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Optimisation of Back-Boost Converter by MPPT Technique with a Variable Reference Voltage Applied to Photovoltaic Water Pumping System under Variable Weather Conditions

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Abstract: This study presents the optimisation of a photovoltaic water pumping system using Maximum Power Point Tracking Technique (MPPT). The optimisation suspends to reference optimal voltage. This technique is developed to assure the optimum chopping ratio of Back-Boost converter. It was experienced in photovoltaic water pumping system in order to optimise its global efficiency and to increase its power instead of linking it directly or using the complex MPPT technique. And it keeps its efficacy at high temperature and with guaranteeing its practical execution simply and easily.

Key words: MPPT techniques, back-boost converter, open circuit voltage, insolation, chopping ratio and photovoltaic water pumping system

INTRODUCTION

The rural zones and isolated areas require an individual power supply to avoid the overload of the electrical network supply and the undesirable cuts; in this case, electricity must be produced starting from a renewable energy source as the solar energy (Jebaraja and Iniyanb, 2004). This latter is a source with no pollution, no noise and renewable (Michel, 1998; Yu *et al*., 2004; Hua and Lin, 2004; Hua *et al*., 1998). But, its major problem resides in the initial cost of the system (Johan *et al*., 1997). With the development of technology, the cost of the PV generator is expected to decrease continuously in the future (Hua and Lin, 2004). In this field, there are two commonly use compositions of Photovoltaic Pumping System (PVPS) (Abidin and Bulant, 2004) the first is battery-buffered PVPS. The PVPS stores water instead of storing electrical energy (Viorel, 2003; a, b). And the second is without battery (Betka and Moussi, 2004; Benlarbi *et al*., 2004; Abdel *et al*., 2005; Langridge *et al*., 1994).

The developed countries tried to adopt intensive planning and programs in order to encourage researchers to find out methods to get the solar energy with less expensive costs (Jebaraja and Iniyanb, 2004; Harsono *et al*., 2003; Barbosa *et al*., 2000).

As Algeria is characterised by its good geographical situation, it receives important quantity of solar radiation during the years and seasons (Meafi, 2000). Various studies have been undertaken until now on the solar energy in Algeria. These studies have proved considerable energy quantity for prosperity, the use and exploitation of this source. In terms of insolation, local daily average is higher than 5 kWh/m2. Period of insolation, on all the territory, annually exceeds 2500 hours and can reach 3900 hours in high plateaus and the Sahara (Anonymous, 2001). Form these examples, the agricultural use of solar energy to produce electric energy and water pumping system is necessary (Vilela *et al*., 2004; Franscisco *et al*., 2004). So that we propose this study and that is represented in studying PVPS. And for the aim of the study is not restricted to theoretical results, but for the exploiting it. This study focuses on the analysis of coupling means, like direct coupling, the focus on the different types of Maximum Power Point Tracking (MPPT) considering climate circumstances and temperature. We propose for this study a new technique of MPPT with variable. Reference voltage based on a fixed percentage of open circuit Voltage (Voc) to become MPPT with variable reference voltage based on two linear functions according to open circuit voltage and insolation. This method keeps the good performance of the MPPT with variable voltage with current (True MPPT) (Langridge *et al*., 1994). For a pumping system, the load is generally a DC or AC motor. For the former, the power-conditioning unit is most commonly a DC/DC chopper. Many types are used such as buck, boost and buck-boost (Maheshappa *et al*., 1998). Recent research has dealt with most of theses converters in order to find the most compatible type in terms of overall power system efficiency (Illan and Josph, 1996; Altas and Sharaf, 1996; Martins *et al*., 1998; Hua and Shen, 1998).

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It is stated that the boost converter is the most convenient for maximum power tracking. Furthermore, if the required output voltage is less than the generated one, it is recommended to use a two stage conversion unit, the boost+step down converter.

If an AC motor is used, an inverter should be included in order to perform the DC/AC conversion stage. This has been reported in (Eskandar and Zaki, 1997)using six steps quasi-square wave inverter.

PWM inverter yields better waveforms at no real increase in cost. Recently, resonant inverters have received attention (Martins *et al.*, 1998) in order to reduce power losses at the inverter level and hence increase the net system power capture.

The various applications of PV systems in various fields require the exploitation of new modes of connections and techniques optimising their effectiveness. Among these techniques, the maximisation of output starting from the maximisation of the mechanical power of output of the system (motor, pump…) (Weiner and Levinson, 1996). In this context, detailed studies of PVPS based on a criterion of optimisation allowing a maximum daily hydraulic storage is carried out in (Barbosa *et al.*, 2000; Karaghouli and Sabounchi, 2000; Pratogeropoulos and Pearce, 2000).

If the direct coupling does not offer good performances, the use of an electronic circuit using a technique of research of the Maximum Power Point (MPPT) is considered. It makes it possible to transfer the maximum of energy from PV generator whatever are the operating conditions (Van and Van, 1998). This technique remains until now the most popular in the photovoltaic field. According to the methods of implementation, one distinguishes three types of MPPT (Langridge *et al.*, 1994).

- MPPT with variable voltage and current (true MPPT).
- MPPT with fixed voltage and varying current.
- A MPPT with variable reference voltage based on a fixed percentage of open circuit voltage.

Aiming at improving the performances of MPPT; the use of a chopper proposed has variable cyclic relationship between 0 and 1. The domain of research for maximum power is limited to the zone of maximum power; thus, reducing the search time. Recent studies have shown the PVPS efficiency, relationship between the delivered hydraulic power and the input power of the generator, can vary between 50 to 60% (Kim *et al.*, 1996).

Various methods of MPPT have been considered in applications of solar arrays (Yu *et al.*, 2004); Hua and Lin, 2004). Previously used methods of achieving this goal include:

- Incremental conductance (IncCond): The system requires more conversion time and a large amount of power loss will result.
- Curve fitting: Is only used in places where the temperature variation is relatively small.
- Artificial neural network: The data acquisition and memory space is more important.
- Perturbation and observation (P and O): In cases in which solar insolation changes rapidly at lower insolation, MPPT control fail to track the MPP.

PHOTOVOLTAIC PUMPING SYSTEM

The proposed photovoltaic pumping water system is shown in Fig. 1. It is a way to bring out and pump water to a limited standard, where it can be stored or used directly (Abdel and Marwan, 2005). And this needs the use of suitable pumps that are frequently used because they can pump water to an acceptable head, even in slow speed.

The use of centrifugal pump needs a preliminary study of the most important charts that characterise it. These charts sum up the relation between the whole variables that control the pumped water quantity to a desirable head (Q-H). In addition, they are related to dimensions, kinds and rotation speed of the pump (Moussi *et al.*, 2004; Saadi and Moussi, 2004).

The chart of the water quantity-head (Q-H) explains the different variations in the head of pumping, according to water quantity which forms bent charts (Betka and Moussi, 2004; Benlarbi *et al.*, 2004). These latter are calculated by the following equations:

$$H = C_1\,\omega^2 - C_2\,\omega Q - C_3 Q^2 \quad (1)$$

$$H = H_g + \Delta H \quad (2)$$

The needed rotation speed to make a pump can be provided by the (BLDC) (Abidin and Bulent, 2004; Langridge *et al.*, 1994). This latter can be used in PV pumping system because it has a good efficiency about 80%, It is small in size, but with a large scale of speed variations and it is flexible in function. Furthermore, it is similar to the DC motor (Moussi and Saadi, 2004). Based on DC motor equations which are given as follow:

$$V_o = 2R\,I_o + 2k_e\omega \quad (3)$$

$$C_m = 2k_e I_o \quad (4)$$

$$C_r = A_c\omega^2 \quad (5)$$

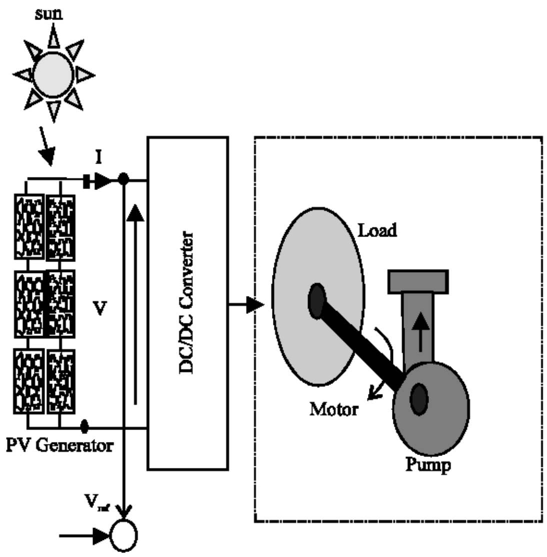

Fig. 1: Schematics of optimal PV water pumping system

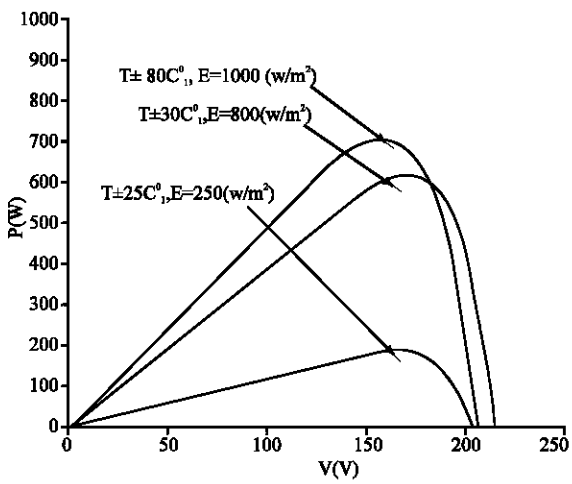

Fig. 2: Effect of insolation and temperature on PV generator power

Two main parameters can directly affect the power of generator which is both the temperature and insolation. The presented characteristics in Fig. 2 explain them clearly. Yet, Fig. 3 explains non-linear relation between the current and voltage of the photovoltaic generator (Hua, *et al*., 1998) and according to the Eq. 6-8.

$$I = I_g - I_{sat}\left[\exp\left(q\left(V+R_s I\right)/\left(AKT\right)\right)-1\right] \qquad (6)$$

$$I_g = \left[I_{sc} + K_I\left(T_c - 25\right)\right]\left(\lambda/100\right) \qquad (7)$$

$$I_{sat} = I_{or}\left[T/T_r\right]^3 \exp\left[\frac{q E_{GO}}{KT}\left(1/T_r - 1/T\right)\right] \qquad (8)$$

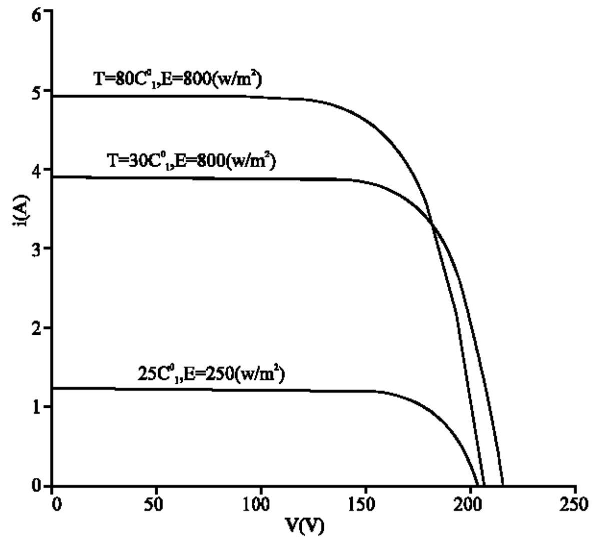

Fig. 3: Non-linear charts of PV generator voltage and current

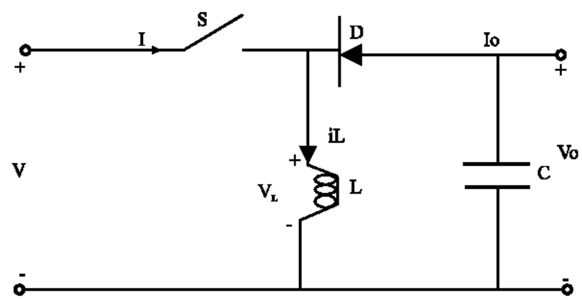

Fig. 4: Circuit of Buck -Boost DC/DC converter

The DC/DC converters of different types where used in the solar energy system deliver the highest power to the load from PV generator with efficiencies about 97%, 93% and 91% for buck, buck-boost and boost chopper respectively. The circuit arrangement of a buck-boost converter is shown in Fig. 4 when S is on, the voltage across L is, $V_L = V$ when S is off, the voltage across L reverses ($V_L = V$), the average voltage across L is zero (Hua and Shen, 1998). The equations are:

$$\alpha = \frac{t_1}{T_1} \qquad (9)$$

$$t_1 = \alpha T_1 \qquad (10)$$

$$t_2 = (1-\alpha)T_1 \qquad (11)$$

The switching period T_1 can be found from:

$$T_1 = \frac{1}{f} = t_1 + t_2 \quad (12)$$

$$\frac{V_o}{V} = \frac{t_1}{t_2} = \frac{\alpha}{1-\alpha} \quad (13)$$

$$Y = \frac{\alpha}{1-\alpha} \quad (14)$$

$$I = \frac{I_o.\alpha}{1-\alpha} \quad (15)$$

DISCUSSION

Several ways have been tried out in order to seek the maximum power point of the P-V characteristic. The ideal way is to calculate the output power and compare it with the ideal one. The system is then pushed toward the optimal operating point. This method is tedious, complex and time consuming, especially difficulties presented to find the ideal maximum power. The optimal power can be achieved in a narrow zone of the output voltage. Therefore, if the output voltage is kept at a predetermined value, a sub-optimal power tracking can be achieved. A reference voltage is used in a control loop in order to drive the DC/DC converter such that V = Vref. Practically, there are two ways to implement this technique which differ in the way of the reference voltage is handled:

The first, the reference voltage can be a constant predetermined value derived from observing the PV generator characteristic and choosing a single value thereafter. This method is also known as fixed voltage control. In practice, this value is chosen around 62-80% of the open circuit voltage Voc measured for a temperature of 25oC and solar insolation of E = 1000W/m2.

The second, knowing that there is a relationship between the open circuit voltage Voc and temperature of a PV module, the value of the reference voltage Vref, can be set as a fraction of Voc. Generally, Vref is chosen in the range 68-77% of Voc.

The supply of the PVPS with the voltages and the optimal currents of true MPPT technique ensures an ideal operation of the system and under certainly maximum powers during any change of the insolation and temperature, as indicated in Fig. 5 and 6 Furthermore, for the technique of fixed voltage, the maximum power can be reached in full insolation. But this performance vanish quickly for weak insolation and reached 88.2897%.These losses of energy are less significant than the MPPT with reference voltage based on percentage of open circuit voltage Voc.

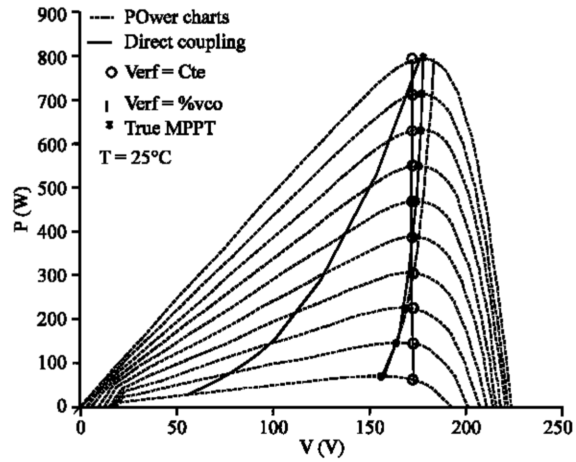

Fig. 5: Power charts of PVPS of different MPPT techniques; T = 25°C

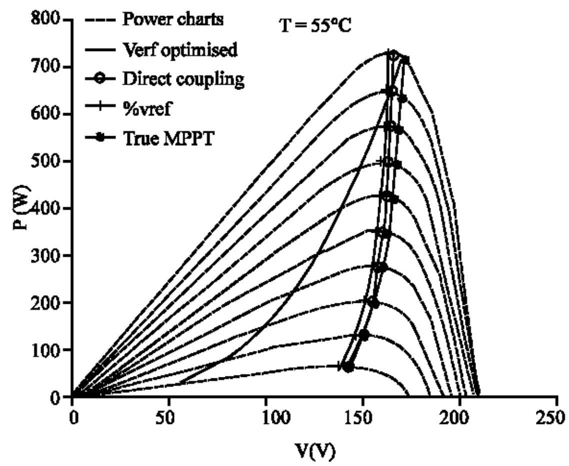

Fig. 6: Power charts of PVPS of different MPPT techniques; T = 55°C

In Fig. 7 and 8, the MPPT technique with referenced voltage based on percentage Voc (% = 0.82), shows the charts one above the other for true MPPT.

The MPPT technique with referenced voltage based on percentage of open circuit voltage loses 1.8% of efficiency comparing with the true MPPT in 25°C and 0.5% in 55°C.

In the proposed technique the reference voltage based on tow segments, the percentage of Voc (% = 0.82) and insolation. The new formula for the reference voltage is:

$$V_{new,ref} = \sigma V_{oc} + \gamma E \quad (16)$$

Were: γ fixed value (for T = 25°C).

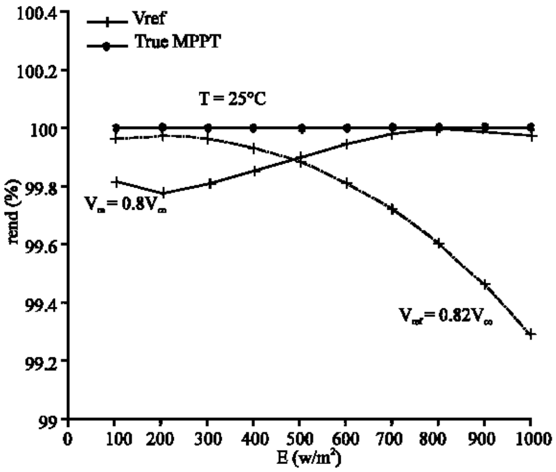

Fig. 7: Efficiency Charts of MPPT with variable reference voltage (Vref = %Voc) ; T = 25°C

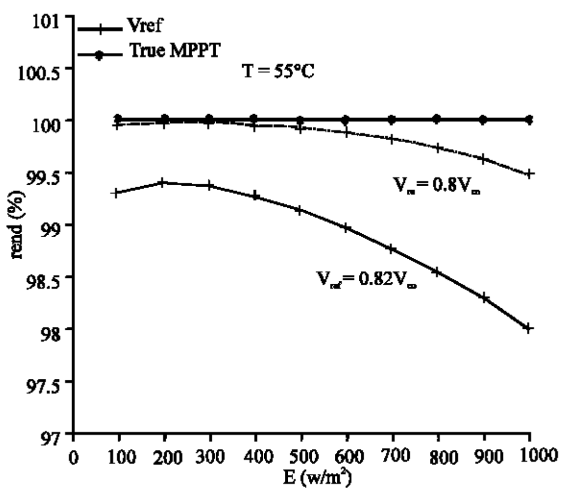

Fig. 8: Efficiency charts of MPPT with variable reference voltage (Vref = %Voc) ; T = 55°C

In order to draw Fig. 9 and 10 that shows the tracking of the technique of maximum power values, the amelioration is clear especially at the high insolation. Fig. 11 and 12 shows the precise details.

The proposed technique approximately corresponds to the true MPPT technique. The technique of percentage reference voltage provides precision for weak insolations, but the more insolation increases; the more remoteness increases at maximum power points, especially at 55°C temperature.

Figure 13 and 14 shows the pumps flowrates for direct coupling and for optimised power, It is clearly seen that the performance of the pumping system are improved if the output power of the photovoltaic generator is optimal

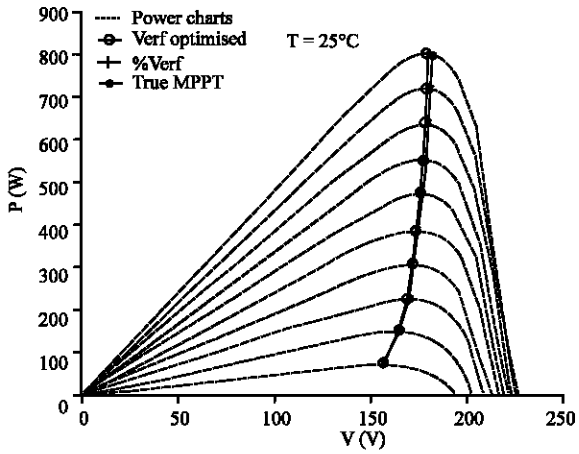

Fig. 9: Power charts of PVPS with optimised MPPT; T = 25°C

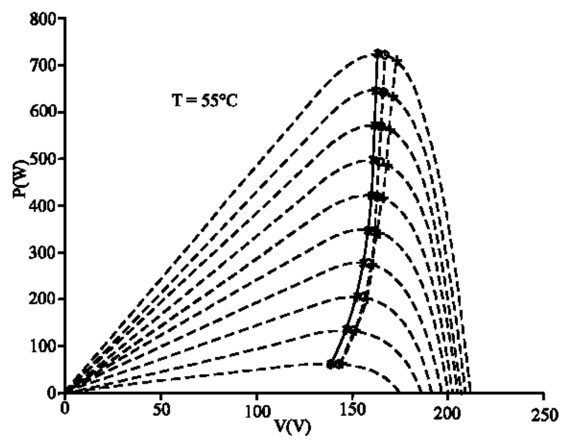

Fig. 10: Power charts of PVPS with optimised MPPT; T = 55°C

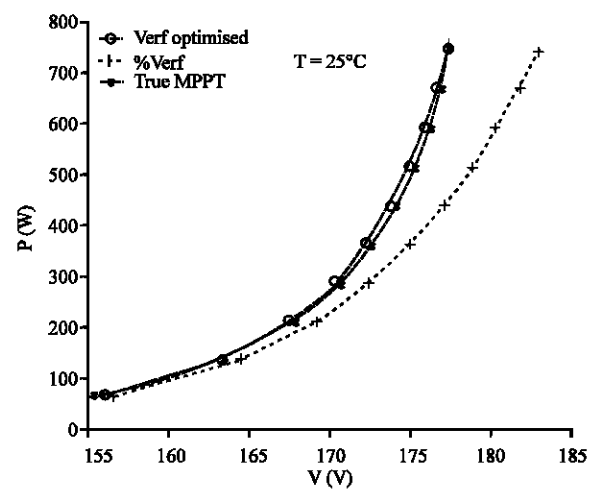

Fig. 11: Zoom in Power charts of PVPS with optimised MPPT, ; T = 25°C

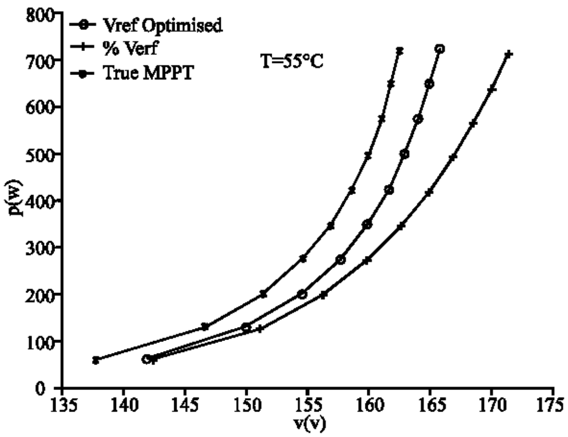

Fig. 12: Zoom in Power charts of PVPS with optimised MPPT; T = 55°C

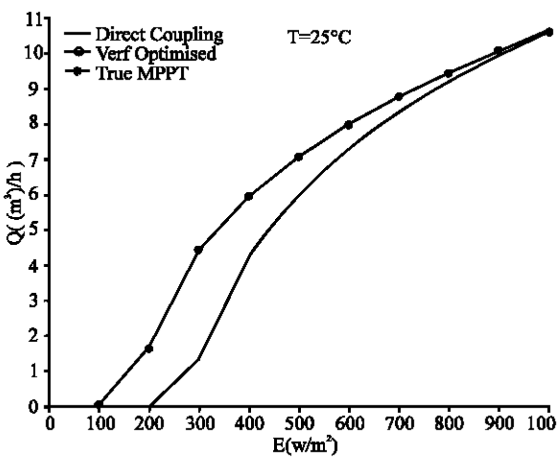

Fig. 13: Water quantity charts of pump with optimised MPPT; T = 25°C

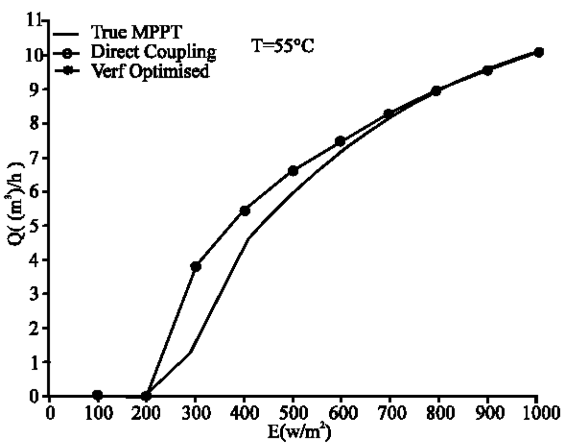

Fig. 14: Water quantity charts of pump with optimised MPPT; T = 55°C

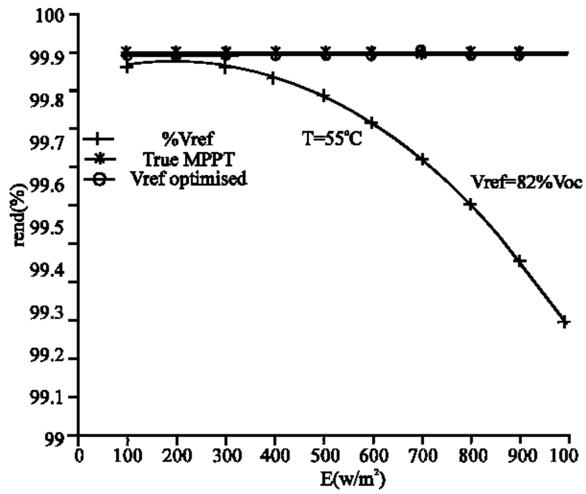

Fig. 15: Optimisation efficiency as a function of insolation ; T = 25°C

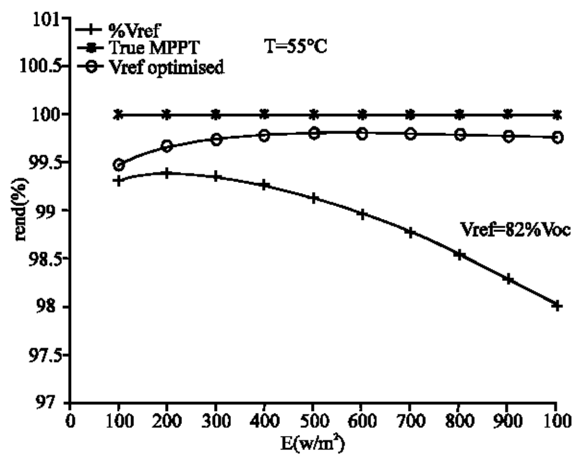

Fig. 16: Optimisation efficiency as a function of insolation; T = 25°C

and the efficiency of PVPS is maximum as shown in Fig. 15 and 16 the efficiency of proposed MPPT technique is identical to True MPPT efficiency in all variation of insolation.

We observe, in 25°C, the optimised system (with MPPT) starts at 100(w/m^2) of insolation radiation that is better than the direct coupling system because this latter starts at 200(w/m^2). But in 55°C both of the systems were influenced by the high temperature where start at 200(w/m^2). This is for the reason of weak power. In addition, there were an improvement in terms of their efficiency by 0.8%, specially at 25°C the efficiency reaches 100%.

Although the proposed model was attained systematically (25°C), it improves the efficiency by 1% in 55°C. The improvement of efficiency means the improvement in systems with important powers. The importance of this study reveals in these systems. This proposed technique shows its efficacy in regions with average temperature, or fixed one (space).

CONCLUSION

Various control techniques were reported and implemented through contemporary equipment. The MPPT technique is to optimise the function of the system. Although the MPPT with variable reference based on percentage of open circuit voltage is approximate to the true MPPT for its results. But the proposed optimisation on this technique makes it with a finite precision, in order to reach maximum power instead of the optimal power. The proposed technique ameliorates the efficiency to 100%, it also keeps its robustness at high temperature. The percentage of efficiency improvement is about 0.8%.

Nomenclature

A ideality factor for a p-n junction
A_c pump torque constant
C1,C2,C3 constants depending on the pump dimensions
E Insolation (w/m^2)
E_{GO} band-gap energy of the semiconductor
f frequency (Hz)
H total head (m)
Hg geodetic head (m)
I generator current (A)
I_0 output current of chopper (A)
I_{or} saturation current (A)
I_s input current of chopper (A)
I_{sat} reverse saturation current (A)
Isc short-circuit current (A)
K Boltzmann's constant
Flux coefficient
K_I coefficient of short-circuit current temperature
charge of an electron
Q flow rate (m3/h)
R Armature circuit resistance (Ω)
Rs series generator resistance (Ω)
T temperature of the solar array
T_1 Switching period of chopper
T_c Cell temperature
T_r reference temperature.
On-time of chopper switching (s)
Off-time of chopper switching (s)
V output generator voltage (V)
V_0 output voltage of chopper (V)
V_{oc} open circuit voltage (V)
Motor speed (rd/s)
Chopping ratio
Duty ratio
Insolation (mW/cm^2)

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