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Simulation of photovoltaic pumping system optimized

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***Abstract*— The exploitation of solar energy potential for the production of electricity proves to be profitable in remote areas, where the extension of the conventional electricity grid would be impossible and expensive.**

The aim of this study is to model and simulate a ground-based photovoltaic pumping system consisting of a DC motor coupled to a centrifugal pump. This assembly is powered by a photovoltaic generator through a DC-DC static converter. Then, we will have to compare between the direct coupling and the coupling with an MPPT control.

Keywords: Photovoltaic, DC-DC converter, optimization, MPPT

I. INTRODUCTION

The extension of conventional power grids, in some remote areas, is costly and sometimes impossible and can be mitigated by the exploitation of solar energy.

Today, the proliferation of renewable energy conversion systems leads us to consider how to make them less expensive and more reliable.

To do this we will have to solve the problems of electrical conversion materials which have a lot of losses to minimize these and to determine the appropriate use of the static converters.

Research on the conversion system will focus on:

The development of an exact mathematical model representing the actual photovoltaic cell and reflecting the influence of different atmospheric conditions on the parameters of the solar cell.

The development of an efficient optimization method that can determine the maximum power point of the I (V) characteristic of the cell for all illumination and temperature conditions as well as all of their changes (fast or slow) .

II. PRESENTATION OF THE STRUCTURE OF THE PUMPING SYSTEM

The pumping system is the combination of a set of interconnected subsystems that are: the photovoltaic generator, the adapter chopper, impedance 'MPPT', the DC motor and the centrifugal pump associated with a discharge pipe.

The figure 1 schematizes the synoptic of such a system. [1]

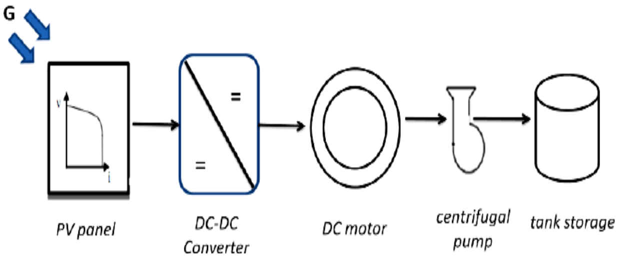

Fig. 1 Structure of a PV pumping system using DC motor

III. SIMULATION OF THE STRUCTURE STUDIED

III.1 SIMULATION OF THE PHOTOVOLTAIC GENERATOR

The simplified model of a photovoltaic generator is described by the following relation

$$I_{PV} = N_P \times I_{ph} - N_P \times Is\left[\exp.\left(\frac{A_t \times V_{PV}}{N_S}\right) - 1\right] \quad (1)$$

Where: $\mathbf{I_{pv}}$ is the current supplied by the photovoltaic generator, $\mathbf{V_{pv}}$ is the voltage at the terminals of the photovoltaic generator, $\mathbf{I_{ph}}$ is the current photo directly proportional to the sunshine,

$\mathbf{N_s}$ is the number of modules in series and $\mathbf{N_p}$ is the number of branches in parallel.

The results of the simulation of a photovoltaic generator are shown in the following figure (Fig.2).

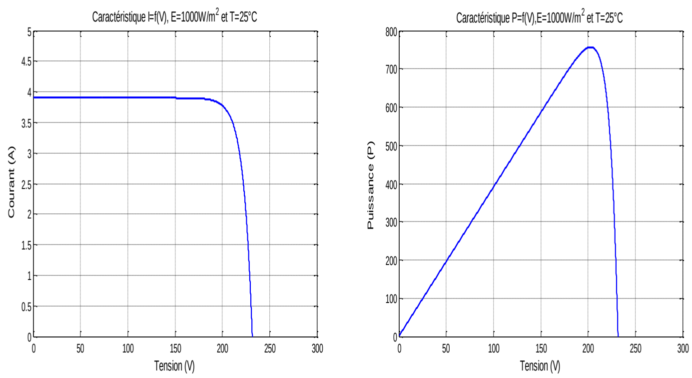

Fig. 2 The electrical characteristics P (V) and I (V) of the panel under standard conditions.

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II1.1.1.INFLUENCE OF THE TEMPERATURE ON THE CHARACTERISTICS I (V) AND P (V):

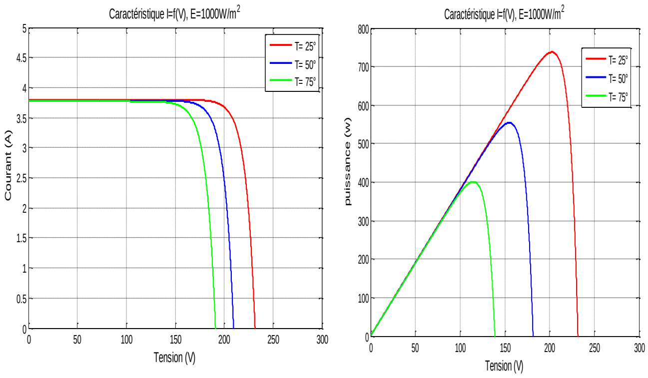


Fig. 3 The influence of temperature on the electrical characteristics I (V) and P (V).

The figure(3) shows that the increase in temperature causes a net decrease in the open circuit voltage and an increase in the short-circuit current, as well as a decrease in the maximum power

III.1.2. INFLUENCE OF ILLUMINATION ON THE I (V) AND P (V) CHARACTERISTICS:

From the figure (4), there is a sharp decrease in the short-circuit current, with respect to the illumination (E) and a small decrease in the open circuit voltage.

It is also noted that the illumination Influences proportionally on the power and the open circuit voltage of the panel.

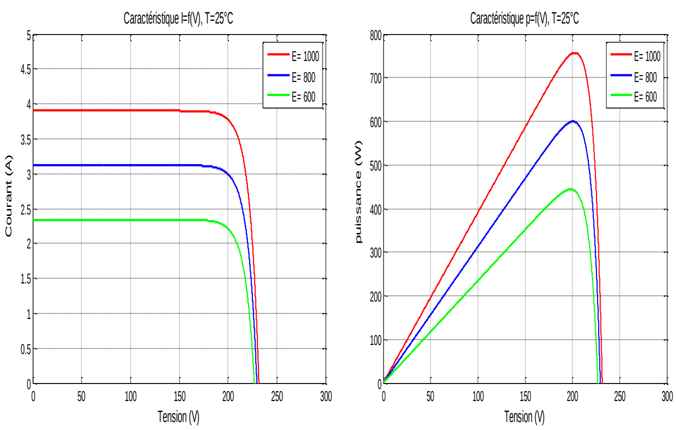


Fig. 4 The influence of illumination on the electrical characteristics I (V) and P (V) of the panel.

III.2. SIMULATION OF THE GROUP (MOTO-PUMP):

III.2.1. SIMULATION OF THE PERMANENT MAGNET MOTOR:

The modeling of the motor is possible from the basic equations of the DC machine. [2]

$$Va = Ra \cdot Ia + La \cdot \frac{d(Ia)}{dt} + \omega.ke \qquad (2)$$

$$Ce = kt \cdot Ia \qquad (3)$$

$$Ce - Cr = j_m \frac{d(\omega)}{dt} \qquad (4)$$

Ke, kt: voltage and motor torque constants.
Ia: the motor frame current.
Ra: the motor frame circuit resistance.
Ce: the electromagnetic motor torque.
Cr: the engine resistive torque.
ω: the motor axis speed.
Representation under state variables: [2]

$$\frac{d(Ia)}{dt} = \frac{1}{La} \cdot (-Ra \cdot Ia - \omega.ke + Va) \qquad (5)$$

$$\frac{d(\omega)}{dt} = (Ce - Cr) \cdot \frac{p}{J_m} \qquad (6)$$

The simulation results of the permanent magnet motor are shown in Figurs (5,6,7,8)

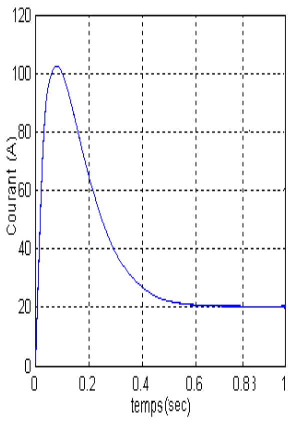


Fig. 5 Current variation of the motor

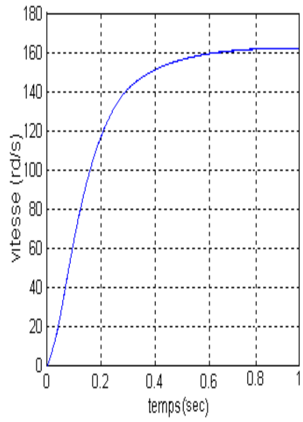


Fig. 6 Variation in engine speed

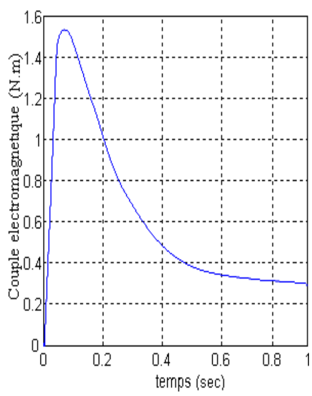


Fig. 7 Variation of electromagnetic torque

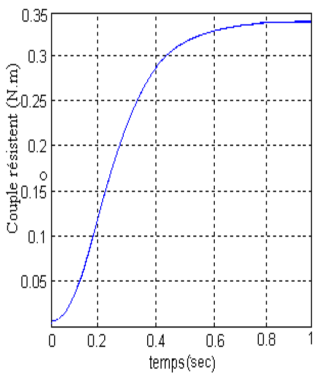


Fig. 8 Torque variation resistant

III.2.2. SIMULATION OF CENTRIFUGAL PUMP:

The load applied to the motor shaft is a centrifugal pump designed to meet precise operating conditions (flow Q to be raised to a height H). The model of the centrifugal pump used is identified by the expression of Plaindre and Petermann [3].

$$H_m = k_0\omega^2 - k_1\omega Q - k_2 Q^2 \qquad (7)$$

With: k_0, k_1, k_2: proper constants of the pump given by the constrictor.

When starting, the torque is limited to the friction torque, (which becomes more important in rotation).

The pump requires a minimum velocity at a given Hm to obtain a non-zero flow rate [3]. Thus, the centrifugal pump opposes a resistive torque Cr which is of the form:

$$C_r = k_r\omega^2 + C_S \qquad (8)$$

kr: coefficients of proportionality [(Nm / rad.s^{-1}) ^{2}]

Cs: the static torque, very small.

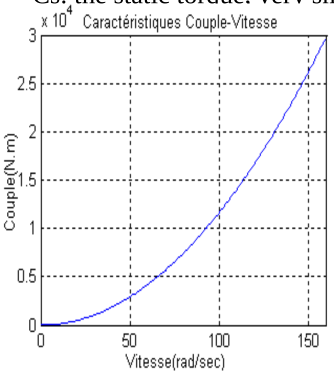


Fig. 9 Torque - speed characteristics

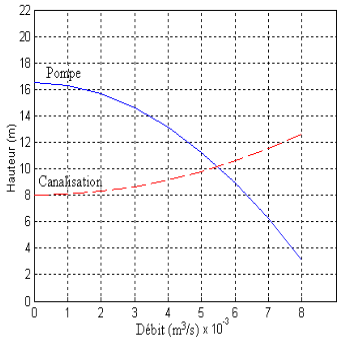


Fig. 10 Characteristics of the pump Hm (Q) and the pipe

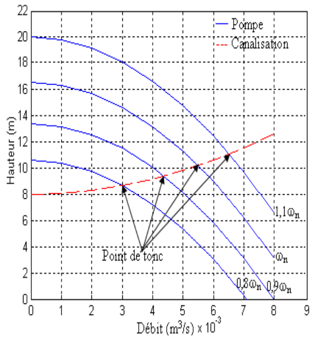
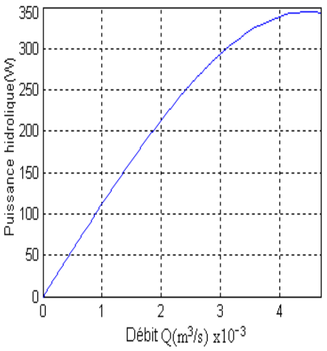


Fig.11 Curve Hm(Q) of the pump used



Fgi.12 Characteristic of hydraulic power different speeds

III.3. SIMULATION OF THE DC-DC BOOST CONVERTER:

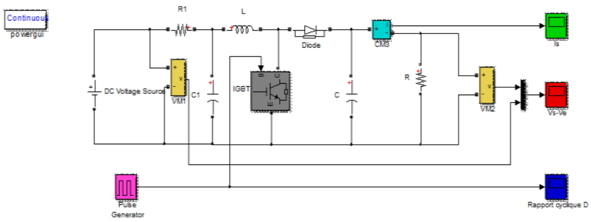


Fig. 12 Simulink model of a DC-DC converter Boost

The duty cycle a (0 <α <1) gives the ratio of the panel voltage to the voltage at the load terminals [4].

The relations used for dimensioning are the classical relations between the output voltage and the input voltage and the duty cycle:

$$V_S = \frac{1}{(1-\alpha)} V_{PV} \qquad (9)$$

An analogous relation binds the mean value of the current in the inductance to the output current:

$$I_{Lmoy} = I_{PV} = \frac{I_S}{(1-\alpha)} \qquad (10)$$

After the simulation we obtained the following results (Fig,13).

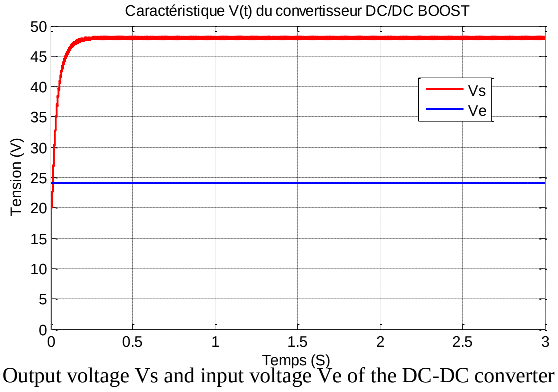


Fig. 13 Output voltage Vs and input voltage Ve of the DC-DC converter

IV. DIRECT COUPLING OF THE DC MOTOR TO THE PV GENERATOR.

This coupling is illustrated in Figure 14. Solar energy is converted into electricity by means of photovoltaic cells. The direct current produced by the solar panels will directly drive the pump motor unit. Solar panels are static elements; the only moving part of the system is the motor-pump group. The illumination varies from the minimum value up to the maximum value of 1000W / m^2.

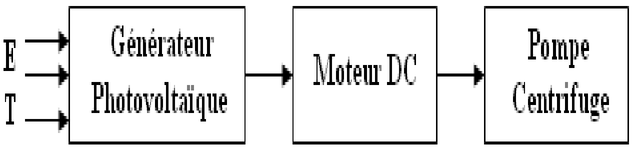


Fig. 14 Direct coupling of a PV pumping system.

The coupling conditions will be:

$V_m \le V_{co}$ and $I_m \le I_{cc}$.

Where:

Vm: the motor voltage at nominal speed.

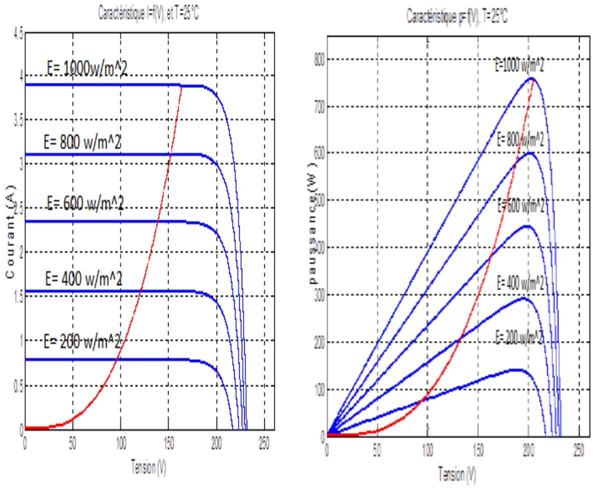
Im: the motor current at nominal speed.

Vco: the open circuit voltage of the PV generator.

Icc: the short-circuit current of the PV generator.

The figures (15) show the patterns of the voltages and powers during the operation of the system in direct coupling.

It is obvious that the centrifugal motor-pump assembly is well suited to the PV system because it allows a start for very low values of sunshine.



Fig,15 The characteristics p (V) and I (V) of a direct coupling for different illuminations and a constant temperature T = 25 °

IV.1. THE EFFICIENCY AND THE QUANTITY OF WATER OF THE SYSTEM IN DIRECT COUPLING:

The quality of the adaptation in direct coupling is defined by the efficiency of the system.

$$\eta_h = \frac{P_h}{P_{GPV}} = \frac{\rho.g.Q.Hm}{E.Ns.Np.S} \qquad (11)$$

With Q: The quantity of water Et is given according to by the following relation: [5]

$$Q = \begin{cases} 0 & si\ E \langle E_t \\ \dfrac{-b+\sqrt{b^2+4a(E-c)}}{2a} & si\ E \rangle E_t \end{cases} \qquad (12)$$

Et = 1000 W / m²; a, b and c are constants.

η_h: hydraulic performance of motor-pump unit
P_h: hydraulic power
P_{GPV}: generator power PV

The figure (16) shows the variations in efficiency as a function of illumination. According to these results, the system works in zone 3 only for high luminance values where the water quantity is maximum and can reach about 10.5 (m³ / s), [5].

In the figure (17), we note that for low illumination values, the operating points deviate from the optimum power. The system then operates on zone 1, where the low efficiency, of the order of 32%. For direct coupling, the pump motor system only operates from 300W / m². With solar radiation of 700W / m², we achieve a performance that allows us an optimal water flow for maximum performance. The motor runs in nominal mode.

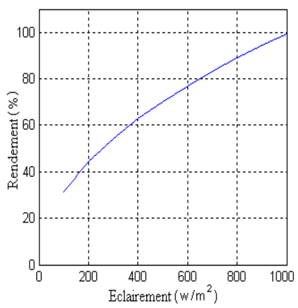


Fig. 16 The yield in direct coupling

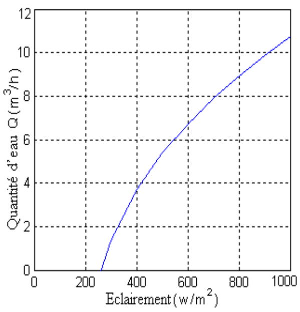


Fig. 17 Water quantity in direct coupling.

Despite the advantages of direct coupling, simplicity, low cost, and good performance, unfortunately such coupling is only possible under specific conditions (temperature, illumination, type and load parameters). So, more sophisticated techniques are needed in most applications.

V . OPTIMIZATION OF THE PHOTOVOLTAIC PUMPING SYSTEM:

The optimization of the photovoltaic pumping system consists in maximizing the quantity of pumped water, which amounts to maximizing the driving speed for each illumination or the generating efficiency PV-engine.

To do this, a boost DC-DC converter is inserted between the photovoltaic generator and the motor-pump unit. A DC-DC converter is a power conversion system with an appropriate control algorithm to extract as much power as the photovoltaic generator can provide.

V.1. BASE OF IMPEDANCE ADAPTATION BY A DC-DC CONVERTER

The MPPT is comparable to a transformer, converting the current and voltage input variables (I, V) into output quantities of the same type (I_{ch}, V_{ch}).

Such as:

$$V_{ch} = G.V \qquad (13)$$

$$I_{ch} = (1/G).I \qquad (14)$$

Where G = Vch / V: is an amplification gain of the DC / DC converter. [6].

$$V_{ch} = R_a I_{ch} + L_a.\frac{dI_{ch}}{dt} + k_e\omega \qquad (15)$$

And the torque of the motor

$$Ce = Kt * Ic \qquad (16)$$

The centrifugal pump opposes a resistive torque:

$$Cr = kr * W^2 + C \qquad (17)$$

Ke(V/rad.s⁻¹), kt(Nm/Ampère) et kr(Nm/rad.s⁻¹) are proportionality coefficients.

On the other hand, we have the mechanical equation:

$$J_m \frac{d\omega}{dt} = C_m - C_r \qquad (18)$$

With Jm: the moment of inertia of the group.

If it is assumed that the converter is ideal, in optimal operation, the maximum power delivered by the generator under a current Iop and a voltage Vop is:

$$P_{op} = V_{op} * I_{op} = V_{ch} * I_{ch} \qquad (19)$$

The optimum G_{op} gain value must be determined according to load and climatic conditions (illumination, temperature). [5]

V.2 MAXIMUM MPPT POWER POINT SEARCH TECHNIQUES BY (P & O) METHOD

The perturbation and observation (P & O) is an approach widely used in research because of MPPT is an iterative and requires only simple measures Vpv and Ipv, it can detect the point of maximum power even when variations sudden radiation and temperature.

As its name implies, the method P & O works with the disturbance voltage Vpv and observing the impact of this change on the output of the photovoltaic panel.

The algorithm of the P & O method is represented by figure (2). [7]

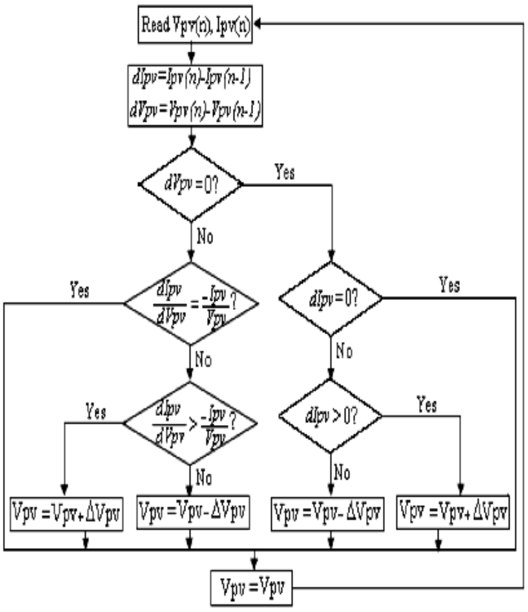


Fig. 18 Organizational chart of the perturbation and observation

At each cycle, V_{pv} and I_{pv} were measured to calculate P_{PV} (k). This value P_{PV} (k) is compared to the value P_{PV} (k-1) calculated the previous cycle.

If the power output increased V_{PV} is adjusted in the same direction as in the previous cycle.

If the power output decreased V_{pv} is adjusted in the opposite direction than in the previous cycle. V_{pv} was so upset at each cycle MPPT.

When the maximum power point is reached, V_{Pv} oscillates around the optimal value VbVmpp. This causes a power loss that increases with no increment of the disturbance. If this increment is not large, the MPPT algorithm responds quickly to sudden changes in operating conditions.

On the other hand, if the step is small, the losses in terms of atmospheric changes slow or stable, but will lower the system can not respond quickly to rapid changes in temperature or irradiation. [8]

The disadvantage of the technique of P & O is that in case of rapidly changing weather conditions, such as a moving cloud, this method can move the operating point in the wrong direction as shown in Figure (19).

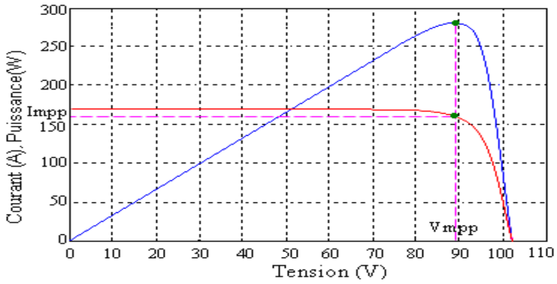


Fig.19 Maximal operating point

Initially, the operating voltage of the converter is in (1),which is the maximum power point.

Assume that a disturbance moves the operating point to point (2). During this period of disruption, the illumination was increased from E1 to E2. This leads to an increase in the extent of output power converter Ppv1 to P_{PV2}.

However, the maximum power point in this light is in (4), which corresponds to maximum power P_{PV}, max, E2.

In the disturbance following the algorithm of P&O increment the operating voltage of the converter (MPPT) much further right to the point (3), and even an increase of power converter will be measured if the illumination was increased E2 to E3 with the new point of maximum power point (5).

In this way, the algorithm of P & O will continue to move the operating point of the converter below the maximum point of real power and more power will be lost.

This incorrect adjustment will continue until the change of illumination slows or stabilizes.

The first solution to this problem is to increase execution speed by using a micro-controller faster.

The second option is to check any rapid change in radiation checking the value of dI_{pv}/dt and neutralizing the tension adjustment if the change of dI_{pv}/dt exceeds a limit.

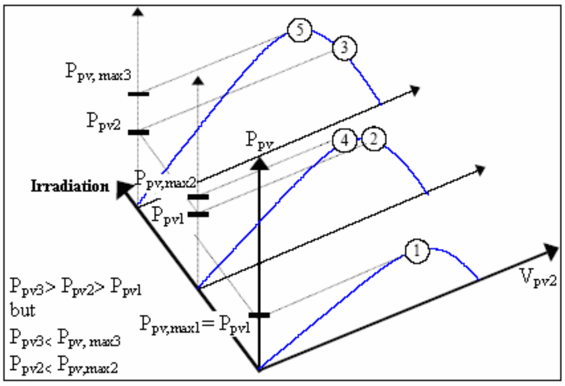


Fig.20 Divergence of the P & O method [8]

VI. COMPARATION BETWEEN AN OPTIMIZED AND UNOPTIMIZED SYSTEM:

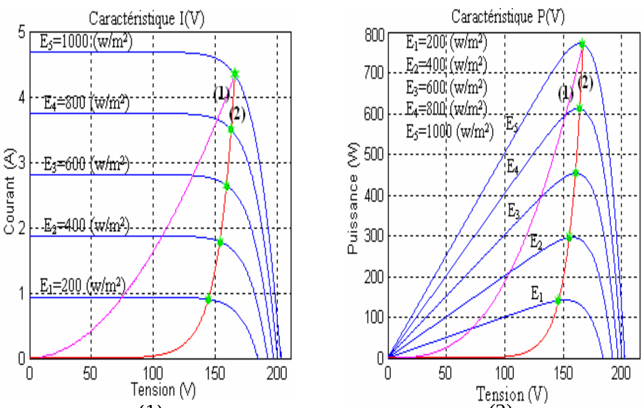
Regardless of the nature of the coupling of the pump unit to the photovoltaic generator, with or without optimization criteria, load characteristic, power, efficiency and quantity of water supplied by the pumping system are the main parameters, allow the evaluation and validation of the operation of the photovoltaic system. [8]

VI.1. LOAD AND POWER CHARACTERISTICS

Figures (21) show the load characteristic.The operation of the system is improved by the use of the MPPT technique, where the MCC is powered by voltages closer to the nominal values, the effect of the technique over direct coupling is very clear for the low values of the " Illumination at 200W / m^2, the supply voltage is increased by as low as 75V during the direct coupling, to a value of 140V as a result.

The powers obtained by the MPPT technique are the highest values possible, hence the operation of the system is ideal. Thus, the overall power of the photovoltaic generator is well exploited. [9]

Figures (21) show the large difference between the maximized power and the direct coupling power.



(1) (2)

Fig. (VI.8) PPV System Load and Power Curve, T = 25 ° C

(1) Direct Coupling (2) Coupling with MPPT

VI.2. CHARACTERISTIC OF THE EFFICIENCY AND THE FLOW RATE OF THE PUMPING SYSTEM

The efficiency calculated is defined by the ratio between the power obtained at the motor output and the maximum power available.

The figure (22) illustrates the efficiency rate, which is 100 % for the idealized MPPT technique, on the other hand the direct coupling is characterized by a low efficiency, especially for low illumination values. However, from E = 900W / m^2 and above, the efficiency values will be close, this approximation shows the good adaptation between the motor-pump unit and the generator for direct coupling at high illuminations.

The figure (23) shows the rates of the flow rates, with the direct coupling and with the MPPT technique as a function of the illumination.

In the case of direct coupling, the system only starts to deliver water at an illumination of 280W/ m^2, therefore the power maximization forces the pump to provide water from 175W / m^2. [5]

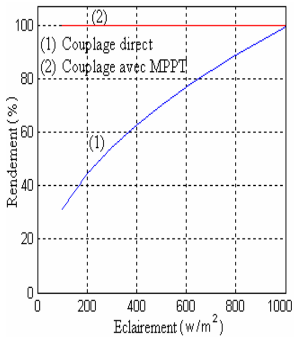


Fig.22. Output of pvp system

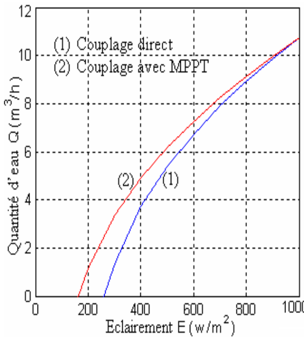


Fig.23 Quantity of water of pvp system

VII. CONCLUSION:

The PV pumping system is an ideal solution for supplying water to sparsely populated, isolated and enclosed areas. For an ideal optimization of the energy delivered by the generator, the MPPT maximization or tracking maximum power technique is used. But this technique has some disadvantages such as the complexity of implantation and the high price. Direct coupling is the simplest, least expensive connection to all the techniques studied.

The true MPPT technique represents an ideal operating case of the PV system, in view of the complexity of the maximum point search system.

The improvements proposed in this work remain always simple, easy for the practical realization, and give powers close to the ideal powers.

The simulation results show that this proposal deserves to be seen more deeply and to be translated into practical implementation.

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