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Maximum Power Point Tracking Using Fuzzy Logic Control

Mohamed M. Algazar[1] , Hamdy AL-monier[2] , Hamdy Abd EL-halim[1],
Mohamed Ezzat El Kotb Salem[3]

ABSTRACT

This paper proposes an intelligent control method for the maximum power point tracking (MPPT) of a photovoltaic system under variable temperature and insolation conditions. This method uses a fuzzy logic controller applied to a DC-DC converter device. The different steps of the design of this controller are presented together with its simulation. The PV system that I chose to simulate to apply my techniques on it is stand-alone PV water pumping system. Results of this simulation are compared to those obtained by the system without MPPT. They show that the system with MPPT using fuzzy logic controller increase the efficiency of energy production from PV.

Keywords: Photovoltaic (PV), Maximum power point tracking (MPPT), Fuzzy Logic Control (FLC), MATLAB/SIMULINK.

I. INTRODUCTION

In our Arabian nation peopled areas is very small comparing to total area because fresh water resources concentrate in these areas. Now, the existing fresh water almost enough for our needs, but in the near future with increasing in people numbers it will be huge problem. On the other hand we have shining sun all the year, so we can use stand alone PV-powered water pumping system to get water in non peopled areas. Unfortunately the actual energy conversion efficiency of PV module is rather low. So to overcome this problem and to get the maximum possible efficiency, the design of all the elements of the PV system has to be optimized.

In order to increase this efficiency, MPPT controllers are used. Such controllers are becoming an essential element in PV systems. A significant number of MPPT control have been elaborated since the seventies, starting with simple techniques such as voltage and current feedback based MPPT to more improved power feedback based MPPT such as the perturbation and observation (P&O) technique or the incremental conductance technique [1-2]. Recently intelligent based controls MPPT have been introduced.

In this paper, an intelligent control technique using fuzzy logic control is associated to an MPPT controller in order to improve energy conversion efficiency.

II. THE PROPOSED SYSTEM

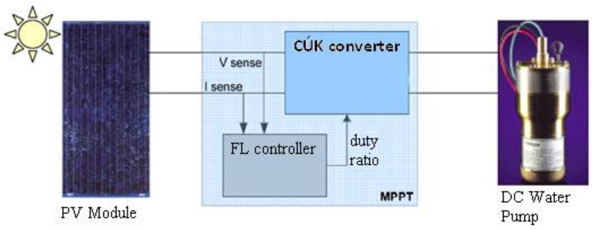

Figure 1 Block diagram of the proposed PV water pumping system.

The proposed system in this paper is stand-alone DC water pumping without backup batteries. As shown in Figure 1, the system is very simple and consists of subsystems: PV module, DC-DC CÚK converter, FL controller and DC water pump. The size of the system is intended to be small; therefore it could be built in the lab.

1) Faculty of Engineer, Electrical Power & Machines Dept., Al-Azhar University, Cairo, EGYPT.

2) Naser High Institute for Engineering and Technology, Electronics & communication Dept., Cairo, EGYPT.

3) B.Sc. Electrical Power & Machines engineer Al-Azhar University, Cairo, EGYPT, 2004.

III. MAXIMUM POWER POINT TRACKING ALGORITHMS

When a PV module is directly coupled to a load, the PV module's operating point will be at the intersection of its I–V curve and the load line which is the I-V relationship of load. For example in Figure 2, a resistive load has a straight line with a slope of $1/R_{load}$ as shown in Figure 3. In other words, the impedance of load dictates the operating condition of the PV module. In general, this operating point is seldom at the PV module's MPP, the optimal adaptation occurs only at one particular operating point, called Maximum Power Point (MPP) and noted in our case Pmax.

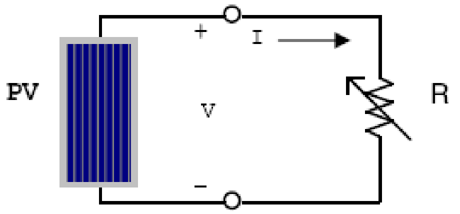

Figure 2 PV module is directly connected to a (variable) resistive load [5].

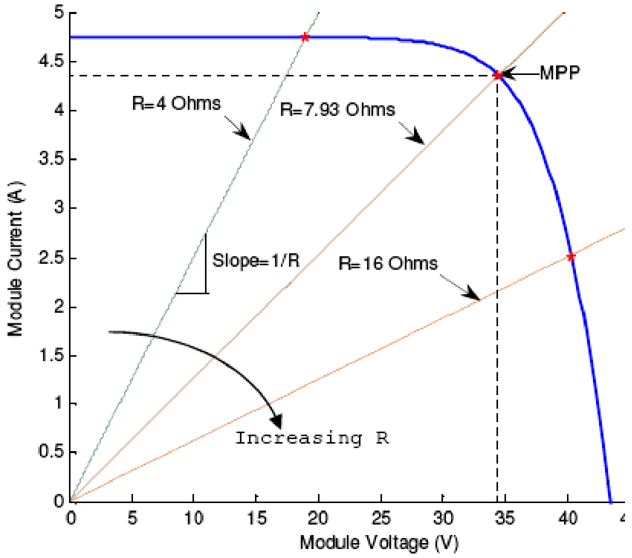

Figure 3 I-V curves of BP SX 150S PV module [14] and various resistive loads simulated with the MATLAB model (1KW/m2, 25°C) [5].

To overcome this problem, it is necessary to add an adaptation device, MPPT controller with a DC-DC Cúk converter, between the source and the load [3].

Furthermore the location of the MPP in the I–V plane is not known beforehand and always changes dynamically depending on irradiance and temperature [6,7]. For example, figure 4 shows a set of PV I–V curves under increasing irradiance at the constant temperature (25 °C), and figure 5 shows the I–V curves at the same irradiance values but with a higher temperature (50 °C).

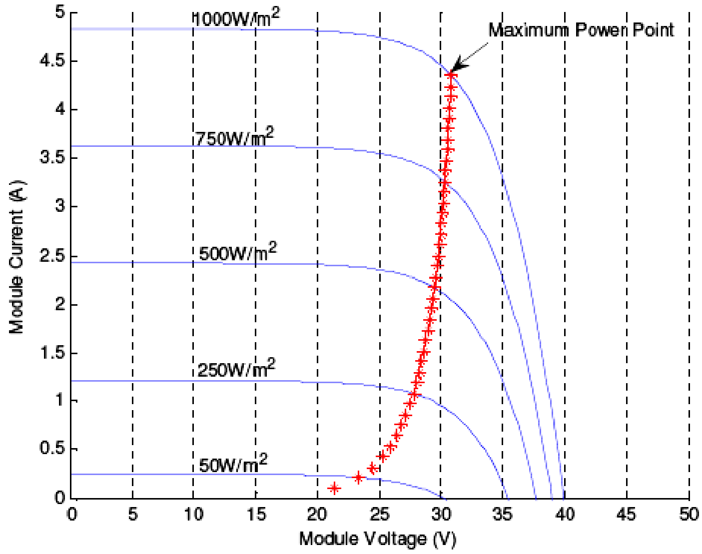

Figure 4 I-V curves for varying irradiance and a trace of MPPs (25 °C) [5].

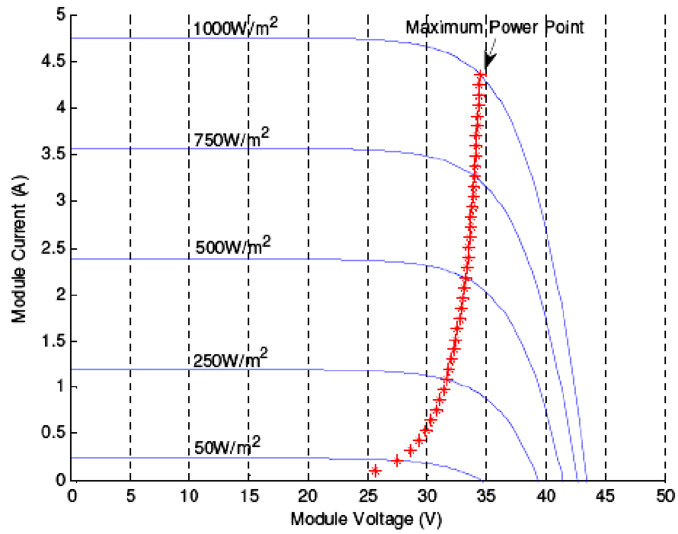

Figure 4 I-V curves for varying irradiance and a trace of MPPs (50 °C) [5].

There are observable voltage shifts where the MPP occurs. So, the MPPT controller is also required to track the new modified maximum power point in its corresponding curve whenever temperature and/or insolation variation occurs.

Many MPPT control techniques have been conceived for this purpose these last decades [1, 4].

Maximum power point tracking algorithms:

- Perturb & Observe Algorithm
- Incremental Conductance Algorithm
- Parasitic capacitances
- Constant Voltage control
- Constant Current control
- Pilot cell
- Artificial Intelligent method (Fuzzy logic control, neural network…)

They can be classified as:

- Voltage feedback based methods which compare the PV operating voltage with a reference voltage in order to generate the PWM control signal of the DC-DC converter [8].
- Current feedback based methods which use the PV module short circuit current as a feedback in order to estimate the optimal current corresponding to the maximum power.
- Power based methods which are based on iterative algorithms to track continuously the MPP through the current and voltage measurement of the PV module [5].

IV. FUZZY LOGIC MPPT CONTROLLER

Recently fuzzy logic controllers have been introduced in the tracking of the MPP in PV systems [9-10]. They have the advantage to be robust and relatively simple to design as they do not require the knowledge of the exact model. They do require in the other hand the complete knowledge of the operation of the PV system by the designer.

The proposed system in this thesis consist of two input variables: error (E) and change of error (CE), and one out variable: duty ratio or duty cycle (D), as shown in figure 6.

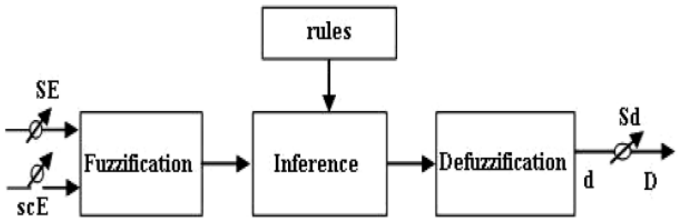

Figure 6 General diagram of a fuzzy controller [3].

A) *Fuzzification*

Membership function values are assigned to the linguistic variables, using five fuzzy subsets: NB (negative big), NS (negative small), ZE (zero), PS (positive small), and PB (positive big). The partition of fuzzy subsets and the shape of membership function, which can adapt shape up to appropriate system, are shown in Figure 7.

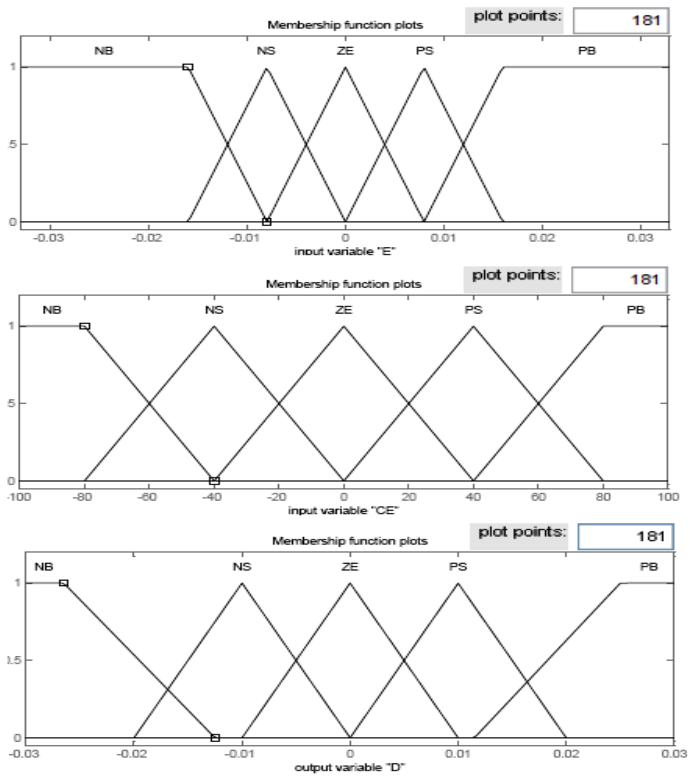

Figure 7 Fuzzy logic membership functions for inputs and output variables.

The value of input error (E) and change of error (CE) are normalized by an input scaling factor. In this system the input scaling factor has been designed such that input values are between -1 and 1.

The triangular shape of the membership function of this arrangement presumes that for any particular input there is only one dominant fuzzy subset. The number of fuzzy subset are chosen depending on the required accuracy, some paper [11] using 7 subset for the same problem but the increasing in accuracy is very small.

The input variables error (E) and change of error (CE) for the fuzzy logic controller can be calculated as follows:

$$E(K) = \frac{\Delta I}{\Delta V} + \frac{I}{V} = \frac{\Delta P}{\Delta V} = \frac{\Delta P}{\Delta I} \qquad (1)$$

$$CE(K) = E(K) - E(K-1) \qquad (2)$$

Where:

I = Output current from PV array.

Δ I = I(k) - I(k-1)

V = Output voltage from PV array

Δ V = V(k) - V(k-1).

B) Inference Method

The composition operation by which a control output can be generated. Several composition methods such as MAX-MIN and MAX-DOT have been proposed in fuzzy tool box in MATLAB. The commonly used method is MAX-MIN is used in this thesis. The output membership function of each rule is given by the MIN (minimum) operator and MAX (maximum) operator. Table 1 shows the rule table for fuzzy logic controller.

C) Defuzzification

Defuzzificaion for this system is the centre of gravity to compute the output of this FLC which is the duty ratio (cycle). The centre of gravity method is both very simple and very fast method. The centre of gravity defuzzification method in a system of rules by

E \ CE	NB	NS	ZE	PS	PB
NB	ZE	ZE	NB	NB	NB
NS	ZE	ZE	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS
PS	PS	PS	PS	ZE	ZE
PB	PB	PB	PB	ZE	ZE

Table 1 Fuzzy rule table.

formally given by:

$$D = \frac{\sum_{j=1}^{n} \mu(D_j) - D_j}{\sum_{j=1}^{n} \mu(D_j)} \qquad (3)$$

Duty ratio, the output of fuzzy logic control uses to control through PWM which generated pulse to control MOSFET switch in DC-DC converter.

D) Fuzzy Logic Control Simulation in MATLAB/SIMULINK

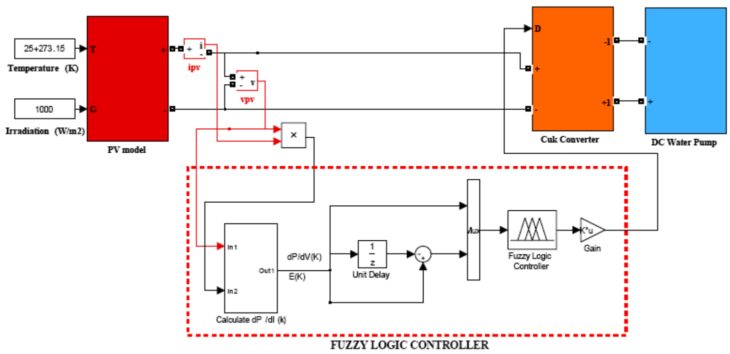

Figure 8 Fuzzy logic controller block.

Figure 8 show details of FLC block in MATLAB/SIMULINK. As I mentioned in beginning of this section, FLC for MPPT have two input variables and one out variables. The first step in shown block is to calculate the input variables using equations (1) and (2), then using FLC block which programmed as mentioned in previous sections to calculate duty ration which is the Pulse Width Modulator input that control the DC-DC converter to give the required output voltage and current.

V. SIMULATION OF PV WATER PUMP SYSTEM WITH MPPT

In this section my technique for MPPT will be tested with the proposed system. Figure 9 shows block diagram of the proposed system (stand-alone PV water pumping system with MPPT using FLC) simulated in MATLAB/SIMULINK.

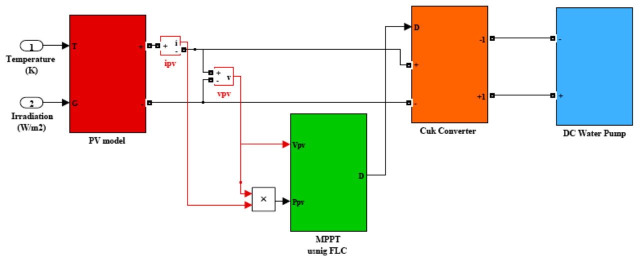

Figure 9 PV water pump system with MPPT simulated in MATLAB/SIMULINK.

First the system will be tested with two certain atmospheric conditions and comparing the result with theoretical data and direct-coupled system.

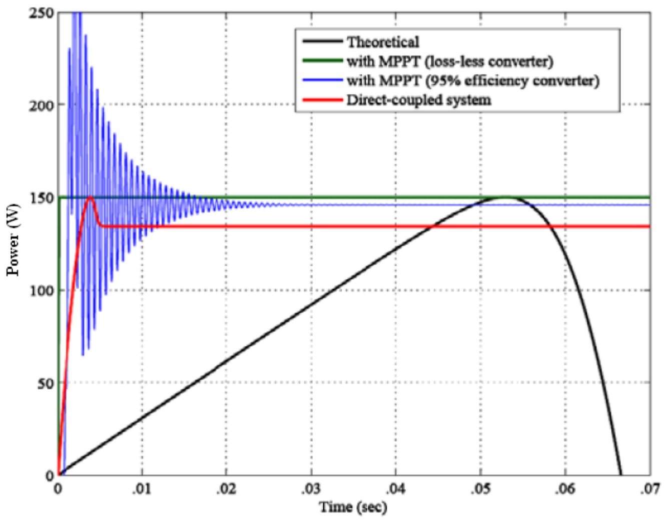

Figure 10 Result of system with irradiance 1000 W/m^2 and temperature 25 ºC.

Figure 10 show the test result for the first test scenario with irradiance 1000 W/m2 and temperature 25 oC. The PV system without MPPT has poor efficiency because of mismatching between the PV module and the DC pump motor load. The power generated by PV system with MPPT (assume loss-less converter) is approximately equal the theoretical maximum generated power at this atmospheric condition. Assuming a DC-DC converter has efficiency more than 95%, the system can increase the overall efficiency compared to the system without MPPT.

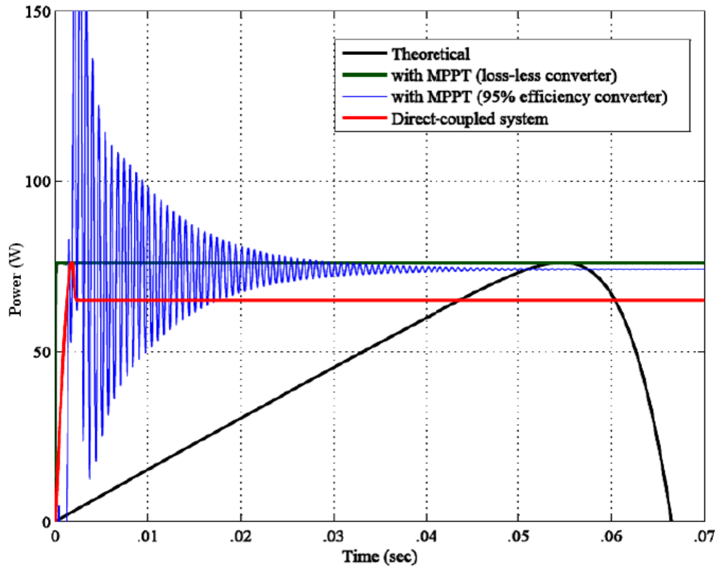

Figure 11 Result of system with irradiance 500 W/m2 and temperature 15 ºC.

Figure 11 show the test result for the second test scenario with irradiance 500 W/m2 and temperature 15 ºC. The result is show that, the PV system with MPPT can increase the overall efficiency compared to the system without MPPT, like that shown in the first test scenario figure 10.

Now for final test scenario and to provide a comparison with the system without MPPT in terms of energy produce and flow rates of water pumped, the system will be simulated using atmospheric data (irradiation and temperature) from National Renewable Energy Laboratory [12] for one day as shown in figures 12 and 13.

The day that I chose to using it's

atmospheric data for test the system is a very sunny day as shown in figure 12 (the irradiance increase gradually from sun rise 5:00 AM to noon then decrease gradually to sun set 6:42 PM) . The reason for this choice is to view clearly the effect of using MPPT in the system.

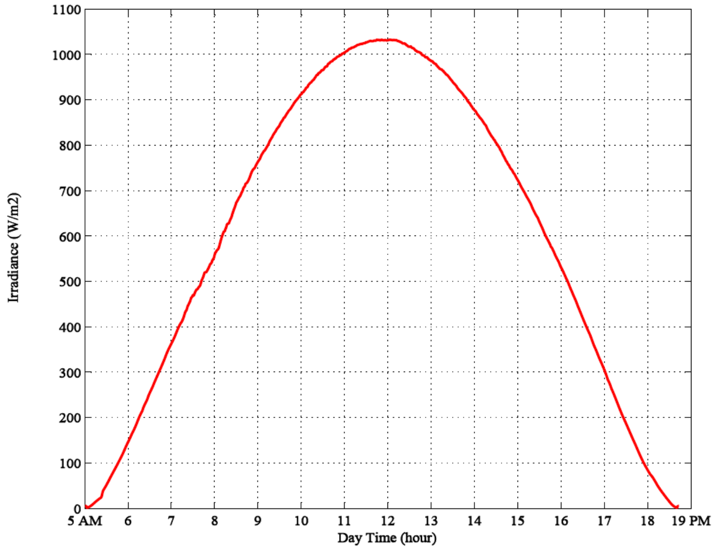

Figure 12 Irradiance vs. time data from 5:00 AM to 6:42 PM for sunny day simulation purpose.

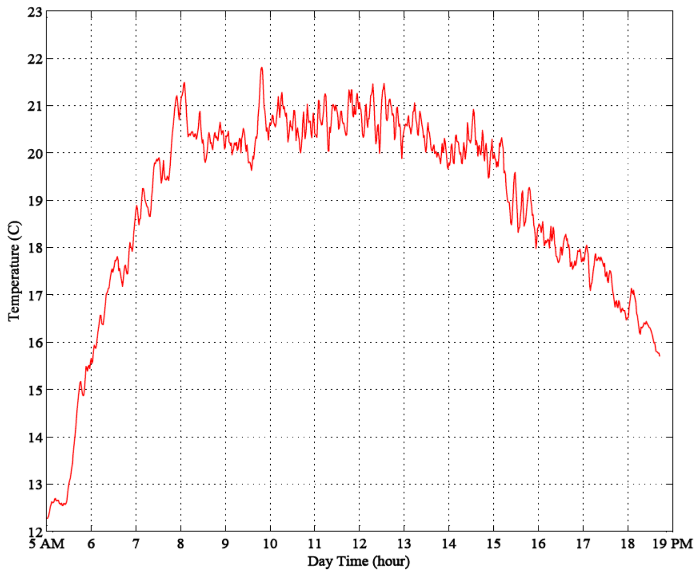

Figure 13 Temperature vs. time data from 5:00 AM to 6:42 PM for sunny day simulation purpose.

The effect of changing temperature over day time for choosing day is small because the temperature value varies in the most day hour around four degrees (18-21 ^{o}C), as show in figure 13.

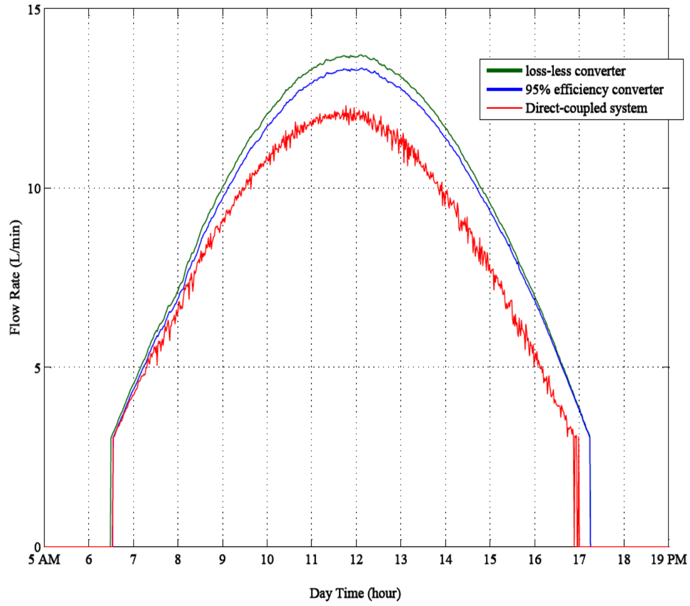

Figure 14 PV system power generating for day time period (from 5:00 AM to 6:42 PM).

Figure 14 show that, the generated power of PV system with MPPT is greater than the direct-coupled system. The difference will be maximum at noon time. It shows also that the system with MPPT has smooth curve over the day, but direct-coupled system has oscillation over the day time. This oscillation will affect on the performance of DC pump the long life run and its life time.

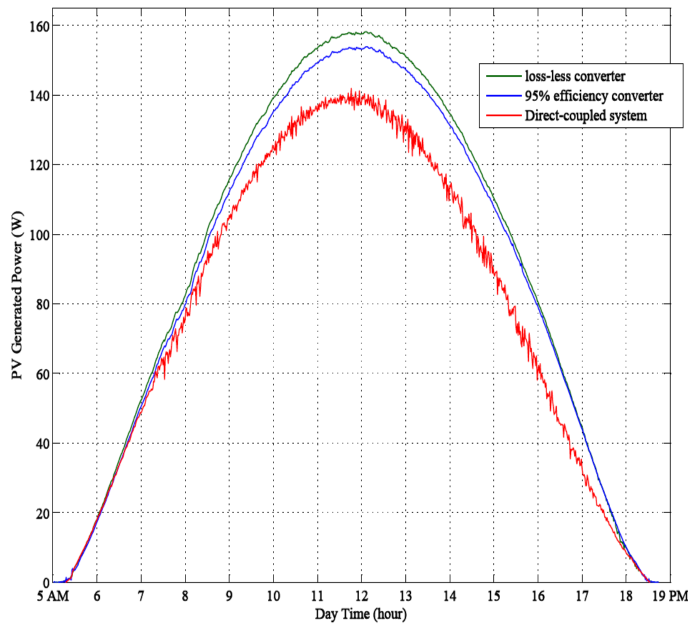

Figure 15 Flow rates of PV system for day time period (from 5:00 AM to 6:42 PM).

As shown in Figures 15, the flow rate of Kyocera SD 12-30 water pump is proportional to the power delivered. When the total dynamic head is 30m, the flow rate per watt is approximately 86.7cm3/W.min. The minimum power requirement of pump motor is 35W [13]; therefore as long as the output power is higher than 35W, it pumps water with the flow rate above.

Figure 15 show also that the direct-coupled PV water pumping system has a severe disadvantage because in the morning the pump will delay starting while the same system with MPPT is already pumping water. Similarly, in the afternoon it goes idle nearly earlier than the system with MPPT. The flow rate of water is also lower throughout the operating period. The figures show that MPPT offers significant performance improvement.

VI. CONCLUSION

The main purpose of this paper was to propose a new technique for MPPT of stand alone PV system using Fuzzy Logic Control. This purpose leads us to achieve many goals, which can be summaries as follow:

- Design and simulate a PV array in MATLAB/SIMULINK using data sheet for commercial PV array, which give us the performance of the PV array (I-V curve and P-V curve) under any atmospheric conditions (irradiance and Temperature) and can be used in any research related with photovoltaic. The result shows that the PV model using the equivalent circuit provides good matching with the real PV module.
- Design and simulate DC-DC Cúk converter and Pulse Width Modulator in MATLAB/SIMULINK (SimPowerSystems) which can be use in any power electronics research.
- Design and simulate a MPPT controller using FLC in MATLAB/ FUZZY TOOL BOX/ SIMULINK.

Finally, this paper presents a simple but efficient photovoltaic water pumping system. It models each component and simulates the system using MATLAB/SIULINK. Simulations use SimPowerSystems in SIMULINK to model a DC pump motor. It performs simulations of the whole system and verifies functionality and benefits of MPPT. Simulations also make another comparison with the system without MPPT in terms of energy produced and flow rate of water pumped using atmospheric conditions for one day. The results validate that MPPT can significantly increase the efficiency of energy production from PV and the performance of the PV water pumping system compared to the system without MPPT. This increasing could bring large savings if the system is large.

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