Maximum Power Point Tracker Based on Perturb and Observe Algorithm for Photovoltaic Energy System under Egyptian Conditions

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Abstract

In this paper, a maximum power point tracker (MPPT) based on perturb and observe algorithm for photovoltaic (PV) energy system is introduced. MPPT is a dc to dc converter that regulates the output power to ensure an optimum value of the PV module voltage to extract the maximum power from PV module. The main objective of this paper is to study the effect of operating the PV system at maximum power point under Egyptian conditions. The overall system is modeled by using MATLAB/Simulink program. The output power and energy from PV system in case of using MPPT based on perturb and observe algorithm are compared to those obtained by the system without MPPT. Results show that, the PV system with MPPT increases the efficiency of energy production harvested from PV.

Keywords: Photovoltaic Energy System, MPPT, Perturb and Observe and Boost Converter

I. Introduction

Renewable energy generation has experienced consistent growth in the last two decades, motivated by the concerns of climate change and high oil prices, and supported by renewable energy legislation and incentives. Solar photovoltaic (PV) is one of the fastest growing energy technologies, with an average annual growth of about 40% in the past decade [1]. Today PV electricity generation has a considerable contribution among other renewable energy sources. At least 28.4 GW of PV systems have been installed in the world last year [2]. At least, 110 TWh will be produced in 2013 by PV systems already installed [2], which represents about 0.5% of the electricity demand of the planet, some countries have reached rapidly significant percentages. These 110 TWh represent the annual consumption of countries such as the Netherlands or Egypt. Many European countries planned to install several big PV power stations in the desert of North Africa which will increase the generation from PV considerably. Despite the technological advances and governmental incentives, the cost of energy produced by grid connected PV energy systems is still relatively high and cannot compete yet with traditional wholesale electricity prices. This motivates the research for creating not only improved solar modules but also more efficient power converters which increase the generated energy from PV systems which can be translated to considerable cost reduction.

Most of Arabian countries have shining sun all the year for example Egypt enjoys excellent solar radiation; the annual global solar radiation is between 1900 and 2600 kW h/m^2 per day from north to south respectively [3]. Solar energy, especially PV energy system generates electricity from sunlight collected by solar modules. PV energy systems are particularly suitable for supplying electrical power to load in many rural remote areas, which have no access to electric utility. Unfortunately, the actual energy conversion efficiency of PV module is rather low. So to overcome this problem and to get the maximum possible efficiency, a maximum power point tracker (MPPT) is used [3,4].

The output power from PV module varies with atmospheric conditions like solar radiation level and temperature as well as their output voltage and current. There is an optimum value for the PV terminal voltage for each radiation and temperature. This optimum value is called the maximum power point (MPP) at this condition. It is crucial to operate the PV energy system near the MPP to improve PV energy system conversion efficiency. MPPT algorithms are usually implemented in the power electronic interface between the PV module and an energy storage device or load for this purpose [5].

MPPT methods are used to track the voltage V_{mpp} or current I_{mpp} at which a PV module delivers a maximum power under a given radiation and temperature. The commonly used MPPT methods are fractional open circuit voltage, fractional short circuit current, Perturb and Observe P&O and Incremental conductance MPPT methods. The P&O and incremental conductance methods are widely used in PV applications due to the ease of implementation [6,7]. The fractional open-circuit voltage method is based on determining a constant value which gives the relationship between MPP voltage and open-circuit voltage to find the optimal operating point. On the other hand, relationship between the MPP voltage and radiation might not be same for different solar cell technologies. It is impossible to determine the optimum voltage by using only one linear function of the open-circuit voltage. Due to that reasons, this tracking method might fail to determine the optimum voltage during fast changing irradiance conditions especially in fractional open-circuit voltage [8].

In recent years, research has been done on improving the capabilities of MPPT algorithms, partly driven by the availability of more powerful control circuitry. However, even a quite simple P&O algorithm can give sufficient accuracy and response speed to assess the power output of PV modules [6]. This tracking method based on the fact that, on the voltage-power characteristic, on the left of the MPP the variation of the power against voltage dP/dV > 0, while on the right, dP/dV < 0 as shown in Fig. 1. If the operating voltage of the PV array is perturbed in a given direction and dP/dV > 0, it is known that the perturbation moved the array's operating point toward the MPP. The P&O algorithm would then continue to perturb the PV module voltage in the same direction. If dP/dV < 0, then the change in operating point moved the PV array away from the MPP, and the P&O algorithm reverses the direction of the perturbation [2].

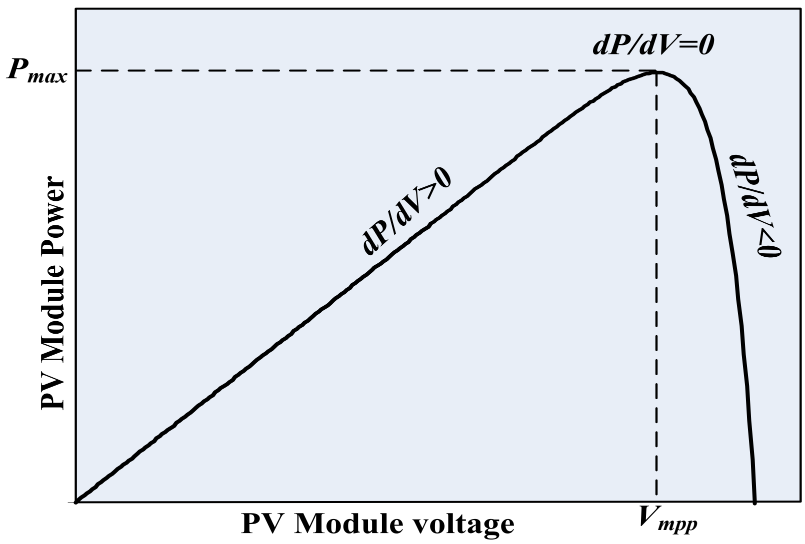

Fig. 1 PV module power -voltage characteristics

Ii. Model of the Proposed System

The simulation of the proposed system has been carried out using MPPT based on P&O method. MPPT P&O technique attempts to find the PV voltage that result in the maximum power point V_{mpp}. Simulation of the proposed system has been implemented using MATLAB/Simulink program; the simulation of the proposed system contains sub models that explained in the following sections:

A. PV cell characteristics

Photovoltaic cell generates electricity from the solar radiation. PV module works under the phenomenon of photoelectric effect, where it directly converts sunlight into electricity. Solar cells are connected in series and parallel to step up the voltage and current of PV module respectively. Solar cell will produce dc voltage when it is exposed to sunlight. Fig. 2 shows the equivalent circuit model for a PV module. Solar cell can be regarded as a non-linear current source. Its generated current depends on the characteristic of material, irradiation and cell temperature. Equations (1), (2) and (3) describe the I-V characteristics of the PV model [10-13].

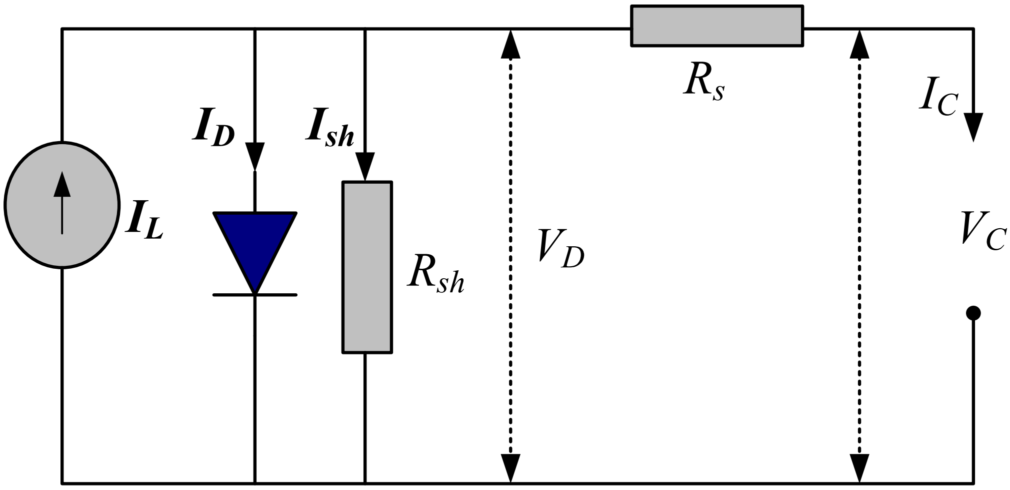

Fig. 3 Equivalent circuit of PV module

$$I_C = I_L - I_D - I_{sh} \tag{1}$$

$$\text{where } V_t = \frac{AKT_c}{q} \text{ , } I_D = I_o \left\{ \exp\left(\frac{V_D}{V_t} \right) - 1 \right\} \tag{2}$$

$$I_L = R\left[I_{L,ref} + \mu_{I,SC}\left(T_c - T_{c,ref} \right) \right] \tag{3}$$

Where:

I_C	Cell current (A).
I_L	Light generated current (A).
I_o	Reverse saturation Current.
q	Charge of electron = 1.6 x 10^{-19} (coulomb)
K	Boltzmann constant (j/K).
A	Ideality factor.
V_t	Thermal voltage.
R_s	Cell series resistance (ohms).
R_{sh}	Cell shunt resistance (ohms).
$\mu_{I,SC}$	Temperature coefficient of the short circuit current *A/°C.*
T_c	PV cell temperature
$T_{c,ref}$	Reference Temperature 25 *°C*

LA361K51S PV module is chosen to be used in MATLAB simulation model. The module is made of 36 multi-crystalline silicon solar cells in series and provides 51 W of nominal maximum power [14]. Table 1 shows the LA361K51S PV module electrical specifications. Fig.3 shows the Simulink model of PV module. Typically, fixed (non adjustable) PV arrays should be tilted toward south by angle equal to the latitude of the array's location to capture the most year round solar energy. If the PV array is mounted with a tilt angle equal to the site latitude, it's perpendicular to the sun twice a year (on each equinox date) and very close to perpendicular for the weeks before and after the equinox; this makes the array perpendicular to the sun's position in the sky for the greatest number of hours throughout the year [10]. The hourly radiations on the horizontal and on the tilted surface by angle equal 22.46º southward

are shown in Fig. 4. These data which are used in simulation are from realistic hourly data of the EL- Owainate city of the Arab Republic of Egypt as a case study.
Figs. 5 and 6 show the P-V and V-I characteristics of the tilted PV module for various time from 8:00 AM to 5:00 PM at April 15th.

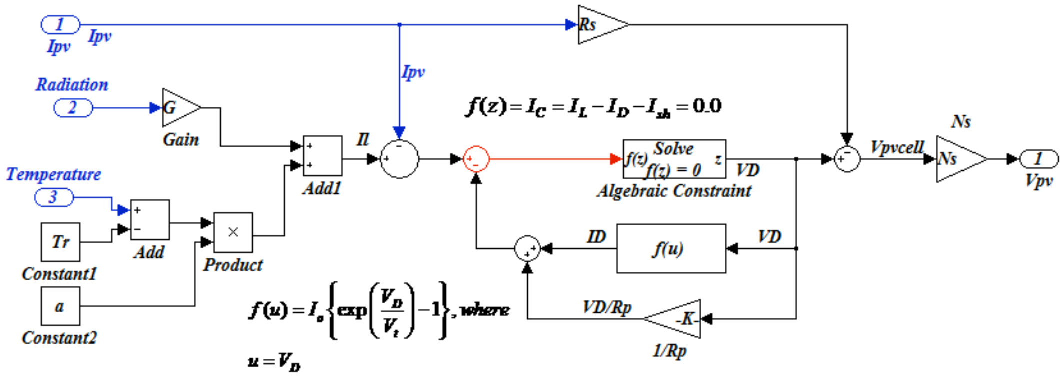

Fig.3 MATLAB Simulink model of PV module

The algebraic constraint block shown in Fig. 3 constrains the input signal $f(z)$ to zero and outputs an algebraic state z. The block outputs the value that produces a zero at the input. The output must affect the input through a direct feedback path, that is, the feedback path contains only blocks with direct feed through [16].

Table .1 Electrical characteristics data of PV module [14]

Characteristics	Specification
Maximum power	51 W
Short circuit current	3.25 A
Open circuit voltage	21.2 V
Current at MPP	3.02 A
Voltage at MPP	16.9 V

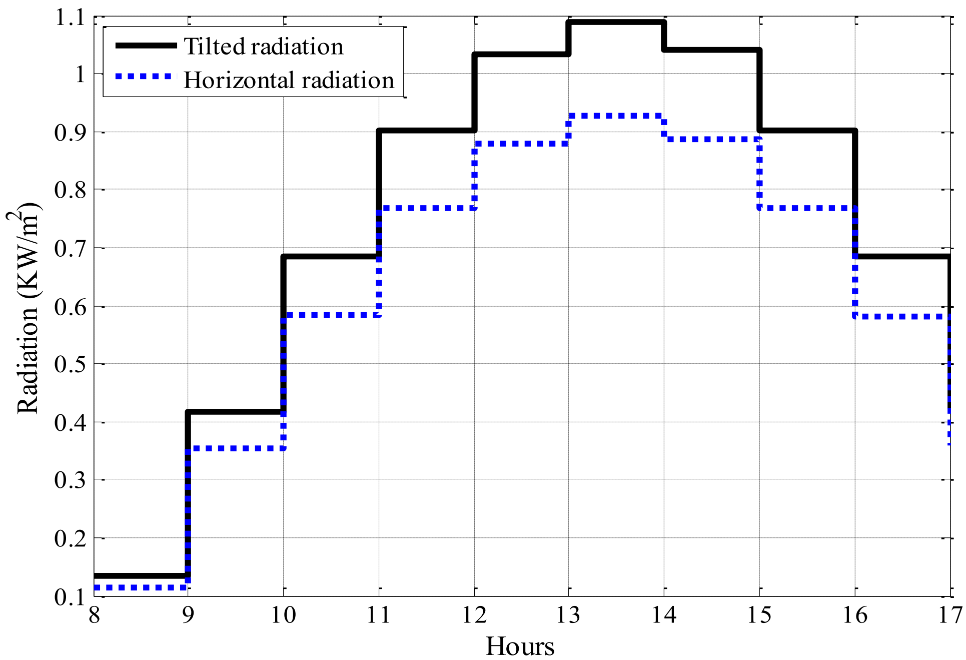

Fig. 4 Average daily hourly radiation in EL- Owainate, Egypt for April 15th

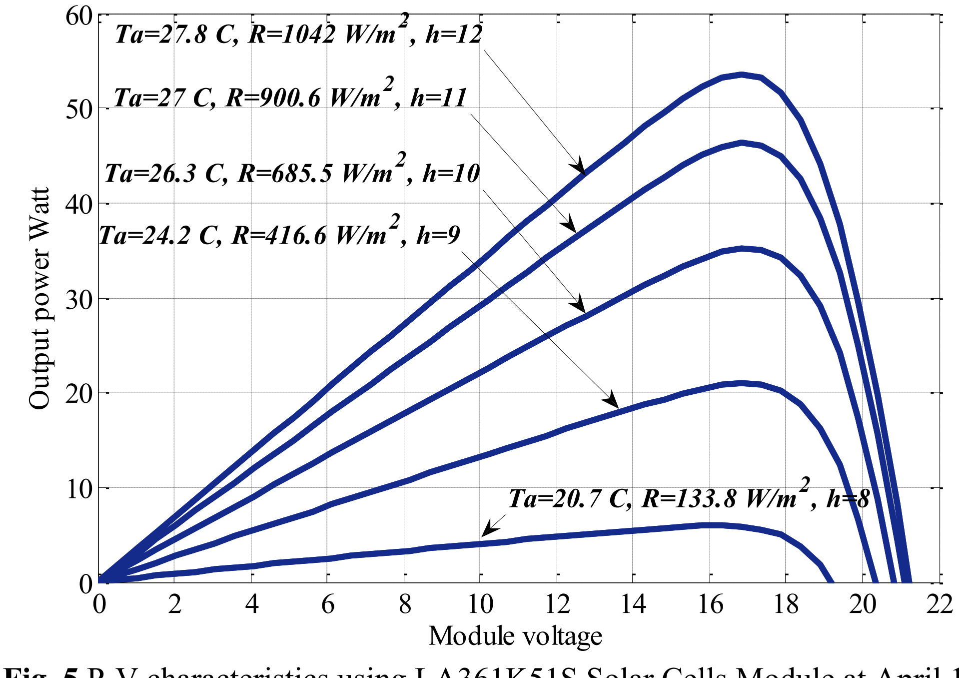

Fig. 5 P-V characteristics using LA361K51S Solar Cells Module at April 15th

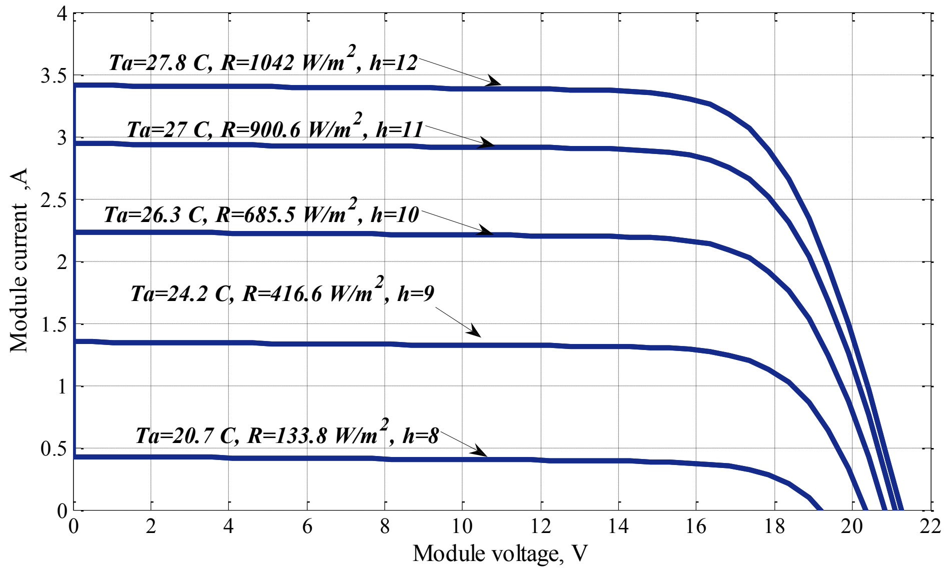

Fig. 6 I-V characteristics using LA361K51S solar cells module for April 15th

B. Mathematical model of boost converter

The input to dc-dc converter is connected to PV array and its output is connected to battery storage. Fig.7 shows the Simulink of mathematical model of boost converter [15]. The inputs of this model are the output voltage and current of PV array. The voltage transfer function of boost converter is written as shown in the following equation:

$$V_i = V_b\,(1 - D) \tag{4}$$

Where,

V_i The terminal voltage of PV array,

V_b The battery voltage.

D Duty cycle.

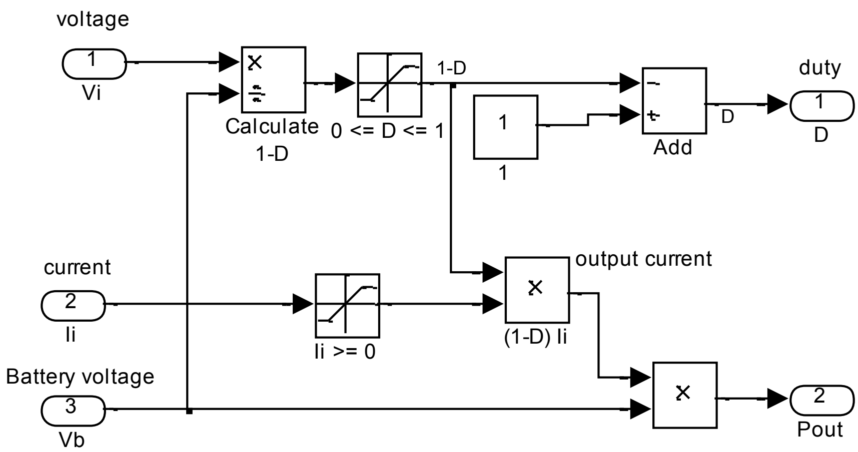

Fig.7 Simulink model of the boost converter

C. Perturb and Observe MPPT algorithm

P&O MPPTs can be implemented with perturbations in the PV module current or PV module voltage reference signal. For the latter case, the PV voltage reference signal is varied as a function of the sign of the perturbation and output power variation in the previous interval. The proposed algorithm which used in this study will track V_{mpp}.

However, it tracks directly the maximum possible power P_{max} that can be extracted from the PV. The flowchart of the proposed MPPT method is shown in Fig. 8. After one perturb operation the current power is calculated and compared with previous value to determine the change of power ΔP (P-P_{old}). If ΔP>0, then the operation continues in the same direction of perturbation. Otherwise the operation reveres the perturbation direction [8-9].

III. Simulation Results

The simulation of the proposed system has been implemented using MATLAB /Simulink program as shown in Fig. 9. The simulation is carried out with the realistic hourly data of the EL-Owainate city of The Arab Republic of Egypt as a case study for various times from 8:00 AM to 5:00 PM at April 15th for the purpose of study the effect of operating of PV system with MPPT on the output power and energy. Output power and energy from PV system are shown in Figs.10 and 11. It is clear from these figures that the output power and energy from PV module in case of using P&O MPPT are greater than output power and energy in case of using constant PV output voltage.

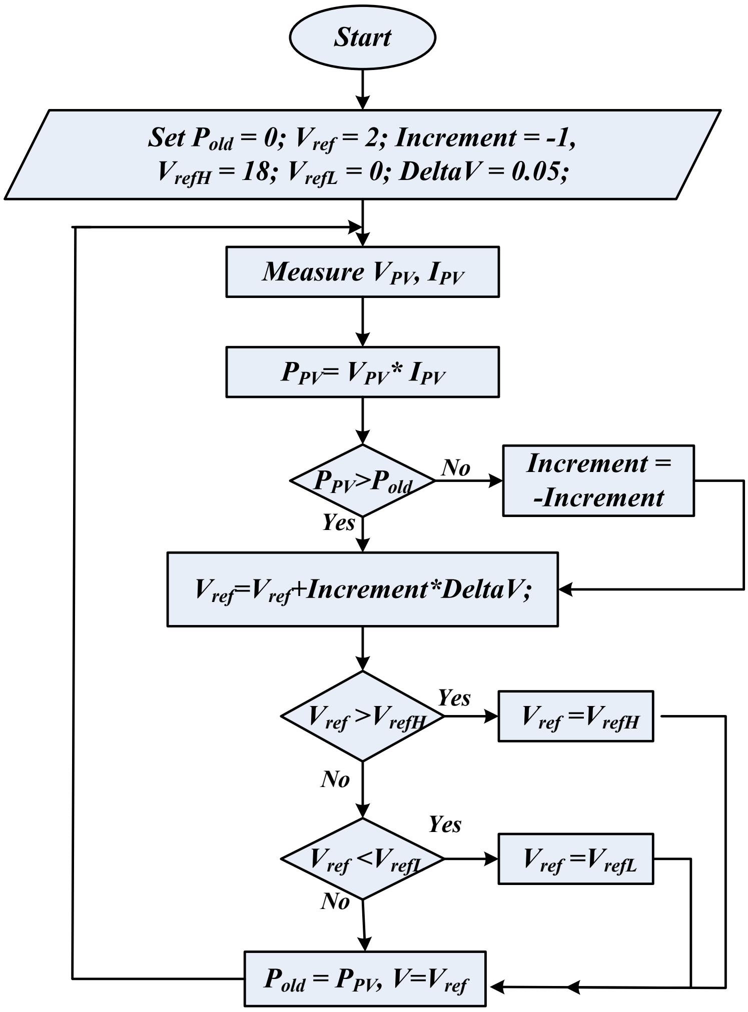

Fig. 8 Flowchart of the proposed P&O MPPT algorithm

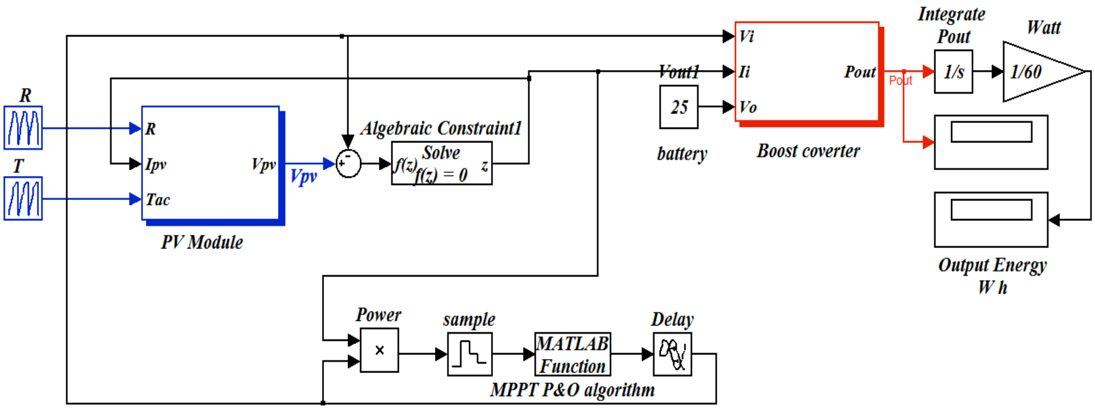

Fig. 9 MATLAB Simulink Modeling of Maximum Power Point Tracker based on P&O algorithm

The function of the algebraic constraint1 block in Fig.9 is solving for I_{pv} that result V_{pv} to convert the current input PV model shown in Fig. 3 to voltage input of PV model.

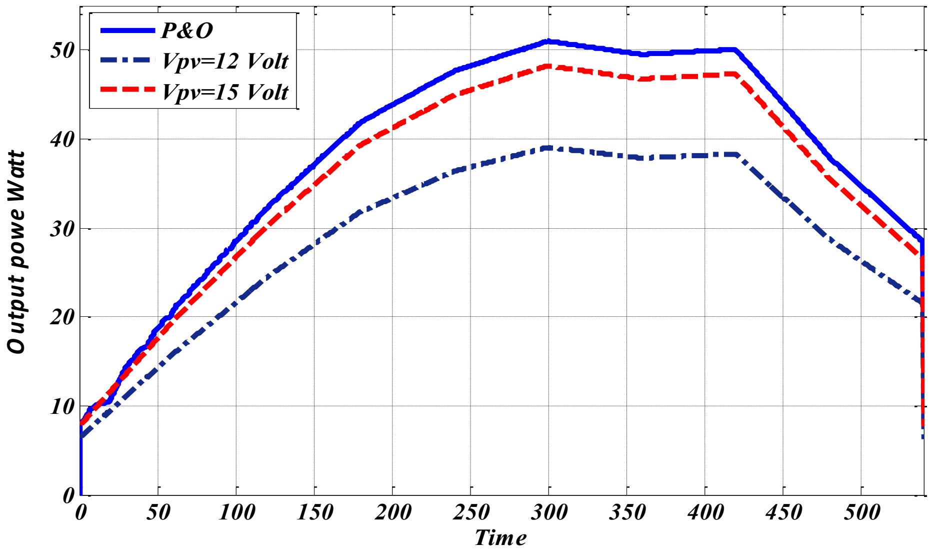

Fig. 10 The output power from PV system with and without using MPPT

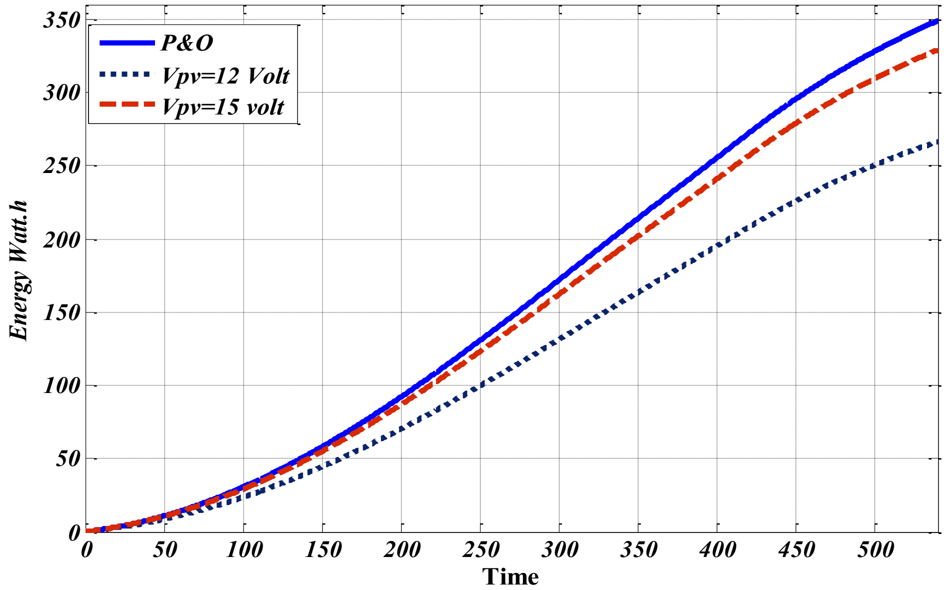

Fig. 11 The output energy from PV system with and without using MPPT

IV. Conclusion

The output generated power from the PV module is changing with the operating voltage of the PV Module for each value of radiation and temperature. There is a maximum power point, MPP at certain voltage of the PV cells. Maximum power point tracker, MPPT is used to track this point. Simulation results reveals that, operation at MPP increases the energy output from one tilted PV module for one day on April from 8^{am} to 3^{pm} from 266 Wh at 12 V PV constant terminal voltage and 329 Wh at 15 V PV constant terminal voltage to 349 Wh with using the proposed technique, i.e the energy increased by 31 % and 6.1% respectively. This increased in the output energy from PV proves the superiority of the proposed algorithm which can be translated to considerable cost reduction of the generated kWh.

References

[1] IEA-PVPS, "Trends in Photovoltaic Applications. Survey report of selected IEA countries
between 1992 and 2012," International Energy Agency - Photovoltaic Power Systems Programme, Tech. Rep. IEA PVPS T1-22:2013.

[2] Dezso Sera. Real-time Modelling, Diagnostics and Optimised MPPT for Residential PV systems. PhD thesis submitted to the Faculty of Engineering, Science & Medicine at Aalborg University Institute of Energy Technology Denmark, January 2009.

[3] Hegazy Rezk, A H M El Sayed. Sizing of a stand alone concentrated photovoltaic system in Egyptian site. Int J Electr Power Energy Syst , 2013; 325:330–45.

[4] Algazar Mohamed M, AL-monier Hamdy, EL-halim Hamdy Abd, Salem Mohamed Ezzat El Kotb. Maximum power point tracking using fuzzy logic control. INT J ELECTR Int J Electr Power Energy Syst, 2012; 39:21–8.

[5] Neil S. D'Souza, Luiz A.C. Lopes, XueJun Liu. Comparative study of variable size perturbation and observation maximum power point trackers for PV systems. Electric Power Systems Research 80 (2010) 296–305.

[6] Uwe Zimmermann and Marika Edoff. A maximum power point tracker for long-term logging of PV module performance IEEE journal of photovoltaics, vol. 2, no. 1, january 2012.

[7] Syafaruddin, Engin Karatepe, Takashi Hiyama. Polar coordinated fuzzy controller based real time maximum-power point control of photovoltaic system. Renewable Energy 2009,1-10.

[8] Tafticht T, Agbossou K, Doumbia ML, Cheriti A. An improved maximum power point tracking method for photovoltaic system. Renewable Energy 2008;33:1508–16.

[9] Chee Wei Tan, Tim C. Green and Carlos A. Hernandez-Aramburo, "Analysis of Perturb and Observe Maximum Power Point Tracking Algorithm for Photovoltaic Applications," *2nd IEEE International Conference on Power and Energy (PECon 08),* Johor Baharu, Malaysia*,* Dec. 1-3, 2008.

[10] Ryan Mayfield. Photovoltaic Design & Installation for Dummies. ® Published by Wiley Publishing, Inc. 2010. ISBN: 978-0-470-59893-1

[11] Huan-Liang Tsai, Ci-Siang Tu, and Yi-Jie Su, "Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK," *Proceedings of the World Congress on Engineering and Computer Science 2008 WCECS 2008*, San Francisco, USA, Oct. 22 – 24, 2008.

[12] Ramos Hernanz, Zamora Belver и Zulueta Guerrero, " Modeling of Photovoltaic Module, *" International Conference on Renewable Energies and Power Quality (ICREPQ'10),* Spain, 23rd to 25th March, 2010.

[13] B.Chitti Babu, R. Sudharshan Kaarthik, Nayan Kumar Dalei, R.Vigneshwaran, Rabi Narayan Das, "A Photovoltaic Energy Conversion System for Water Pumping Applications -Modeling and Simulation, " *International symposium on Photovoltaic Science and Technology, Indian Institute of Technology,* Kanpur, 13 Jan., 2010.

[14] LA361K51S -Multi-crystalline photovoltaic module datasheet.

[15] Ali. M. Eltamaly "Modeling of Fuzzy Logic Controller for Photovoltaic Maximum Power Point Tracker," *Solar Future 2010 Conf. Proc.,* Istanbul, Turkey, Feb. 2010, pp. 4-9.

[16] MATLAB help.
http://www.mathworks.com/help/simulink/slref/algebraicconstraint.html