Using P&O Based Sensorless Method In Single-Axis Solar Tracker

Soroush Ghabusnejad*, Ashkan Majdi*, S. Alireza Davari*‡

*Electrical Engineering Faculty, Shahid Rajaee Teacher Training University, Lavizan, Tehran, Iran

(sghabousnejad@yahoo.com, ashkan.majdi@gmail.com, davari@sru.ac.ir)

‡ Corresponding Author; S. Alireza Davari, Tel: +90 312 123 4567,

Fax: +98212297006, davari@sru.ac.ir

Received: 23.12.2018 Accepted:04.02.2019

Abstract- This paper presents a power and light sensor-less P&O (perturbation and observation) based single-axis tracking method. This method can be utilized in both solar power stations and standalone systems, such as a building or water pumps to track the sun. With the help of a stepper motor, the angle of incidence is changed constantly while a controller simultaneously compares the maximum received power from each angle, As a result, the system will find correct direction toward the sun. In this method the maximum value of solar energy is captured at any time during a day. Its manufacturing cost is much less than sensor based solar trackers and also it can accurately track the sun in different weather conditions such as cloudy sky. The advantage of this system is that it works regardless of any current or light sensors. The proposed method is verified by the simulations and experiments.

Keywords Solar tracker, sensor-less single-axis tracker, solar energy, solar PV panel.

1. Introduction

Solar energy is known as a sustainable source of energy on earth. There are a range of technologies that the solar energy can be captured by using them. One of them is solar photovoltaic (PV). A solar PV module is a current source, i.e., it produces the current that its amplitude depends on the insolation level on the surface of the PV module. The characteristic curves (I-V and P-V) of a PV module is nonlinear and there is only one maximum power point (MPP) under full exposure to sunlight [1]. I-V and P-V characteristics of a PV module change in different temperature and insolation. Thus there can be a lot of I-V and P-V curves for a single PV module that all of them have a unique maximum power point. Scientists have been widely studying to update the methods of achieving the optimum curve and maximum power point at any time of the day. There are two steps to reach this objective: 1) finding the optimum curve, 2) finding the maximum power point. Several methods have been provided in order to find the maximum power point (MPP). The MPPT techniques available in the literature are based on the impedance matching logic and can be categorized to four main groups: 1) perturb and observe (P&O), 2) incremental conductance (InC), 3) fractional open-circuit voltage (FOCV), and 4) fractional short-circuit current (FSCC)[2],[3],[4]. P&O and InC are also known as online methods because they do tracking without isolating PV module from the system. However, they have some disadvantages such as their oscillations around the maximum power point.

Alternatively, finding the optimum curve can be performed by solar trackers. It has been shown in the literature that using the simplest solar tracker can increase the efficiency of the panel by about 10-20% compared to that of the fixed panels [5]. With the help of the accurate trackers, according to previous researches, about 20%-50% more solar energy can be captured depending on geographical location [6]. As trackers are capable of directing the PV modules toward the sun. Such devices change their orientation throughout the day to follow the sun's path to maximize the energy capture as a result of minimizing the angle of incidence between the incoming light and the PV module [7]. Generally, two main types of trackers have been investigated in the literature: passive (mechanical), and active (electrical) trackers [8], [9]. In general, the passive trackers can be categorized as manual adjustment of the panel [10], thermal expansion of a shape memory alloy [11], and two bimetallic strips made of aluminum and steel [12]. On the other hand, the active trackers are classified as a microprocessor based,

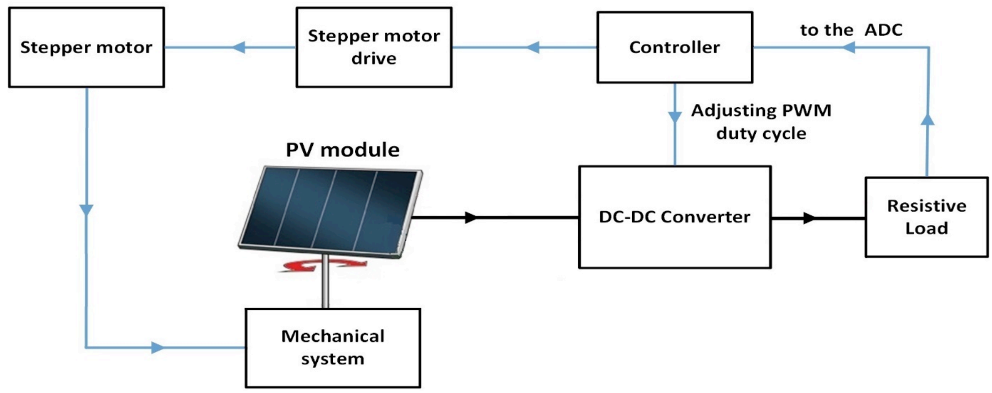


Fig. 1. Schematic diagram of the complete system

computer-controlled systems which are based on the date and time, auxiliary bifacial solar cell based, and a combination of these three systems [8].

The active trackers, due to their higher accuracy, have been considered more. Among the mentioned types, microprocessor and computer based method are more efficient and economic. Those techniques could be applied by two kinds of hardware: single-axis and dual-axis [13]. Single-axis solar trackers only track one direction which is the daily path of the sun while dual axis solar trackers track the sun path in two directions which are daily and seasonal motions of the sun [14], [15]. According to the researches in dual-axis trackers, when seasonal motion of the sun is considered the efficiency is improved by about 4% [16]. Thus, using dual-axis trackers does not seem necessary due to the increase of cost and complexity. In [8], it has been concluded that active based single-axis tracker system is less complex to design and maintain. The tracking method that has been proposed in [8] is based on a standalone single-axis solar tracker. The method works in three modes: automatic, preset, and manual. In automatic mode a PIC microcontroller rotates the PV panel to balance the light intensity at both LDR (light-dependent resistor) sensors. In preset mode which is mainly for conditions like cloudy sky (sensors receive low voltage) the PV panel is programmed to rotate 2 degrees towards west in every 15 minutes. In manual mode, it allows the panel to rotate to the desired angle by manually increasing or decreasing the angle via the input of the PIC microcontroller. This method is dependent on the light sensors which are located on the surface of PV module. Yet, using cheap sensors or mounting them on the surface of the PV module not only increases the tracking error but also reduces the system robustness. A sensor-less dual-axis solar tracker was implemented in a research by [17] and it was shown that 19.1%-30.2% more solar energy can be captured depending on the seasons by utilizing the tracker. It uses solar map equations for setting altitude and azimuth angles which means a new set of data will be needed by changing the geographical location of the PV module. It also utilizes two stepper motors to adjust these angles which increases the cost. The geographical location techniques are open-loop methods in which the accuracy depends on the pre-saved data. The dual-axis tracker designed by [18] uses two distinct strategies: normal tracking strategy which is sensor based, and daily adjustment strategy in which the primary axis is adjusted once a day and the secondary axis is regulated to rotate at a constant speed of 15 degree per hour. Annual average cosine loss of the other strategy for flat PV systems is estimated to be below 1.3%.

In this paper, a power sensor-less P&O based single-axis solar tracker has been proposed, MPPT algorithm is based on P&O method and the tracker also is based on perturbation and observation method. Unlike previous researches in the field of active trackers the proposed method is dependent on LDRs, geographical equations, or time-based positioning. The proposed algorithm is closed-loop that can be applied in every location. The proposed P&O single-axis tracking method is evaluated by means of the experiments. It can work properly in every weather condition such as cloudy sky. The structure of the paper is as follows: In section 2 the model of the system is studied. Section 3 consists of the proposed P&O based single-axis tracking method, and in section 4 the results will be analyzed and the last section is allocated to conclusion.

2. System Design

The schematic diagram of the proposed single-axis solar tracker is shown in Fig. 1. The tracker consists of a PV module, a controller, a stepper motor to track the daily path of the sun, mechanical components and a DC converter.

As mentioned, there are two goals to be achieved by the solar tracking systems. The first is finding the optimum curve which will be achieved by the mechanical system. The second is finding the MPP in the curve which will be performed by the DC converter.

2.1. Mechanical system

The mechanical system used for the proposed method is rather simple. A gear box is used to connect the axis of the PV structure to the stepper motor. A hinge is installed for adjusting the mounting angle of the PV manually. By using this hinge the second axis adjustment is provided. Since this angle could be fixed due to the geographical position and the season of the year, manual adjustment will be sufficient. Fig. 2 shows the installed mechanical system.

The mechanical gear is designed to coordinate the torque-speed characteristic of the stepper motor with the mechanical characteristic of the PV module and also to decrease the friction effects. The gear box has two gearwheels: the primary gearwheel and the secondary gearwheel with the gear ratio of N1/N2=1/3 . Using this ratio, each rotation step is converted to 0.6° and as a consequence the tracking error will be decreased. Also, the gear box increases the holding torque by the factor of three. Nominal holding torque of the utilized stepper motor is 8 Kg-cm which means the driving torque is approximately 24 kg-cm.

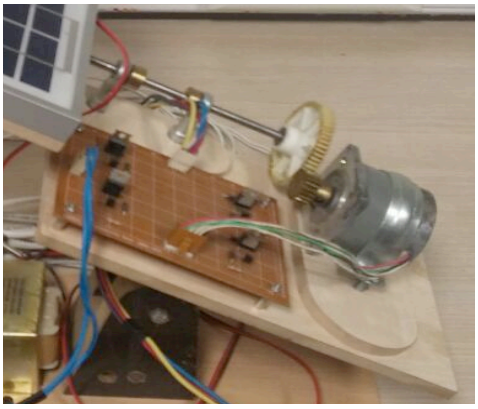


Fig. 2. The installed mechanical system

2.2. DC converter

The measured V-I characteristic of the utilized PV module is depicted in Fig. 3. This curve is achieved by experimental tests in the laboratory. As it is known a boost converter is needed to match the load impedance to the optimal value. It is necessary to calculate the standard ranges of the boost converter's components based on system's objectives. In order to design the boost converter, the value of the duty cycle should be known. It is clear that the MPP is achieved in 64% of the duty cycle for the test condition. Thus, this duty cycle is used for the converter design. Note that this duty cycle is achieved in a specific insolation level but it will be valid because the converter is designed for the maximum power that can be achieved from the under test PV panel. Thus, considering system's frequency (32kHz) and also the maximum value of duty cycle (0.64), the maximum range of the inductor will be calculated as follows [11]:

$$L_b = \frac{R_{Load}}{2f}(1-D)^2 D \qquad \text{(1-a)}$$

$$L_b = \frac{390}{2\times 32000}\times (1-0.64)^2 \times 0.64 = 505\mu H \qquad \text{(1-b)}$$

where D is the duty cycle, R_{Load} is the load resistance in ohms[Ω] , and f is the switching frequency in Hertz [Hz]. The load resistance is selected so that the maximum power is reached. For this purpose, this resistance is 390 ohms.

Also the capacitor's minimum value can be calculated [11]:

$$C_{\min} = \frac{V_0}{V_r\, f\, R_{Load}} D \qquad \text{(2-a)}$$

$$C_{\min} = \frac{100}{32000\times 390}\times 0.64 = 5\mu F \qquad \text{(2-b)}$$

where V_0 is the output voltage in volts [v] V_r is the ripple voltage in volts, and $C_{\min}$ is the minimum value of output capacitor in micro farads [μF] the ripple ratio (V_r/V_0) equal to 0.01 is selected in this research. Table 2 summarized the system design criteria both electrical and mechanical.

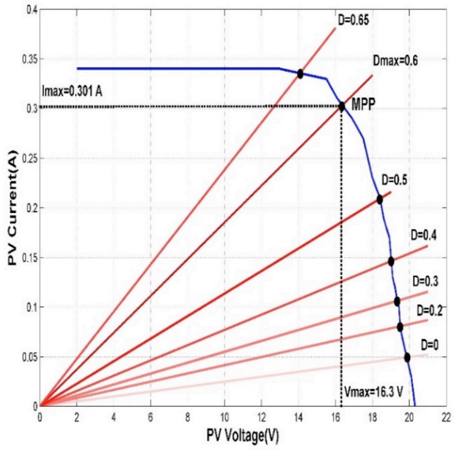


Fig. 3. Measured V-I characteristic of the utilized PV module

2.3. Controller

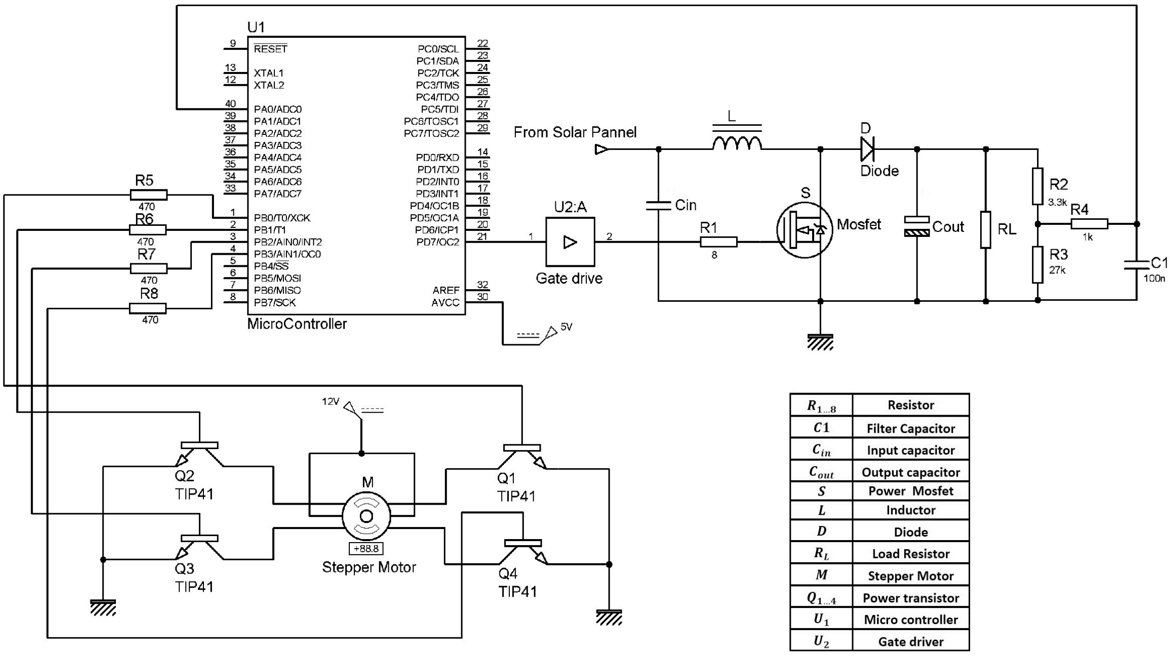
The stepper motor and the boost converter are controlled by an ATMEGA32 microcontroller which is inexpensive and available. Note that if the prototype is going to the industry more professional microcontrollers can be considered. However, the purpose of using this microcontroller is the indication of the ability to implement the proposed method with an inexpensive microcontroller with weak processing power.

The circuit diagram of the whole electrical system is shown in Fig. 4.

3. Proposed P&O Based Single-axis Tracking Method

In this paper, two stages are combined and performed in one algorithm, i.e., finding the optimum curve which will be achieved by the angle regulation, and finding the maximum power point on the selected curve. This combination removes the need for the photo sensor.

The P&O method has been widely used to find the MPP in fixed cells [19]-[23]. In this method, a certain value is added to the reference voltage or it is subtracted from it. The result is observed and is compared with the last recorded value. Consequently, it will be converged to the optimum reference voltage. This theory is used to find the optimum angle of the solar cell. Fig. 5 shows the flow diagram of the proposed method. First, the angle reference is set to the western most angle. Then the controller chooses a primary value for duty cycle of the boost converter (D=0) and with the help of the ADC unit and the sampler circuit it saves the output voltage in this duty cycle. The controller changes the duty cycle step by step (ΔD=0.04) and also saves the voltage values in each step. The voltage values in each two consecutive steps will be compared and when the second value is lower than the first value it means that the voltage value of the previous step is the MPP at the examined angle. When the first MPP in the first angle of incidence is found, the system will rotate towards the defined direction (east) then the MPP subroutine will be called in the new angle of incidence. As a consequence, the system will save a new M-



$R_{1...8}$	Resistor
$C1$	Filter Capacitor
C_{in}	Input capacitor
C_{out}	Output capacitor
S	Power Mosfet
L	Inductor
D	Diode
R_L	Load Resistor
M	Stepper Motor
$Q_{1...4}$	Power transistor
U_1	Micro controller
U_2	Gate driver

Fig. 4. Schematic diagram of the complete system

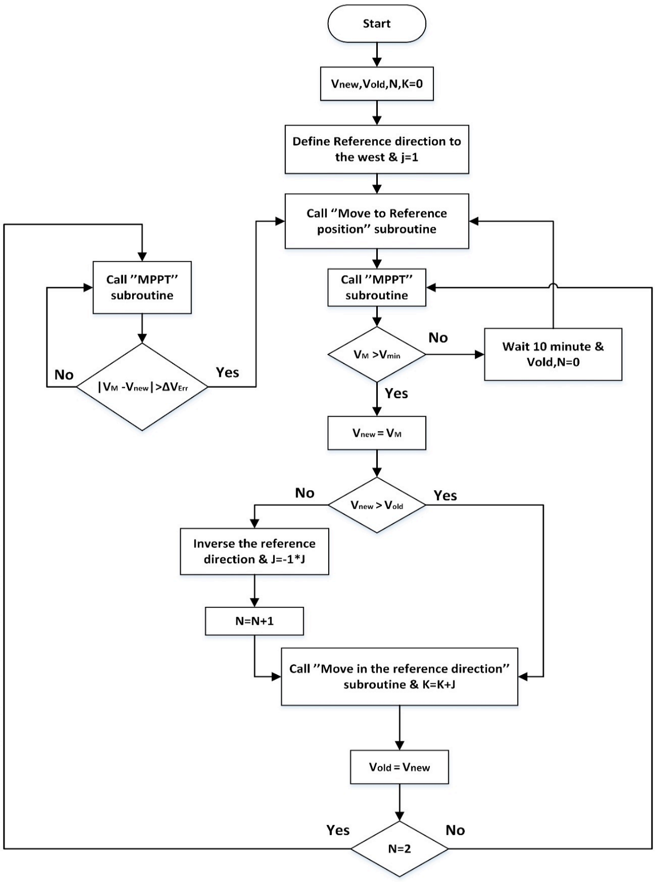


Fig. 5. Flow diagram of the proposed sensorless tracking method

PP value in a new I-V curve. These two maximum power points are compared with each other to find the correct direction toward the sun, i.e., if the second MPP value is larger than the first one, it means that the system's first rotation direction is correct and if it is not, the system changes the rotation direction. This algorithm continues until the best curve and MPP in that curve is reached in the output of the PV module. Note that after each change of the rotation direction a counter will be activated in the program and if the value of this counter is more than 2, the system will stop changing the angle of incidence. The algorithm should detect the need for angle change. Thus, the MPP subroutine will be performed for the selected angle till the voltage value differs more than 2 volts.

Table 1. Test System Specification

PV module in daylight	
MPP voltage	9-17.1 [V]
MPP Current	50-292 [mA]
O.C. voltage	18-22 [V]
S.C. current	20-340 [mA]
maximum power	5 [W]
Converter	
Input capacitor	0.1 [µF]
Output capacitor	22 [µF]
Switching frequency	30 40 kHz
Input inductance	0.6-0.8 [mH]
MOSFET switches	IRF3205
Diode	MUR120
Gate driver	HCPL3120
Processor	
Type	ATmega32
Frequency	8 [MHz]
Load	
Resistance	390 [Ω]

Table 2 System design criteria

electrical system	Converter	Source	5w solar Panel
		output power	16w
		switching frequency	40Khz
		sampling frequency	125Hz
		sampling accuracy	0.10%
		efficiency	91%
		Voltage ripple	2%
		Current ripple	2%
	Actuator & Drive	stepper motor	6 pole unipolar 1.8 degree
		Unipolar drive	Max 20Hz switching
Mechanical system	type	gear box	low speed output shaft
	type of move	step rotation	0.6 degree

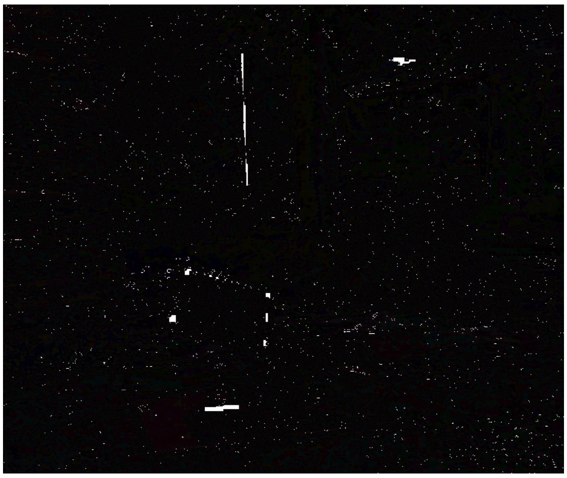


Fig. 6. Complete experimental set-up

4. Results

In order to evaluate the proposed algorithm, a tracker in a small scale has been built. The technical specification of different parts of the tracking system are summarized in Table 1. Fig. 6 shows the complete experimental set-up in the test condition.

The experiment was performed on November. 16. 2016 at 12:50. The initial position of the panel was set to 90°. The control system began to run the MPPT algorithm at this angle. The maximum power was found after 0.6 sec. the maximum voltage was 27.5 V approximately. The voltage values from the initial one to the maximum value is depicted as MPPT1 in Fig. 7-a. Afterward, a single step was added to the position and the degree reached to 104.4° by the proposed algorithm. Note that the microcontroller produced 24 pulses in each step and each pulse equals to 0.6 degree which results in a sum of 14.4 degree for each step. The MPPT algorithm was run for the second time and the maximum voltage due to this angle was attained. The maximum value was 27 V. The procedure of the voltage in this angle is depicted as MPPT2 in Fig. 7-a. Since the achieved voltage was less than the previous one the direction of rotation had to be reversed. Thus the position angle was returned to 90° and a new MPPT was run. The procedure is shown as MPPT3 in Fig. 7-a. The decrease of the angle continues to 75.6°and The MPPT4 was run in this position.

The maximum voltage was achieved at 30.5 V. Then the position was decreased to 61.2° and MPPT5 was run. The maximum voltage was 29.5 V. Since this voltage was less than the previous one the algorithm knows that the angle should be returned to the 75.6° and that was optimum angle of incidence. The position of the tracker is shown in Fig. 7-b. Note that the optimum angle at the time of the experiment (77.5°) is calculated from the hour angle [24] as follows

$$w = 15°(time - 12) \quad (3\text{-a})$$

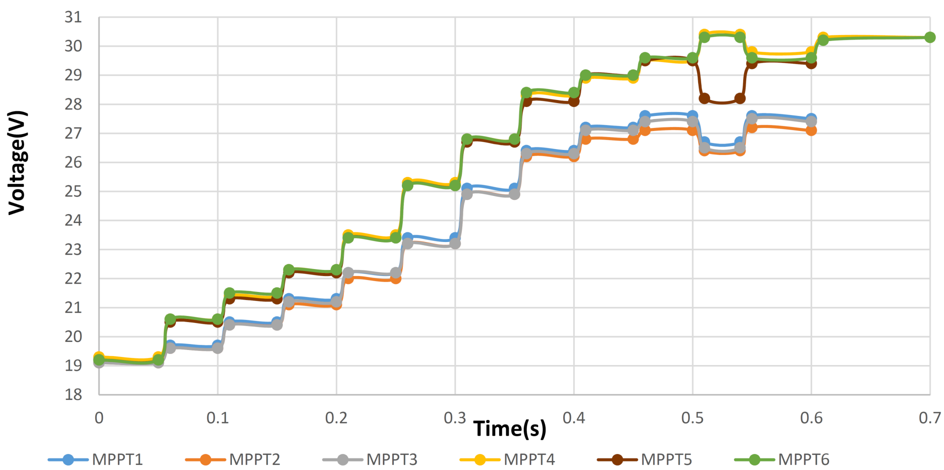
$$w = 15°(12:50 - 12) = 12.5° \quad (3\text{-b})$$

$$\partial = 90° - 12.5° = 77.5° \quad (3\text{-c})$$

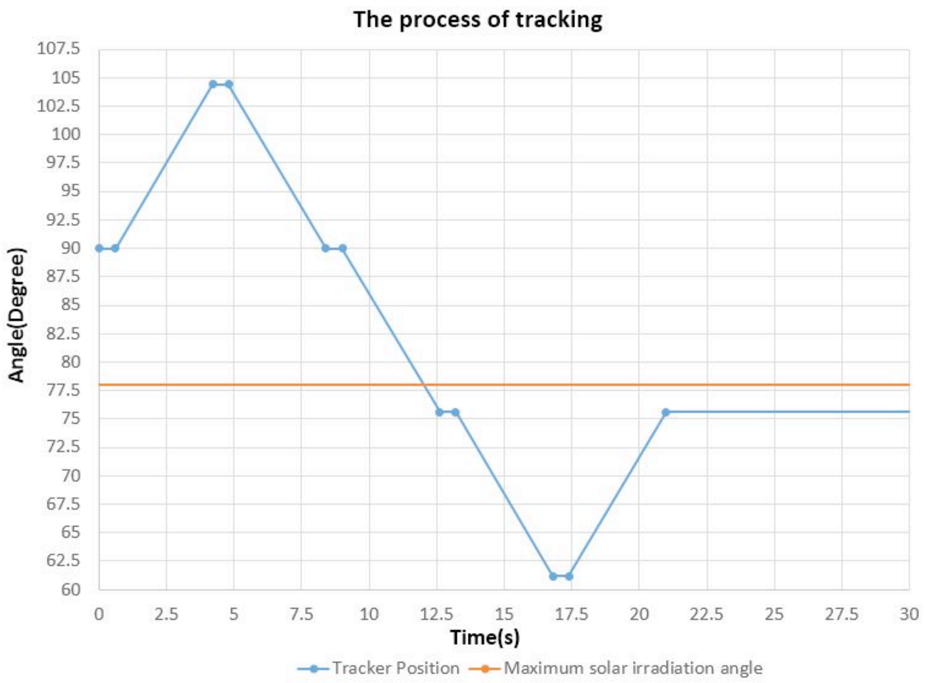
where w is the sun's angular deviation from the reference angle 90° and ∂ is the optimum angle of incidence at the time of the experiment.

The procedure of the load power and PV power is depicted in Fig. 8. It shows that the losses in the converter is 0.6 w approximately.

The robustness of the proposed algorithm in the dirt and mud polluted condition was also studied. Fig. 9 shows a photo of the system in this condition. Fig. 10 shows the voltages and the selected angle of incidence in the mud polluted condition. It can be seen that error is 5°. It is deduced that the mud disturbance has increased the convergence error but it has not caused any divergence. The procedure of the load power and PV power in distorted condition is depicted in Fig. 11. The losses in this condition is approximately 0.8 w.

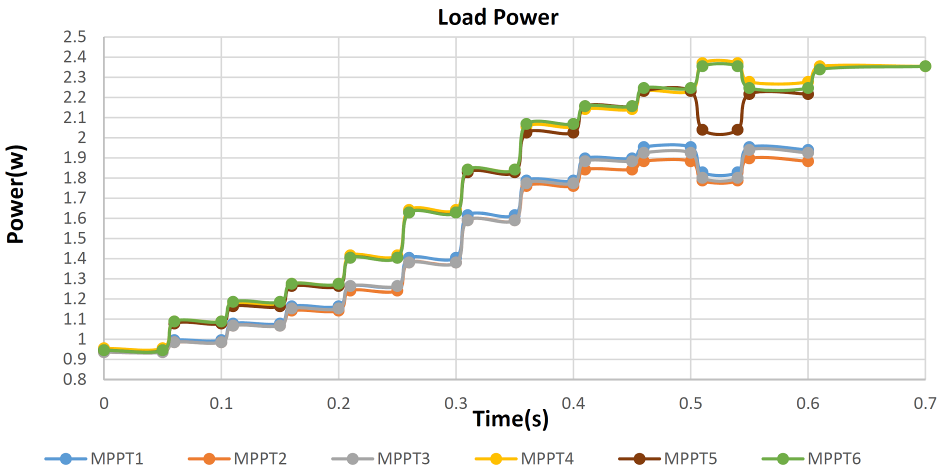


a

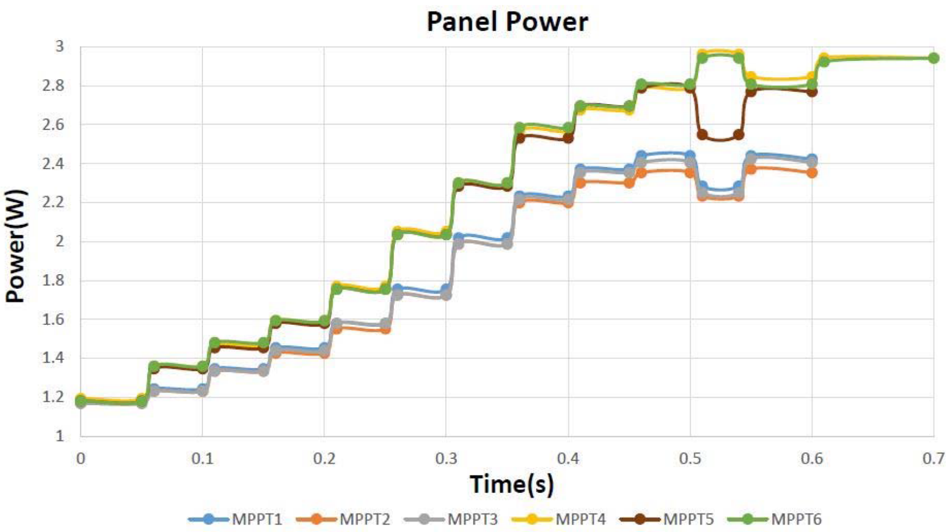


b

Fig. 7. Converging procedure of the proposed tracking method **(a)** The output voltage of the converter for different angle of incidence, **(b)** The selected angle of incidence during the tracking algorithm



a



b

Fig. 8. The powers during the performance of the proposed tracking algorithm **(a)** The load power, **(b)** The PV power

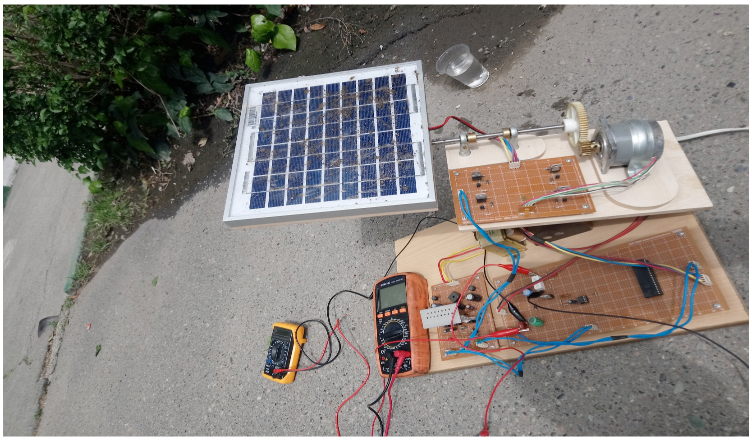
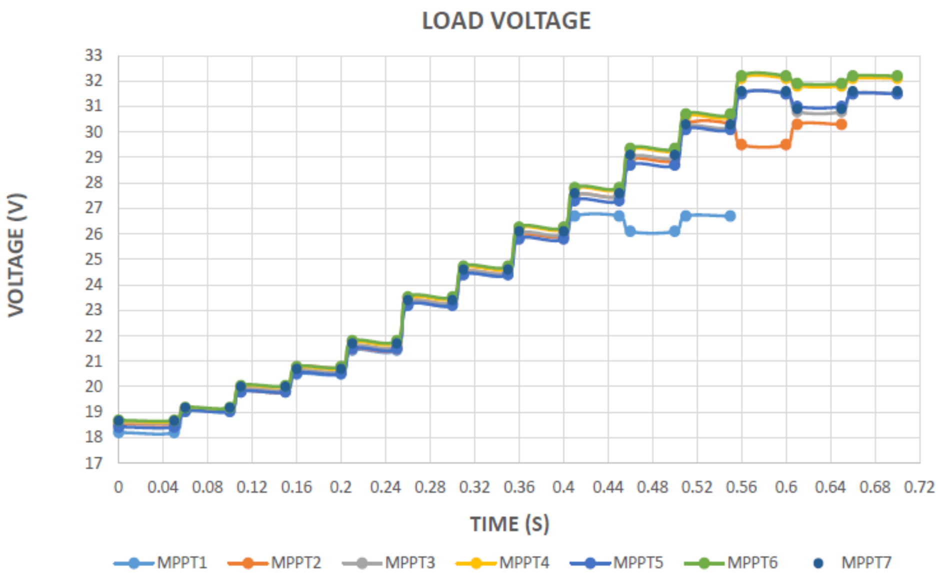
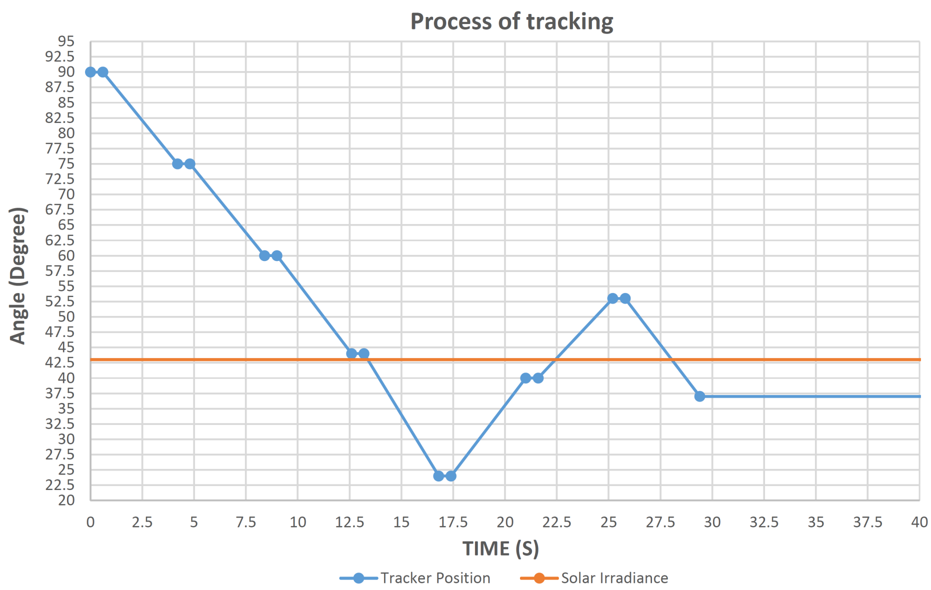


Fig. 9. mud polluted panel

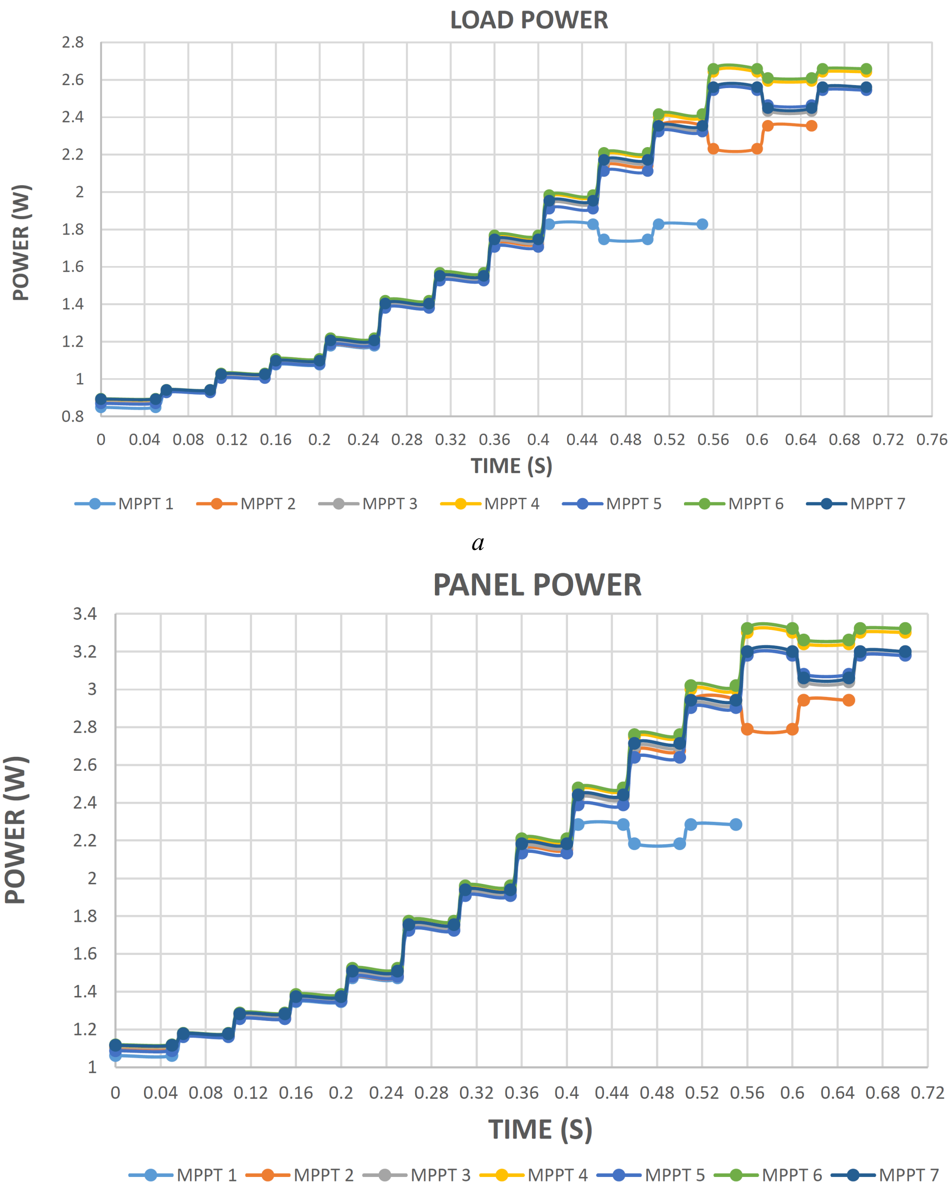


a



b

Fig. 10. Converging procedure of the proposed tracking method in mud/dirt condition **(a)** The output voltage of the converter for different angle of incidence, **(b)** The selected angle of incidence during the tracking algorithm



b

Fig. 11. The powers during the performance of the proposed tracking algorithm in mud/dirt condition **(a)** The load power, **(b)** The PV power

5. Conclusion

In this paper a sensor-less P&O based single-axis solar tracker was presented. Two P&O methods are applied in two levels in the proposed method. The angle of incidence is perturbed and the maximum power point is found in that angle via the inner layer P&O method. The angle of incidence is corrected via the outer level P&O method. Based on the characteristic of the P&O based method, the need for the light sensor is removed. Also, since the observation is performed via the measured voltage, neither current nor power measurement is used in the proposed method. The proposed method is not dependent on the azimuth, altitude angle, and geographical equations and it can be applied in any weather condition. The experimental tests show maximum 1.5 degree for the error of the optimum angle which is less or the same in comparison with similar reasearches done before. Future works can be done in applying such systems as a guidance for a group of solar panels to track the sun.

References

[1] Subudhi, B., Pradhan, R.: ‘A comparative study on maximum power point tracking techniques for photovoltaic power systems’, IEEE Trans. Sustain. Energy, 2013, 4, (1), pp. 89–98.

[2] Carlos Arturo Robles, Adalberto Ospino Castro, Jose Casas Naranjo: ‘Dual-Axis Solar Tracker for Using in Photovoltaic Systems’, International Journal of Renewable Energy Research. Turkey, Vol 7, No 1, 2017, pp. 137-145.

[3] Reisi, A. R., Moradi, M. H., Jamasb, S.: ‘Classification and comparison of maximum power point tracking techniques for photovoltaic system: A

review', Renew. Sustain. Energy Rev., 2013, 19, pp. 433–443.

[4] Ishaque, K., Salam, Z.: 'A review of maximum power point tracking techniques of PV system for uniform insolation and partial shading condition," Renew. Sustain. Energy Rev., 2013, 19, pp. 475–488.

[5] Vieira, R.G., Guerra, F.K.O.M.V., Vale, M.R.B.G., et al.: 'Comparative performance analysis between static solar panels and single-axis tracking system on a hot climate region near to the equator', Renew. Sustain. Energy Rev., 2016, 64, pp. 672-681.

[6] Quesada, G., Guillon, L., Rousse, D.R., et al.: 'Tracking strategy for photovoltaic solar systems in high latitudes', Energy Convers. Manage., 2015, 103, pp. 147-156.

[7] Daraban, S., Petreus, D., Morel. C.: 'A novel MPPT (maximum power point tracking) algorithm based on a modified genetic algorithm specialized on tracking the global maximum power point in photovoltaic systems affected by partial shading', Energy, 2014, 74, pp. 374-388.

[8] Chin, C.S., Babu, A., McBride, W., et al.: 'Design, modeling and testing of a standalone single axis active solar tracker using MATLAB/Simulink', Renew. Energy, 2011, 36 (11), pp. 3075-3090.

[9] Athanasios G. Sarigiannidis ; Spyridon A. Stathis ; Antonios G. Kladas: ' Performance evaluation of MPPT teqniques for PV array incorporated into Electric Vehicle roof', International conference on Renewable Energy Research and Applications, 2015, pp. 1069-1073.

[10] Mwithiga, G., Kigo, S.N., 'Performance of a Solar Dryer with Limited Sun Tracking Capability', Journal of Food Engineering, 2006, 74, pp. 247-252.

[11] Poulek, V., 'Testing the New Solar Tracker with Shape Memory Alloy Actors', IEEE Photovoltaic Specialists Conference, 1994, 1, pp. 1131–1133.

[12] R. Boukenoui ; R. Bradai ; A. Mellit ; M. Ghanes ; H. Salhi: 'Comparative analysis of P&O, modified hill climbing-FLC and adaptive P&O-FLC MPPTs for microgrid standalone PV system', International conference on Renewable Energy Research and Applications, 2015, pp. 1095-1099.

[13] Sallaberry, F., Pujol-Nadal, R., Larcher, M., et al.: 'Direct tracking error characterization on a single-axis solar tracker', Energy Convers. Manage., 2015, 105, pp. 1281-1290.

[14] Chong, K.K., Wong, C.W.: 'General formula for on-axis sun-tracking system and its application in improving tracking accuracy of solar collector', Solar Energy, 2009, 83 (3), pp. 298-305.

[15] Barker, L., Neber, M., Lee, H.: 'Design of a low-profile two-axis solar tracker', Sol. Energy, 2013, 97, pp. 569-576.

[16] Lubitz W. D.: 'Effect of Manual Tilt Adjustments on Incident Irradiance on Fixed and Tracking Solar Panels', Applied Energy, 2011, 88, pp. 1710-1719.

[17] Fathabadi, H.: 'Novel high efficient offline sensorless dual-axis solar tracker for using in photovoltaic systems and solar concentrators', Renew. Energy, 2016, 95, pp. 485-494.

[18] Yao, Y., Hu, Y., Gao, S., et al.: 'A multipurpose dual-axis solar tracker with two tracking strategies', Renew. Energy, 2014, 7, pp.88-98.

[19] Hussein, KH., Muta, I., Hoshino, T., et al.: 'Maximum photovoltaic power tracking: an algorithm for rapidly changing atmospheric conditions', IEE Proc. Gener. Transm. Distrib., 1995, 142, pp. 59–64.

[20] Subash Gautam ; Debendra Bahadur Raut ; Prabesh Neupane ; Dhan Prasad Ghale ; Rabin Dhakal, ' maximum power point tracker with solar prioritizer in photovoltaic application', International conference on Renewable Energy Research and Applications, 2016, pp. 1051-1054.

[21] Ahmed Ali ; Ali N Hasan ; Tshilidzi Marwala, 'Perturb and observe based on fuzzy logic controller maximum power point tracking', International conference on Renewable Energy Research and Applications, 2014, pp. 406-411.

[22] Femia, N., Petrone, G., Spagnuolo, G., et al.: 'Optimization of perturb and observe maximum power point tracking method', IEEE Trans. Power. Electron., 2005, 20, pp. 963–73.

[23] Ahmed, J., Salam, Z.: 'An improved perturb and observe (P&O) maximum power point tracking (MPPT) algorithm for higher efficiency', Appl. Energy, 2015, 150, pp. 97–108.

[24] Schowengerdt, R. A. 'Optical radiation models', Remote Sensing, 2007, pp. 45–88.

[25] J.Canadaa, M.P.Utrillasb J.A.Martinez-Lozanob, Design of a sun tracker for automatic measurement of spectral irradiance and construction of an irradiance data base in the 330-1100 nm range, Renew, Energy 32 (12) (2007) 2053-2068

[26] J. Wu, X. Chen, L, Wang, 'Design and dynamics of a novel solar tracker with parallel mechanism'. IEEE/ASME Trans. Mechatron 21 (1) (2016) 88-97.

[27] Kazuhiro Kajiwara ; Nobumasa Matsui ; Fujio Kurokawa: ' A new MPPT control for solar panel under bus voltage fluctuation', International conference on Renewable Energy Research and Applications, 2017, pp. 1047-1050.