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Design and Simulation of Photovoltaic Water Pumping System

Tourkia Lajnef, Slim Abid, Anis Ammous

Abstract— ***the power source for pumping water is one of the most promising areas in photovoltaic applications. This paper presents the performance of the photovoltaic plant especially in the case of climatic and load fluctuations. The studied system consists of the PV array, the ACmotor, the centrifugal pump and using an MPPT algorithm to improve the efficiency of the PV system. This methodology allows an optimal control and monitoring of inverters by calculating the duty cycle of the DC-DC converter and the voltage/frequency control. Each subsystem is modeled in order to simulate the whole system in MATLAB/SIMULINK. The non linear averaged modeling technique of the converters is used in order to picture accurately the PV system behavior during a low simulations time.***

Index Terms— ***Photovoltaic pumping system, MPPT, inverters, simulation model, control.***

I. INTRODUCTION

Renewable energy sources are being increasingly implemented in many applications due to the growing concern of environnemental pollution. Photovoltaic (PV) is a technology in which the radiant energy from the sun is converted to direct current .The use of photovoltaic as the power source of pumping water is considered as one of the most promising areas of PV application.

The advantages of using water pumps powered by photovoltaic systems include low maintenance, ease of installation, reliability and the matching between the powers generated and the water usage needs. Photovoltaic powered water pumping systems require only that there be adequate sunshine and a source of water. Photovoltaic water pumping systems are particularly suitable for water supply in remote areas where no electricity supply is available. Water can be pumped during the day and stored in tanks, making water available at night or when it is cloudy. The pumped water can be used in many applications such as domestic use, water for irrigation and village water supplies [1-3].

The main objective of the present work is to develop a general method for the evaluation of the long term performance of a direct coupled photovoltaic powered water pumping system with maximum power point tracker. In the present work, the variations in system performance resulting from solar source variations have been taken into consideration to establish a model for the complete system.

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***** Correspondence Author (s)
Tourkia Lajnef, Pursuing Ph.D., National School of Engineers (ENIS), Sfax, Tunisia
Slim Abid, Professor at the National School of Engineers (ENIS), Sfax, Tunisia
Anis Ammous, Professor at the National School of Engineers (ENIS), Sfax, Tunisia

Also, a computer program is developed for each component to simulate the performance of the different components of the PV pumping system. The effects of system parameters variations on system performance have been studied using these models to determine the optimum system parameters.

II. PHOTOVOLTAIC PUMPING SYSTEM

Normally, the water pumping system consists of a PV generator (2.1Kw), a three phase inverter and a submersed motor-pump group of 1.5KW.

To improve the performance of a PV pumping system, a DC-DC converter known as a maximum power point tracker (MPPT) is used to match continuously the output characteristics of a PV array to the input characteristics of a motor pump.

The Simulink model diagram of the global system is given by the figure**1**.it includes all these elements from the:"PV-DC/DC-DC/AC-MAS-Pumps association.

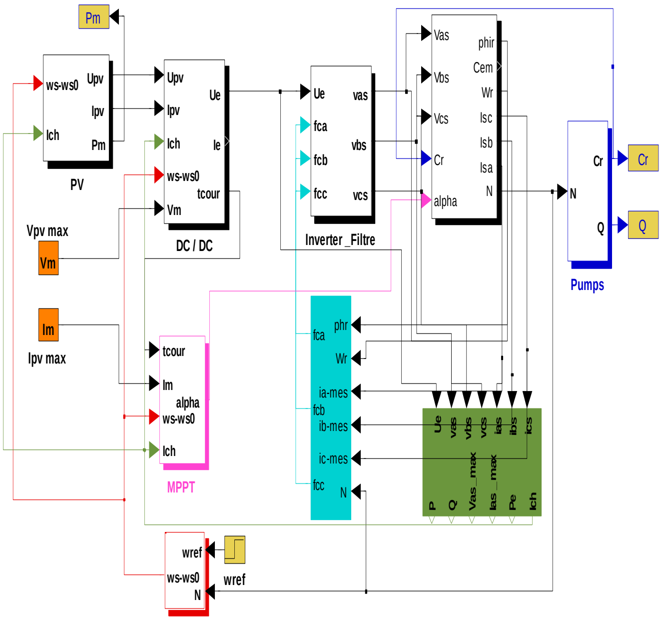

Fig .1. Global PV pumping system association

A. PV module

The PV cell is simulated by the single-diode model given [4] by the characteristic I=f (V) as follows:

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$$I_{pv} = I_{ph} - I_s\left[\exp\left[(q/nKT).(V_{pv}+I_{pv}.R_{serie})\right]-1\right] \quad (1)$$
$$-(V_{pv}+I_{pv}.R_{serie})/R_{shunt}$$

B. Motor and pump model

Will referring to [5], the simulate model of the induction motor is described by the following equations set (2) expressed in the phase model of stator and rotor voltages.

$$\begin{cases} V_{sa} = R_s i_{sa} + \dfrac{d}{dt}\phi_{sa} \\ V_{sb} = R_s i_{sb} + \dfrac{d}{dt}\phi_{sb} \\ V_{sc} = R_s i_{sc} + \dfrac{d}{dt}\phi_{sc} \end{cases} \begin{cases} V_{ra} = R_r i_{ra} + \dfrac{d}{dt}\phi_{ra} \\ V_{rb} = R_r i_{rb} + \dfrac{d}{dt}\phi_{rb} \\ V_{rc} = R_r i_{rc} + \dfrac{d}{dt}\phi_{rc} \end{cases} \quad (2)$$

The magnetic flux can be expressed as:

$$\phi = LI \quad (3)$$

The electromagnetic torque is given by:

$$C = 3pM\begin{bmatrix} i_{sa}i_{rb}\sin\left(\theta-\dfrac{2\pi}{3}\right)+i_{sb}i_{ra}\sin\left(\theta-\dfrac{4\pi}{3}\right) \\ -(i_{sa}i_{ra}+i_{sb}i_{rb})\sin\theta \end{bmatrix} \quad (4)$$

The centrifugal pump is also described by an $H(Q)$ characteristic given by [6].

$$H = C_1 w_m^2 - C_2 w_m Q - C_3 Q^2 \quad (5)$$

Where C_1, C_2 and C_3 are constant parameters.

$$H = H_g + \Delta H \quad (6)$$

Where, H_g is the geometrical height which is the difference between the free level of the water to pump and the highest point of the canalization, and ΔH is the pressure losses in the whole canalization, they are given by:

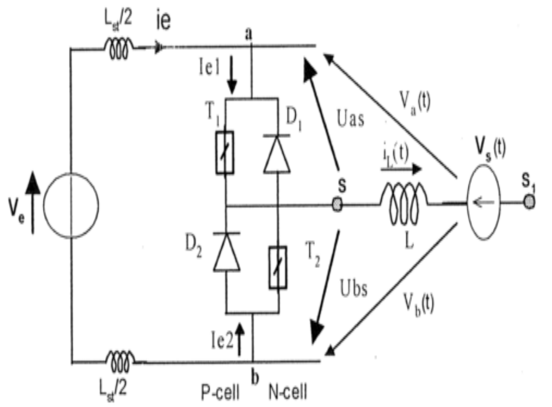
$$\Delta H = \left(\lambda\frac{1}{d}+\xi\right)\frac{8Q^2}{\pi^2 d^4 g} \quad (7)$$

With, λ is a coefficient of the regular pressure losses in the canalization, l length, and d diameter; ξ is a coefficient of the local or singular pressure losses in elbows, valves, and connections of the canalization.

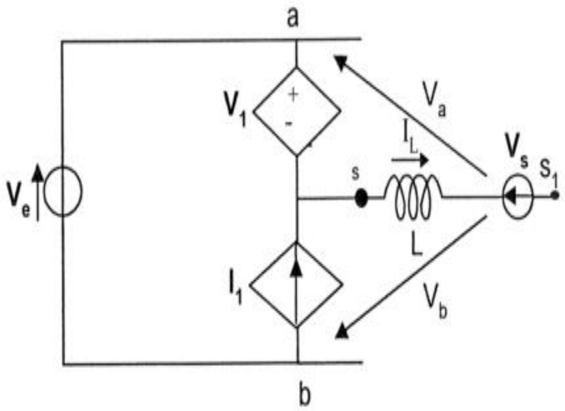
C. Averaged model of the converters

The simulation of power electronic systems behavior using semiconductor refined models gives an accurate results, but unaffordable. The structure of switch cell is given in fig. 2, it have two basic switching cells (P-cell and N-cell).

Each cell consists of one controlled switch and one diode. The two active switches are directly controlled by external control signals. The diodes are indirectly controlled by the state of the controlled switches and the circuit conditions. The load is presented by an inductor L and a voltage source (Vs). The DC loop inductance is modeled by an inductor L_{st}. Depending on the sign of the load current I_L (t), only two devices (one controlled device and one diode) operate simultaneously [7, 8, 9, 10].



(a)



(b)

Fig.2. (a) The PWM-Switch, (b)The equivalent circuit of the PWM-Switch averaged model

The proposed averaged model of the PWM-switch is presented in fig.2.b. This model contains a controlled voltage source (V_1) and a controlled current source (I_1).

The PWM-switch is the only nonlinear element which is supposed to be responsible for the non linear behavior of the converter.

Considering Ts as the switching period of the controlled switches and (d) the duty ratio which is the ratio of the on-time value (Ton) of the upper controlled switch (T_1) and the switching period Ts.

In fig 2.b, the current source (I_1) and the voltage source (V_1) are given by

$$\begin{cases} V_1 = \langle U_{as}\rangle \\ I_1 = \langle i_{e2}\rangle \end{cases} \quad (8)$$

Where <U_{as}> and <i_{e2}> are the time averaged values of the instantaneous terminal waveforms U_{as}(t) and i_{e2}(t) respectively over one cycle Ts.

Fig.2. pictures the adopted switching characteristics of the MOSFETs (U_{as}(t), i_{e1}(t)) and the free-wheeling diodes (U_{bs}(t), i_{e2}(t)) during Ts. eg1 and eg2 are the driving signal of the controlled components T1 and T2, respectively. We notice that Dc loop inductance, the reverse recovery phenomena and the dead time δ between the two driving signals are taken into account.

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Fig 3 shows the case when $i_L(t)$ is positive, so only the controlled components T1 and the diode D2 operates. In this paper we have chosen the MOSFET's devices for the controlled switch and the PIN devices for diodes. We notice that the load current i_L is considered constant and equal to the averaged value of the real current $i_L(t)$ in the load over the switching period Ts. During devices turn-on and turn-off phases, the different voltage magnitude are given by

$$V_x = -(L_{st}(\frac{dI_F}{dt} + \frac{dI_R}{dt}) - V_d)$$

$$V_{RM} = -(Ve + L_{st}\frac{dI_R}{dt} - V_t)$$

$$V_{st} = L_{st}\frac{dI_F}{dt}$$

$$V_q = Ve + V_d - L_{st}\frac{dI_F}{dt}$$

The averaged values of the voltage across the device of the voltage source V_1 and current I_1 are obtained by integrating the voltage and the current evolutions shown in figure 9 over one cycle Ts. The parameter δ is the dead-time fixed by the user to eliminate the simultaneous conduction of the two controlled devices of the bidire ctional PWM-switch.

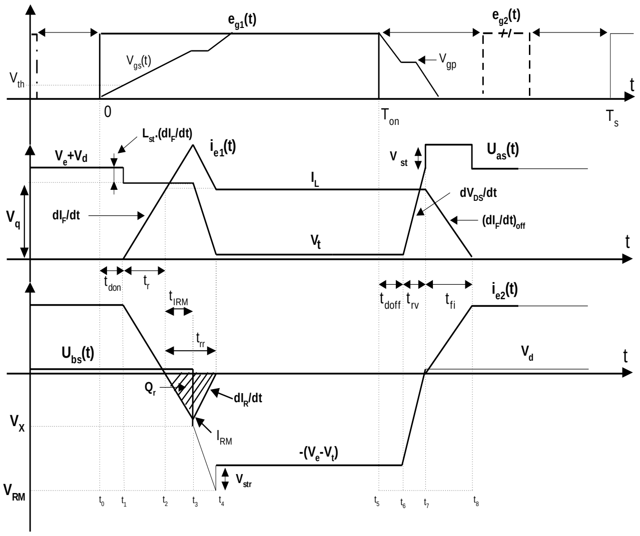

Fig.3. The adopted switching characteristics of the controlled and the diode devices in the PWM-switch

III. RESULTS

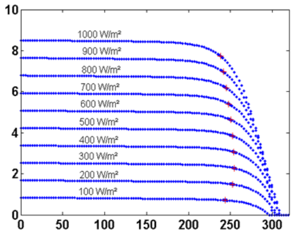

Fig.4. I(V)Characteristics

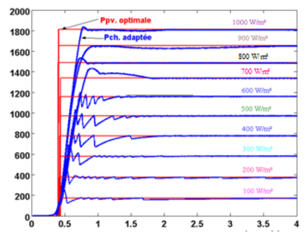

Fig.5. PV power adjustment

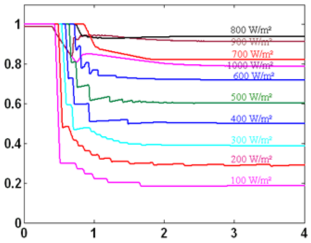

Fig.6. Variation of duty cycle

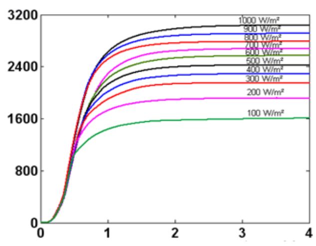

Fig.7. Speed of the MAS

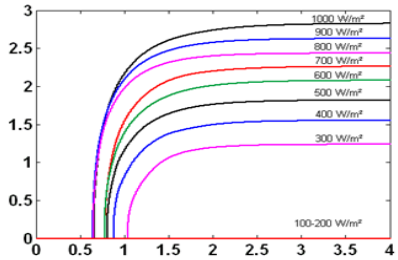

Fig.8.Variation of the pump flow

The simulated results obtained with the SIMULINK tool, for a given different solar radiation has showed a good performance. As examples ,we have present the variation versus the time of the PV(I(V) and power), duty cycle, the motor speed and the pump flow illustrated respectively by figures 4,5,6,7and 8.

We repeated the same simulation work by varying ambient temperature .shows that it does not greatly affect the performance of the PV pumping system output compared to solar radiation.

The results are depicted in figures 9, 10, 11, 12 and 13 respectively.

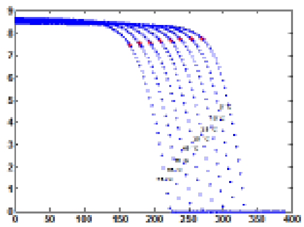

Fig.9. Characteristic V(I)

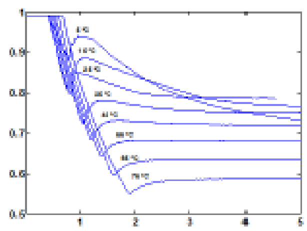

Fig.10. Variation of duty cycle

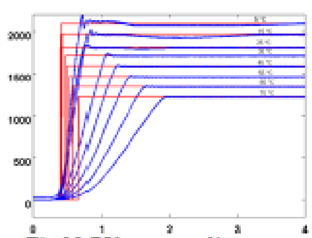

Fig.11.PV power adjustment

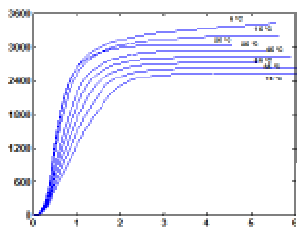

Fig.12.Speed of the MAS

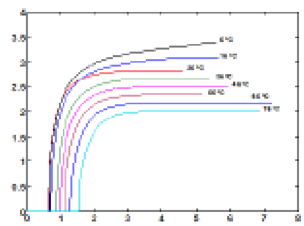

Fig.13.The pump flow

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IV. CONCLUSION

In this paper, we have presented a SIMULINK model of a photovoltaic structure made up of a PV generator, MPPT converter supplying an asynchronous motor –pump.

The main conclusion remarks are summarized as follows:

1- A remote PV pumping system unit was designed.
2- We have studied and applied a new controls deduced for this type of pumping system tacking into account the elimination of storage battery.
3- The use of MPPT algorithm that maximizes the energy transfer towards the whole system.
4- The static and dynamic performances were presented by simulations.

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Tourkia LAJNEF was born in Zarzis, Tunisia, in 1981.She received the MS degree in electrical system from the Ecole National d'ingenieur de Tunis (ENIT), Tunisia, in 2008. Where she is currently pursuing the Ph.D degree in electrical engineering. His research interests are simulations and dispatch of renewable energy sources.

Slim ABID was born in Sfax, Tunisia in 1978.He received the MS degree in electrical engineering from the Ecole National d'ingenieur de sfax (ENIS), Sfax, Tunisia, in 2004, and the Ph.D degree in electrical engineering from ENIS, Sfax, Tunisia, in 2009.

Anis AMMOUS was born in Sfax, Tunisia. He received the electrical engineering degree from the National School of Engineers (ENIS), Sfax, Tunisia in 1994, the Ph.D. degree in electrical engineering from the Institut National des Sciences Appliquées (INSA) of Lyon, France in 1998 and the HDR degree in electrical engineering in 2003.

He is currently a Professor at the National School of Engineers (ENIS), Sfax, Tunisia and the responsible of the Power Electronic Group (PEG) at the ENIS. His current research interests are power semiconductor device modeling, the electro thermal modelisation , power system simulations and designs. Among his works is the optimization of power converters topologies in renewable energies applications. He is the author of two patents and author or co-author of more than 50 scientific papers.

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