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SIMPLE MAXIMUM POWER POINT TRACKER BASED ON PERTURB AND OBSERVE TECHNIQUE FOR PV MODULE

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ABSTRACT

Solar energy can play an important role in solving the energy problems in those countries lie in the Sun Belt. Photovoltaic (PV) energy is one of the useful applications for solar energy. For any PV module, both current and voltage vary proportionally to the load and the solar radiation level as a nonlinear relation, which causes the continuous variation of the maximum power point (MPP). Since the maximum power for a certain load can be taken from the PV module at a distinct point for each radiation level, maximum power point tracking (MPPT) can be used to follow the optimum operating point. This paper presents design and build a simple MPPT based on perturb and observe technique for a small DC load driven by a PV module. The experimental results showed that using the proposed MPPT promotes a good matching between the PV module and its load. According to the good matching, the daily output energy can be increased by about 37-42% more than that of the direct coupling between the load and the PV module.

Keywords: solar energy; maximum power point tracking; photovoltaic module characteristics; load matching; control circuits.

1. INTRODUCTION

From the continuous decrease in the energy sources with the great increase in energy demand all over the world, solar photovoltaic (PV) energy can be considered one of the promising and favorable renewable energy sources. It has more advantages such as renewable, maintenance free, long life without pollution effect [1, 2]. Due to the lower conservation efficiency of the PV generation with the considerably high initial costs, great efforts have been concentrated to increase the output power from the PV systems under various operating conditions to enhance the overall system efficiencies and decreasing the system costs [3].

Since, the output from any PV system varies with solar radiation intensity over the day hours; it can be maximized by increasing the incident solar energy on the surface of the PV system. This can be achieved by utilizing sun tracking system, which follows the sun beamin either daily or seasonally movements or both [4]. Singh *et al*., [5] reported that the efficiency of the fixed PV system can be increased by 10-25% via a sun tracking system, depending on the site location and the type of the sun tracker. The increase in the system efficiency through the sun tracking is resulting from keeping the sun beam perpendicular to the surface of the PV system all time [6]. Although sun tracking is useful in many solar installations, it still has some disadvantages such as increasing the system complexity, adding more costs and may boost the overall PV system temperature in some regions, which can eliminate the system efficiency [7].

The PV system can be utilized at any voltage and current (from open circuit to short circuit) according to the connected load. The nonlinear nature of the PV system, current-voltage (I-V) or power-voltage (P-V), makes the output from the system is maximum at one point only according to a certain solar radiation level and surface temperature called maximum power point (MPP), which continuously changes with the variation of the operating conditions [8]. Figure-1 shows the I-V characteristic of a PV module indicating the MPP [9]. To track the MPP and hence to increase the system efficiency, a maximum power point tracker (MPPT) should be used to maintain the operating point near the MPP as possible [10].

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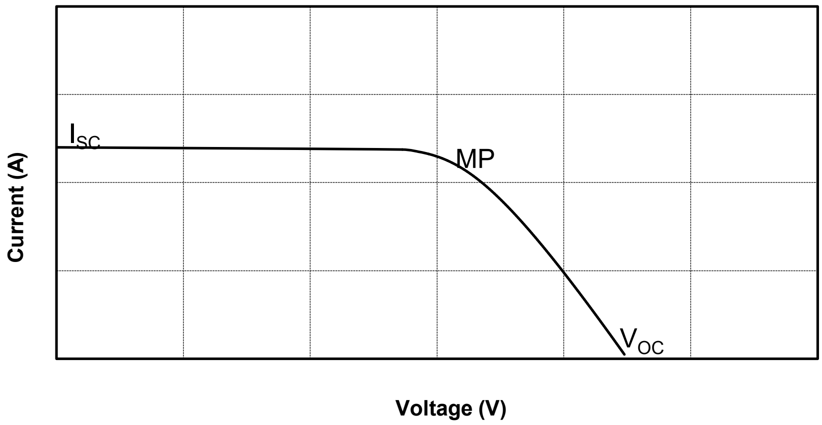

Figure-1. I-V characteristic of a PV module indicating the MPP [9].

Different MPPT techniques have been introduced over the years to extract the optimum power from the PV systems. These systems can be categorized according to the principles of operations such as solar energy, module parameters, dynamic performance, complexity, regulation speed, and so on [11 & 12]. MPPT can be classified according to the method of controlling and seeking MPP as follows [13]; constant voltage control [14]; open voltage technique [15]; Short circuit pulse technique [15]; incremental conductance [16]; neural network [17]; Fuzzy controller [18]; perturb and observe [10 & 11]; hybrid methods [19].

In constant voltage MPPT control, only the value of MPP voltage of the PV system (V_{MPP}) is used as a reference voltage in order to drive the operating voltage to the MPP. At any instant, the system always compares the operating point voltage with this reference voltage (V_{MPP}) and continuously adjusts the duty ratio of the used converter. It is a simple technique that did not use any inputs other than MPP voltage, as reference voltage value [13 & 15]. According to the fact that the MPP voltage is always a percentage of the open circuit voltage of any PV system (V_{MPP} = 76% V_{OC}), the MPP can be tracked using open voltage method within a tolerance of 2-4% [13]. The only parameter needed to be measured in the open circuit method is the open circuit voltage. The short circuit current of the PV system (I_{SC}) also can be used to adjust the MPP current at different irradiance levels and operating temperatures depending on the fact that the MPP current is a certain percentage of the short circuit current of the PV system considering the short circuit technique. The only parameter required for this control is the measured short circuit current of the system at all instants [15]. The incremental conductance technique depends on the fact that the slope of the I-V characteristic of the PV system is zero at the MPP. In other words, the system compares the instantaneous and incremental conductances of the PV system to get the operating MPP [13]. Due to the continuous change in the MPP of the PV system with environmental conditions, the neural network (NN) can match well with the nonlinear nature of the operating voltage and current of the PV system. NN can be used to estimate the MPP voltage of the system and adjust the duty ratio required for driving the operating point to MPP [20]. The calculation system also can be used in MPPT applying fuzzy control method to track the MPP through a mathematical system to preciously detect the parameters of the MPP without requirement a lot of measurements [13]. Among the MPP methods, the perturb and observe can be considered the simplest technique for tracking the optimal operating point in any PV system. In this technique, according to the desired intervals, the system periodically increases or decreases the operating point by a certain increment and continuously compares the voltage and current (power) with the previous perturbation to reach the MPP. This method can lead to some oscillations around the MPP [21 & 22].The hybrid MPPT uses more than one technique to increase the system accuracy but it becomes more complicated. It can use, for example, NN with fuzzy controller [19] or NN with perturb and observe [23].

This paper presents a simple, low cost and accurate MPPT based on a simple perturb and observe technique for tracking the maximum power point of a PV module coupled with a DC fan load via the MPPT. The MPPT used a PC based data acquisition system including Analog/Digital (AD) & Digital/Analog (DA) card (ADDA). The ADDA card is used mainly for ; i) measuring and recording the system parameters such as module voltages and currents as well as the environmental parameters as solar intensity and module temperatures, ii)providing the control signals needed for different perturbations so as to adjust the duty ratio of the step-down dc/dc converter for tracking the MPP. For comparing, the system use another identical PV module connected directly (without MPPT) to the same load to evaluate the advantages of using the desired MPPT, with respect to the power gain. The two PV modules are installed on the same mechanical structure and parallel to each other.

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2. System description

Figure-2 shows the schematic diagram of the PV system with the MPPT. In the PV system, the proposed MPPT using a step-down converter is used to connect the PV module to a DC fan load. The MPPT used the perturb & observe control technique to adjust the system operating point at its MPP all times. The driving circuit of the MPPT takes its signal from the PC via digital to analog (DA) card according to the algorithm processed by the PC. The proposed driving circuit are periodically adjusting the duty ratio of the dc-dc converter. The PC also is used to manipulate and save all the required system measurements.

2.1 PV modules and load

Two identical PV modules and the same two DC loads are used in the system for comparison purposes. One of PV modules is connected to the load via the proposed MPPT and the other is directly coupled to the load (without MPPT). The PV module is a thin film with a rated output power of 64 W and optimal operating voltage and current of 16.5 V and 3.8 A, respectively at Standard Test Conditions (STC, 25 °C & 1000 W/m^2). Table-1 describes the electrical parameters of the PV module at STC, while Figure-3 shows the two PV modules at the fixed structure and the DC fan load. To achieve the optimal performance over the year, the PV modules are fixed at the same mechanical structure keep them facing south with 30 deg tilted at climate of Cairo, Egypt (Latitude of 30° 2' 38" North, Longitude of 31° 14' 9" East) [24]. Two identical DC fan loads are coupled to the modules; one was connected via the proposed MPPT and the other is directly coupled to the other PV module.

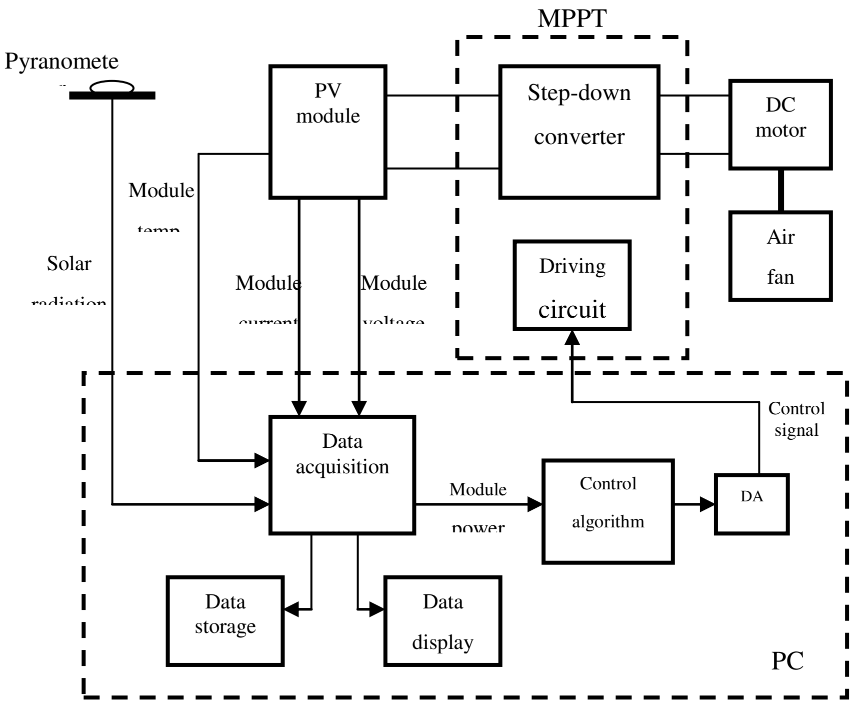

Figure-2. A schematic diagram of the PV system with the MPPT.

Table-1. The electrical parameters of the PV module at STC.

Parameter	Value
Maximum power	64 W
Voltage of the open circuit	21.8 V
Current of the short circuit	4.8 A
Voltage of MPP	16.5 V
Current of MPP	3.88 A
Dimension	136.6 * 74.1 * 3.2 cm
Weight	9.710 kg

Figure-3. PV modules at the mechanical structure and the DC load.

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2.2 MPPT

A step down MPPT is used in the circuit of the PV system shown in Figure-2 to couple the PV module with the DC load for seeking the optimal operating power from the PV system. Figure-4 displays a schematic diagram of the MPPT. It consists of a driving circuit drives NPN transistor via two input and output filters and freewheeling diode. The driving circuit is a pulse width modulation circuit (PWM) with adjusted duty cycle via the control signal received from the data acquisition card installed in a PC. The control signal can be adjusted according to the perturbations pattern algorithm.

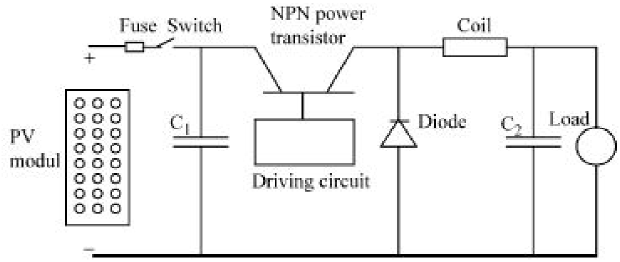

Figure-4. A schematic diagram of the MPPT.

As shown in Figure-4, The PV module is connected to the dc load across the MPPT circuit which contains the following;

- Input fuse for electrically protecting the circuit and ensuring save operation against over current or short circuit.
- Input switch for cutting the load on and off with suitable rated value according to the maximum circuit power.
- Input and output capacitive filters C_1 (1500 µF) and C_2 (470 µF) with the inductor of 150 mH that were used in the input and output passes. The input filter (C_1) isutilized to diminish the input voltage and current fluctuations, while the output filter is a low pass filter that consists of an inductor (L) and a capacitor (C_2). The inductor is used to store the energy during the on periods of the duty cycle and to supply it to the load during the off periods, to maintain supplying power to the load.
- Freewheeling diode of rate 15 A at the output side.
- NPN power transistor of 200 W rated (MJ802) is used in MPPT circuit. The power transistor running on and off by driving circuit with adjustable duty ratio according to the perturbation algorithm. Table-2 gives the technical specifications of the power transistor.
- The driving circuit is the Pulse Width Modulation (PWM) that adjusts the duty cycle of the driving signal according to the received control signal from the DA card. The control signal from the DA card is derived according to the perturb and observe algorithm running by the PC. The driving signal is train of pulses used to drive the power transistor via an isolation circuit. Figure-5 shows driving signal.

Table-2. Technical specifications of the power transistor.

Item	Specifications
Transistor	Power MJ802
Type	NPN silicon
Collector-Emitter voltage (V_{CE})	100 V
Collector-Base voltage (V_{CB})	100 V
Emitter-Base voltage (V_{EB})	4 V
Collector current (I_C)	30 A
Base current (I_B)	7.5 A
Transistor power (P)	200 W
DC current gain (h_{FE})	25-100
Operating and storing junction temperature	-65 to 200 ^{o}C
Collector-Emitter breakdown voltage (BV_{CE})	100 V

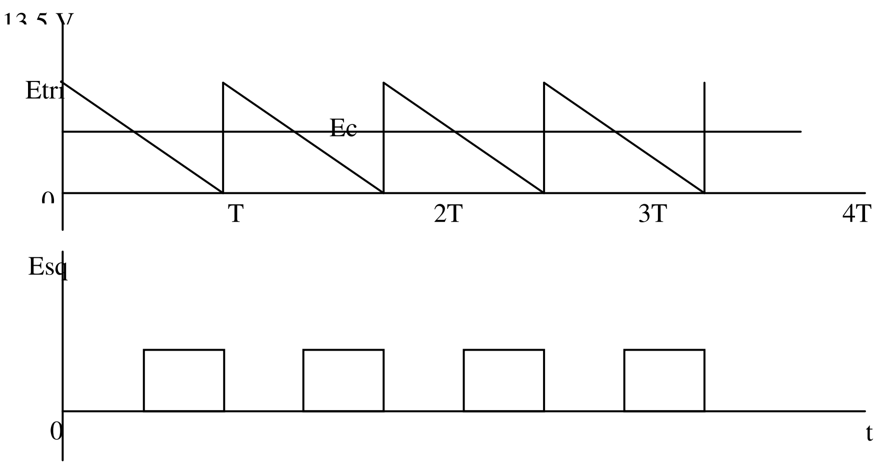

Figure-5. Driving signal of the MPPT.

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The operation of the MPPT shown in Figure-4 is as follows; i) when the transistor is turned on, the diode is reverse biased and the PV module feeds the power to the load through the inductor that stores its energy until the transistor is turned off, ii) when the transistor is turned off, the diode is forward biased and the stored energy in the conductor forces the current to flow to the dc load. Figures 6 & 7 display the circuit for the two possible cases for the power transistor (on and off). According to this mechanism of operation, the electrical power is continuously fed the DC load all times.

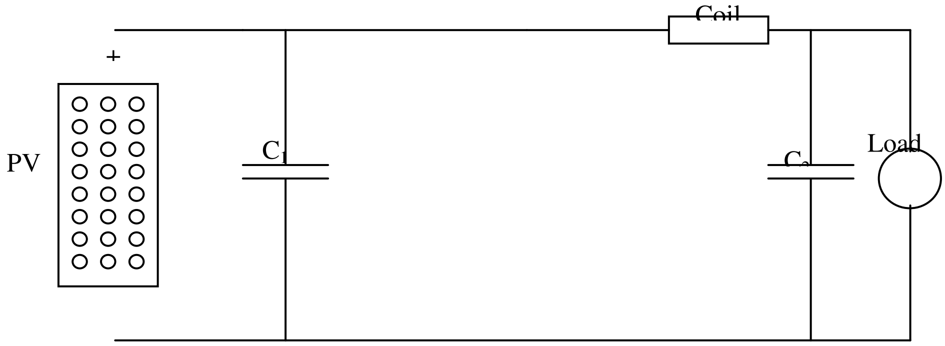

Figure-6. The PV system circuit in case of transistor is on.

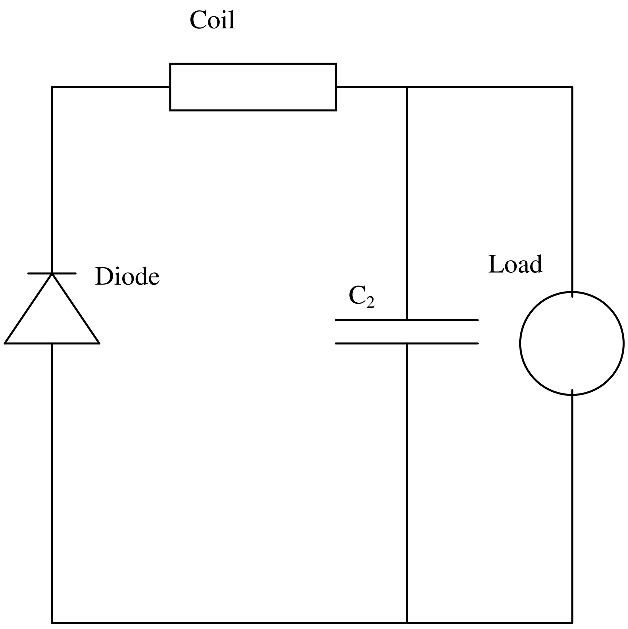

Figure-7. The PV system circuit in case of transistor is off.

2.3. ADDA Card

The ADDA card is used for measuring the system parameters as well as for controlling the MPP. The ADDA card receives the analog signals from the different transducers in the PV system such as module voltages, currents, surface temperatures and the solar radiation intensity. These values are the main measured parameters of the PV system and also used for controlling the MPP. The ADDA card consists of two main components as follows;

a) Analog-digital component (AD-574) converts the input voltage signals from the different transducers into digital signals, which can be manipulated by the PC for comparing, storing and displaying.

b) Digital-analog component (DA-PM7548GP) used for converting the desired digital control signal from the PC (detected by the perturb and observe algorithm) to the required analog value for adjusting the duty ratio of the PWM for controlling the MPP. Table-3 gives the main features of the ADDA card.

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Table-3. The main features of the ADDA card.

AD		DA	
Converter	**AD574**	**Converter**	**PM7548GP**
Channels	8 single-ended inputs	Channels	One channel
Resolution	12 bits	Resolution	12 bits
Input range	±5V, ±2.5V, ±1.25V, ±0.625V	Output range	0 to 5 V or 0 to 10 V
Conversion time	25 μSec	Settling time	30 μSec
Accuracy	0.015% of reading	Reference voltage	Internal –5V and –10V
Nonlinearity	± 1 bit	Output capacity	±5 mA max
Amplification gain	x1, x2, x4, x8 and x16		
Trigger mode	By software, pacer, and external trigger		
Data transfer	By software or interrupt		
Overvoltage	Continuous ±30V max		

The system voltage can be measured by voltage transducer with electrical isolation between its input and output (25-P-LV type). It has a high conversion ratio (1000-2500) using a small measuring resistance between (100-350 Ω) and considerable power supply of (± 12-15 V). For the voltage measurements, a current proportional to the measured voltage must be passed through an external resistor, which is installed in series with the primary circuit of the transducer. Another multi-range current transducer with a suitable measuring range (0-25 A) and high conversion ratio (1-1000) using (± 15V) power supply was used for system current (25-NP-LA type). The current transducer has an excellent accuracy, very good linearity, low temperature drift, optimum response time, wide frequency bandwidth, no insertion loses, high immunity to external interface, and current overload capability. The surface temperature of the PV system and the solar intensity were also measured by using thermocouple (K-type) and Kipp & Zonen pyranometer (774035-CM5 thermopile type), respectively. The pyranometer has been installed on the mechanical structure parallel to the PV modules to measure the same surface solar intensity as shown in Figure-3. Finally, the small (milli Volts) signals from the temperature and solar radiation measurements have been amplified by amplification circuits to match the input range of the AD component, shown in Table-3.

2.4 System operation and algorithm

The data acquisition system in the circuit shown in Figure-2 is used to collect and save the system parameters such as solar radiation intensity, module surface temperature, module voltage, current and operating power. Also, it processes the algorithm that tends to force the operating point (current and voltage) to the optimal operating one. The algorithm starts with reading the system and the environmental parameters. According to the instantaneous voltage, current (power) of the system, the algorithm applies a certain consequent perturbation in one direction, such as increasing or decreasing the operating voltage by small increments, and then it continuously measures and records the operating current, voltage and power after each perturbation. If the power tends to increase, then the next perturbation will be in the same direction (increasing or decreasing the operating voltage) otherwise it will be in the opposite direction. These steps will be repeated continuously until the difference between two successive values of measured operating poweris almost zero. Then the maximum power point is reached and the PV module delivers its maximum power to the load. The algorithm starts new perturbations according to variations of the value of either solar intensity or PV module temperature at a certain increment. Figure-8 represents the flowchart of the used perturb and observe algorithm for the MPPT.

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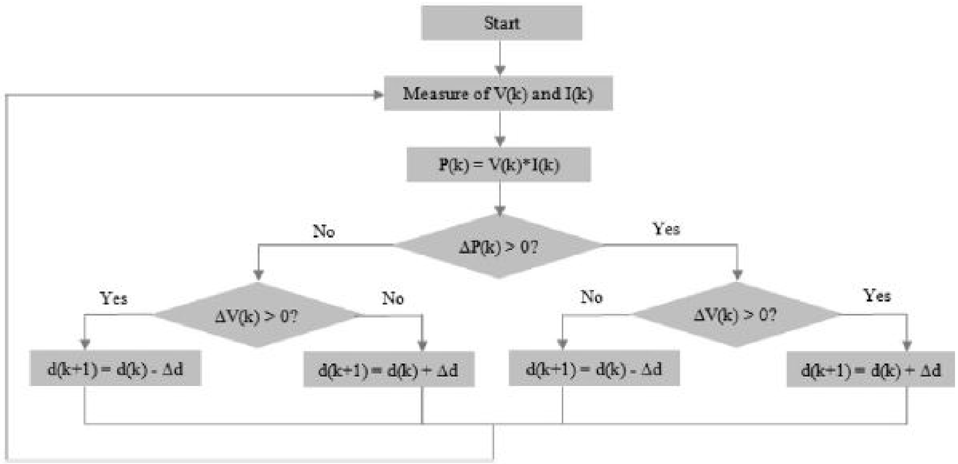

Figure-8. Flowchart of the perturb and observe algorithm for the MPPT.

3. RESULTS AND DISCUSSIONS

The system was assembled and tested in the test field of solar energy department (NRC), Cairo (30° 2' N and 31° 14' E). For comparison, the results are recorded from the two identical PV modules with two identical fan loads (Figure-2) one coupled directly to the load (direct power) and the other coupled via the proposed MPPT. Figures 9-11 show the recorded operating power from the two modules for three days at different environmental conditions. Fig. 9 for a clear day, Figure-10 for a cloudy followed by clear hours day while Figure-11 representing a sunny day with fast small changes in solar radiation. It is clear that the MPPT increases the output power from the PV module over that of the direct coupling one for all days. The amount of energy gain is differing according to the nature of the solar intensity in that day. Figure-12 compares the power delivered from the two PV modules (with and without MPPT) against the solar radiation level. It is clear from the figure that the power gain is almost the same for all radiation levels.

Figure-13 gives the daily percentage increase in the output energy of the PV module with MPPT over that of direct coupling during one month. From the figure it can be concluded that the proposed MPPT increases the power delivered to the load by about 32-45% depending on the nature of the solar radiation level.

Also, it should be noted that using the MPPT can start the PV system early morning and keep working late afternoon with more operating hours than that of the direct coupling one. These additional working periods come from the power gain using the MPPT which enables the load to be started at lower solar radiation level. Thus, in turn enhancing the total system efficiency. Figure-14 shows the efficiency of the MPPT during a sunny day. The matching efficiency of the MPPT is in the range of 90% due to measurement and amplification circuit errors.

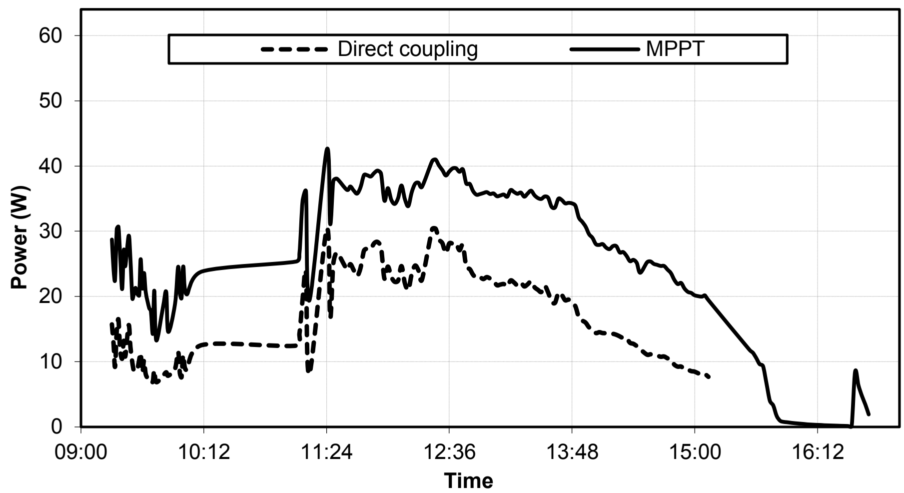

Figure-9. System power in case of direct coupling and with MPPT measured in a clear day.

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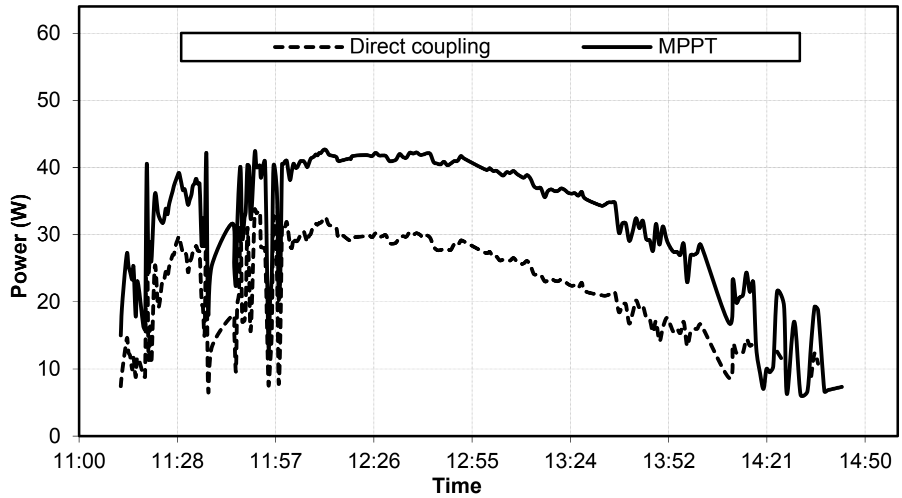

Figure-10. System power in case of direct coupling and with MPPT measured in a cloudy followed by clear hours day.

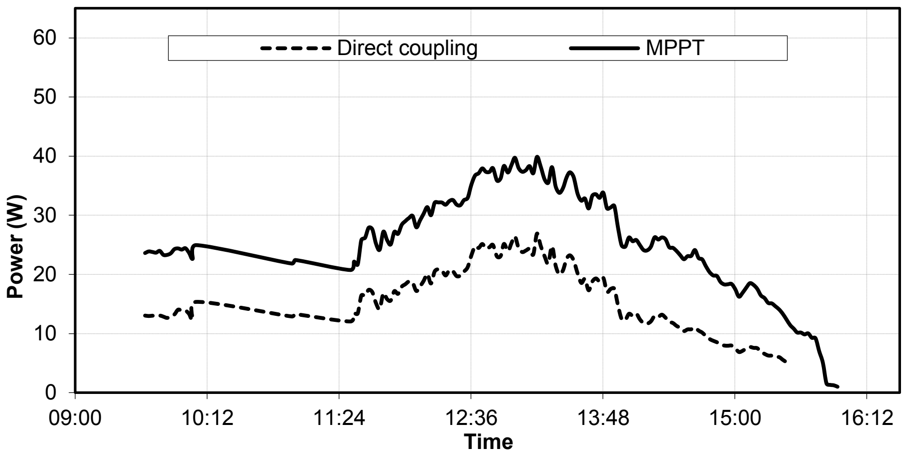

Figure-11. System power in case of direct coupling and with MPPT measured in a sunny day with fast small changes in solar radiation.

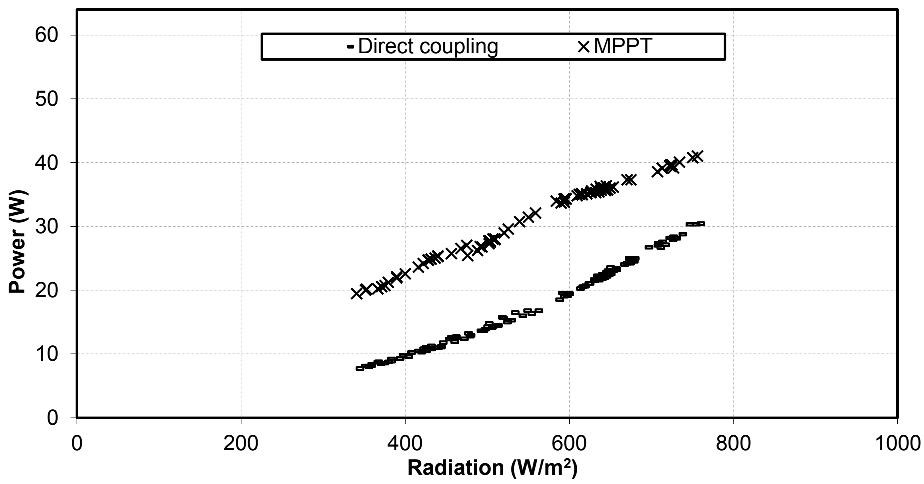

Figure-12. The power delivered from the two PV modules (with and without MPPT) against the solar radiation level.

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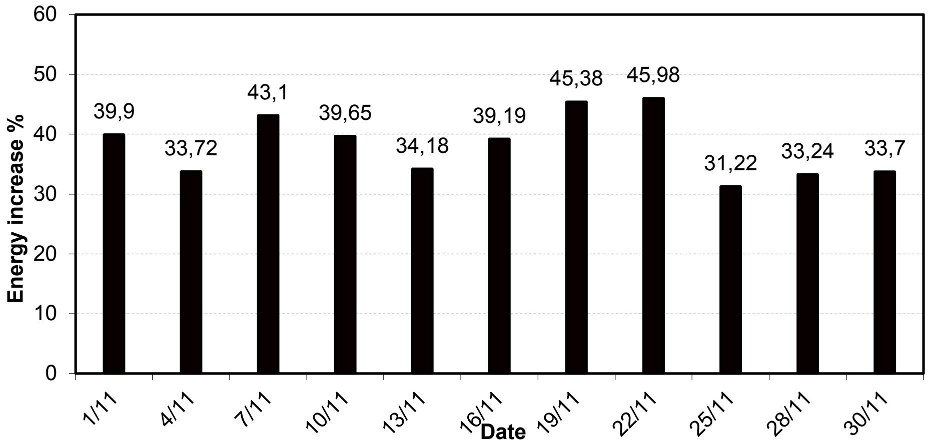

Figure-13. The daily percentage increase in the output energy of the PV system by the MPPT during one month.

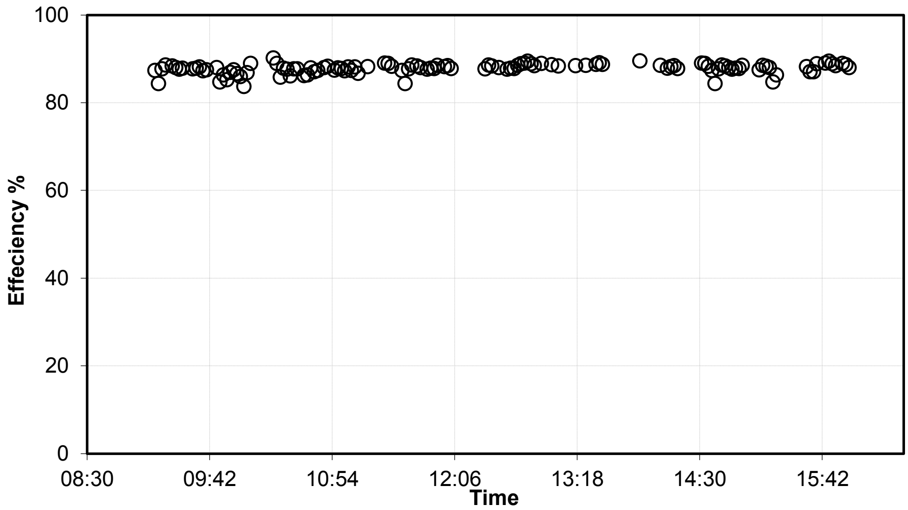

Figure-14. Efficiency of the MPPT during a sunny day.

4. CONCLUSIONS

A simple MPPT based on perturb and observe algorithm was designed and built for connecting a PV module to the DC load for optimizing the load power and enhancing the PV energy utilization. The MPPT uses a step-down converter with input and output filters. The input filter is a pure capacitance while the output one is L-C circuit. A PWM driving circuit was used to drive power NPN transistor via changing the duty ratio of the driving signal according to the perturbation technique. ADDA card was used for data acquisition and for generating the control signal from its DA card according to the perturb and observe algorithm. Two identical PV modules were connected to the same DC loads (with and without MPPT) for comparison purposes. The results showed that MPPT increases the PV module power, increases the total system efficiency and maintains more operating hours especially in early morning and late afternoon hours. The proposed MPPT is very simple, as it requires no more complicated hardware and uses only the ADDA card that already used for data acquisition.

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