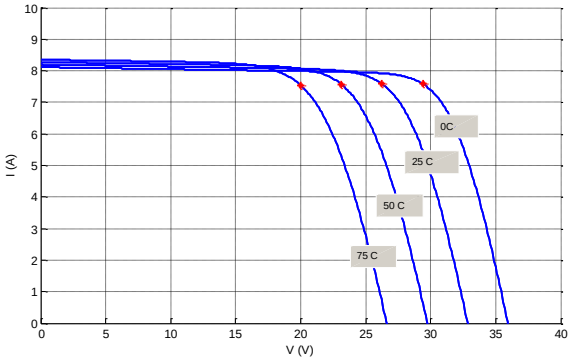

Fig. 5 Current VS Voltage Characteristic curve (G=1000W/m^2)

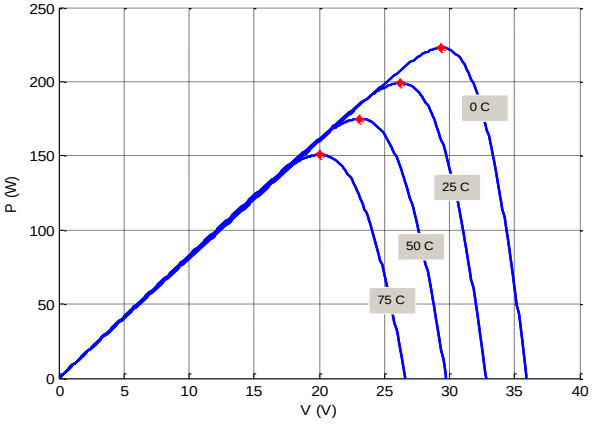

Fig. 6 Power VS Voltage Characteristic curve (G=1000W/m^2)

The figures (3,4,5,6) represents the I-V & P-V characteristics and PV module reflecting the influence of various insolation fig(3,4) and temperature fig(5,6), the module current is proportional to the received sunlight, while the open-circuit voltage changes slightly with the sunlight, optimum power is also proportional to the solar irradiation .

Temperature is important parameter for operation of PV cells, their change produce change of open circuit voltage, their increase create decrease of maximum power point of PV module.

2.1.2 Characteristic of PV module under partial shading condition:

In this subsection we study the effects of partial shading on the operation of PV panels, authors in [6] has define the phenomenon of partial shading as a major cause of reducing energy yield in a large solar photovoltaic array , and may be due to due to tree leaves falling over it, birds or bird litters on the array, shade of a neigh boring construction, passing clouds etc.

By another way under partial shading condition some parts of PV array does not receive uniform insolation, and for PV module is considered to be shaded if three or more of its cells are receiving lower than normal insolation [7].

The shaded modules behave as a load instead of generator, which produces the hot spot problem, This problem (hot spot) can be avoided by driving the current of non-shaded PV modules through the bypass diode [8]. A partially shaded module can be modeled by two groups of PV cells connected in series inside a module Figure (7) [9].

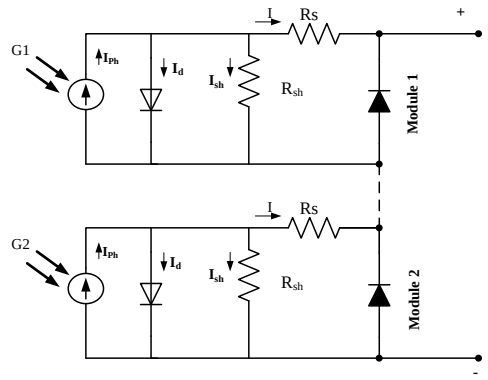

Fig. 7 Circuit diagram of partial shaded modules.

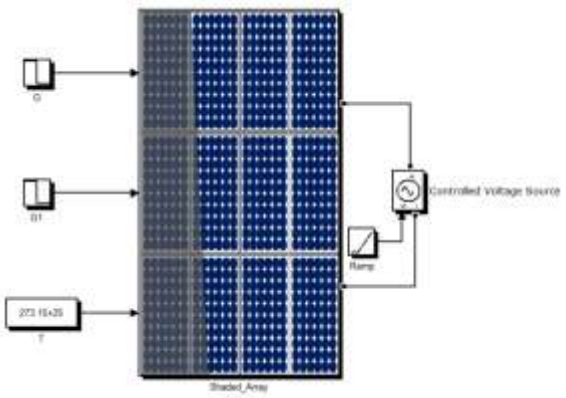

Fig. 8 Simulink Block of partially shaded Array .

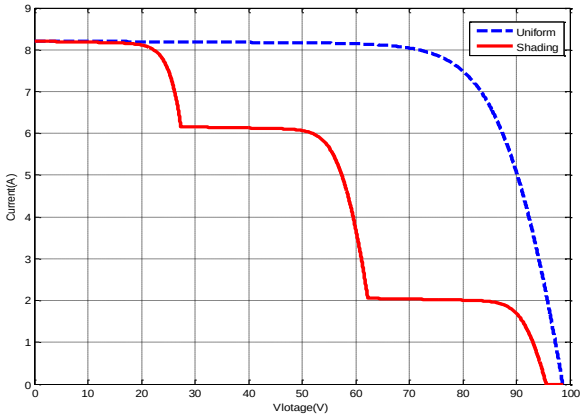

Fig. 9 Comparison between I-V curve uniform and partially shaded PV array .

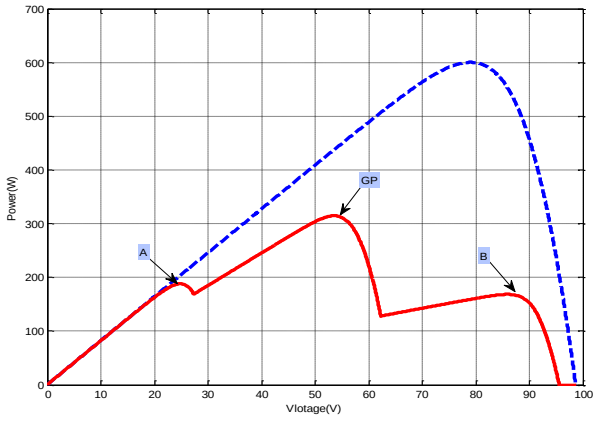

Fig. 10 Comparison between P-V curve uniform and partially shaded PV array

Figure (8) present subsystem block of simulation of partially shaded array ,this last contain 3 module recorded in series , the results of simulation ,figures (9,10) show reduction of power delivered by PV array if it compared with same array under uniform insolation .

2.2 DC-DC boost converter

There are various topologies of DC-DC converter buck , boost ,and buck-boost , Buck converter is usually used for charging batteries and water pumping systems [10,11], The boost topology is used for stepping up the voltage. the Boost converter has higher energy efficiency than the Buck converter

We used a boost DC-DC converter in this system Fig .11. It consists of a boost inductor, controlled switch, diode and a filtering capacitor [4].it's present some advantage can obtain a higher energy efficiency than for the case if the MPPT would be based on the Buck converter, and it's input current continuous [11,12].

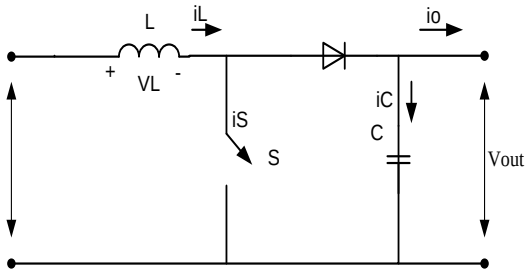

Fig. 11 Boost converter

2.3 Search of the maximum power point tracking (MPPT)

Many method have been proposed to track the maximum power point such as Perturb & Observe (P&O) method, Incremental Conductance (IncCond) algorithm, artificial neural network (ANN)[18] , Parasitic Capacitance, Voltage Based Peak Power Tracking, Current Based peak power Tracking & sliding mode [13,14,23]. Perturb and observe have many advantages like, simplicity, easy to implement and less acquired parameters, have simple structure [13,14,15], its main disadvantage being the oscillation of the operating point around the maximum power point [13,14]. To solve this problem we propose using a fuzzy logic based control algorithm.

2.3.1 Classification of MPPT methods

Author in [16] classify MPPT Algorithms three categories ,the first based voltage and second based current and the last based duty cycle of DC-DC converter ,the two categories characterized by his approximates duty cycle constant and the resulting real maximum power can be losses .,the third category treated by [17] and determine his effectiveness under rapidly changing insolation .

Author in [19] also classify MPPT to three category, Offline MPPT methods ,it's based physical characterization of PV panels, like MPPT based open circuit voltage and short circuit current method.

The uses of fuzzy logic present several advantages, not required a mathematical model of the system [20,21], eliminates their drawbacks of conventional MPPT such Slow converging, oscillation in steady-state condition, During cloudy days when the irradiance varies quickly the operating point moves away from the maximum optimum point. [22]

Fuzzy logic was introduced in 1965 with the work of L .Zadeh [24]. He has formalized the representation and the processing of knowledge with imprecise or approximate variables to solve high complexity systems.

The objective of the fuzzy logic control method is to track the maximum power point of a photovoltaic generator for different irradiations. The maximum power that corresponds to the optimal operating point is determined for different level of irradiation.

2.4 MPPT fuzzy controller design

MPPT fuzzy controller was designed and simulated using the Simulink Fuzzy Logic Simulink Toolbox represented in (Fig. 12,14):

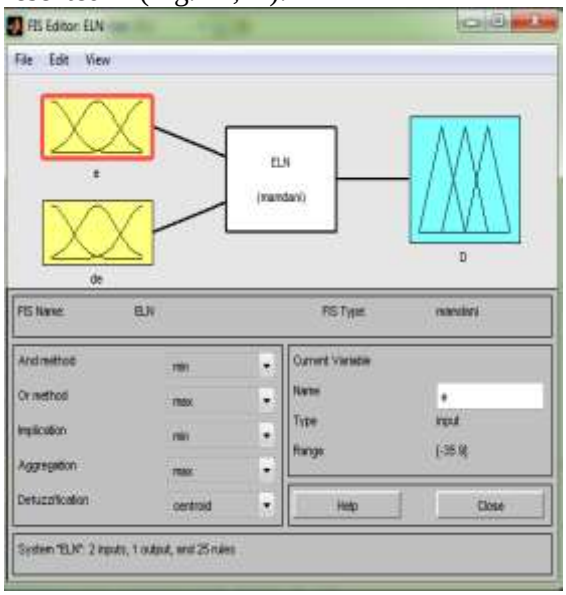

Fig. 12 General diagram of fuzzy controller MPPT MATLAB

A Fuzzy Logic Controller (FLC) consists of three blocks (Fig.13):

- Fuzzification.
- Inference.
- Defuzzification.

2.4.1 Fuzzification

The variable E and CE are expressed as follows:

$$E(k)=\frac{P_{ph}(k)-P_{ph}(k-1)}{i_{ph}(k)-i_{ph}(k-1)} \quad (1)$$

$$dE(k)=E(k)-E(k-1) \quad (2)$$

where Pph(k) and Iph(k) are the power and current of the PV array, respectively.

Therefore, E(k) is zero at the maximum power point of a PV array.

The input E(k) shows if the operating point of the load is situated to the left or right of the maximum power point of the PV curve. If this value is positive, then the operating point is to the left of MPP, otherwise, the operating point is to the right of MPP. The second input variable dE(k) shows the direction and allows us to estimate the speed of convergence to the point MPP operating point.

Knowing these two inputs we can decide what will be the change we must impose to the duty cycle given to a boost chopper. To increase the voltage operating point, D must be increased and vice versa.

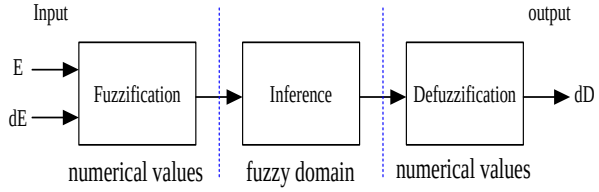

Fig. 13 Basic structure of the fuzzy controller MPPT

2.4.2 Inference:

The used inference method is "Mamdani", that is the most commonly used inference method. It uses the MIN operation for the "AND" operator and MAX for the "OR". Inference rules can make the right decision for output to dD from the values of the inputs E and dE. In our work we chose the rules presented in the (Table 1): variable E and dE are expressed as follows:

2.4.3 Defuzzification

Generally There are 2 methods of defuzzification, The defuzzification method used in this work is the FLC center of gravity.

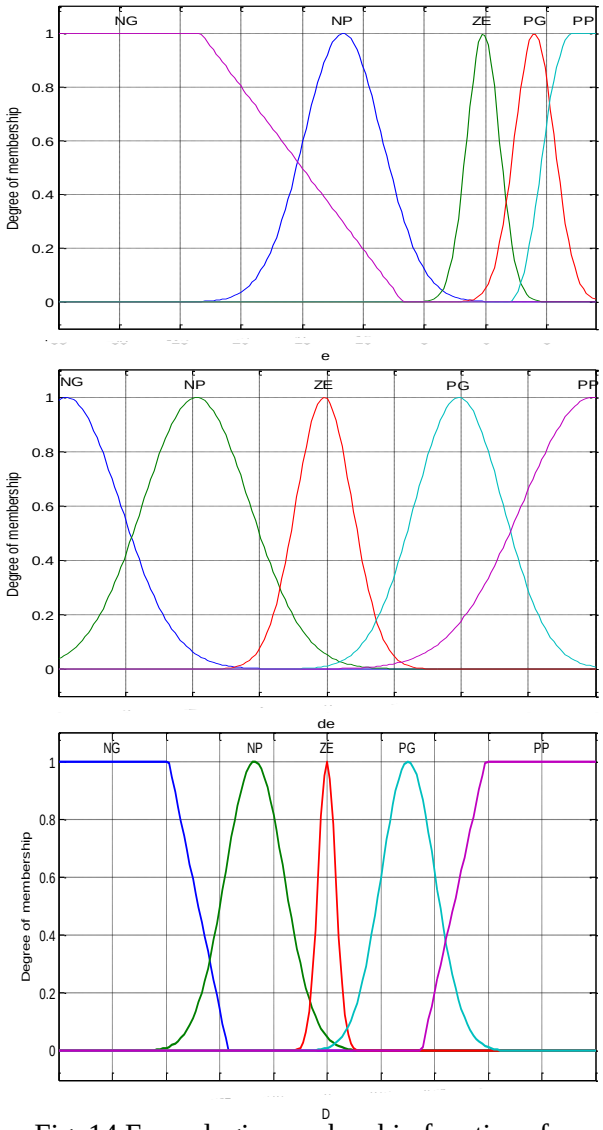

Fig. 14 Fuzzy logic membership functions for inputs and output variables

2.5 Inverter

The inverter provides three-phase system voltages variable in amplitude and frequency to operate with variable loads and frequency (from 0.1 up to 1 time the rated frequency) [25]. The current is modulated sinusoidally to obtain a high efficiency. The pulse frequency is maximal 2kHz. The phase voltage can be expressed as follows [25]:

$$\begin{bmatrix} Van \\ Vbn \\ Vcn \end{bmatrix} = \frac{E}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\begin{bmatrix} C1 \\ C2 \\ C3 \end{bmatrix} \quad (3)$$

2.6 BLDC

Many types of electrical motor have been used to entrain water pump, brushed DC motor is used in [26, 10, 27], this type figure15 present many

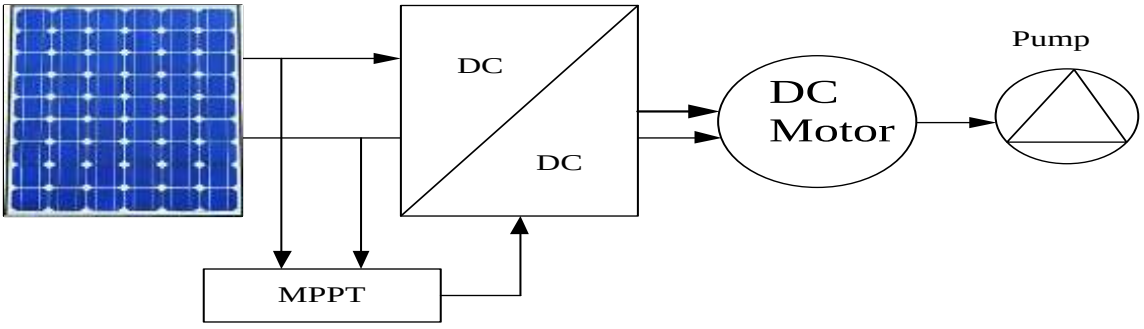

Fig. 15 Block diagram of the D.C water pump

advantage, pumping system based brushed DC motor is the simplest because water pump is coupled directly with DC–DC converter but it has some disadvantages like difficulty of entertain DC Motor faults, induction motor is more robust and less expensive motor [28] the structure of photovoltaic pumping system based three phase induction motor presented in figure 16 .

The Brushless DC (BLDC) motors present many advantage like having better mechanical characteristics, high efficiency, high dynamic response, small size construction [29]. In the last decade, brushless dc motors have begun to replace brushed dc motors and induction motors for small scale pumping applications [31].

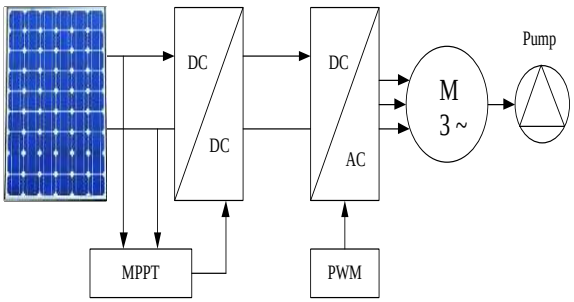

Fig. 16 Block diagram of the A.C water pumping system

To simulate the BLDC, we have selected the three phase's model. It is defined in [30] by the following equations of stator and rotor voltages:

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} R_a & 0 & 0 \\ 0 & R_b & 0 \\ 0 & 0 & R_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L_a & M_{ab} & M_{ac} \\ M_{ba} & L_b & M_{bc} \\ M_{ca} & M_{cb} & L_c \end{bmatrix} P \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} + U_n \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \quad (4)$$

Where

u_a, u_b, u_c : Stator winding phase voltage (V)

R_a, R_b, R_c : Stator winding resistance (Q);

i_a, i_b, i_c : Stator winding phase current (A);

e_a, e_b, e_c : Stator winding back EMF (V);

L_a, L_b, L_c : Self-inductance (H);

M_{ab}, M_{ac}, M_{cb} : Mutual-inductor (H);

Equation (4) can be written as:

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} P \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} + U_n \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \quad (5)$$

$$T_e = \frac{1}{w}(e_a i_a + e_b i_b + e_c i_c) \quad (6)$$

The expression of electromagnetic torque produced by the stator windings is

$$J \frac{dw}{dt} = T_e - T_L - Bw \quad (7)$$

Where:

Te: magnetic torque (N.m)

T_L: load torque (N.m)

B: damping factor (N.m.s/rad) ;

w: motor speed (rad / s)

J: motor moment of inertia (kg/m).

2.7 Centrifugal pump model

The centrifugal pump applies a load torque proportional to the square of the rotational speed of the motor[25].

Centrifugal pump is the most commonly employed type of pumps [32, 10], it has a relatively high efficiency, and it is capable of pumping a high volume of water [10].

The performances (Q ', H' and P ') are given in terms of the speed using the following relationships:

Fig. 18 boost converter output voltage

$$Q' = Q\frac{\omega'}{\omega} \quad (9)$$

$$H' = H(\frac{\omega'}{\omega})^2 \quad (10)$$

$$P' = P(\frac{\omega'}{\omega})^3 \quad (11)$$

3 Analysis of Results

Fig. 18 show that output voltage DC/DC Boost converter we note that the system follows the variations of irradiation figure15. The curve contain Two variation two variation from 200w/m^2 to 600 w/m^2 and 600 w/m^2 to 1000 w/m^2

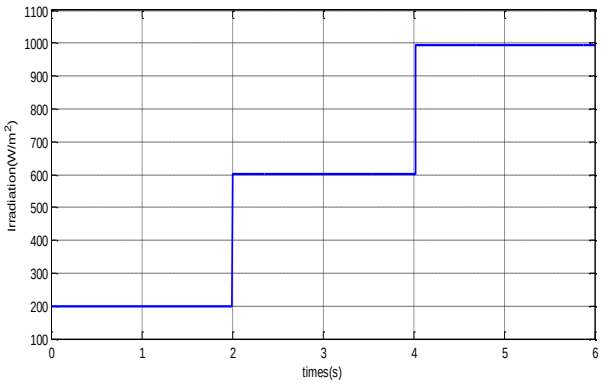

Fig. 17 variation of insolation

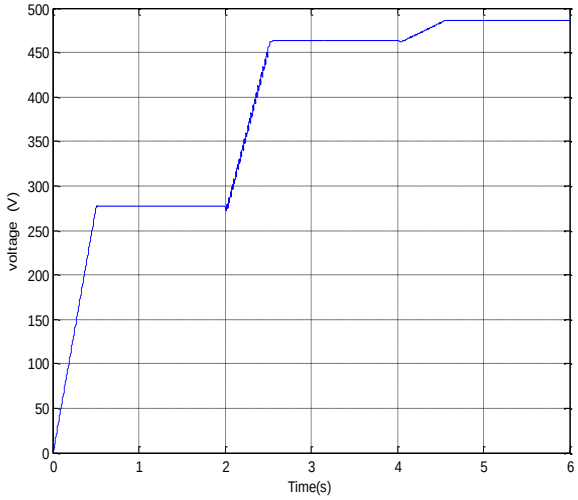

Fig. 18 boost converter output voltage

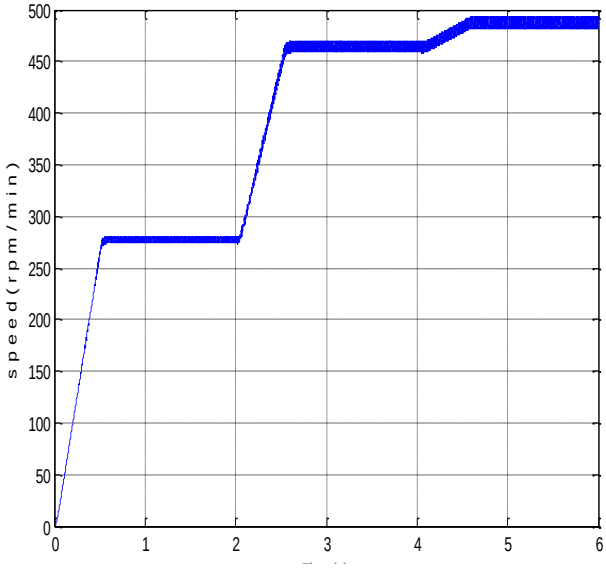

Fig. 19 Rotor speed Wm (rad/s)

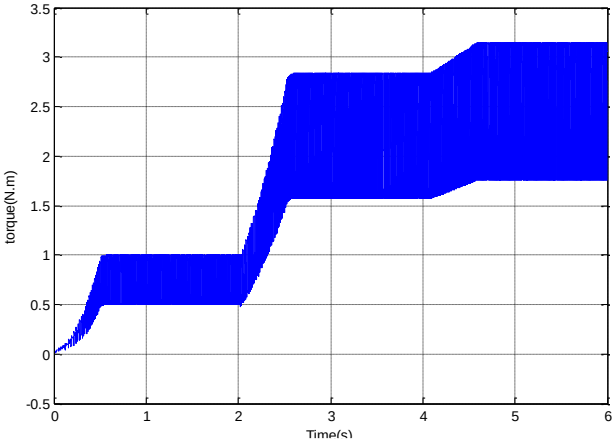

Fig.20 Electromagnetic torque Te (N*m)

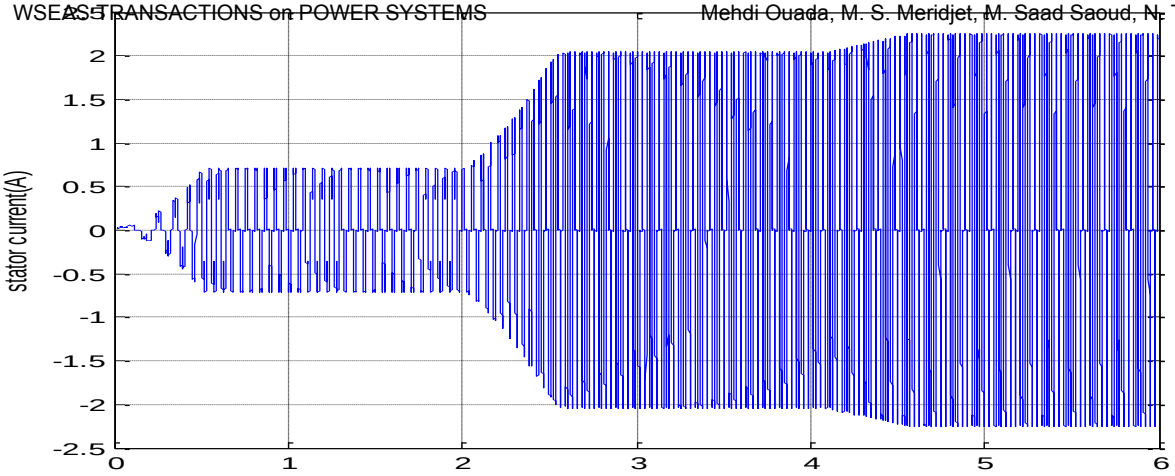

Fig. 21 Stator current phase a (A)

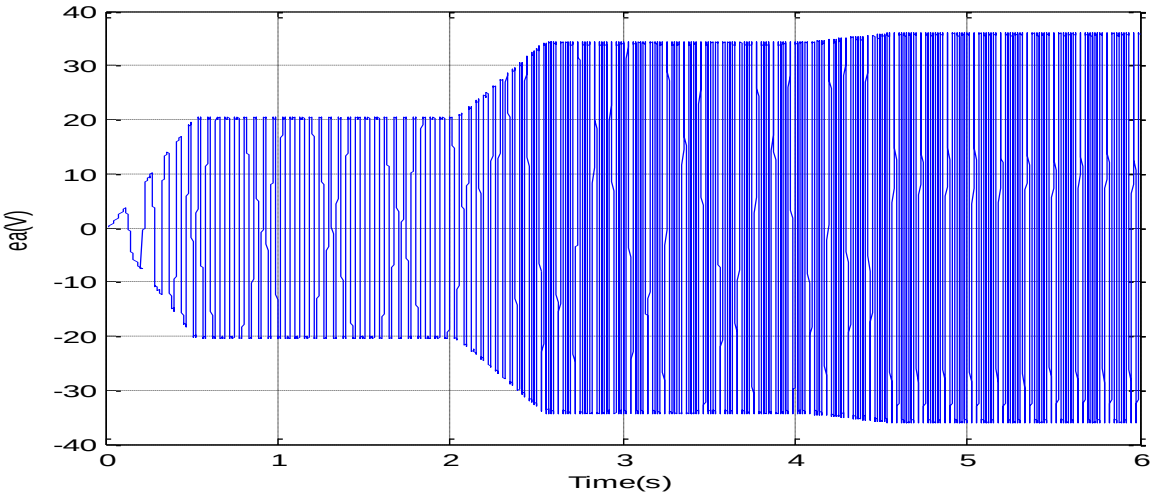

Fig.22 Stator back EMF e_a (V)

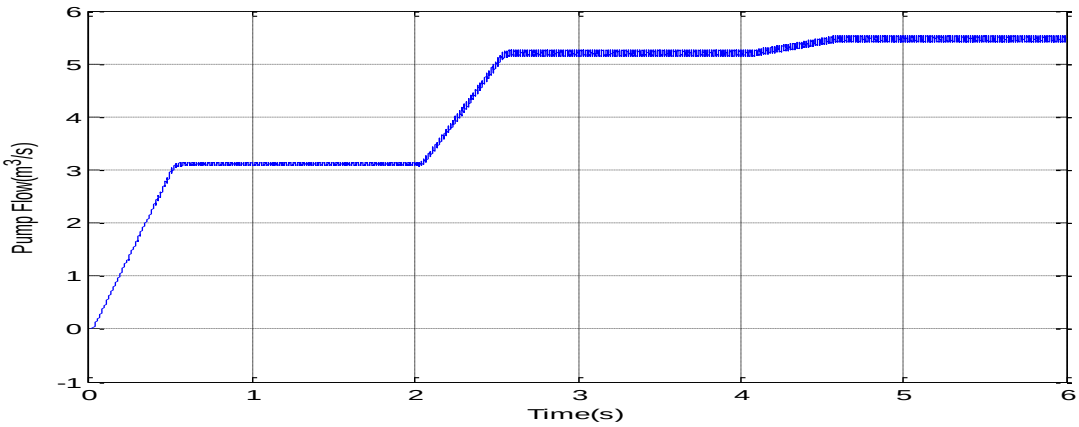

Fig. 23 Pump flow

During this time there was an increase 0-0.57and 2-2.6and 4-4.6 of the voltage versus time is the regime transition. At t = 0.57 and 2.6 and 4.6 is the steady state affected the voltage remains substantially constant .

The curves of figures 19,20,21,22,23 shows that there is an almost linear increase. The speed increase until at the time instant t = 0.57s and it remains constant until t = 1.5 then track the variation of sunlight . In starting regime, There is a strongly pulsating torque and in steady state the electromagnetic torque follows the resistant torque of pump.

Finally we note also robustness of used control under rapidly changing weather condition .

4 Conclusion

Photovoltaic energy conversion is one of the alternatives of renewable energy sources, since the advent of major applications in the world , and has shown its flexibility and its ability to operate in several environments. This is an interesting solution to conventional means of production.

To ensure the operation of a photovoltaic generator at its maximum power point, MPPT controllers are often used. These controllers are intended to effectively track the MPP and thus minimize the error between the operating power and the maximum power which is the reference variable as a function of the load and the climatic conditions.

The optimal choice of the method of tracking depends mainly on the given specifications.

In this article we were interested in a MPPT fuzzy logic control that gave in general good performances. The studied method can be redesigned quickly and present a robustness to variations of the solar irradiation.

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