Design of a Real-Time Automatic Solar Tracker System on Solar Panels Based on RTC and Servo Motor

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Abstract

The increasing demand for energy has driven the need to develop efficient and environmentally friendly renewable energy sources. One of the most promising alternative energy sources in Indonesia is solar energy. However, the efficiency of conventional solar panels remains relatively low due to their fixed position, while the direction of sunlight changes from morning to afternoon. This study aims to design a real-time automatic solar tracker system capable of adjusting the orientation of solar panels according to the sun's movement based on actual time. The system is controlled by an Arduino Nano microcontroller supported by a Real Time Clock (RTC) DS3231 module as a time controller and an MG996R servo motor as the panel orientation actuator. The test results show that the system can automatically move the panel with an average rotation of 8° every 30 minutes, from 08:00 to 17:00 local time. Based on measurement data, the use of a solar tracker increases the solar panel's power output by up to ±30% compared to a static panel without tracking. This system has been proven to significantly improve solar energy absorption efficiency and can be applied to both household and industrial scales in regions with high sunlight intensity.

Keywords: *Solar Tracker, Solar Energy, Solar Panel, Real-Time, RTC Module*

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Introduction

Energy plays a crucial role in supporting various human activities, ranging from household needs and industrial operations to transportation systems. The growth of the population and advancements in technology have contributed to a global increase in energy consumption from year to year. However, the majority of the current energy supply still depends on non-renewable resources such as coal, petroleum, and natural gas. This dependency not only leads to the depletion of energy reserves but also exacerbates environmental issues, including air pollution and the rise of greenhouse gas emissions that contribute to global warming.

The increasing demand for sustainable energy has encouraged many countries, including Indonesia, to develop environmentally friendly renewable energy sources. Solar energy has become one of the most promising alternatives, considering that Indonesia is located in a tropical region with high solar radiation levels almost throughout the year. This condition provides a great opportunity for the utilization of Solar Power Plants (PLTS) as an alternative energy solution. However, the remaining challenge is how to optimize sunlight absorption throughout the day to improve the efficiency of the solar power system.

Fixed solar panels have limitations in maximizing sunlight capture because the direction of sunlight changes from morning to evening, following the movement of the sun from east to west [1]. To overcome this issue, a solar tracking system, known as a solar tracker, is required to adjust the orientation of the solar panel so that it continuously faces the direction of the sunlight. The solar tracker system can be controlled not only by light sensors but also automated based on time [2]. With an orientation that remains optimal, the efficiency of energy absorption by the solar panel can be significantly improved.

This study aims to design a real-time automatic solar tracker system capable of moving solar panels according to the changing position of the sun based on actual time. The system utilizes an RTC (Real Time Clock) module to accurately read the time and adjust the panel's position according to the sun's coordinates at that specific moment. Thus, the solar panel can automatically and precisely follow the sun's movement from morning to evening.

The system is also designed so that the solar panel can automatically return to its initial position (east-facing) at night, making it ready to follow the sun's movement again the next day. Thus, this system is expected not only to improve the efficiency of the solar power plant (PLTS) but also to reduce dependence on light sensor–based tracking systems, which are less effective under cloudy or adverse weather conditions.

Literature Review

The growth of the population and global economic advancement have significantly driven a drastic increase in energy demand from year to year [3]. According to projections by the International Energy Agency (IEA), if no transition is made toward environmentally friendly and sustainable energy sources, global energy consumption could rise by more than 25% by the year 2040.

To date, most of the world's energy demand still relies on fossil-based sources, such as coal, petroleum, and natural gas. These types of energy sources are non-renewable, meaning they are limited and cannot be replenished in a short period of time [3]. In addition, the combustion of fossil fuels produces carbon dioxide (CO_2) emissions and other greenhouse gases, which are among the main contributors to global warming, climate change, and air pollution. This poses a serious threat to environmental sustainability and human health.

Renewable energy refers to energy derived from natural sources that can be naturally and sustainably replenished, such as solar, wind, hydro, biomass, and geothermal energy. This type of energy is considered a key solution to addressing the global energy crisis and reducing environmental degradation. In Indonesia, the potential for renewable energy sources is abundant, particularly solar energy, due to the country's geographical position along the equator.

Solar energy can be converted into electrical energy using solar panels. However, solar panels are generally installed in a fixed position (non-movable), making them less efficient in capturing sunlight. Therefore, it is necessary to design a system capable of adjusting the orientation of the solar panels to follow the movement of the sun, known as a solar tracker system.

2.1 Solar

A solar cell is an electronic component that functions to convert sunlight into electrical energy by utilizing the working principle of the photovoltaic effect. Due to this operating principle, solar cells are also commonly referred to as photovoltaic cells [4]. The basic structure of a solar cell is formed by the junction of two semiconductor materials with different characteristics namely, P-type and N-type together creating a P-N junction. This component is classified as a light sensor based on the photovoltaic effect because of its ability to convert the intensity of received light into electrical voltage. When the surface of the cell is exposed to light, a direct current (DC) voltage appears at its output terminals, typically ranging from 0.5 to 1 volt, depending on the design and technical specifications of the solar panel or cell [4], [5].

The P-N junction plays a crucial role in creating an internal electric field that enables the separation and movement of electrical charges such as electrons and holes. When P-type and N-type semiconductor materials are joined, electrons from the N-type side flow toward the P-type side, while holes from the P-type side move in the opposite direction. This movement results in the formation of a region known as the depletion zone, where an electric field with a specific direction is established, causing the N-type side to become relatively positive compared to the P-type side. When sunlight strikes this junction area, the energy from photons generates pairs of charge carriers in the form of electrons and holes. The established electric field drives the electrons toward the negative terminal and the holes toward the positive terminal, thus creating an electric current that can be utilized, as illustrated in Figure 1 [5].

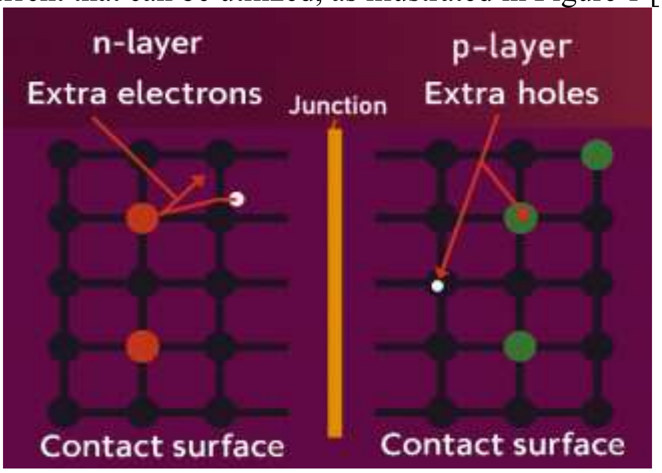

Figure 1. Junction between N-type and P-type in a Semiconductor

The voltage generated by a single solar cell unit is generally quite small and insufficient for practical applications. Therefore, several solar cells need to be connected in specific configurations—such as series, parallel, or a combination of both—to form a solar module or solar panel capable of producing higher voltage. Figure 2 illustrates the arrangement of solar cells forming a solar panel. If the voltage from a single panel still does not meet the system's requirements, multiple panels can be interconnected again in series, parallel, or combined configurations to obtain the output voltage and power that match the specifications of the electrical system being operated [5].

Figure 2. Illustration of a Solar Cell and Solar Panel [5]

2.2 Solar Charge Controller

A solar charge controller is a device that functions to regulate the flow of direct current (DC) from the solar panel to the battery and the load. This device plays an important role in preventing overcharging by automatically stopping the charging process when the battery voltage reaches its maximum limit. Figure 3 shows an illustration of a solar charge controller. The system commonly employs the PWM (Pulse Width Modulation) method to manage the battery charging process and limit the current flowing to the load. In solar power systems, batteries are typically charged at voltages between 14 and 14.7 volts, while a 12 volt solar panel can produce an output voltage ranging from 16 to 21 volts [6]. Without this controller, batteries are highly susceptible to damage due to overcharging and uncontrolled voltage fluctuations.

Figure 3. Solar Charge Controller

The specifications of the Solar Charge Controller to be used are shown in Table 1.

Table 1. Detailed Specifications of the Solar Charge Controller

Fitur	Spesifikasi
Baterry Voltage	12 Volt / 24
Charge / Discharge	Volt
current	10A
Maximum solar input	50 Volt
Operating Temperature	-31 C 140 C

2.3 18650 Battery

Batteries are generally divided into two main categories: primary batteries, which can only be used once, and secondary batteries, which are rechargeable and can be used repeatedly [5]. One example of a secondary battery is the 18650 type, a cylindrical lithium-ion battery. This type of battery is widely used in various devices, such as portable electronics, electric vehicles, and energy storage systems, including solar power installations such as Solar Power Plants (PLTS) and power banks.

Batteries play an essential role in solar power generation systems (PLTS) as power supply stabilizers for loads. Their function involves two main stages charging and discharging which depend on the intensity of sunlight. When sunlight is sufficient, the solar panel generates electricity; if the production exceeds the load demand, the excess energy is stored in the battery. Conversely, when there is no solar radiation, the stored energy is used to supply the load. This series of processes forms one complete operational cycle of the battery in a solar power system. Figure 4 shows an illustration of the 18650 battery used in this study.

Figure 4. Illustration of the 18650 Battery

2.4 Arduino Nano ATmega328

The Arduino Nano based on the ATmega328 is a compact microcontroller developed using the ATmega328 chip from the AVR family [7]. Despite its small size, this device is equipped with core features similar to those found on the Arduino Uno, making it highly suitable for electronic projects that require a compact design, such as sensor systems, IoT applications, robotics, and wearable devices. Figure 5 presents an illustration of the Arduino Nano ATmega328 used in this study.

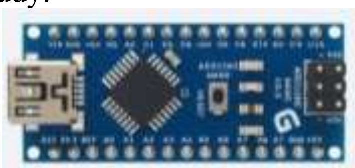

Figure 5. Arduino Nano ATmega328

2.5 RTC (Real Time Clock) Module

The Real Time Clock (RTC) module is an electronic device designed to record and maintain accurate time information, including hours, minutes, seconds, as well as date, month, and year [8]. Its function continues to operate even when the main system, such as a microcontroller or Arduino, is turned off or not receiving power. This is made possible because the module is equipped with a backup battery typically a CR2032 type which allows the timekeeping process to continue without relying on an external power source. Figure 6 shows an illustration of an RTC module.

Figure 6. RTC DS3231 Module

The Real Time Clock (RTC) module plays an important role in controlling time and synchronizing the movement of the solar panel automatically in accordance with real-time conditions in the solar tracking system. The use of this module allows the panel's position to follow the sun's path based on time data rather than relying solely on light intensity.

2.6 Servo Motor

A servo motor is a rotary actuator capable of operating in two directions (clockwise and counterclockwise) using a closed feedback system, in which the position of the motor shaft is sent back as feedback to the servo motor's internal control system [9].

In a real-time automatic solar tracker system, the servo motor functions as the main actuator that enables the solar panel to move precisely toward the direction of sunlight based on actual time (real-time) data or light intensity.

2.7 Buck Converter XL4015

The XL4015 module is a type of DC-to-DC step-down converter used to reduce high input voltage to a lower, stable output voltage. This module is known for its high efficiency and is commonly applied in various electronic systems, such as power supplies for Arduino microcontrollers, portable devices, and solar energy systems.

In a solar tracker system designed to follow the movement of the sun to improve light-capturing efficiency, the XL4015 Buck Converter plays an important role in delivering appropriate and stable voltage to various electronic components involved in the operation of the solar tracker system being developed.

2.8 Solar Tracker System

A solar tracker is a mechanical and electronic-based system designed to adjust the orientation of solar panels so that they continuously face the position of the sun directly throughout the day. In this way, the system aims to optimize the absorption of solar radiation, thereby achieving more efficient energy conversion from sunlight into electrical energy.

Research Methodology

The solar tracker system design method was carried out by collecting data through three main approaches: direct observation, documentation, and equipment testing. Through direct observation, the author obtained data by closely monitoring the performance of the system circuit while the device was operating and producing output. During this process, the author actively observed the system's response to every change that occurred. In the documentation stage, the author gathered information about the components used in the system's construction by referring to datasheets, integrating both hardware and software aspects, and consulting other technical references. The author also reviewed relevant literature and scientific journals to strengthen the theoretical foundation of the system design. In the testing phase, the author conducted trials on the assembled device to ensure that the system operated according to its intended purpose and initial design.

3.1 Block Diagram Design

The block diagram designed for this test, as shown in Figure 7, serves to simplify the system design process and assist in identifying and localizing potential errors. This diagram provides an overall overview of the system's workflow. Through this block representation, the functional flow of each component can be analyzed more easily, thereby facilitating comprehensive planning and hardware design.

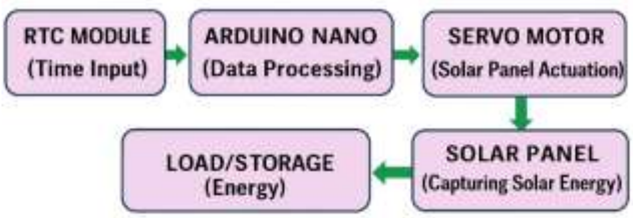

Figure 7. System Block Diagram

This solar tracker system is designed based on the principle of time monitoring obtained through the Real Time Clock (RTC) module. The RTC module provides real-time time information, which is then received and processed by the Arduino Nano microcontroller. Based on this data, the Arduino calculates the ideal position for the solar panel to continuously face the direction of incoming sunlight. This information is used to control the servo motor responsible for adjusting the panel's position. With this configuration, the solar panel can automatically adjust its orientation to follow the sun's movement from morning to evening. The electrical energy collected by the solar panel is then directed either for immediate use by the load or stored in an energy storage system, such as a battery, for later utilization.

3.2 Hardware Design

The hardware design of the solar tracker system plays a key role in realizing the automatic solar panel orientation control based on time or the position of the sun. The hardware consists of the physical circuitry of components such as the solar panel, RTC (Real Time Clock) module, Arduino microcontroller, servo motor, LCD display, battery, and power control circuit. Its main function is to serve as an interface that allows communication and coordination among components according to the defined control logic. Figure 8 shows the schematic diagram of the designed hardware.

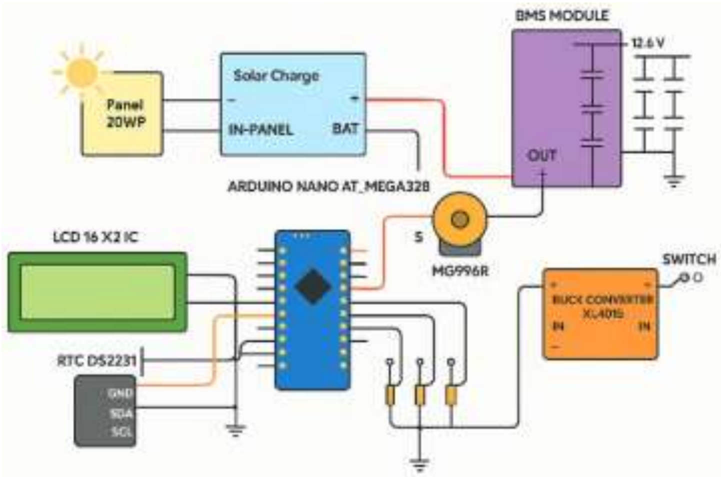

Figure 8. Schematic Diagram

Based on the schematic diagram, this system is an automatic solar panel controller operated by an Arduino Nano ATmega328 microcontroller and equipped with several supporting components. The 20WP solar panel serves as the main power source, supplying energy to the solar charge controller, which manages the charging process of the 18650 battery. This process is carried out through the Battery Management System (BMS) module, which ensures safe charging and maintains the voltage within safe limits (12.6V, 8.4V, and 4.2V).

The Arduino Nano microcontroller acts as the central control unit of the system, receiving time input from the RTC DS3231 module, which enables the system to operate based on real-time data. The time information is displayed on a 16x2 LCD with an I2C interface connected to the Arduino.

The MG996R servo motor is used to automatically adjust the position of the solar panel, directed by the Arduino based on time data from the RTC. The motor is controlled through a PWM signal generated by the Arduino, with its power supply regulated via a switch.

For regulating the output voltage to the load, the system uses an XL4015 buck converter module, which steps down the battery voltage to match the load requirements. The system is also equipped with several push buttons as manual inputs to the Arduino, allowing users to perform additional controls or specific configurations directly.

Overall, this system is designed to optimize solar energy absorption by automatically adjusting the position of the solar panel based on time, while efficiently and safely managing the distribution and storage of energy to the battery and the load.

3.3 Flowchart Design

When designing a program in software, a flowchart is first created to illustrate the processes that occur within the program and the working system of the device, as shown in Figure 9.

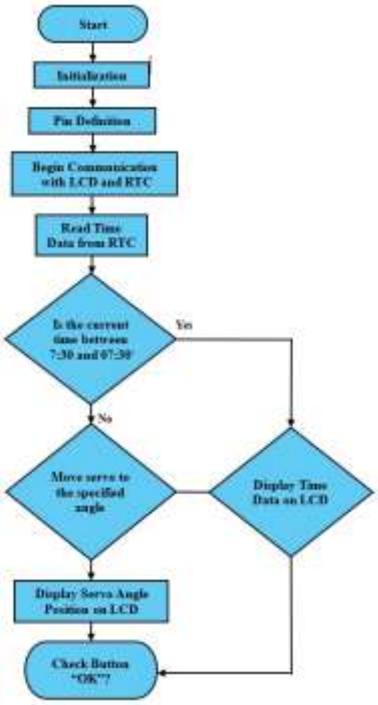

Figure 9. System Flowchart

The flowchart of this solar tracker system illustrates the logical sequence of the automation process used to control the orientation of the solar panel based on time. The process begins with the system initialization stage, where the microcontroller performs initial setup to establish communication with the connected components. Next, the input and output pins are defined, including those for the Real Time Clock (RTC), LCD, servo motor, and buttons. Afterward, the system activates communication with the LCD and RTC, enabling it to read the current time data.

The next stage is reading the time data from the RTC module. The system then checks the current time. If the time falls within the range of 5:30 PM to 7:30 AM, meaning it is nighttime or before sunrise, the system will not move the panel but will only display the current time on the LCD screen. Conversely, if the time is outside this range (during daylight hours), the system will rotate the servo motor to a specific angle predetermined based on the time. This angle adjusts the solar panel so that it always faces toward the sun.

After the servo motor is moved, the system will display the servo angle position on the LCD as feedback for the user. Finally, the system will check whether the "OK" button is pressed by the user. If the button is pressed, the system can perform further actions, such as saving the position or restarting the cycle. If not, the system will return to the time-reading process and continue running the cycle repeatedly.

3.4 Software Design

The software design of this system uses the Arduino IDE as the main platform for developing the automatic control program. The Arduino IDE was chosen because it supports microcontroller programming using the C/C++ language and provides a lightweight, user-friendly interface for writing, compiling, and uploading code to the hardware. In its application, the program is developed to retrieve real-time data from the Real Time Clock (RTC) module, which is then used to calculate the rotation angle of the servo motor that controls the orientation of the solar panel. The panel is directed according to the sun's position based on the current time. Information such as the clock and servo angle position is displayed on a 16x2 LCD screen as a user interface. All processes, including initialization, data reading, and actuator control, are managed within the Arduino program, enabling the system to operate automatically and in an integrated manner according to the design objectives.

3.5 System Placement Design

In the system placement design of the developed device, a plastic panel box was used, as shown in Figure 10. The use of this panel box aims to organize the system circuitry neatly and protect it from potential external disturbances.

Figure 10. Circuit Enclosure

3.6 Device Testing Method

After all hardware components were fully assembled and the software was successfully programmed and properly integrated, the testing process of the solar tracker system was carried out. The solar panel was positioned in an open area, aligned with the sun's movement path from east to west. This testing aimed to evaluate the system's ability to automatically adjust the panel's position according to time changes and to ensure that the servo motor moved according to the angles defined in the program logic.

The system testing was conducted continuously over two full days, starting from sunrise until sunset. The purpose of this testing was to evaluate the overall performance of the system and to observe the extent of the increase in electrical power efficiency produced by the solar tracker system compared to a stationary (non-moving) solar panel.

3.7 Data Processing Method

The data processing method in this system was carried out through direct observation of the information displayed on the LCD screen, the movement of the servo motor, and the changes in the orientation of the solar panel during system operation. This observation aimed to ensure that all system mechanisms operated automatically and in accordance with the time logic programmed into the microcontroller.

Table 2. Servo Motor Movement on the Solar Panel

Num	Time	Servo Angle (panel position)°
1	8.00	35
2	8.30	43
3	9.00	51
4	9.30	59
5	10.00	67
6	10.30	75
8	11.00	83
9	11.30	91
10	12.00	99
11	12.30	108
12	13.00	116
13	13.30	124
14	14.00	132
15	14.30	140
16	15.00	148
17	15.30	156
18	16.00	164
19	16.30	172
20	17.00	180

The solar panel is designed to move every 30 minutes, starting at 08:00 with an initial position of 35°, and ending at an angle of 180° at 17:00. During this period, a total of 18 movements occur, with each interval producing an average angular change of approximately 8°. These angle values are presented in Table 2. To simplify the programming and implementation process, the angles were rounded to the nearest whole number.

Results

4.1 Solar Tracker System Design Results

The solar tracker system design presents the overall results of the constructed device, as shown in Figures 11 and 12. After the device design was successfully completed, testing was conducted by taking measurements during the system's operation, followed by a discussion of the solar tracker's working mechanism and an explanation of the final testing results.

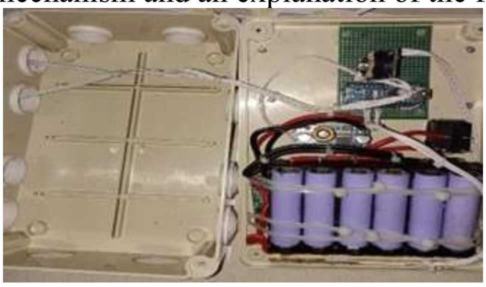

Figure 11. System Circuit Enclosure

Figure 12. System Circuit Enclosure

This solar tracker system operates based on time mapping corresponding to the rotation angle of the solar panel, allowing the panel to automatically follow the direction of sunlight from morning to evening. When the system is activated, the Arduino Nano performs an initialization process and establishes communication with the Real Time Clock (RTC) module and the LCD. The time information obtained from the RTC is then converted by the Arduino into angular values used to control the position of the servo motor. The servo movement begins at 08:00 a.m. with an initial angle of 35°, and gradually increases by 8° every 30 minutes until reaching a maximum position of 180° at 17:00 p.m., representing the westward direction. Outside of these hours, between 17:30 and 07:30, the system resets the servo position to 0°, indicating that the panel returns to its initial east-facing position in preparation for the following day.

4.2 Measurement Results

To determine the extent of the increase in electrical power generated by the solar panel through the use of a solar tracker, direct measurements of current and voltage were conducted. These measurements were carried out under constant load conditions to ensure that the comparison results accurately reflected the effect of panel movement on the conversion of solar energy into electricity. Data were collected from the device every hour, and the measurement results were systematically recorded. In addition, measurements were also performed on a solar panel without a solar tracker system as a comparison. The data from both conditions were then analyzed to evaluate the performance difference, allowing for the assessment of how much power improvement could be achieved using the solar tracker compared to a stationary solar panel. Table 3 presents the measurement data of the system using the solar tracker, taken on June 9, 2025, from 08:00 a.m. to 05:00 p.m.

Table 3. Measurement Results with Solar Tracker on June 9, 2025

Time	Panel Position	V_{Panel} (V)	V_{Load} (V)	Current (I)	Power (W)
08.00	35°	19,81	1,11	0,11	0,122
08.30	43°	20,09	1,73	0,22	0,380
09.00	51°	20,17	2,38	0,29	0,690
09.30	59°	20,21	2,34	0,28	0,642
10.00	67°	20,22	2,30	0,28	0,655
10.30	75°	20,11	2,09	0,25	0,523
11.00	83°	19,98	1,52	0,20	0,304
11.30	91°	20,19	2,11	0,25	0,528
12.00	99°	20,35	2,46	0,30	0,738
12.30	108°	20,41	2,61	0,32	0,835

13.00	116°	20,30	2,73	0,32	0,874
13.30	124°	20,44	5,51	0,69	3,802
14.00	132°	20,52	8,71	1,05	9,146
14.30	140°	20,61	8,12	1,01	8,201
15.00	148°	20,76	7,71	1,03	7,941
15.30	156°	20,11	3,08	0,41	1,263
16.00	164°	19,37	1,34	0,15	0,201
16.30	172°	18,29	0,94	0,13	0,122
17.00	180°	18,49	0,51	0,08	0,040

The measurement results taken without the solar tracker on July 9, 2025, can be seen in Table 4.

Table 4. Measurement Results Without Solar Tracker on June 9, 2025

Time	Panel Position	V_{Panel} (V)	V_{Load} (V)	Current (I)	Power (W)
08.00	90°	18,54	0,81	0,08	0,065
08.30	90°	19,12	1,46	0,18	0,263
09.00	90°	20,21	2,29	0,24	0,550
09.30	90°	20,20	2,21	0,25	0,552
10.00	90°	20,15	2,09	0,24	0,502
10.30	90°	20,02	1,90	0,23	0,437
11.00	90°	19,99	1,48	0,17	0,252
11.30	90°	20,16	2,01	0,23	0,462
12.00	90°	20,41	2,65	0,25	0,663
12.30	90°	20,61	3,12	0,32	0,998
13.00	90°	20,72	3,67	0,45	1,652
13.30	90°	20,64	5,19	0,51	2,647
14.00	90°	20,38	6,33	0,54	3,418
14.30	90°	20,21	4,81	0,47	2,260
15.00	90°	19,41	1,82	0,24	0,437
15.30	90°	19,02	1,41	0,17	0,240
16.00	90°	19,71	1,34	0,16	0,214
16.30	90°	19,51	1,11	0,12	0,133
17.00	90°	19,44	0,91	0,09	0,082

Meanwhile, the measurement results using the solar tracker on July 10, 2025, are shown in Table 5.

Table 5. Measurement Results With Solar Tracker on June 10, 2025

Time	Panel Position	V_{Panel} (V)	V_{Load} (V)	Current (I)	Power (W)
08.00	35°	20,43	6,43	0,76	4,887
08.30	43°	20,26	7,62	0,87	6,629
09.00	51°	20,12	8,76	1,06	9,286
09.30	59°	20,22	8,04	0,96	7,718
10.00	67°	20,30	7,29	0,89	6,488
10.30	75°	20,42	8,78	1,05	9,219
11.00	83°	20,51	10,31	1,19	12,269
11.30	91°	20,53	9,57	1,12	10,718
12.00	99°	20,53	8,83	1,05	9,272
12.30	108°	19,73	8,72	1,07	9,330
13.00	116°	18,95	8,59	1,09	9,363
13.30	124°	19,64	8,55	1,06	9,063
14.00	132°	20,33	8,48	1,02	8,650
14.30	140°	20,36	5,99	0,71	4,253

15.00	148°	20,39	3,49	0,41	1,431
15.30	156°	19,84	2,64	0,27	0,713
16.00	164°	19,29	1,79	0,11	0,197
16.30	172°	19,64	1,79	0,17	0,304
17.00	180°	19,97	1,79	0,19	0,340

Meanwhile, the measurement results without the solar tracker on July 10, 2025, can be seen in Table 6.

Table 6. Measurement Results Without Solar Tracker on June 10, 2025

Time	Panel Position	V_{Panel} (V)	V_{Load} (V)	Current (I)	Power (W)
08.00	90°	19,72	3,39	0,05	0,170
08.30	90°	19,92	3,81	0,25	0,953
09.00	90°	20,11	4,21	0,50	2,105
09.30	90°	20,21	5,73	0,69	3,954
10.00	90°	20,31	7,29	0,89	6,488
10.30	90°	20,41	8,74	1,05	9,177
11.00	90°	20,51	10,29	1,19	12,245
11.30	90°	20,53	9,57	1,13	10,814
12.00	90°	20,54	8,85	1,06	9,381
12.30	90°	19,74	8,71	1,07	9,320
13.00	90°	18,94	8,58	1,08	9,266
13.30	90°	19,63	8,54	1,05	8,967
14.00	90°	20,32	8,49	1,02	8,660
14.30	90°	20,35	5,97	0,71	4,239
15.00	90°	20,38	3,49	0,41	1,431
15.30	90°	20,10	2,21	0,31	0,685
16.00	90°	19,28	0,91	0,11	0,100
16.30	90°	19,20	0,94	0,12	0,113
17.00	90°	19,13	0,93	0,10	0,093

4.3 Final Test Results

Based on the measurement data, a comparison graph of the output power was created between the solar panel equipped with a solar tracker and the solar panel without a tracking system. This graph provides a visual representation of the performance differences between the two systems in generating electrical energy under relatively similar lighting conditions and time periods. From this comparison, it can be observed how significant the role of the solar tracker is in improving the efficiency of solar energy conversion, especially during certain periods when the light intensity and the angle of sunlight incidence change significantly throughout the day.

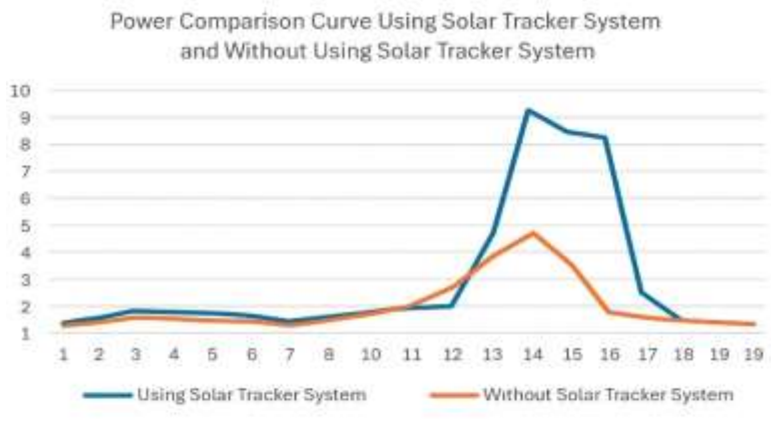

Figure 13. Power Comparison Curve on June 9, 2025

The curve in Figure 13 illustrates the comparison of output power between the solar panel equipped with a solar tracker and the conventional solar panel without tracking. Based on the measurement data taken on June 9, 2025, starting at 08:00 AM and ending at 05:00 PM, as presented in Tables 3 and 4, a noticeable difference in power output can be observed during most of the observation period. This indicates that using a solar tracker can significantly improve the system's performance in generating electrical power.

The solar panel equipped with a solar tracker consistently demonstrated superior performance compared to the panel without a tracker. The most significant increase in power output, based on observations, occurred at 2:00 PM and 3:00 PM, where the system with the solar tracker produced a much higher output. This finding reinforces that the implementation of solar tracking technology is effective in optimizing sunlight absorption, especially when the angle of incidence is not perpendicular to the surface of conventional panels. Consequently, energy conversion efficiency can be maintained even when light intensity and direction change.

The second curve shown in Figure 14 is derived from the processed data in Tables 5 and 6, illustrating the comparison of output power between the solar panel equipped with a solar tracker and the panel without a tracking system. The measurements were conducted on June 10, 2025, from 08:00 AM to 05:00 PM under clear lighting conditions. Based on the curve, it can be seen that the solar panel equipped with a solar tracker, represented by the blue line, generally produced higher power compared to the static panel. This trend appears consistent across nearly all observation points throughout the measurement period.

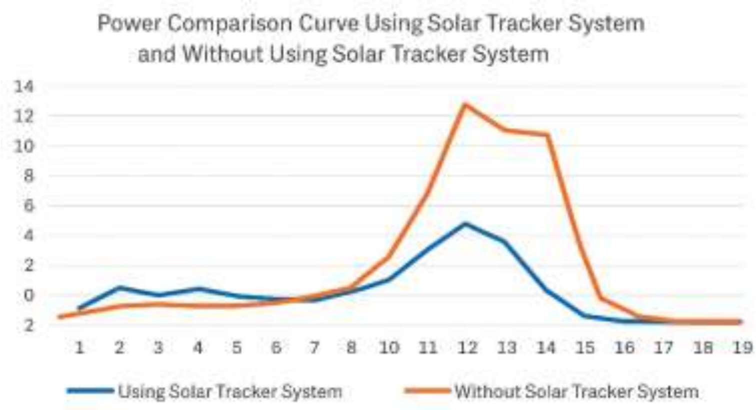

Figure 14. Power Comparison Curve on June 10, 2025

A noticeable power difference was recorded at 09:00 AM, where the solar panel equipped with the solar tracker produced approximately 30% higher power compared to the panel without tracking. This result indicates that the implementation of a solar tracker can effectively enhance the efficiency of solar energy absorption, especially when the sun's position is still at an inclined angle relative to the fixed panel surface, resulting in a suboptimal irradiation angle.

Conclusion

The design and implementation of an automatic solar tracker system utilizing an RTC module and servo motor to enhance the performance of solar panels have been successfully developed. This system is designed to accurately follow the movement of the sun based on time, ensuring that the panel remains at the optimal angle to capture sunlight throughout the day. Unlike light sensor–based methods, this system does not require light intensity detection, making it simpler to control and more stable under various weather conditions. Test results indicate that using this system can effectively improve energy absorption efficiency and produce more optimal power output. The system's performance stability and its ability to automatically track the sun’s movement make it suitable for both household and industrial applications, particularly in regions with high sunlight exposure throughout the year.

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