IMPROVING PV PERFORMANCE USING MICROCONTROLLER-BASED MPPT AND SUN TRACKING SYSTEMS

[1]ABD EL-SHAFY A. NAFEH, [2]TAREK M. E. ABOU SALTOUH, [3]FATEN H. FAHMY, [4]HOSAM K. YOUSEF

[1,2,3]Electronics Research Institute, Cairo, Egypt
[2]Faculty of Engineering, Cairo University, Egypt
E-mail: [1]abdelshafyn@yahoo.com, [2]engtarekmoh@gmail.com, [3]faten@eri.sci.eg, [4]hosamkm@yahoo.com

Abstract - This paper aims to improve the performance of a photovoltaic (PV) module by using each of the maximum power point (MPP) tracker and sun tracker. The experimental implementation of both trackers is carried out in this paper. The maximum power point tracking (MPPT) system is implemented, in this work, by using AVR ATmega microcontroller and a DC-DC converter. Whereas, the sun tracking system is implemented by using the same type of microcontroller and an H-bridge. The control system of the implemented MPP tracker is designed based on utilizing the perturb and observe (P&O) peak-power tracking algorithm, which can be implemented easily in this work, and PI controller. While that of the sun tracker is designed based on utilizing the optical tracking technique, which is chosen, in this work, due to its simplicity and independence on the geographical location. Experimental results indicate that the use of the implemented trackers gives good results for both the MPPT and sun tracking systems.

Index Terms - DC-DC converter, H-bridge, MPPT, Single-axis sun tracking.

I. INTRODUCTION

Significant progress has been made over the last few years in the research and development of renewable energy systems such as wind, sea wave and solar photovoltaic (PV) systems. Among these resources, solar PV energy is considered nowadays as one of the most reliable, daily available, and environment friendly renewable energy source [1]-[6]. However, unfortunately, the PV systems have two main problems which are low efficiency of conversion, especially in low insolation levels, and that the power produced by PV modules varies with weather conditions in a continuous manner [7]-[9]. Moreover, the current-voltage (I-V) characteristic of the PV modules is nonlinear and varies with insolation and temperature. At the same time, there is a unique point on the I-V curve, called maximum power point (MPP), that can supply maximum power to the load [7]. In addition, the amount of solar radiation incident on a surface of a PV panel varies with geographic location, time of the day, and panel orientation relative to both the sun and the sky [3]. In the literature, there are two common trackers that can be used to improve the performance of PV panels, which are MPP tracker and sun tracker [5], [9]. The maximum power point tracking (MPPT) systems involve power electronic converters that are controlled and operated according to certain MPPT algorithms with the aim to continuously extract maximum power from the PV panels throughout the daylight. While, the physical sun tracking systems involve control systems to align the PV panels to be continuously perpendicular to the sun's rays throughout the day in order to receive maximum solar radiation and optimize the efficiency of PV panels [2], [3]. Many MPPT algorithms have been developed and implemented in the literature. Examples of these algorithms are the perturb and observe (P&O), the incremental conductance, the artificial neural networks, the fuzzy logic algorithms, etc. [1]-[10]. These algorithms vary in complexity, sensors required, convergence speed, cost, range of effectiveness, implementation hardware, popularity, and in other respects. In addition, in literature also, sun tracking mechanisms can be classified based on the rotation axis to single-axis and dual-axis. The general features that characterize an efficient tracking mechanism are its ability to cover a wide range of space, its robustness against wind disturbances, and its low power consumption. Single-axis trackers have one degree of freedom as an axis of rotation. Three orientations of single-axis solar trackers are common: horizontal, vertical, and tilted. Also, the dual-axis trackers have two degrees of freedom that act as axes of rotation. These axes are typically normal to each other. The primary axis is the one that is fixed with respect to the ground. The secondary axis is the one referenced to the primary axis. There are various common implementations of dual trackers. Their classification is based on orientation of their primary axes with respect to the ground [2], [3], [5].

In this paper, the performance of a PV module is improved by using each of the P&O-based MPP tracker and single-axis sun tracker. The experimental implementation of both trackers is carried out, in this case, by designing the appropriate DC-DC converter and H-bridge, respectively. Both tracking systems are controlled by using an inexpensive advanced virtual RISC (AVR) ATmega16 microcontroller.

II. THE PROPOSED EXPERIMENTAL SYSTEM

The configuration of the proposed experimental tracking PV system is shown in the block diagram of Fig. 1. This system comprises two main systems, which are the MPPT system and the sun tracking system. The MPPT system includes the PV module, the DC-DC buck converter, the DC load, and the MPPT controller, which is implemented, in this work, by using a microcontroller. Also, this system includes an auxiliary system for PV data collection and monitoring, which is called, in this work, the data collection and monitoring unit. In addition, the sun tracking system includes the PV tracker structure, the DC motor and gear box unit, the H-bridge, and the sun tracker controller, which is implemented also, in this work, by using a microcontroller.

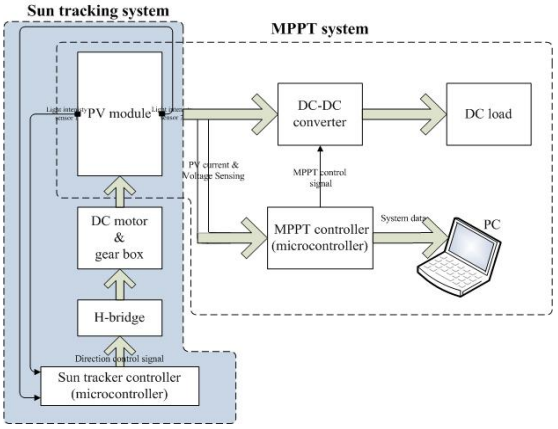


Fig. 1 Configuration of the proposed tracking PV system.

A. The Designed MPPT System

The detailed block diagram of the designed MPPT PV system that is required to be implemented and utilized for MPPT is shown in Fig. 2. The utilized PV module, in this work, is the LORENTZ LC80-12M PV module type that can provide $80W_p$ of maximum power at standard test conditions (STCs) [11]. A buck-type DC-DC converter is designed to match the PV output characteristics to the DC load and to track the MPP of the PV module accordingly. The converter power switch is built by using one power MOSFET whose ratings are 500V and 20A. This converter has a switching frequency of 31.2 kHz and it can operate at any isolation level. It is to be noted that the MOSFET current rating may be doubled, if required, by connecting a second similar MOSFET in parallel with the main one, also the MOSFET voltage rating can be increased by inserting a fast power diode in series with the main MOSFET transistor. The flyback power diode D is chosen to be of a fast switching type. The output inductor L is designed and wound on a ferrite-core with air-gap to prevent core saturation that might be caused by a large value of DC current component passing through it. The output inductor filter together with the input and output capacitors filters (i.e., C_{in}, and C, respectively) are designed according to the procedure described in [9]. Fig. 2 shows, also, that a programmable load is used as the DC load for the considered system.

The ATmega16 microcontroller is used here, as the main element of the designed control system, to provide the buck converter with the required PWM control signal that is necessary for MPPT of the PV module. It is to be noted, here, that the details of the designed control system include:

- AVR ATmega16 microcontroller
- interface circuits which comprise of current and voltage sensors and signal conditioners connected to the microcontroller A/D converter
- driving circuit of the power MOSFET
- PV data collection and monitoring unit

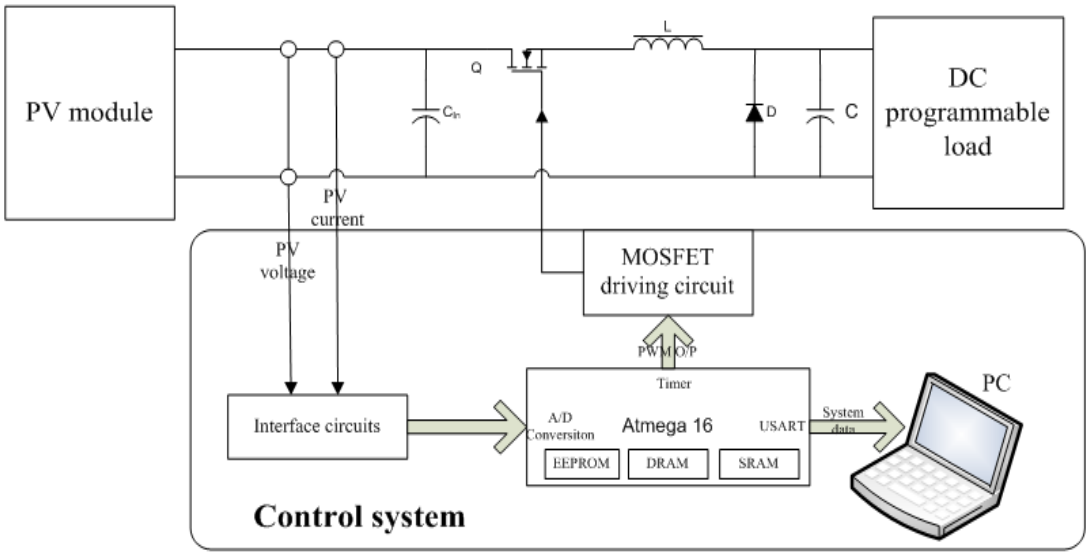


Fig. 2 The designed MPPT system.

The microcontroller that is used in this system is an 8-bit AVR ATmega16 microcontroller from ATMEL. On it a program can run to govern the control of the MPPT system. Where, it is used to read the measured input PV voltage and current to yield the output PWM signal of the DC-DC converter.

At the same time, this microcontroller is used, also, to communicate with the personal computer (PC) to send the measured current values of the PV current, voltage, and power of the PV module to the PC through serial communication USART; for the purpose of monitoring and collecting the PV experimental data. The considered microcontroller has an A/D converter features that are 10-bit, eight channels, successive approximation A/D converter, that can be used by the control program to read the signals required for the control purposes. The 8-bit resolution is chosen to be adequate for the present application. Also, the used microcontroller has three timers with PWM outputs and program-controlled duty cycle of maximum frequency of 31.2 kHz when driven by a crystal that generates a clock frequency of 8 MHz. This microcontroller was chosen, in this case, because it has the necessary features for the proposed system, such as an on-chip A/D converter, PWM outputs, 8-bit architecture, high clock rate, low-power consumption and low cost [5], [9].

The software design, in this case, includes the flowchart of the designed P&O MPPT algorithm, which is shown in Fig. 3. This algorithm starts with reading the PV voltage V_{PV} and PV current I_{PV}. The PV power is then calculated from these two parameters. Afterwards, a comparison is done between the PV power and its previous value. Consequently, another comparison is done again between the PV voltage and its previous value to determine whether to increment/decrement the reference PV voltage V_{ref}.

B. The Designed Sun Tracking System

The detailed block diagram of the designed sun tracking system, which is indicated in Fig. 4, illustrates that the considered sun tracking system is composed of the following detailed components:

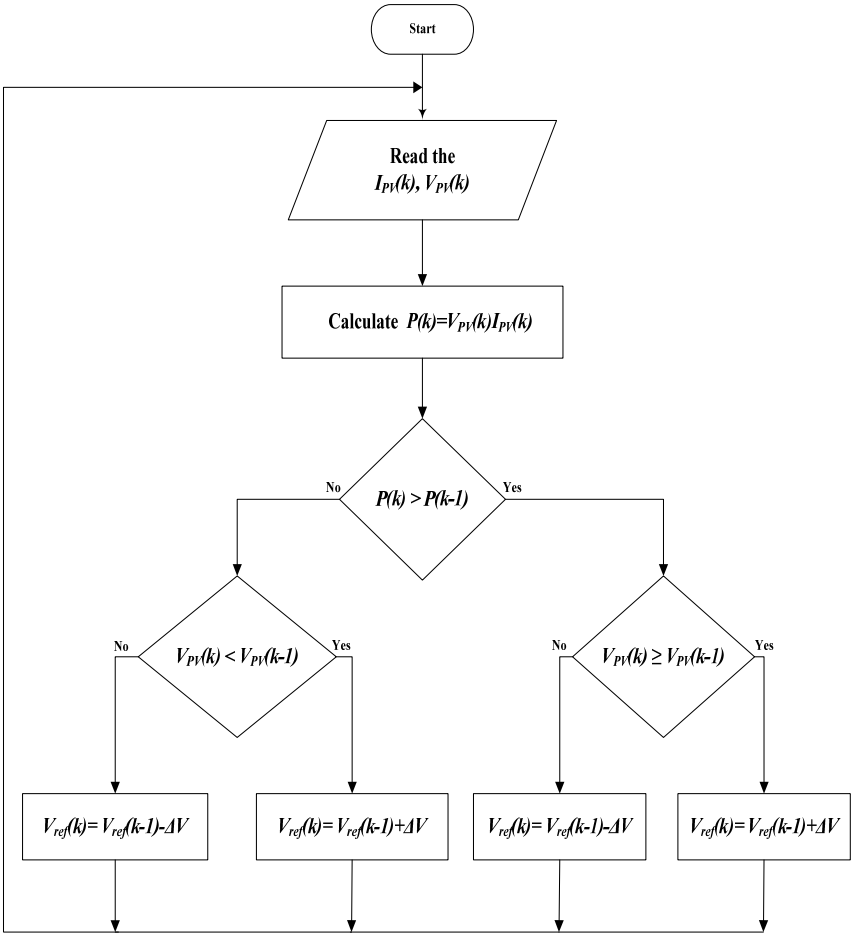


Fig. 3 Flowchart of the P&O algorithm.

- The tracker structure that holds the PV module
- The DC motor and gear box that rotates the solar tracker
- The high power H-bridge that can supply the DC motor with the suitable voltage polarity; to rotate it in a certain direction or to reverse its rotation.

- The dead time generator and driving circuits unit that is necessary to drive the four power MOSFETs of the H-bridge and at the same time protects each of two MOSFETs on the same arm of the H-bridge from being short-circuited i.e., to be not conducted at the same time.
- The microcontroller that is responsible for controlling the overall sun tracking system, by receiving the measured sensors' signals, processing them, and finally outputting two digital control signals that are responsible for rotating the solar-tracker motor in the direction that tracks the sun.

The considered sun tracking system is designed, in this work, to rotate the used PV module to track the sun in the East-West direction only (i.e., single-axis tracking). Noting that the used PV module has a fixed tilt angle to the horizontal that equals the site latitude angle ϕ of the considered site. LDR1 and LDR2 are two light dependant resistors or sensors for light intensity detecting. If one of the two LDRs gets more light intensity than the other, an error signal will occur in node voltages that are sent to the appropriate ADC channels of the microcontroller. The microcontroller then calculates this error signal and compensates for it by rotating the tracker motor in one direction, otherwise the microcontroller will reverse the direction of the rotation till the generated error signal is vanished. At this instant, the light intensities on both LDRs will be equal. If the two LDRs are illuminated equally by the sun, the error signal calculated by the microcontroller will equal to zero and consequently the microcontroller will not generate any logic signal to rotate the motor.

Therefore, the main purpose of the designed sun tracking system is to use the microcontroller to control the H-bridge that can rotate the motor of the sun tracker in a certain direction or to reverse its rotation according to the position of the sun in the sky.

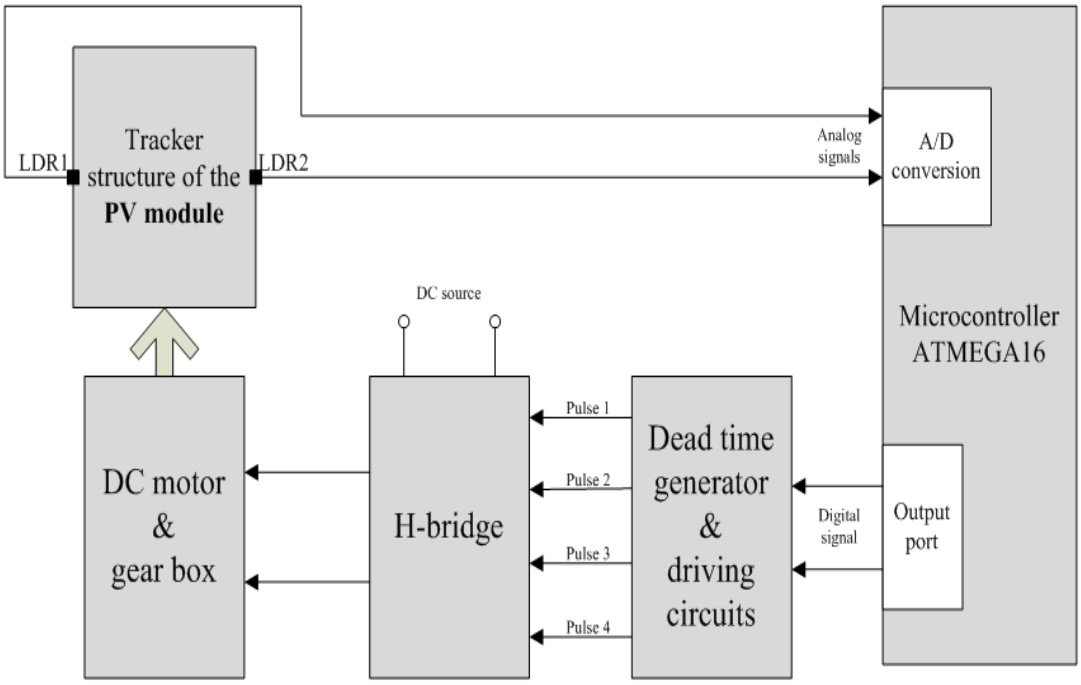


Fig. 4 The designed sun tracking system.

The microcontroller that is used in this system is of the same type as that of the MPPT system. On it, also, a program can run to govern the control of the sun tracking system. Where, it is used to read the two measured voltage signals of the LDRs, that are proportional to the corresponding incident light intensity on each of them, to yield the on-off switching control signal of the H-bridge that is suitable for directing the PV module towards the sun position in the East-West direction. The software design, in this case, includes the flowchart of the sun tracking control system, which is shown in Fig. 5. This flowchart starts with initialization of the data, variables, ADC converter, and ports of the ATmega16 microcontroller. Afterwards, the program starts to read two signals that are the output voltage signals of the LDR1 and LDR2 voltage dividers (i.e., the light intensity voltage signals). Then, the program calculates the error signal e(k), as the difference between these two voltage signals. After that the error sign is checked, whether it is positive or negative. If it is a positive sign CX register is filled with 0, otherwise it is filled with 1 to indicate a negative sign and in this case the error is negated. The next decision is to show that if the absolute error is greater than or equals certain error value ε, then the program will output signals to rotate the tracking motor in one direction or reverses its rotation depending upon the sign of the

error that is stored in the CX register. Otherwise, if the absolute error is lower than ε, then the program will stop the motor rotation. Afterwards, the program returns to read new values of the light intensity voltage signals and continues again to do the previous same steps, to track the sun in the East-West direction.

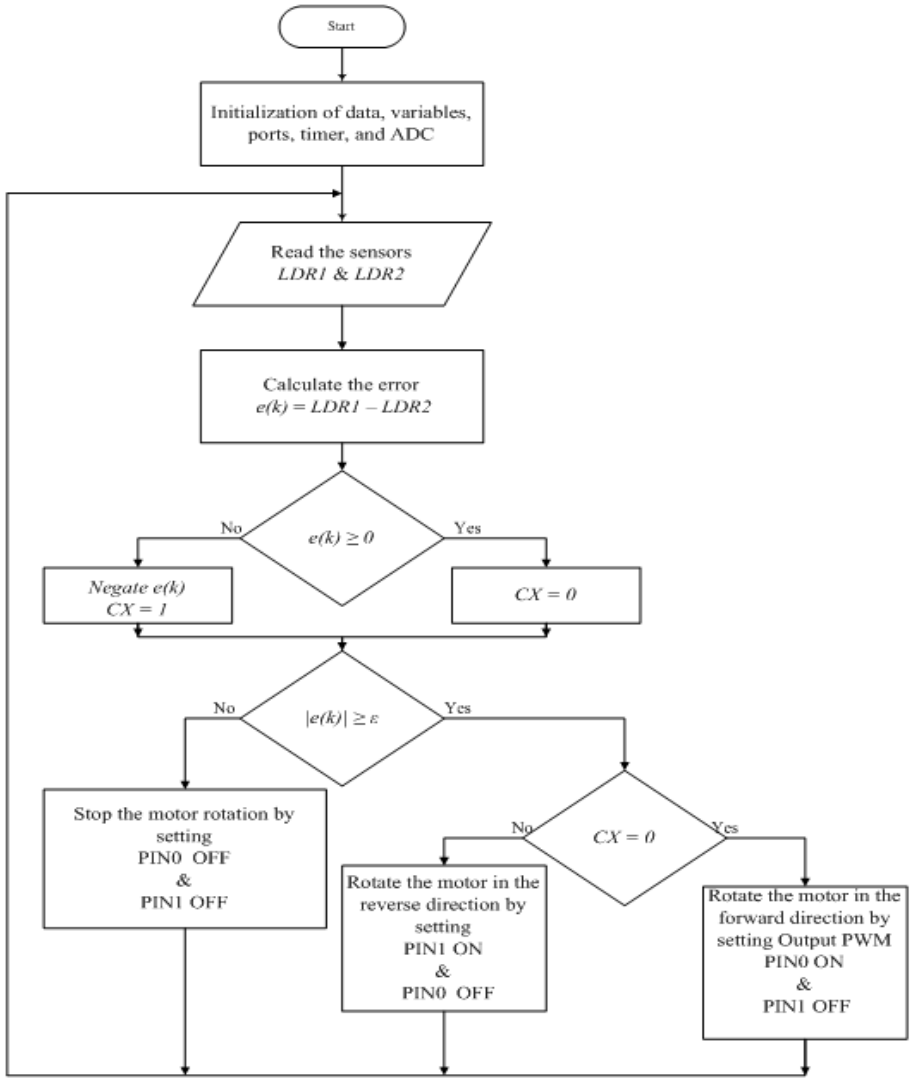


Fig. 5 Flowchart of the sun tracking control system.

III. EXPERIMENTAL SETUP OF THE DESIGNED HYBRID TRACKING SYSTEM

The experimental setup of the designed MPPT and sun tracking systems, or simply referred hereinafter as the designed hybrid tracking system, is divided into two parts: the electronic-part and the mechanical-part. Fig. 6 shows a photo of the mechanical-part of the considered system. This part includes the sun tracker mechanical structure that holds the utilized PV module, together with the DC motor and gear box that rotates the shown tracker structure. Fig. 7 shows a photo of the experimental setup of the electronic-part of the considered system, which includes the designed MPPT system, sun tracking system, and PV data acquisition system.

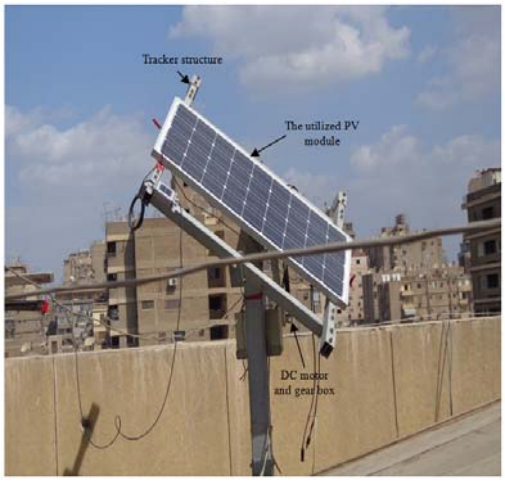


Fig. 6 Mechanical-part of the designed hybrid tracking system.

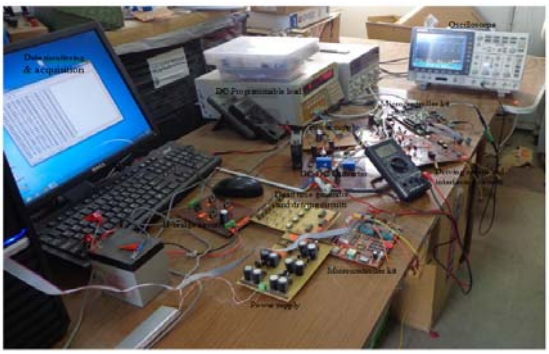


Fig. 7 Experimental setup of the electronic-part of the designed hybrid tracking system.

IV. EXPERIMENTAL RESULTS

The experimental results of the designed sun tracking system indicate the results of the implemented system hardware using the developed software. In this work, the designed tracking system is tested at the roof top of the Electronics Research Institute (ERI), Dokki, Cairo, Egypt. The latitude and longitude of the considered site are 30° 06' N and 31° 25' E, respectively.

Fig. 8 to 10 show different comparisons between the sun tracking and fixed PV systems with and without MPPT. Such that Fig. 8 is dedicated for the hourly incident global solar insolations on the surfaces of the sun tracking and fixed PV modules, Fig. 9 is for the hourly PV module temperatures of the sun tracking and fixed systems, and Fig. 10 is for the hourly output powers of the four utilized PV modules of the considered global experimental system (i.e., the modules which are mounted on the holding structures of the sun tracking and fixed PV systems and operated with or without MPPT). Thus, these three figures indicate that the collected global solar insolation of the sun tracking PV system is higher than that of the fixed PV system during the daylight hours of the considered testing day (i.e. March, 31, 2015). Also, the figures indicate that the PV output power of the module which is mounted on the designed hybrid tracking system (i.e., mounted on the designed sun tracking system and operated with the designed MPPT system) is the highest among the output powers of the other three systems during the daylight hours of the considered testing day.

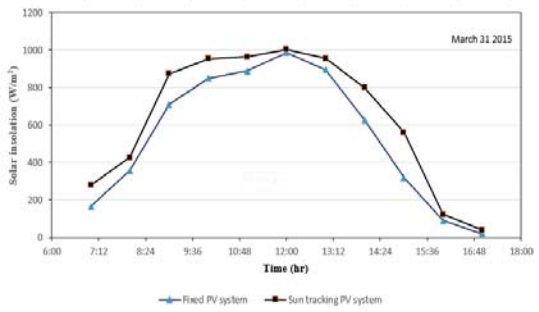


Fig. 8 Global insolation incident on the PV module during the daylight hours of the testing day.

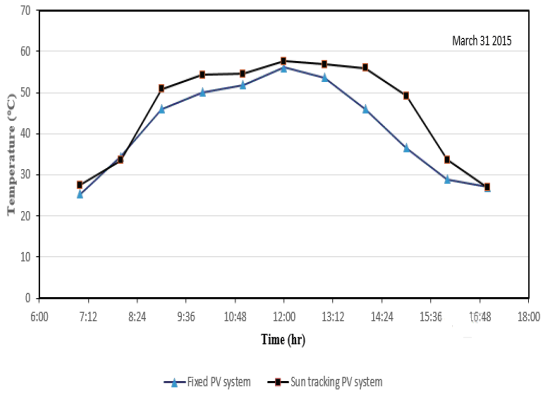


Fig. 9 PV module temperature during the daylight hours of the testing day.

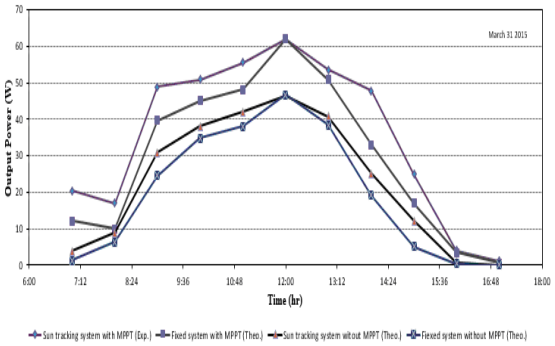


Fig. 10 The PV output power during the daylight hours of the testing day.

Table I shows a comparison between the collected daily irradiations by the fixed and sun tracking PV systems. Thus, this table indicates that the designed single-axis sun tracking system can boost the daily collected irradiation with 18% over that collected by the fixed PV system.

Also, Table II shows a comparison among the daily generated energies from the fixed and sun tracking PV systems that are operated with or without MPPT. Therefore, this table illustrates that the designed single-axis sun tracking PV system that is operated with MPPT (i.e., the designed hybrid tracking system) is the best and can boost the daily generated energy with 79.64% over that generated by the fixed PV system.

Table I The collected daily irradiation during the testing day.

Type of system	Fixed PV system	Sun tracking PV system
Daily irradiation (Wh/m2/day)	5919.16	6983.77
Increase in daily irradiation due to using sun tracker (%)	-	18

Table II The generated PV energy during the testing day.

Type of system	Fixed PV system	Sun tracking PV system without MPPT	Fixed PV system with MPPT	Sun tracking PV system with MPPT
Daily generated energy (Wh/day)	214.89	248.99	321.84	386.04
Increase in daily generated energy due to using sun tracker and/or MPP tracker (%)	-	15.86	49.77	79.64

CONCLUSIONS

The utilization efficiency of the PV modules could be enhanced by continuously operating these modules at their MPP and/or maximizing the incident solar insolation on their surfaces. An appropriate stand-alone PV system that includes both the MPPT and single-axis sun tracking systems has been suggested and implemented experimentally in this work. The control of the two tracking systems was implemented experimentally based on utilizing the low cost 8-bit AVR ATmega microcontroller, such that the control technique of each tracking system was implemented by designing the suitable assembly language code. The design of the MPPT system was mainly based on utilizing the P&O algorithm, due to its simple structure and ease of implementation, and the PI controller. While, the design of the sun tracking system was mainly based on utilizing the optical method, due to its ease of implementation and independence on the geographical location. In addition, this work implemented an extra data monitoring and collection unit for monitoring and storing the experimental PV results. Experimental results indicated that the use of the implemented MPP and sun trackers gave a good MPP operation of the used PV module at all working atmospheric conditions and, at the same time, increased the global insolation incident on its surface. Also, the experimental results, in this regard, showed that the output PV power during the daylight hours of the testing day was greatly enhanced when the MPP tracker is utilized in conjunction with the sun tracker. In addition, the experimental results indicated that the designed single-axis sun tracker was capable of maximizing the daily collected irradiation incident on the tracking PV module by about 18% compared to the fixed module during the daylight hours of the testing day. Also, the experimental results, in this regard, showed that the daily generated PV energy during the daylight hours of the testing day was greatly enhanced by about 79.6%, if the designed sun tracking PV system with MPPT was utilized.

REFERENCES

[1] F. Keyrouz, “Enhanced bayesian based MPPT controller for PV systems,” IEEE Power and Energy Technology Systems Journal, vol. 5, pp. 11-17, March 2018.

[2] H. Fathabadi, “Novel online sensorless dual-axis sun tracker,” IEEE/ASME Transactions on Mechatronics, vol. 22, pp. 321-328, Feb. 2017.

[3] A. Al Nabulsi and R. Dhaouadi, “Efficiency optimization of a DSP-based standalone PV system using fuzzy logic and dual-MPPT control,” IEEE Transactions on Industrial Informatics, vol. 8, pp. 573-584, 2012.

[4] C. Hua, Jongrong Lin, and a. C. Shen, “Implementation of a DSP-controlled photovoltaic system with peak power tracking,” IEEE Transactions on Industrial Electronics, vol. 45, pp. 99-107, Feb. 1998.

[5] Tarek M. El-Sayed, Abd El-Shafy A.Nafeh, Faten H. Fahmy, and Hosam K. Yousef, “Microcontroller-based sun tracking system for PV module,” International Journal of Smart Grid and Clean Energy, vol. 7, no. 4, pp. 286-296, Oct. 2018.

[6] W. De Soto, S.A. Klein, and W.A. Beckman, “Improvement and validation of a model for photovoltaic module performance,” Solar Energy, vol. 80, pp. 78-88, 2006.

[7] T. Esram and Patrick L. Chapman, “Comparison of photovoltaic array maximum power point tracking techniques,” IEEE Transactions on Energy Conversion, vol. 22, pp. 439- 449, June 2007.

[8] Satarupa Bal and B. C. Babu, “Comparative study between P&O and current compensation method for MPPT of PV energy system,” Proc. of the Students Conference on Engineering and Systems, Allahabad, Uttar Pradesh, India, 16-18 March 2012.

[9] Tarek M. El-Sayed, Abd El-Shafy A. Nafeh, Faten H. Fahmy, and H. K. Yousef, “Experimental implementation of P&O MPPT algorithm for PV module using microcontroller,” Proc. of the 4th International Conference on Industrial Engineering and Applications (ICIEA 2017), Nagoya Institute of Technology, Nagoya, Japan, , pp. 294-304, April 21-23, 2017.

[10] M. Elgendy, B. Zahawi, and D. Atkinson, “Evaluation of perturb and observe MPPT algorithm implementation techniques,” Proc. of 6th IET International Conference on Power Electronics, Machines and Drives (PEMD), Bristol, UK, 27-29 March 2012.

[11] Tarek M. El-Sayed, Abd El-Shafy A. Nafeh, Faten H. Fahmy, and Hosam K. M.Yousef, “PV parameters estimation using a developed iterative method,” International Journal of Scientific Research Engineering and Technology, vol. 1, no. 1, pp. 13–17, Jan. 2015.

★★★