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Modeling of a photovoltaic pumping system using centrifugal pump and DC motor

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Abstract:

The use of photovoltaic (PV) array for pumping water is one of the most promising techniques in solar energy applications. This paper presents an analysis of constituent of a PV pumping system. The PV water pumping system consists of a photovoltaic generator, a DC-DC boost converter, a DC motor, a centrifugal pump and a storage tank. The modeling of PV cells, Boost converter, PMDC motor and centrifugal pump has been studied and developed. Different results of simulation are presented.

1. Introduction

Renewable energy is an important component of the new Moroccan energy strategy. Indeed, our country has a great potential in renewable energy, its exploitation will cover a significant part of its growing needs, and contribute to the protection of the environment. By 2020, the installed power from renewable energies will represent about 42% of the park, which 14% will come from solar energy.
The use of solar energy for pumping water is one of most promising area. With the increase use of this technology, great attention has been allowed to their design and their optimal use. In this work, we present an analysis of the operation of a PV pumping system, using DC motor and the centrifugal pump. The general block diagram of a photovoltaic pumping system is shown in Figure 1.

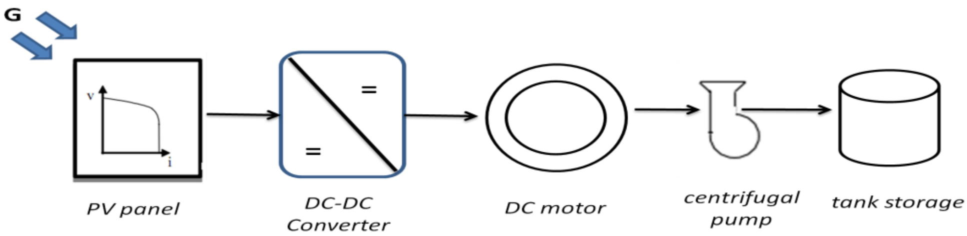

Figure 1: Structure of a PV pumping system using DC motor

2. Modeling of PV pumping system:

2.1. Model of the PV generator:

The photovoltaic generator is constituted by modules. Each module is formed by PV cells. The solar cell represents the elementary power conversion unit. When the solar radiation reaches the surface of the PV generator, the solar cells converts the solar energy into electrical energy by the "photovoltaic effect" process [1]. Equivalent circuit of a PV cell is shown in Figure 2. It consists of a diode in parallel with a current source, and two resistors. The current is proportional to the radiation.

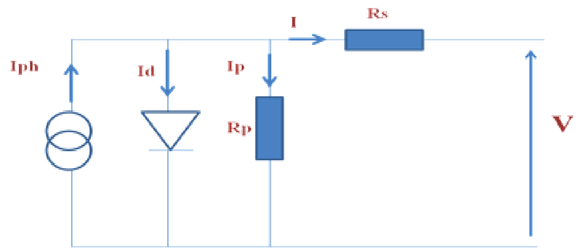

Figure 2: Equivalent circuit of a photovoltaic cell

$I = I_{ph} - I_d - I_p$

With $I_d = I_0 (\exp(V_j*q/(K_0 *T))-1)$ And $I_p = (V+ R_s I)/R_p$

$$I = I_{ph} - I_0 (\exp(V_j*q/(K_0 *T))-1) - (V+ R_s I)/R_p$$

Where: $\mathbf{K_0}$ the Boltzmann constant, **T** the absolute temperature, and **q** is the electron charge. Rp and Rs are two resistors representing losses in the cell. The simulation of a solar panel of 36 cells submitted to an illumination of 1 000 W / m², at T = 25 ° C, gives the following characteristics:

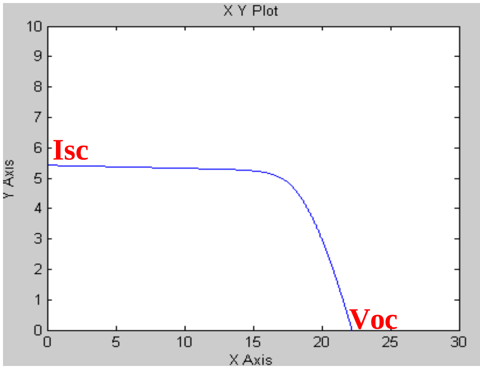

Figure3.a: Characteristic current-voltage of the panel

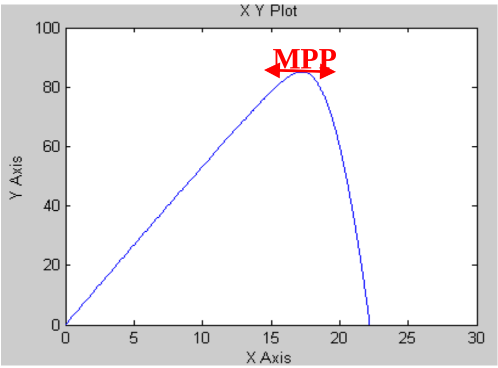

Figure3.b: Characteristic power-voltage of the panel

According to this simulation, we obtained the following results:
The short-circuit current is: Isc = 5,45 A, the open circuit voltage is Voc= 22,2V and the maximum power is Pm = 82 W.

2.2. Boost chopper model:

The DC-DC boost converter is used as an adapter between the PV generator and the motor-pump group. The circuit diagram of boost converter is shown in figure 4. It is a power electronic converter whose output voltage is higher than the input one. It supplied by a DC input source Vpv, through an inductance L. The controlled switch used is a MOS transistor. The circuit includes also a diode D and a capacitor filter C [2].

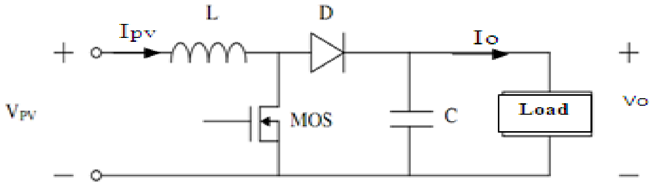

Figure4: DC-DC boost converter

The command of the MOS transistor is characterized by the duty cycle α and the period T [2, 3].

- On the first sequence [0,αT], the MOS transistor is ON, and the diode is OFF, equations are:

$$\begin{cases} Vpv = L\, dIpv/dt \\ C\, dVo/dt + Io = 0 \end{cases}$$

- On the second sequence [αT,T]:

$$\begin{cases} Vpv = L\, dIpv/dt + Vo \\ Ipv = C\, dVo/dt + Io \end{cases}$$

The equation of the output voltage depending on the input voltage, and the duty cycle can be expressed as: $$\mathbf{Vo} = \frac{\mathbf{1}}{\mathbf{1-\alpha}}\mathbf{Vpv}$$

Simulation of DC-DC boost converter, supplied by an input voltage Vpv = 3V, discharging into a load R=0.1Ω, has given the following results:

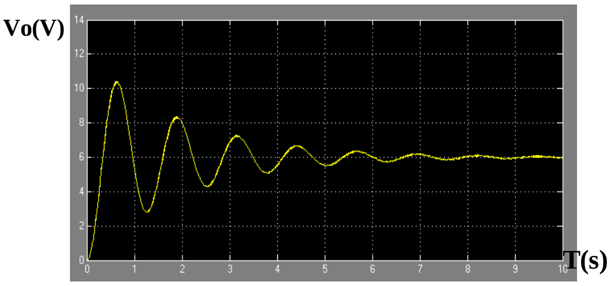

Figure5.a: Output voltage of the boost converter DC-DC for Vpv = 3V and α = 0.5

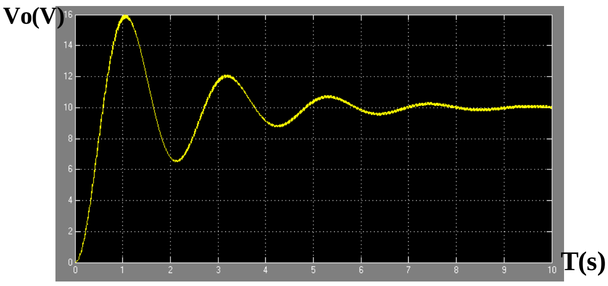

Figure5.b: Output voltage of the boost converter DC-DC for Vpv=3V and α= 0.7

We note that with an input voltage Vpv = 3 V and a duty cycle α = 0.5. Output voltage Vo of the chopper is around 10V before stabilizing at the value Vo ≃ 6 V.
Figure 5.b shows that if we change the value of duty cycle α to 0.7, the output voltage is 16V at the beginning before stabilizing at Vo ≃ 10V.
We deduce that the variation of Vo depend of the variation of duty cycle α. The boost converter enables the PV generator to operate at a desired value when an adequate control is performed. However, the adaptation is performed when Vpv and Ipv are respectively equal to Vopt and Iopt.

2.3. Model of PMDC motor:

Several types of AC and DC motors are available for PV pumping systems [4, 5]. The motor choice depends on many factors: requirements of the size, efficiency, price, reliability and availability. Among different kinds of DC existing motors, the permanent magnet motors (PMDC) are most commonly used in PV pumping systems [4]. They provide a high torque at the start. Brushed motors are rarely used, because their brushes should be changed periodically, pump must then be removed of the drilling for changing the brushes [6]. Mathematical relationships that describe the model of a DC motor are expressed as follows [7]:

$$\begin{cases} U = RI + E\text{: Terminal voltage of the armature} \\ E = K\,\Phi\,\omega \text{ : Electromotive force} \\ Te = K'\,\Phi\, I\text{: Electromagnetic torque} \end{cases}$$

Where: K' is the constant torque, Φ is the magnetic flux through the turns, K is the constant of electromotive force, R armature resistance, and ω is the angular speed of the rotor.
The mathematical equation that describes the relationship between the voltage and the speed of rotation is: $$\boldsymbol{E} = \frac{\mathbf{U}}{(\boldsymbol{Km}\,\emptyset)}$$

Km, the constant of the construction motor, depends on the number of pairs of poles, and the number of conductors per section.

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2.4. Model of centrifugal pump:

Depending on the application, and different water sources (wells, drilling, pumping river, etc..) different types of pumps are used. In photovoltaic pump, the centrifugal and the volumetric pumps are the most used [8]. The centrifugal pump considered in this study applies a torque proportional to the square of the rotational speed of the motor [9]: $Tr = Kc * \omega^2$

Where Kc is the proportionality constant [$(Nm/rad.s^{-1})^2$] and ω is the rotational speed of the motor ($rad.s^{-1}$).

Any pump is characterized by its output power, which is given by:

$$P = \frac{Pu}{\eta} \quad \text{with: } Pu = \rho\, g\, H\, Q$$

where: η is the overall performance; ρ is the fluid density(Kg/m^3); g is the gravity acceleration (m^2/s); His the height of rise (m) and Q is the water flow (m^3/s).

The operating point of the motor-pump is located at the intersection between the mechanical characteristics of useful torque of motor Tu = f (ω) and resistive torque of pump Tr = f (ω).

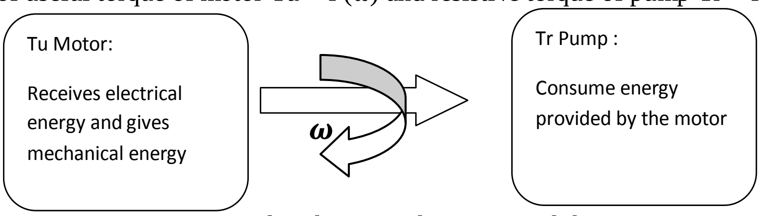

Figure 6: coupling between the motor and the pump.

The flow rate of the pump is proportional to the rotational speed of the motor; however, at start we must have a minimum speed to obtain a flow [6].

3. Maximum power point MPP Technical research:

The MPPT control (Maximum Power Point Tracking) is a functional component of a PV system; it allows the optimal operating point of the PV generator, in different conditions. Whether analog or digital control [10], the control principle is the same; it is based on an automatic variation of the duty cycle α to the appropriate value, in order to exploit the maximum power output of PV generator. Many MPPT algorithms have been developed by researchers around the world. The perturbation and observation (P & O) method is an approach widely used in research of MPP [11, 12]. Its principle is simple [11]: if the voltage of the PV generator is perturbed in one direction and dP / dV> 0, the algorithm P & O could then continue to disrupt the PV voltage in the same direction. If dP / dV <0, then we have an overrun of the MPP, the P & O algorithm reverses the direction of the disturbance. The direction search of the MPP and the algorithm of this method are presented in Figure 9.a and Figure 9.b.

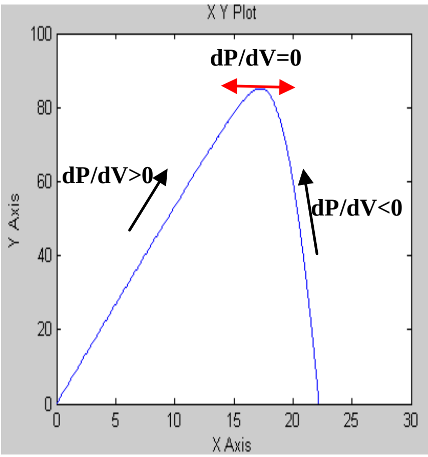

Figure 9.a*:* Direction search of the MPP

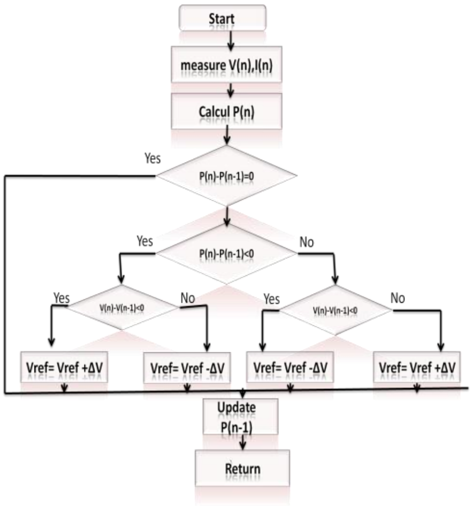

Figure 9.b: Organizational chart of the perturbation and observation

The simulation of P&O algorithm at a temperature of 25 ° C has given the following results:

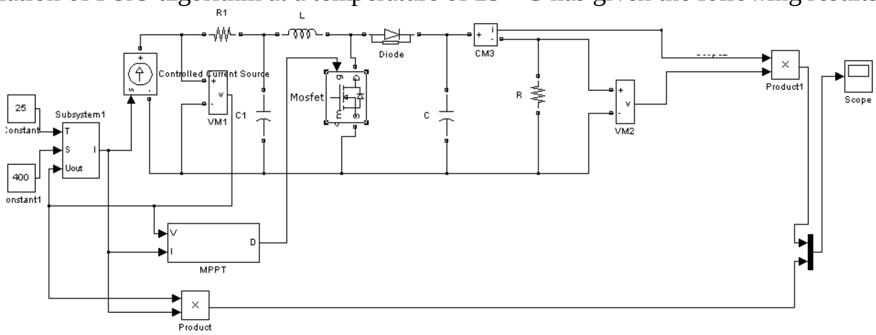

Figure 10: Simulink model of coupling PV generator with and without MPPT command

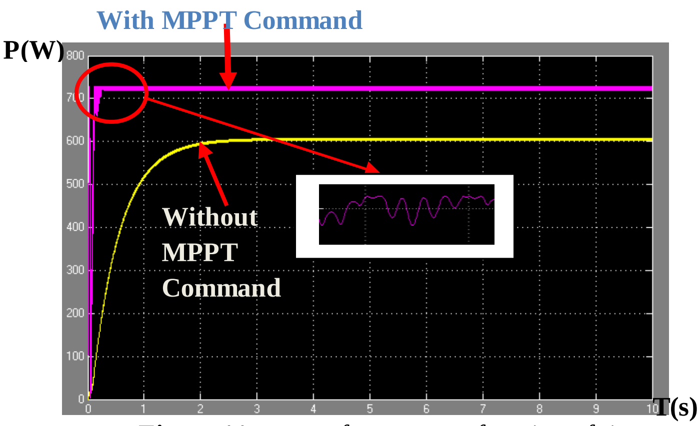

Figure 11: curve of power as a function of time

Powers obtained by the MPPT technique values are the highest. But, in despite of the use of these methods there is always problem of oscillations around the MPP which influence on system performance. In literature, others algorithms are used: the method followed by constant voltage [5], the method of constant current [14], the incremental conductance (IncCond) [13] and the method of fuzzy logic control (FLC), which provides good yields [8].

4. Conclusion:

This work has presented an overview of the components of a PV pumping system. We have presented relationships, and mathematical models of each part of the system. Then we have simulated the operation of PV generator with MPPT control using perturbation and observation (P&O) algorithm, having its characteristics. We have presented the operation of the DC-DC converter that allows achieving MPPT control, which forces the PV system to work around its maximum power.

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