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ARDUINO UNO AVR ATMEGA328 MICROCONTROLLER BASED DUAL AXIS SOLAR TRACKER DESIGN

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Abstract. *The paper presents a different approach for dual axis solar tracker design in order to capture much output power and energy of solar panel. The Arduino Uno AVR ATmega328 microcontroller is utilized as the main controller for the horizontal and vertical axis movement of solar tracker through servomotor. Command and instruction are compiled with C language programming to translate the breadth first search method prior to be uploaded into the Arduino Uno AVR ATmega328 microcontroller. The control mechanism by means of the dual axis solar tracker is to find the stable position of solar panel before the breadth first search algorithm calculates and records the maximum output power. The performance of the proposed design of solar tracker is tested under cloudy and clear sky conditions where the output power of solar panels is measured with and without solar tracker. The measurement results indicate that the maximum output power of solar panel can be reached 4-6 times much higher than the solar panel without solar tracker.*
Keywords: Microcontroller, Arduino Uno, Dual axis, Solar tracker, Maximum power

1. **Introduction.** It is highly important to maximize the utilization of solar energy in order to support the energy demand of society. Several factors that affect the energy output of such systems include the photovoltaic material, geographical location of solar irradiances, ambient temperature and weather, angle of sun incidence, and orientation of the panel [1]. In this respect, the capturing and harvesting design systems are one of the main challenges due to the scattering characteristic of sun light. The better electrical energy capture can be obtained if the receiver by means of the solar panel is perpendicular to the sun light direction. The higher thermal energy can be yielded if the heliostat or mirror can be arranged and concentrated to reflect the sunlight to the focal point in solar tower thermal power plant. Therefore, it is necessary to have some mechanisms to rotate the solar panel or heliostat with simple approach and lower power consumption for the better energy utilization of solar energy.

In photovoltaic (PV) applications, the optimal output power and energy can be achieved by modification of electrical connection of panels/modules, provision maximum power point tracking (MPPT) control and designing solar tracker [2, 3]. The electrical connection by means of total cross-tied (TCT) and bridge link (BL) provides more electrical path of power to the terminal output than simple series-parallel (SP) connection, especially during partial shading condition. In comparison, the MPPT control operates to obtain the optimum voltage at every input environmental conditions in order to obtain the maximum output power and energy [4]. In terms of solar tracker, the maximum output power and

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energy can be reached because the maximum sunlight direction might be entering the panel surface.

The application of solar tracker to maximize the potential power and energy output for photovoltaic application is quite challenging. In the condition of maintaining of solar panel at the fix position, it consequently causes the less optimal of power and energy output. However, the additional components are required when the solar tracker is available. It means the photovoltaic systems come up with additional costs and system complexity. The costs might be the price of electronic components and other supporting components including electric motors, while the system complexity is from the additional wiring and adjoint placement of controller. The power consumption is another challenging in designing the solar tracker. It is expected that the lowest power consumption is considered as the optimal design. It is due to all power needs to the solar tracker obtained from the terminal output of PV panels. In this respect, only small portion of PV power output is utilized for powering the electronic and motor controls of solar tracker.

Several designs of solar tracker have been published in scientific community. The design of two-dimensional axis of solar tracker has been reviewed considering the trajectory movement and functional model for the efficient and effective tracking system performance [5]. Also, an intelligent control of solar tracker has been successfully proposed in single and dual axis control system movements to increase the performance of solar tracker, to estimate the accurate trajectory movement of Sun across the horizon, to maximize the output power generation of solar panel with solar tracking system [6]. Similarly, a machine learning model is utilized as the accurately predictive model of real-time monitoring of energy production from solar panels supported by dual-axis trackers under different climate condition [7]. These previous approaches are then improved by considering the accumulative parasitic energy losses during tracking movement in order to optimize the annual solar energy production for fixed position and dual-axis solar tracker of solar panels [8].

The performance of solar tracker is improved by auxiliary electronic sensor components. There was a design of solar tracker with the utilization of light dependent resistor (LDR) [9]. The tracking mechanism is designed as a low-cost active tracking system of dual-axis trajectory movement with closed-loop control, utilizing light dependent resistor (LDR) sensors as the inputs of the system to adapt the geographical position of solar panel [10]. However, it is quite tricky to determine the optimal angle for LDR placement since the sunlight direction is time-variable. The approach of solar tracker design with energy saving regarding the control mechanism has been also proposed with tele-control using global positioning system (GPS) [11]. The controller will always try to move the solar panel in the maximum direction of sunlight with the reference signals from the GPS and embedded with proportional integral derivative (PID) for high accuracy trajectory. However, such approach has given and added complexity design with of course the additional costs. The solar tracker with microcontroller has been designed with the fixed angle movement of solar panel based on the Sun movement in the equator region [12]. However, the Sun displacement crossing the equator is by seasonal movement with variably astronomical position. Therefore, it is still necessary to have manual adjustment periodically in order to have maximum tracking performance. In this respect, it is still quite challenging to design a solar tracker with simple design and control algorithm, low power consumption and cost with maximum tracking performance.

This paper deals with new approach of dual-axis solar tracker design utilizing the Arduino Uno AVR ATmega328 microcontroller as the main controller. The work is claimed more advanced than the single axis-based microcontroller for automatic tracking system [12]. The proposed design has several prominent design where the automatic reset system is provided to bring the solar panel facing the East direction automatically during morning time to wait the Sun start shining. Also, the proposed system requires no sensor because the solar panel itself is assigned as the sunlight sensor [13, 14]. The sensor based solar tracker is more complicated and expensive because it needs one sensor equipped with a radiance limiting tube and extra mechanical components. However, in this case, the movement of solar panel to the optimal sunlight direction is merely conducted after the evaluation of the output power through the breadth first search algorithm when the solar panel reaches the stable position. In addition, the power consumption of servo motor is very low that indicates the promising application for the large scale of photovoltaic systems.

The article is organized as follows. The literature review regarding the significancy study of solar trackers has been shown in this Section 1. In Section 2, the configuration of the proposed systems is presented. Section 3 provides the information of tracking algorithm and design of dual axis solar tracker. Following in Section 4, testing performance and discussion are presented. Finally, Section 5 shows the conclusion of this study.

2. **Configuration of the Proposed Systems.** The prototype design of dual axis solar tracker can be seen in Figure 1. The horizontal axis movement of solar panel is controlled by the motor servo X, while the vertical axis movement of solar panel is controlled by the motor servo Y. The solar panel itself functions as the sensor to respond to the maximum sunlight intensity in order to produce maximum output power and energy. Under the solar panel with the maximum output power of 80 W, there is control box where the Arduino Uno microcontroller and electronic input/output circuit components exist including the liquid crystal display (LCD) monitor to display the output power measurement. Another important circuit is the controller circuit where the solar tracker operates according to the algorithm or computer program embedded into the microcontroller circuit.

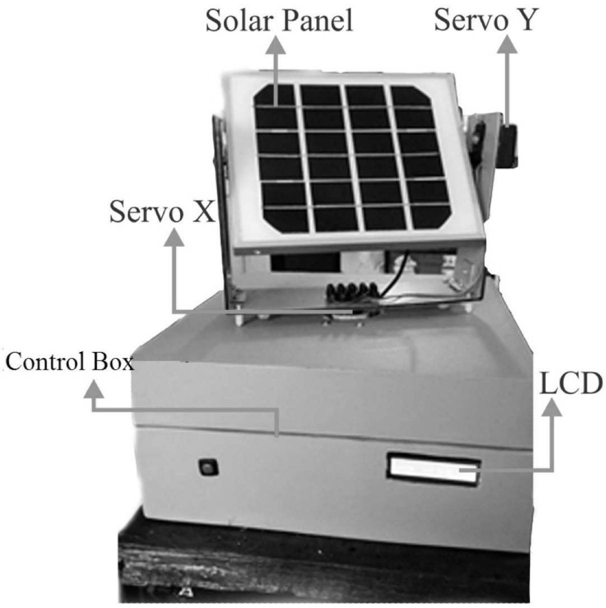


Figure 1. Prototype design of dual axis solar tracker

Figure 2 shows the schematic design of dual axis solar tracker where the solar panel functions as the movement sensor. In this respect, there are diode and potentiometer connected between solar panel and battery. The diode is utilized to prevent the battery supplying current to solar panel. Meanwhile, the potentiometer which is connected to the Arduino Uno microcontroller is utilized to regulate the sensitivity of solar tracker. Every output information of solar panel is sent to the microcontroller circuit. The maximum voltage of solar panel is the reference point to microcontroller circuit to command the motor servo movement. As results, the solar panel is able to move horizontally and vertically based on this maximum voltage. The LCD is to display the output current of

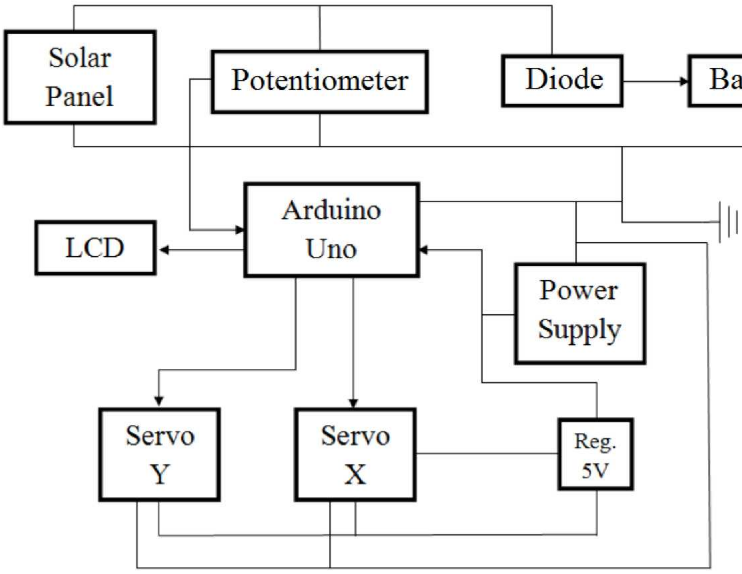


FIGURE 2. Schematic design of dual axis solar tracker

solar panel under the stable condition after searching the maximum output power/energy. The power supply of 12 V is the main power source to the microcontroller circuit and other circuit components.

3. **Tracking Algorithm and Design of Dual Axis Solar Tracker.** The paper introduces the search algorithm to find the data of maximum power point according to accepted key argument. With the two arguments, there will be always two possibilities, i.e., the data is found or not. The algorithm is the blind search method based breadth first search as the collective procedure to trace the search space. In this case, the tracking procedure for maximum power point is continued until the solution is obtained. The purpose of continuous tracking is to observe the possibility to find the candidate solution. The term 'blind' in this respect is due to the fact that there is no initial information in the searching process.

The technique of blind search is less-practical for the complex problems; however, the method provides a base for the information searching strategy [15]. In this case, the breadth first search is conducted in all nodes in every level from left to right in sequence as shown in Figure 3. After one level is complete, the search step is moved to the next level continuously until the optimal solution is found. The advantages of breadth first search method are that the solution is always obtained with the best solution and no deadlock tracking. If the solution is more than one, then the minimum solution will be taken. However, the method requires high computational memory to store all nodes information in order to observe more nodes in beneath level and consequently needs time computational effort to converge [16].

The breadth first search method is the main software program for the designed dual axis solar tracker systems. The algorithm is written in C language programming based Arduino Uno AVR ATmega328 microcontroller. The set of command lines (written listing program) is usually stored with the extension [* .ino or * .pde] and compiled with Arduino IDE. After the file is compiled, and then uploaded to the Arduino Uno microcontroller using USB cable in order to assign the microcontroller as a system controller according to the preferable system performance. The design of microcontroller software in this paper aims to recognize and to process data sent by the sensor as the input device and vice versa to send data to other output devices. The software is embedded (downloaded) on Arduino Uno microcontroller so that the solar tracker can function as an expected. In addition,

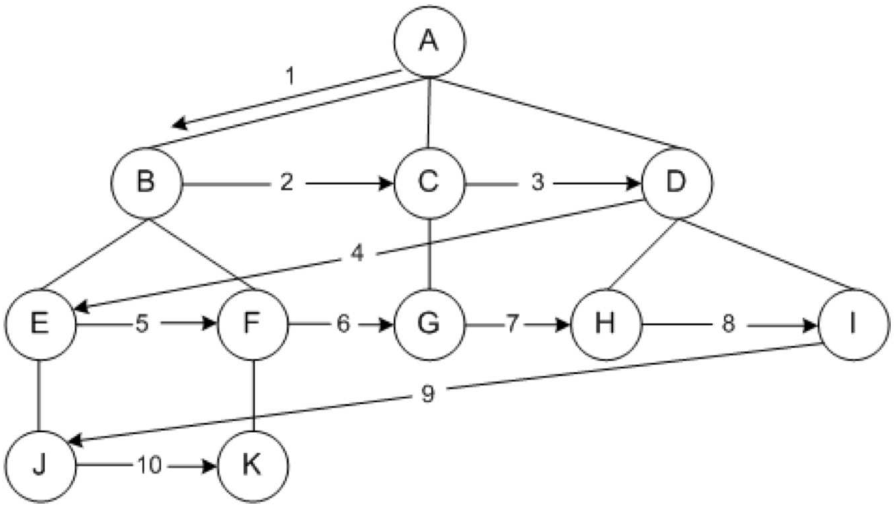


FIGURE 3. Search tree of breadth first search method

the software design is intended to process digital data embedded within the Arduino Uno microcontroller architecture so that the microcontroller can receive information being sent remotely.

The solar tracking system includes the software design. The software design is based on scanning method where the breadth search method as explained in the previous section is implemented to rotate the solar panel either horizontally or vertically according to the servo motor movement. The servo motor always moves to the maximum sunlight intensity in order to obtain the optimal output power and energy. Meanwhile, the hardware design covers the microcontroller and mechanical circuits design.

The microcontroller circuit is the Arduino Uno with the chip of Arduino Uno AVR ATmega328 microcontroller with sorts of facilities, for instance, PWM, serial communication, ADC, timer, interrupt, SPI and I2C. The minimum circuit systems requirement of microcontroller ATmega328 can be seen in Figure 4. The Arduino has all supporting components to the microcontroller performance. It is very simple to activate the Arduino with only USB cable connection to computer through AC-DC adaptor.

The feature characteristics of Arduino Uno AVR ATmega328 microcontroller are provided in Table 1. The Arduino microcontroller operates at the external voltage from 6 to 20 V. If the applied voltage is less than 7 V, the microcontroller might be unstable. On the other hand, if the applied voltage is over than 12 V, the voltage regulator might be overheated and damaging the microcontroller board. Therefore, the recommended input voltage is in the range between 7 V and 12 V. In terms of memory, the Arduino microcontroller has 32 kB where 0.5 kB is used as the *bootloader* besides the SRAM of 2 kB and EEPROM of 1 kB. In this type of microcontroller, there are 14 pins that can be used for input and output channel according to the functions of *pinMode*, *digitalWrite* and *digitalRead*. All pins may send and receive DC current with maximum of 40 mA and internal *pull-up* resistor of 20-50 kΩ.

4. **Testing Performance and Discussion.** The testing design is important to evaluate the performance of the proposed dual axis solar tracker. It is expected that the solar tracker must be able to position the solar panel perpendicular to the direction of sunlight. In this design, the reference of solar tracker movement is considerably similar to the pseudo motion of the Sun in the equator region where the Sun rises in the East and Sun sets in the West. In this research, the measurement performance is divided into three scenarios, i.e., the output power measurement without solar tracker, horizontal and vertical trackers movement, and dual axis movement.

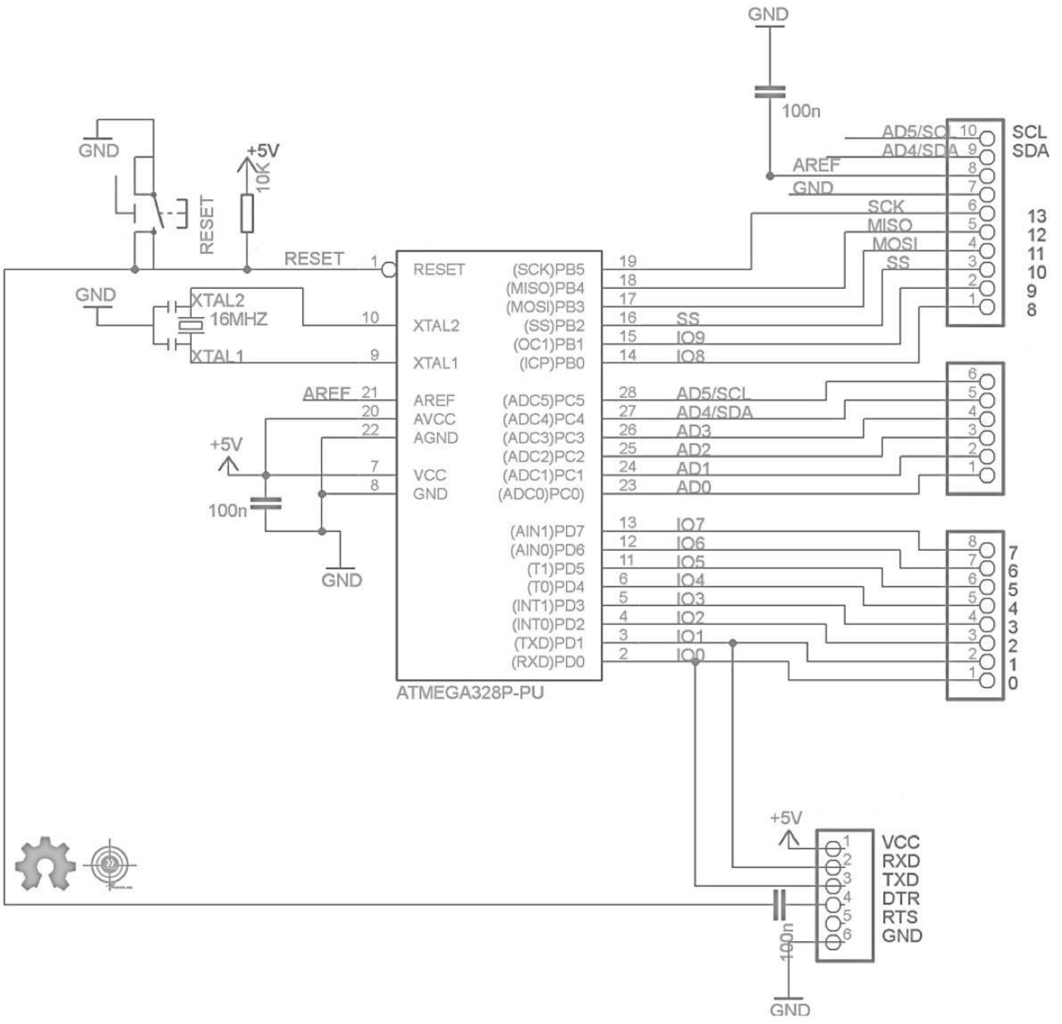


FIGURE 4. Minimum circuit of microcontroller ATmega328
(https://www.electroschematics.com/10955/build-arduino-bootload-atmega-microcontroller-part-1/)

TABLE 1. Characteristics of Arduino Uno AVR ATmega328 microcontroller

Specifications	Parameters
Operating voltage	5 V
Input voltage (recommended)	7-12 V
Input voltage (limited)	6-20 V
Digital I/O	pin 14
Analog input	pin 6
DC Current per I/O	pin 40 mA
DC Current for 3.3 V	pin 50 mA
Flash Memory 32 kB	0.5 kB utilized by *bootloader*
SRAM	2 kB
EEPROM	1 kB
Clock speed	16 MHz

The performance of solar panel without solar tracker is conducted with static instalment of solar panel in the flat position in order to receive the sunlight optimally. The test was conducted under clear sky condition from 8 a.m. to 4 p.m. with the static position of solar panel. This test is done by measuring the value of voltage and current on the solar panel. Measurement data of output power is conducted at intervals every 1 hour with the results

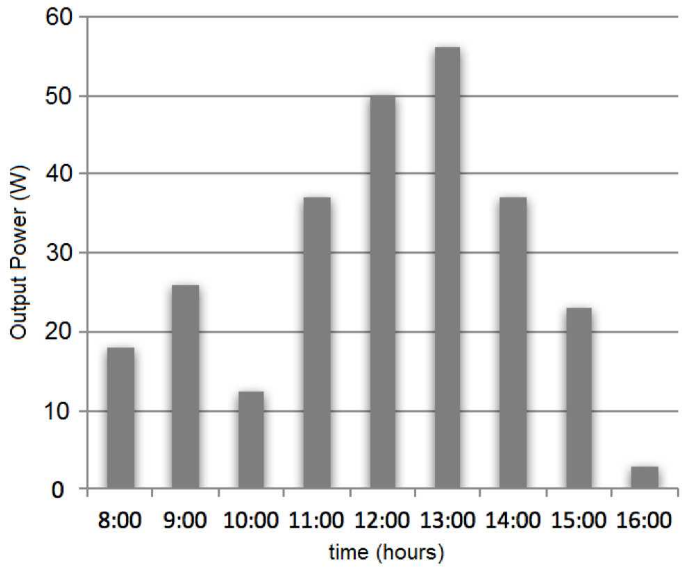


Figure 5. The output power of solar panel without solar tracker under clear sky measurement

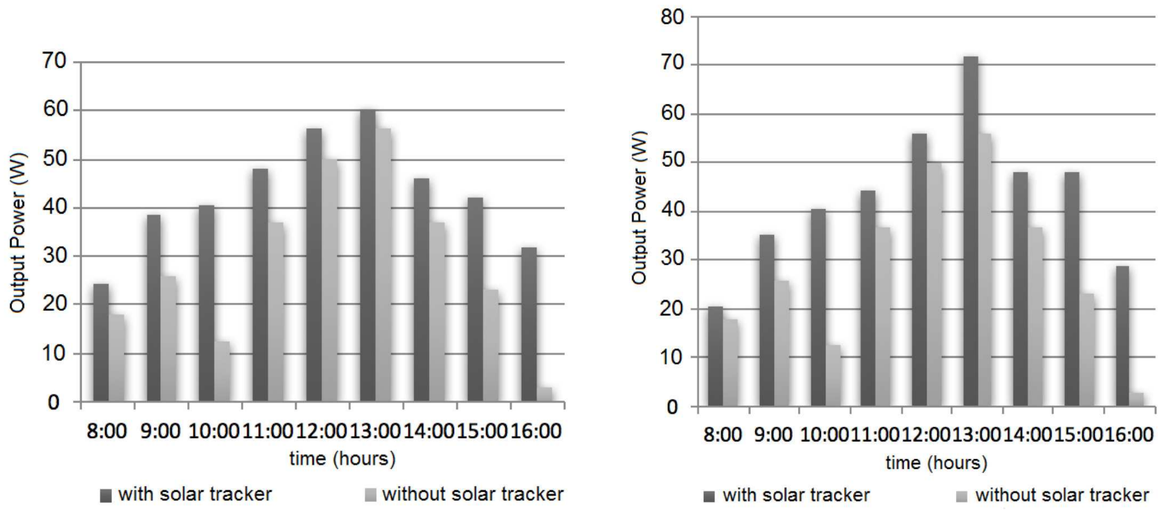
as shown in Figure 5. The maximum output power of solar panel is obtained between 12 a.m. and 1 p.m. with range output of 50-56 W. The minimum power is obtained during morning (10 a.m.) and afternoon (4 p.m.) times with the output power of 12 W and 2.8 W, respectively.

The testing scenario for individual horizontal and vertical trackers movement is conducted under clear sky condition with controlling the servo degree of movement with 3° and time delay of 10 seconds to reach the stable solar panel position. In this measurement, it is important to obtain the servo position while searching the stable solar panel position for the output power measurement.

For the only horizontal tracker movement, the solar panel reaches the stable position when the solar panel angle of 48°, 57°, 78°, 90° and 93°. It is noticed that the servo motor only consumes 87 mA under measurement of 54° and 57° of solar panel position. The stable solar panel condition is important in this respect because the designed software based breadth first search algorithm will make the solar panel stop for 10 seconds before trying to find the optimal solar panel position according to the maximum output power. Meanwhile, during the vertical tracker movement, the stable solar panel position is reached when the solar panel angle of 30°, 48°, 72°, 90° and 93°. Again, the servo motor just consumes 86 mA at the solar panel position of 27° and 30°. Similarly, the breadth first search algorithm will stop the solar panel for 10 seconds and to record the maximum output power.

The measurement is considered as tracking mechanism of solar panel dynamically to search the maximum intensity of sunlight. The measurement of output power was conducted from 8 a.m. to 4 p.m. with the time interval of 1 hour. The setting of solar tracker under this movement is the servo motor for the horizontal movement will only be once to scanning the sunlight intensity, while the servo motor for vertical movement will calibrate the solar panel position in order to obtain the maximum intensity of sunlight.

The first scenario is the solar tracker movement with attempting to follow the pseudo movement of Sun from East to West in equator region. The testing results of output power under cloudy sky condition can be seen in Figure 6(a). The results show that the solar panel with tracker produces 24.5-60 W during the period of 8 a.m. - 1 p.m. and the output power starts decreasing from 46 W at 2 p.m. to 32 W at 4 p.m. In this respect, much output power can be yielded with solar tracker movement compared to the system



(a) Cloudy sky (b) Clear sky

Figure 6. Output power performance of dual axis solar tracker

without solar tracker [17]. Significant output power is obtained with 4 and 6 times higher during morning at 10 a.m. and afternoon at 4 p.m., respectively. These results indicate that the proposed design of solar tracker operates as expected even though under cloudy sky condition with significant output power production.

In comparison, the solar tracker performance under clear sky condition can be seen in Figure 6(b). Similar to the output power measurement results under cloudy sky condition, much output power can also be obtained compared with the condition of solar panel without solar tracker. The best output measurement is reached at 1 p.m. when the solar panel produces 71 W. In this respect, the solar tracker may respond very well under clear sky condition with 4-6 times higher at 10 a.m. and during afternoon at 4 p.m.

5. **Conclusions.** The paper has presented the different approach of dual axis solar tracker design for solar panel application in order to obtain the maximum output power. The proposed design of solar tracker utilizes the Arduino Uno AVR ATmega328 microcontroller as the main controller. The control algorithm is based on the breadth first search algorithm to find the optimal direction for the maximum sunlight intensity by rotating the servo motor in horizontal and vertical axes. The performance of solar tracker is tested under cloudy sky and clear sky conditions by measuring the maximum output power of solar panel. The performance of solar tracker design operates similarly under cloudy sky and clear sky condition with 4-6 times much higher output power obtained by the solar panel compared to the solar panel systems without solar tracker. Therefore, the proposed tracker system is promisingly applied for the large capacity of solar panel due to the low power consumption to the servo motor movement. In future, the multi-axis of solar tracker is developed by considering the astronomical position of Sun across the sky and geographical location of solar panels in order to maximize the output power and efficiency performance of solar panels.

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