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Modeling and Performance of the Photovoltaic pumping system

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Abstract – The photovoltaic (PV) pumping system is a widely used in Mauritania to ensure the water supply in rural area for populations needs. This system is composed by three main parts: The PV Generator (PVG), impedance matching (DC/DC Power Convert), and the hydraulic part (coupling of a PMDC motor and a centrifugal pump).

Two mathematical motor –pump models for PV application, were proposed in this article to contribute in the studies of PV pumping sizing. These models link directly the operating water current to the voltage and electrical power to the flow rate of the pump versus total head.

In this article we study the simulation in Matlab/ Simulink environment the characteristics of a PV pumping system (submersible pump case); The three parts quoted for an overview of the performance of the system, taking into account the climate parameters (solar irradiance, and ambient temperature), and the effect of the total manometric head (HMT) on the pumped flow rate. The models were based principally, on the analysis of the experimentation results for one centrifugal pump, coupled to converter motor. The current, the voltage, the electrical power, the flow rate and the head were the monitored dates. Current-voltage and electrical power-flow have modeled characteristics of the modeled motor-pump. The improved models yielded satisfactory results. In ordre to validate the simulation, we use the meteorological data of Rosso city, which is a region of southern Mauritania.

Keywords: PVG system; DC/DC; Power; Converter; motor-pump; flow rate; HMT.

I. Introduction

Several research projects have been carried out on the renewable energy conversion systems and their applications which can be summarized in the following two points: The search for precise mathematical models that represent the real photovoltaic cell made it possible to retain the works of [Shatadru Biswas al 2018] and [Hichem Othmani al 2017] and the selected models were designed to reflect correctly the influence of different atmospheric conditions on solar cell parameters. In this context, we must not forget to mention other works on optimization methods such as those of [A.Hamidat al 2008], [Imene Yahyaoui al 2015] and [R. Dehini1 al. 2018].

The search for the development of a determined mathematical model, which represents the optimization of the hydraulic part, made it possible to retain the work of [B. Berbaoui al 2018, Omveer Singh al 2016, Y. Belkassmi al 2017, and Y. Bakelli al, 2012]. These different researches have had the objective of proposing a use of photovoltaic pumping for any lighting condition and temperature.

II. Description and modeling of the photovoltaic pumping system

II.1 System description

The system studied is shown in Fig. 1, we have three parts that make up the PV pumping system; a PVG consisting of four PV panels connected in series with a capacity of 190 Wp for each, The PV panel parameters are shown in table I, a DC/DC Power Convert, and a permanent magnet DC motor coupled directly to a centrifugal pump, sensor less motor and a controller.

The Photovoltaic module rated at 1000w/m² solar irradiation and 25°C cell temperature. The rated power of PV devices does not give an accurate indication of the outdoor performance, especially when the PV modules aren't a brand new one. The controller performances are shown in table II.

Parameters	Value
Rated power	190 watt
Rated voltage	25,8V
Rated current	7,36A
Open circuit voltage	32,3V
Short circuit current	8,18A

Table I. Datasheet of the SOLTERRA-190 module

Item # 1222	1222
Lift [m]	0-40m
max. flow rate [m ³ /h]	7.5
Max. efficiency [%]	48
PVG nominal voltage DC	72- 96V
PVG open circuit voltage	200V
Solar generator [Wp]	350-1200
Max. motor current (A)	9.5
Pump type	Centrifugal
Motor power	1.7kw
Motor rate	900-3300

Table II. Controller performance

This study was performed at the Higher Institute Technological Education (ISET- Rosso) (16°30 North latitude, 15°48 West longitude at 8m altitude above the sea level).

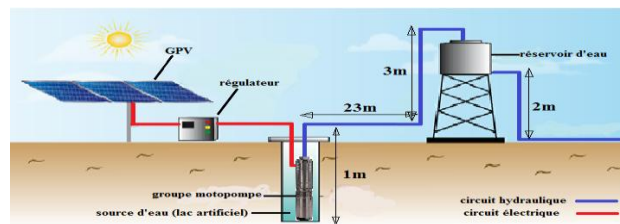


Figure. 1. The experimental setup

II.2 PVG System modeling

A photovoltaic module is composed by photovoltaic cells, connected between them in series or in parallel, in the literature we can find two types of PV cell modeling; the model with a single diode or the other with two diodes, [Abdellahi Ba et al, 2018], in our case, we use that with a single diode Fig.2. This cell generates a current-voltage (I-V) characteristic that is strongly nonlinear, and that voltage-power (P-V).

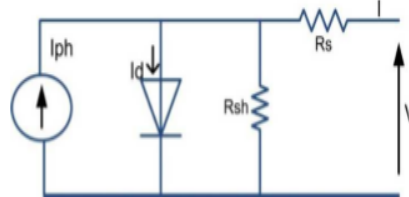


Figure. 2. Electrical model of the photovoltaic cell

From this circuit, and applying Kirchhoff's law, we shall derive the following equations:

$$I = I_{ph} - I_s \left(\exp \left(\frac{V + R_s I}{V_t} \right) - 1 \right) - \frac{V + R_s I}{R_{sh}} \quad (1)$$

with: V_t : the thermal tension written as $= (A * K * T) / q$, A : is the ideality factor of the diode, $(K=1, 38.10^{-38} \text{ J/K})$ is the Boltzmann constant, T : is the ambient temperature in °C, $(q=1, 02. 10^{-19} \text{ C})$: is the electron charge, I_{ph} : is the photocurrent it is proportional to the solar irradiation flux, I_s : is the diode saturation current, R_s and R_{sh} : are respectively the series and parallel resistance of the cell, V and I : are respectively the voltage and the current of the cell.

There are several characteristics of the solar cell that enables us to determine the working areas of the cell. PV cell displays none linear I-V and P-V characteristic curves. We plot the I-V and P-V characteristics of a module, shown in Fig. 3.

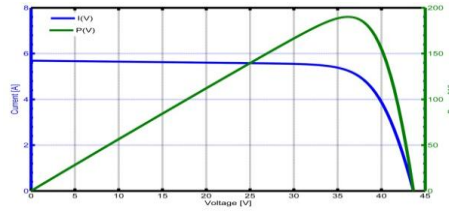


Fig. 3. I-V Characteristic and P-V characteristic curve of a PVG

II.3 Motor-pump modelization

The mathematical models of the inverter and the motor pump set are described in a great number of research papers. Thus, we can quote [Daud and Mahmoud,2005 ; Hadj Arabe et al, 2006 ; Kou et al, 1998 ; Mezghanni et al, 2007, and Pande et al, 2003]. These models describe the characteristics of each component of the pumping subsystem as the inverter, the motor or the pump. But these models do not give a direct relationship between the operating electrical powers of the pump. In this paper, we use a mathematical model which directly links the output water flow rate Q versus the input operating electric power P and total head h. this model is based on the analysis of the experimental results of one type pumping subsystems [Hmidat et al, 2007; Hamidat and Benyoucef, 2008].

With regard to the equation (2) connecting the characteristic I-V of the pump with the pumping height and the equation (3) in form Q-V which develops characteristics to obtain the performance curves of the pump are proposed by the authors. In the case of the current versus the voltage, we found that it is linear. For this reason, we suggested the following equation [Hadj Arab al, 2006]:

$$I(V) = aV + b \quad (2)$$

$$Q(V) = cV^2 + dV + e \quad (3)$$

With I and Q being positive. Where a, b, c, d and e are parameters easily obtained by means of an iterative Newton technique.

The researchers, [Hadj Arab al, 2006] generalized the model for all heights by linking all the coefficients a, b, c, d and e to the pumping height h by the following second-degree equations:

$$a(h) = a_0 + a_1h + a_2h^2 + a_3h^3 \quad (4)$$

$$b(h) = b_0 + b_1h + b_2h^2 + b_3h^3 \quad (5)$$

$$c(h) = c_0 + c_1h + c_2h^2 + c_3h^3 \quad (6)$$

$$d(h) = d_0 + d_1h + d_2h^2 + d_3h^3 \quad (7)$$

Where the constant a_i , b_i , c_i and d_i are the secondary parameters and depend only on the pumping subsystem type. On the other hand, the model which gives P (Q) of the pump motor unit for different pumping heights has been developed by [Hadj Arab al, 2006]. This model directly links the useful electrical power P a function to the water flow of the pump Q as follows:

$$P(Q, h) = a0j(h)Q^3 + a1j(h)Q^2 + a2j(h)Q + a3j(h) \quad (8)$$

The principal parameter $a_{ij}(h)$ are constants depend of the pumping system.

III. Results and discussions

The meteorological, electrical and hydraulic parameters were monitored for four days. Table III shows the medium value of the parameters. Throughout these days the PV panel was mounted at a tilt angle of 17 ° for the two first days and 7.5 ° for the two last days and oriented to magnetic North.

TABLE III. Parametre of the four studied days

Days number	01	02	03	04
Irradiation (kWh/m ² /Day)	7.83	9.22	7.97	8.49
Temperature (°C)	29.52	33.03	40.22	29.06
Tilt angle (°)	17	17	7.5	7.5

The simulations are developed to obtain the models parameters applied to pump motor. It is necessary to physically separate the pump motor to develop in the rest of this work, simulations of current-voltage characteristics $I(V)$ and the power-flow $P(Q)$. For each head, we obtained two measured curves: the $I-V$ and the $P-Q$ relationship of the motor pump.

(Fig.4) illustrates an example of the characteristics obtained for the pump centrifugal using the experimental measurement. which represent the dependence of the current versus the voltage for each head.

From the result, we have tried to find simple mathematical expression, which allow us to adjust the experimental value. In the case of the current versus the voltage, we found that it is linear. The $P(Q)$ characteristics of the one tested subsystem are carried out and plots for each total head. An example of the measurement values are shown in Fig 5. **Figs.6 and 7** show an example of the experimental values obtained for one head. Thus to define the $I-V$ and $P-Q$ characteristics, we need to solve of linear equations. For this, at one head, according to (h) we have different measurements of I , V , P and Q **with Q being positive**. In order to validate the obtained general models, a comparative study of the previous and the present characteristics was made in Figs. 6 and 7, we illustrated the previous and the present characteristics of the centrifugal pump the head. As shown very well in Figs.6 and 7 the curves agree.

Figures 4 and 5 represents the variates of $I(V)$ and $P(Q)$ in function of head value ($h=2\text{ m}$, $h=4\text{ m}$ and $h=6\text{ m}$), instead of figures 6 and 7 represents site value for one day.

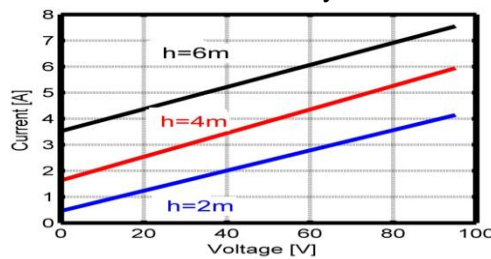


Fig. 4. $I(V)$ for different h

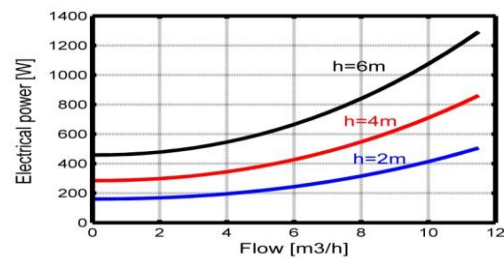


Fig.5. $P(Q)$ for different h

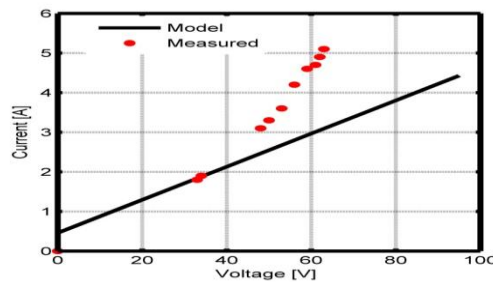


Fig.6. $I(V)$ curve model validation

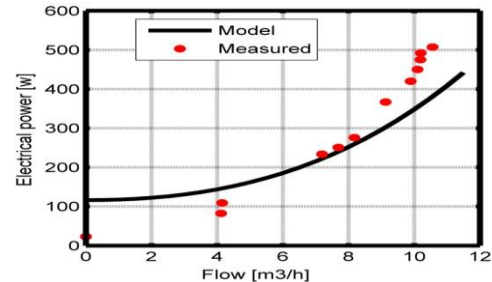


Fig. 7. $P(Q)$ curve model validation

IV. CONCLUSIONS

In this research a PV water pumping system in Mauritania climate has been designed as case study for a small farm in the Higher Institute Technological Education (ISET- Rosso) was selected and discussed. This system is suitable for many rural zones since it's designed to work with free cost and doesn't need maintenance.

The modelization and the validation of the models of the PV array and the PV pumping subsystem, allow us to simulate the performance of the PV pumping systems for several sites. The analytical model has given a great adjustment of the $I-V$ electrical characteristic curves of the PV array versus solare irradiance and ambiente temperature. Concerning the pumping subsystems, the model for $I(V)$ and $P(Q)$ of PV array is found to be suitable with experimental curves. The development of the one motor-pump unit models allows us to obtain the operating point of the system and the pumped flow rate. The one model is based on experimental result of several photovoltaic pumps, which have been characterized completely in the pumping test facility to obtain the parameter of the models, are established for centrifugal pump (Lorentz ps1200 c-sj8-5) with DC motor.

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