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Monitoring solar heat intensity of dual axis solar tracker control system: New approach

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A R T I C L E I N F O

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A B S T R A C T

Control of the amount of solar energy successfully absorbed by photovoltaic system equipment that can follow the movement of sunlight vertically and horizontally at any time is a very urgent need. The method used in this research activity is the utilization of the ESP8266 microcontroller as the primary control of photovoltaic movements that can follow the direction of sunlight based on information from the Light Dependent Resistor (LDR) sensor. The data variables measured and stored include current, voltage, and temperature, which are then processed and transmitted by the ESP 8266 microcontroller to the user through the Internet of Things (IoT) media to the BLINK application. The experimental results show that the proposed system using the ESP8266 microcontroller and LDR sensor increases efficiency, accuracy, speed, and convenience in the monitoring and control system of sunlight intensity by an average of 65%, compared with the manual monitoring system.

1. Introduction

Renewable energy sources, namely solar energy, which is extensive throughout the year. Geographically, the opportunity for the availability of solar energy is quite significant, which is in the energy range of 4.8–6.0 kWh/m^2. By 2050, it's anticipated that the amount of electricity produced worldwide from RE sources will reach almost 45 trillion kWh. By 2020, 20% of Europe's total energy consumption was expected to come from renewable sources. By 2040, the Asia Pacific Economic Cooperation (APEC) countries' installed capacity would total 6235 GW, with 35% of that coming from renewable sources [1]. Solar energy's large availability needs to be maximized in everyday life, such as solar power plants [2]. The utilization of solar energy for various activities in everyday life has several advantages; among others, the energy is available abundantly, easy to maintain, has no noise, is able to work automatically, and can be applied on and off the grid [3]. In addition to having advantages, the utilization of solar energy has obstacles, namely the limited time in the absorption of sunlight at sunrise and sunset and the uncertain intensity of light or solar radiation. Due to these limitations, an innovation is needed to track the movement of sunlight [4].

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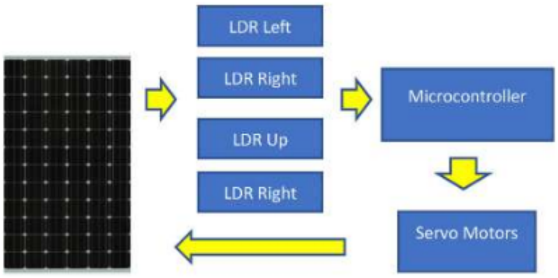

Fig. 1. Block diagram of dual axis solar tracker movement instrumentation system.

As a country in the equatorial region, Indonesia has the potential for a solar tracker is, a photovoltaic system consisting of a support structure equipped with a motor [5]. This system is designed to automatically direct the solar panels throughout the day so that they always face the sun and capture maximum sunlight [6]. Therefore, there are several classifications of solar trackers, namely the classification of solar trackers based on the control system used, the driver used, the tracking strategy used, or on the basis of the degree of freedom of the movement exhibited by the system. Solar trackers based on the control system are divided into two, namely the open sun movement tracking system and the closed sun movement tracking system [7]. The open type of solar tracking system is where the control signals provided to the motors are based on the current input data and system algorithms only. The system has no feature to observe and evaluate the output data with respect to the desired output [8]. Whereas a sun tracking system based on closed control means a sun movement tracking system that provides feedback control to detect errors and provide the necessary drive signals by the motor.

Based on the drive system used, sun tracking systems are classified into passive sun tracking systems and active sun tracking systems. A passive tracking system is a system that uses thermal expansion of a low-boiling gas material or liquid that is compressed and pushed to one side or the other as a method to track the movement of sunlight, while an active tracking system is a system that tracks the movement of sunlight by utilizing microprocessor technology, motors, and light sensors to increase the amount of solar energy absorbed [9]. In addition, sun tracking systems are also distinguished by freedom of movement. The first is a single-axis tracking system with one degree of freedom in one axis of rotation, and the second is a double axis with two degrees of freedom as the axis of rotation [10].

Research on solar trackers has been widely developed, including the use of Bluetooth modules as a communication medium between Arduino and Android applications to improve the performance of solar trackers that can be monitored via smartphones. The study also compared the power received by solar panels using a 2-axis solar tracker to provide 11.57% greater power output compared to static solar panels [6]. A two-axis tracking system to obtain energy from sunlight using Arduino Uno as the central controller of the system and four light-dependent resistors (LDRs) have been used to detect sunlight and maximum light intensity. Two servo motors have been used to rotate the solar panel according to the sunlight source detected by the LDRs. Furthermore, an ESP8266 WIFI device is used as an intermediary between the device and the IoT monitoring system [11]. The IoT monitoring system is a website that serves to store data. The efficiency of this system has been tested and compared with a single axial sun tracker. As a result, the two-axis solar tracking system produces more power, voltage, and current [12].

A sun tracking system can substantially increase electricity production on photovoltaic systems, utilizing feedback control theory and light-dependent resistor four LDR sensors and microcontroller-based electronic circuits [13]. A dual-axis sun tracking system generates more energy as the solar array can remain aligned perpendicular to the sun. Comparative results have been presented between static and automated stand-alone dual-axis solar systems, showing that integrated grid systems have better performance. Photovoltaics converts solar energy into electrical energy by absorbing the intensity of sunlight. However, the intensity of sunlight absorbed always changes in one day, so the intensity of sunlight absorption between morning, afternoon, and evening is different. This causes the power output of the photovoltaic to be unstable. However, a device that can already overcome this is called a solar charge controller [14].

Based on several previous studies, a dual-axis solar tracker system has been carried out to absorb as much energy as possible by utilizing ESP8266 microcontroller technology and LDR sensors. Therefore, this study discusses the control and instrumentation system of the 160 WP dual-axis solar tracker system that utilizes ESP8266 microcontroller technology and LDR sensors.

2. Material and methods

The block diagram for the instrumentation design of dual-axis solar tracker control system based on an ESP8266 microcontroller and light sensor is shown in Fig. 1. Fig. 1 shows the block diagram of the dual-axis solar tracker control system based on the movement of sunlight. In principle, the control system for tracking the movement of sunlight has two axes: the horizontal axis (azimuth) and the vertical axis (elevation). The working process for the dual-axis solar tracker system is that the light sensor detects the intensity of the surrounding light and produces a proportional electrical signal. The signal from the light sensor is sent to the microcontroller [15]. The microcontroller compares the received signal with a predetermined reference value or threshold. Based on the comparison, the microcontroller calculates the position changes that need to be made by the solar panel to face the sun optimally [15]. The microcontroller generates output signals that are sent to the motors on the horizontal shaft and vertical shaft of the solar tracker, and then the

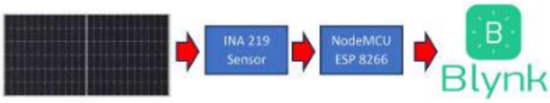

Fig. 2. NodeMCU ESP 8266 system with solar panel.

Fig. 3. Dual axis solar tracker instrumentation system design with LDR and ESP 8266.

motors move the shafts so that the solar panels move to follow the sun's movement accurately [16]. This process continues throughout the day so that the solar panels always face the sun at an optimal angle to maximize the reception of solar energy.

Many of the systems described in earlier literature use Bluetooth modules with constrained capability and range, and they frequently rely on microcontrollers without internet access [17]. However, this study uses the ESP8266, whose WiFi integration allows for an internet connection and real-time solar panel control, monitoring, and data analysis. In addition to improving solar tracking and control, this promotes integration with the Internet of Things (IoT) idea, laying the groundwork for more flexible and integrated solar energy solutions into a broader energy infrastructure.

2.1. Servo motors

A *servo motor* is a direct current (DC) motor equipped with a control circuit with a closed feedback system that is integrated with the motor. The position of the rotary axis in the servo will be informed back to the control circuit inside the servo motor [18]. The servo motor comprises a DC motor, gearbox, variable resistor or potentiometer, and control circuit. The servo motor in this dual-axis solar tracker system can work clockwise (CW) and counterclockwise (CCW). CW is the direction of rotation of the servo motor in the clockwise direction. When the servo motor is activated to rotate CW, the shaft will move clockwise when viewed from the direction of the motor shaft exit. CCW is the direction of rotation of the servo motor counterclockwise. When a servo motor is enabled to rotate CCW, its shaft will move counterclockwise when viewed from the motor shaft exit direction. The ability of a servo motor to rotate both CW and CCW allows for flexible use in various applications. For example, in a dual-axis solar tracker, a servo motor on the horizontal shaft can move the solar panel to the left (CW) or right (CCW) to follow the sun's movement from east to west throughout the day. The selection of the appropriate rotation direction depends on the application's specific needs and the system configuration. A servo motor controller such as a microcontroller will provide appropriate control signals to rotate the servo motor in the desired direction (CW or CCW) based on the logic and calculations performed in the sun tracking system [19].

2.2. NodeMCU ESP 8266

NodeMCU ESP8266 is an IoT-based microcontroller module that can be used as one of the controller components to control the sun tracking system, such as in Fig. 2. NodeMCU ESP8266 can connect and control sensors, servo motors, and other devices involved in sun tracking. The NodeMCU ESP8266 provides various input/output (I/O) pins that are used to connect and control these devices. The NodeMCU commands the INA219 sensor, where the INA219 sensor is useful for reading the voltage and current values generated by the solar panel. The INA219 sensor reading uses an I2C communication line with a high level of precision. Furthermore, the measurement results and data collection are sent via IoT to the Blynk application.

Sensor Data Acquisition: ESP8266, connected to various sensors, captures data from light, temperature, or position sensors. ESP8266 to transmit to an external data source as a monitoring tool or for further analysis. Based on the sensor data and calculation of the required angle, the ESP8266 generates the proper control signals to drive the servo motor to the desired position.

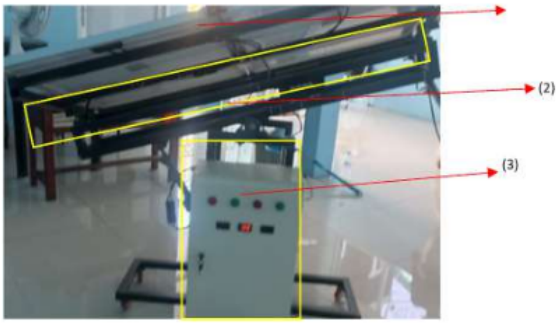

Fig. 4. Solar tracker dual axis hardware.

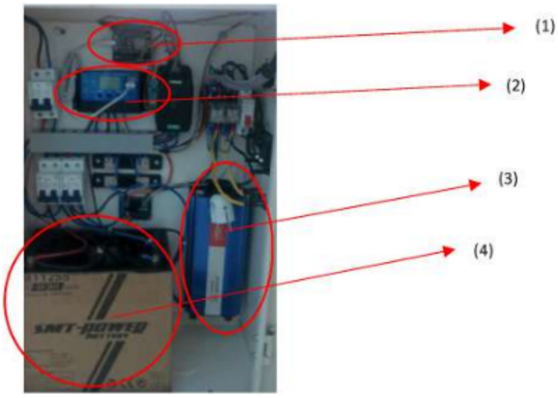

Fig. 5. Solar panel control hardware.

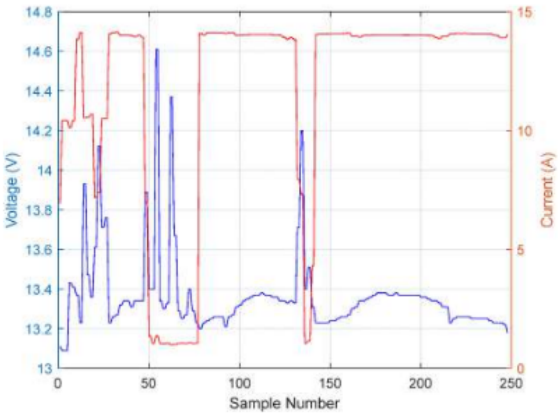

Fig. 6. Graphic of solar panel voltage and current measurements.

3. Result and analysis

This section presents the results of the design, measurement, and analysis of an instrumentation system that uses NodeMCU ESP8266 to measure voltage, current, and power in solar panel installations. These results include an analysis of measurement accuracy, system stability, and responsiveness to voltage, current, and power value changes. In addition, the advantages generated by the use of ESP8266 in this system will also be discussed, as well as the possibility of further development to improve the efficiency and reliability of the instrumentation system for measuring voltage, current, and power in solar panel installations as shown in Fig. 3.

The results of assembling the hardware components for the dual-axis solar trakcer using the ESP8266 microcontroller are shown in Fig. 4. Fig. 4 shows the dual-axis solar tracker hardware consisting of (1) Solar Panels, (2) A mechanical frame made of iron as a load-

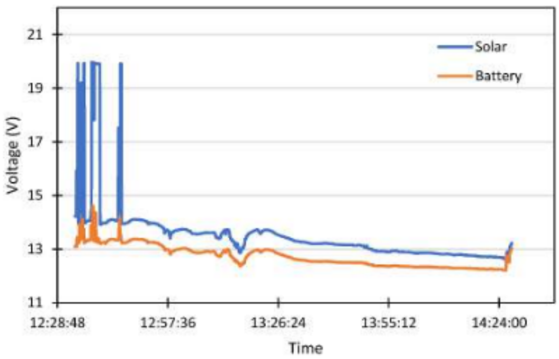

Fig. 7. Comparison between voltage solar panels and battery.

bearing solar panel, and (3) a control box panel. This control box panel is the command and control hub for the complete sun tracker system. Inside, the ESP8266 microprocessor serves as the operating brain, interpreting sensor data and issuing commands to the actuators. This ESP8266 microcontroller not only controls the sun tracking mechanism, but it also has Wi-Fi communication capabilities, allowing for remote connection and real-time system monitoring. Aside from the ESP8266, the control box panel contains various communication modules, a power supply to power the entire system, and protection components like as fuses to safeguard the device from power surges or overcurrent. The control box panel is divided into several electronic hardware components, as shown in Fig. 5.

Fig. 5 shows the control hardware components to move the solar panels, consisting of (1) ESP8266 microcontroller, (2) Solar charge controller, (3) Inverter (4) Solar panels battery. The dual-axis solar tracker operation starts with the LDR sensor attached to the microcontroller receiving sunlight intensity, and then the resistance of the LDR changes its value. Changes in this resistance value will be proportional to changes in sunshine intensity. The ESP8266 microcontroller will transform the number of analog signals into digital signals via the embedded analog to digital converter component. The microcontroller system then processes this digital data to calculate the intensity of sunlight received by the solar panels. The microcontroller system will move the solar panels into the optimal position using instructions to the servo motor based on the sunshine intensity calculation.

These measurements include various important parameters such as voltage, current, and temperature. Careful analysis of the data over a limited period of time reveals the performance of the solar panels and their potential efficiency in generating electrical energy from sunlight. The test results for trials are shown in Fig. 6.

Fig. 6 shows that the voltage generated by the solar panel during the measurement process shows a fluctuating voltage. This is because, during the measurement, an object covers the sunlight or changes in the sun's position. Changes in the sun's position or objects that cover sun rays cause changes in temperature in the solar panel module, resulting in fluctuating voltage and current. This is in accordance with the first Kirchoff's Law equation regarding the ideal solar cell output current shown in Equation (1).

$$I = I_{ph} - I_d \tag{1}$$

In addition, the mathematical equation that explains the I–V characteristics of photovoltaic solar cells is shown in Equation (2).

$$I_d = I_s\left[exp\left(\frac{qV_{oc}}{N_sKAT_o}\right) - 1\right] \tag{2}$$

Inserting the value of I_d in Equation (1) results in the ideal solar cell output current as shown in Equation (3).

$$I = I_{ph} - I_s\left[exp\left(\frac{qV_{oc}}{N_sKAT_o}\right) - 1\right] \tag{3}$$

In an ideal case, the photovoltaic solar cell module produces photons directly proportional to the lighting and radiation intensity. Several parameters affect the output of a photovoltaic module device, as shown in Equation (4).

$$I = N_p * I_{ph} - N_p * I_s\left[exp\left(\frac{q(V + IR_s)}{N_sKAT_o}\right) - 1\right] \tag{4}$$

Equation (4) describes the photocurrent I_{ph} proportional to the incident flux and independent of V (or Rs). This shows that the current generated is linearly dependent on solar radiation and is also affected by temperature according to the following I_{ph} equation illustrated in Equation (5).

$$I_{ph} = [I_{sc} + K_i(T_o - T_r)] * \frac{G}{G_{ref}} \tag{5}$$

Equation (5) elucidates that the efficacy of solar panels is contingent upon a multitude of pivotal aspects. The G factor elucidates the

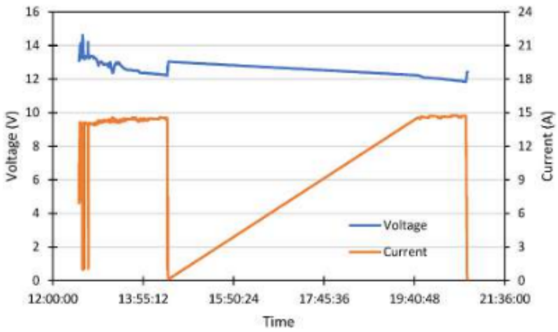

Fig. 8. Result of battery instrumentation.

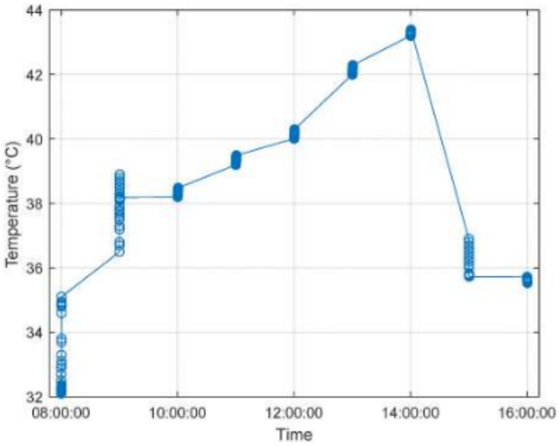

Fig. 9. Heat intensity of solar panels.

direct correlation between the output current of a solar panel and the intensity of solar radiation it receives. In addition, temperature is a significant factor that influences the performance of solar panels. Temperature variations within the solar panel have a direct effect on the amount of current produced, with higher temperatures generally leading to a decrease in the efficiency of the solar cell. The equation presented offers a comprehensive analysis of the impact of factors such as sunshine intensity and temperature on the efficiency of solar panels. A comprehensive comprehension of these dynamics is crucial in the process of designing and optimizing solar panel systems. Solar tracker applications are of particular importance in the context of maximizing solar radiation absorption, while also considering temperature considerations, with the ultimate goal of attaining ideal energy efficiency.

Fig. 7 shows that the average voltage generated by the photovoltaic is about 13.52 V, while the average voltage stored in the battery is about 12.73 V. The average voltage difference between the Photovoltaic and battery is 0.79 V. The voltage difference shows that the transfer of energy from the solar panel to the battery is efficient, this is indicated by the small difference value.

As for the battery system, the test results are as follows in Fig. 8. Current measurements on a battery indicate the amount of electrical charge flowing into or out of the battery during charging or discharging. This current data shows how well the battery undergoes the charging process and how much power can be generated when the battery is used to supply electricity. Stable current test results that are in line with battery specifications indicate good performance and the ability of the battery to store and release energy efficiently. If the test results show a low or fluctuating voltage outside the normal range, this could indicate a problem with the battery cells or management system. A significant voltage drop during battery use could indicate low battery capacity or unfavorable conditions for use. The result of experimental heat intensity is presented in Fig. 9.

Based on the analysis of temperature data and subsequent experimental verification, it was observed that there was a notable increase in temperature during the time range between 13:00 and 14:00. This increase in temperature exhibited a positive correlation with the intensity of solar radiation. During the specified temporal interval, the solar panel equipped with a two-axis tracking system exhibited ideal performance by consistently aligning its orientation towards the sun, hence maximizing energy absorption. It is imperative to acknowledge that the efficacy of a solar tracker in responding to variations in thermal intensity is contingent not only upon the intensity of solar radiation, but also upon the constituent materials, motor functionality, and additional mechanical elements incorporated within the tracker system. The prompt highlights the significance of the tracker's prompt and precise response to high temperatures. This is essential for maintaining the solar panels' optimal alignment with the sun, hence maximizing the efficiency of solar energy conversion into electricity.

4. Conclusions

The following is the conclusion of the results of designing a dual-axis solar tracker with temperature, voltage, current, and power measurements, namely:

1. The designed dual-axis solar tracker system has proven to be very effective in optimizing solar energy absorption. With the ability to move the solar panel horizontally and vertically following the sun's movement, the system can significantly increase solar energy reception compared to fixed solar panels.
2. The measurement of temperature, voltage, current, and power in the solar panel installation through NodeMCU ESP8266 has sufficient accuracy. The data generated is reliable and provides valuable information in monitoring and evaluating the performance of solar panel systems.
3. The system can respond to temperature, voltage, current, and power changes in real time. This allows users to monitor and identify changes in conditions that may affect the efficiency and performance of the solar panel installation.
4. In further development, integration with a remote monitoring system and automatic notification setup to report the condition and performance of the solar panel system in real time can be done. The use of intelligent algorithms and artificial intelligence can also be applied to improve the efficiency and reliability of solar tracking.

Credit author statement

Izza Anshory Conceptualization; Methodology; Formal analysis; Writing-original draft. Jamaaluddin Writing-review & editing. A'rasy Fahruddin Writing-review & editing. Ahmad Fudholi Supervision; review, writing-review & editing. Yadi Radiansah Revision. Dalmasius Ganjar Subagio Revision. Yusuf Suryo Utomo Revision. Oo Abdul Rosyid Revision. Kamaruzzaman Sopian Supervision; review, writing-review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors are unable or have chosen not to specify which data has been used.

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