DESIGN AND DEVELOPMENT OF CONTROL MONITORING FOR REAL-TIME CLOCK (RTC) IMPLEMENTATION IN A SOLAR CELL TRACKER USING NAIVE BAYES METHOD BASED ON WEB SERVICE

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ABSTRACT

The efficiency of solar panels is often limited by their static position, which only allows optimal energy capture at certain angles throughout the day. To overcome this challenge, a solar tracker system was developed that automatically adjusts the panel's position to follow the sun’s movement, enhancing energy capture efficiency. This study explores the implementation of a solar tracker using a Real Time Clock (RTC) and the Naive Bayes method to optimize panel orientation based on the sun’s position. The system, controlled by the NodeMCU ESP32 and powered by an MG995 servo motor, predicts sun movement using historical data for proactive adjustments. Testing shows a 5.47% improvement in energy efficiency over conventional systems, demonstrating its potential in renewable energy applications.

Keywords : Real Time Clock, Solar cell Tracker, Naive Bayes, Optimization, Energy Efficiency, Solar Panels

1. INTRODUCTION

Indonesia, as an archipelago, possesses abundant natural resources that can be harnessed as energy sources for sustainable living. However, over time, the availability of these natural resources has been depleting, and to address this, renewable energy sources (EBT) have become the best alternativ. Renewable Energy (EBT) is currently developing rapidly, not only because of its increasingly affordable cost but also due to the growing awareness of the importance of using environmentally friendly energy sources. As a tropical country, Indonesia has a high intensity of solar radiation, averaging around 4.8 kWh/m2 per day across its regions. The ideal time to harness sunlight using solar cells is around 4 to 5 hours each day.

One commonly used alternative is Solar Power Plants (PLTS), an environmentally friendly electricity source because it does not rely on fossil fuels. Solar energy, which forms the basis of PLTS, is abundantly available, making it relatively low-cost. In the quest for new energy sources, it is essential to meet several critical criteria, including the ability to generate sufficient energy, economic viability, and minimal negative impact on the environment. Its utilization in Indonesia is regulated under the Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia, or Permen ESDM Number 26 of 2021. Research and development efforts in new energy focus on harnessing solar energy, both directly and indirectly, through the use of solar panels. These solar panels can convert solar energy into electrical energy, known as solar cells, thereby meeting the aforementioned criteria.

The current issue is that most solar panels are static or non-moving, resulting in suboptimal solar energy absorption. This is because the fixed position of the solar panels only faces upwards, without tracking the Earth's rotation that causes the sun's position to change continuously. Consequently, solar panels do not always receive maximum exposure to solar energy, as the optimal position for energy absorption is when the solar panels are perpendicular to the sunlight, following the sun's rise and set. When the entire surface of the solar cells is exposed to sunlight, the absorption becomes optimal.

The development of systems within solar cells involves using servo motors to move the panels according to the sunlight, known as Solar Trackers. Solar Trackers typically use LDR sensors. However, the use of these sensors is less effective due to certain challenges, such as high power consumption and complex maintenance. Therefore, the development of this Solar Tracker system requires replacing the LDR sensor with a Real-Time Clock (RTC). Implementing a Real-Time Clock (RTC) as a replacement for the LDR Sensor using the Naïve Bayes algorithm can provide accurate time management. Additionally, this Naïve Bayes method can determine the best angle for the tracker on the solar panels based on the time, resulting in the most optimal solar energy output.

Based on the background that has been outlined, the author is keen to create a design titled "DESIGN AND DEVELOPMENT OF CONTROL MONITORING WITH REAL-TIME CLOCK (RTC) IMPLEMENTATION ON SOLAR CELL TRACKER USING NAIVE BAYES METHOD BASED ON WEB SERVICE." This design is expected to be applied, broaden knowledge, and be further developed for future renewable research. The problem formulation derived from this background includes two main points: first, how the control monitoring design works using Real-Time Clock implementation on a solar cell tracker with the Naïve Bayes method based on web service; and second, whether this design can produce optimal voltage in its application.

2. METHOD

2.1 Research Design

The research method used in this study is Research and Development (R&D), focusing on the development and enhancement of a device. According to Sugiyono (2015), this research method is employed to produce specific products that require a needs analysis and effectiveness testing to ensure the product can function optimally within the broader community. The steps in research and development, as outlined by Sugiyono (2015), include several stages. The first stage is identifying potential and problems, where R&D begins with the recognition of a potential problem supported by data, either from other research reports or activity documentation. Next, data collection is conducted to gather information useful for planning. Following this, the product design stage takes place, resulting from initial research, and may include a new work plan or product. The design is then validated to assess its feasibility, with evaluations from experienced experts. If necessary, design revisions are made to improve or add alternatives to the initial concept. The next stage involves limited product testing to collect data on the product's effectiveness, efficiency, and appeal. Based on the test results, product revisions are carried out to address any identified shortcomings. Design validation is then performed through actual use testing in real conditions. If further deficiencies are found, final product revisions are made to refine the device. The final step is limited production, where the developed product will be produced in small quantities.

2.2 Device Design

The process of designing a monitoring control system to implement a Real-Time Clock (RTC) on a Solar Cell Tracker using the Naive Bayes method follows a research and development approach. This method is chosen because it can produce a specific product and test its effectiveness. The design of this tool involves several key components, starting from the block diagram design to the wiring diagram that regulates the overall system operation.

In the design phase, several sensors are used, including the RTC, which functions as the determinant of the solar cell's movement angle to optimally position the panel towards the sunlight. The ACS712 current sensor is used to measure the current generated by the solar cell, while the voltage is measured using a voltage divider circuit, where the input voltage (Vin) comes from the solar cell and is divided by two resistors to produce an output voltage that can be read by the ESP32. The data obtained from these various sensors will be processed by the ESP32 microcontroller, where the Naive Bayes algorithm is applied to process the generated current and voltage data.

The output of this process focuses on the charging and discharging system of the battery. If the current and voltage received are less than required, the Naive Bayes algorithm will instruct the system to charge the battery. Conversely, if the current and voltage have reached the maximum limit, the system will discharge the battery through a relay to prevent overcharging. There are two relays, one for the load and one for the battery.

The ESP32 also has monitoring capabilities through an LCD display or web service, where the servo movement angle is determined by the RTC according to the programmed time. The data generated from the solar cell will be reused to activate the control system through the battery, which has been regulated to lower the voltage to 5VDC using a Buck Converter.

In its implementation, the solar panel is positioned horizontally to face the sunlight from east to west. The operation of this tool begins with the solar cell receiving sunlight and generating electrical energy. The ESP32 microcontroller initializes the input and output pins to read data from the current and voltage sensors on the battery and solar cell. The data that has been read is then sent to the RTC, which will determine the panel's movement angle according to the sun's position based on the observed time. The servo motor will move according to the predetermined angle, ensuring that the solar panel is always in an optimal position for energy absorption.

The output of the current and voltage values is then analyzed by the Naive Bayes algorithm and PVSystem software to determine the next steps in the charging and discharging process. The data processing results are then sent to a web server for control and monitoring. If the data cannot be read through the web, the LCD can be used as an alternative to read the generated current and voltage values.

Hardware used in this system includes a 10 WP solar panel, which is a photovoltaic panel that efficiently converts sunlight into electrical energy. The specifications of this solar panel indicate that it has a peak power of 10W, with a maximum voltage of 18V and a maximum current of 0.56A.

RTC DS3231 module is another important component used to keep time with high accuracy, including seconds, minutes, hours, and years, with very low power consumption of 500nA.

Solar Charge Controller (SCC) is used to regulate the charging of the battery from the solar panel, with specifications that support a working voltage of 12/24V and a charging current measured up to 20A. The SCC ensures that the battery is charged according to the proper limits.

ESP32 microcontroller is very suitable for IoT (Internet of Things) applications because it can communicate wirelessly and control various devices with a board size of 57 mm x 30 mm and an input voltage of 3.4 ~ 5 V.

Motor Servo MG995 is used to move the solar panel following the predetermined angle, with high torque at an operating voltage of 4.8V to 6V.

ACS712 current sensor is used to detect electric current through the Hall effect, whether it is direct current (DC) or alternating current (AC), with an output sensitivity of 185 mV/A.

Resistors are used to limit the flow of electric current in the circuit, with a resistance specification of 1KΩ and a tolerance of ±5%.

Relay module is a component that functions as an electromechanical switch to control the tool's system, with a coil voltage specification of 5V and a maximum current of 2A.

Buck Converter LM2596 is a power converter that lowers the input voltage to a lower output voltage with high efficiency, supporting an input voltage of 3 – 40V and an output that can be adjusted from 1.5-35V.

12VDC battery is used as an energy backup from the solar panel when in off-grid conditions. This battery is a dry cell type with a capacity of 7.5 Ah and a nominal voltage of 12VDC.

Liquid Crystal Display (LCD) functions as a display device for monitoring the data generated by the system, with a display format of 16 characters x 2 rows, and a supply voltage of 5V.

Software used includes Arduino IDE for programming the ESP32 microcontroller, and Web Service for controlling and monitoring the current and voltage on the tool through the HTTP Request protocol.

With all these components, this Solar Cell Tracker system is expected to maximize the use of solar energy with high efficiency and optimal control.

2.3 Testing Techniques

Testing techniques are carried out to ensure that the device functions as intended and works properly. The design of this device aims to move the solar cell to follow the movement of sunlight, maximizing its energy absorption. The testing technique for this device involves taking data every hour, from 06:00 AM to 05:00 PM, to determine the optimal angle obtained from sunlight. This data is then used to compare the efficiency of solar cell utilization with a tracker that follows the sun's movement, using a Real-Time Clock (RTC) with the Naive Bayes method, versus a solar cell without a tracker. Based on the results of the device testing, data analysis is conducted by comparing the current and voltage produced to determine the optimal angle of the solar cell relative to the sun based on time.

Testing of 10WP Solar Panel

This test ensures that the RTC can respond to commands from the ESP32 using the Naive Bayes algorithm and provide accurate time and date. The testing steps include preparing the tools and materials, connecting the WiFi hotspot to initialize the ESP32, opening the web service to view the time and date display, and checking the LCD to ensure the accuracy of the time and date. The time interval difference is recorded to determine the RTC's accuracy.

Testing of Solar Charger Controller (SCC)

The SCC test aims to ensure that the SCC can receive voltage from the solar panel and regulate the output voltage safely for charging the battery. The testing steps involve connecting the solar panel to the SCC input, measuring the input voltage with a multimeter, connecting the battery to the SCC output, and measuring the output voltage with a multimeter to ensure that the voltage is within a safe range for the battery.

Testing of 12VDC Battery

The 12V battery test aims to evaluate the battery's performance, capacity, and health condition. The testing steps include turning off all loads connected to the battery, using a multimeter to measure DC voltage, and recording the voltage reading to ensure that the battery is functioning properly, with a full voltage typically between 12.6V and 12.8V.

Testing of Real-Time Clock (RTC)

This test examines the accuracy of the time, day, and date on the RTC to ensure it matches the set time. The steps include synchronizing the RTC with an accurate time source, letting the RTC run for a certain period, and then comparing the RTC time with the accurate time source to record the time difference and calculate the daily deviation rate.

Testing of ESP32 Microcontroller

The ESP32 test aims to ensure the functionality, performance, and stability of the microcontroller under various conditions. The testing steps include preparing the tools and materials, connecting the WiFi hotspot to initialize the ESP32, and opening the web service to monitor the display, ensuring that the data is correctly read.

Testing of Relay Module

The relay test aims to ensure that the relay module can control the electrical flow according to commands from the ESP32. The steps include preparing the tools and materials, connecting the WiFi hotspot to initialize the ESP32, opening the web service to control the ON/OFF of the DC lamp, and timing the interval between the ON/OFF commands using a stopwatch.

Testing of ACS712 Current Sensor

The ACS712 current sensor test aims to ensure the sensor's performance and reliability in measuring the electrical current flowing through the device circuit. The testing steps include preparing the tools and materials, ensuring the device is connected to the power battery, correctly placing the multimeter probes, setting the multimeter to DC (mA), recording the current readings, and comparing the results with the LCD and web service displays.

Testing of Voltage Divider using Resistor

The voltage divider test aims to ensure that the voltage divider system using resistors can read the voltage from the battery and solar cell sources. The steps include preparing the tools and materials, ensuring the device is connected to the power battery, measuring the voltage with a multimeter, and recording the voltage readings, then comparing the results with the LCD and web service displays.

Testing of MG995 Servo Motor

The MG995 servo motor test aims to ensure the functionality, accuracy, and reliability of the motor under various conditions. The testing steps include connecting the servo motor to a microcontroller or servo tester, setting the microcontroller program to send PWM (Pulse Width Modulation) signals with various angle values, observing the servo motor's response, and verifying that the rotation angle matches the expected values.

Testing of LM2596 Buck Converter

The LM2596 buck converter test aims to ensure that the device can step down DC voltage to the desired value, from 12VDC to 5VDC. The testing steps involve measuring the input and output voltage of the buck converter using a multimeter and recording the results to ensure that the output voltage meets the expected values.

By conducting these series of tests, it is expected that all components of the device will function according to the design, ensuring the research objectives are successfully achieved.

2.4 Data Analysis Techniques

In writing this final project, the data collection methods used include several techniques. First, literature review, which involves the examination, exploration, and analysis of theories relevant to the research problem. This review helps the researcher understand the research context, identify gaps in previous research, and establish a strong theoretical foundation from various sources such as books, journals, scientific articles, and other documents. Second, the library method, which is similar to a literature review but with a broader scope. In addition to reviewing reference books, this method also involves gathering information from lecturers, colleagues, family members, and relevant online sources. The goal is to obtain theoretical foundations and references that support the writing of the final project.

Next, observation is conducted by directly observing the object or phenomenon being studied. The researcher goes into the field to collect data and information that may not be accessible through literature or laboratory work, making observation essential for obtaining accurate and accountable data. Additionally, the experimental method is used, where trials or experiments are conducted to obtain empirical data. In the context of the final project, experiments can be conducted to test hypotheses or to develop and test the programs or systems created, with the results used to solve the research problem. Finally, discussion is carried out by consulting and seeking guidance from the supervising lecturer or other experts in the relevant field. Through these discussions, the researcher can obtain constructive feedback, suggestions, and criticism to improve and refine the research and final project design.

2.5 Research Location and Time

The planning and preparation period started in January 2024 and continued until August 2024. Data collection and device design were conducted in the WIB time zone, specifically in the city of Surabaya, at the Surabaya Aviation Polytechnic.

3. RESULT AND DISCUSSION

Research Results

In this chapter, the author will explain the results of the design and testing of the components used. The testing stages include evaluating the system plan developed in chapter 3, with the goal of assessing system performance and ensuring that the built system aligns with the planned design. This testing involves evaluating both the hardware and software used in this research. The author uses a 16x2 LCD and Web service as monitoring devices, with the ESP32 as the programming core and other hardware components to control the Solar Cell Tracker, which is managed using the Naïve Bayes algorithm. The software plays a crucial role in building an optimal system in this research. The testing stages include hardware design, hardware testing, software design, designing the Naïve Bayes method for the system, writing the program using Arduino IDE, designing the Web service, and testing the overall system.

Hardware Design

In this chapter, the author will detail the results of the design and testing of the components used in the Solar Cell Tracker system. The testing conducted covers various aspects, including energy conversion, battery testing, Solar Charger Controller (SCC) testing, Real-Time Clock (RTC) testing, ESP32 microcontroller testing, ACS712 current sensor testing, LM2596 Buck Converter testing, MG995 servo motor testing, relay testing, and Liquid Crystal Display (LCD) testing. Each test aims to ensure that these components function properly and meet the specifications required for this system.

Solar Panel Testing

The solar panel testing was conducted to assess the ability of a 10WP solar panel to convert solar energy into electrical energy. This component converts sunlight into electricity, which is then directed to the SCC, relay, and current and voltage sensors for further readings. The test was conducted by exposing the solar panel to direct sunlight in an open circuit condition, without load, and then checking the voltage using a clamp meter and the current using a multimeter. The test results showed that the solar panel could produce the highest voltage at noon, with an output of 21.75V and a current of 2.42mA, indicating that the solar panel performed very well under clear weather conditions.

12VDC Battery Testing

The 12VDC battery serves to store backup energy from the solar panel and provides the necessary voltage for the ESP32 microcontroller to operate the system. The testing was conducted in two types of experiments: first, measuring the voltage directly at the positive and negative terminals of the battery; second, measuring the voltage with the battery connected to the device circuit or in an off-grid condition. The results showed that the battery performed well, with an average voltage of 12.8V when not in use and 13V when the device was activated. The tolerance between the LCD and clamp meter readings was 0.05 or 5%, indicating that the battery was in excellent condition and fit for use.

Solar Charger Controller (SCC) Testing

The SCC, or Solar Charger Controller, is an electronic component responsible for regulating and managing the battery charging process from the solar panel. This test was conducted to ensure that the SCC performs its function effectively, safely, and efficiently, ensuring that the output voltage is stable and matches the battery's specifications. The test results, conducted from morning to evening, showed that the SCC functioned well, stabilizing the charging voltage within the normal limits for the battery.

Real-Time Clock (RTC) DS3231 Testing

The Real-Time Clock (RTC) DS3231 is used to keep accurate and continuous time, even when the system is powered off. This test was conducted by synchronizing the time and date read from the LCD, web service, and the actual time. The results showed that the RTC accurately set the time, date, month, and year, with no significant differences between the readings on the LCD, web service, and the actual time.

ESP32 Microcontroller Testing

The ESP32 microcontroller serves as the brain of the Solar Cell Tracker system, controlling and receiving data from various sensors such as the RTC, ACS712, servo motor, and buzzer. The data processed by this microcontroller is then transmitted and displayed on the web service. The testing was conducted to ensure that the ESP32 operates correctly, and the results showed that each pin functioned normally, with the microcontroller capable of receiving 5VDC from the power source.

ACS712 Current Sensor Testing

The ACS712 current sensor is used to measure electrical current, both direct current (DC) and alternating current (AC). This test was conducted using a small indicator lamp load, and the results showed that the sensor was able to read the current produced, although the current read was small due to the use of the indicator lamp. The differences in current readings between the solar cell and the battery were due to the solar cell producing current based on the intensity of the light it received, while the battery provided a more stable and consistent current.

LM2596 Buck Converter Testing

The LM2596 Buck Converter is used to step down the DC voltage from the source to the desired voltage according to the specifications. This test was conducted by measuring the input and output voltages using a multimeter. The test results showed that the Buck Converter effectively stepped down the voltage from 12V to 5V, with no damage to the device.

MG995 Servo Motor Testing

The MG995 servo motor is a key component in the Solar Cell Tracker system, allowing for precise and automatic adjustment of the solar panel's angle to maximize energy capture efficiency. The testing was conducted by controlling the servo using PWM signals generated by the ESP32 microcontroller, and the results showed that the servo was able to move the solar panel accurately according to the desired angle.

Relay Testing

The relay is used to control the flow of electrical current in the circuit using a smaller control signal. The relay testing was conducted to ensure that both the load and solar cell relays functioned correctly. The results showed that the relays performed well, including charging the battery and turning the indicator lamp on and off according to the preset conditions.

Liquid Crystal Display (LCD) Testing

The LCD is used to provide information in the form of data readings useful for monitoring the device's condition manually. The test was conducted to ensure that the LCD could display the monitoring data of solar cell voltage, battery voltage, solar cell current, battery current, date, month, year, connection status, and current angle. The test results showed that the LCD performed well, displaying all the necessary data for manually monitoring the device.

Overall, the test results demonstrated that all components in the Solar Cell Tracker system functioned well and met the required specifications, allowing the system to operate optimally in maximizing solar energy capture.

Software Design

The software design for this project involves implementing the Naïve Bayes method to optimize the angle of the solar panel by adjusting the servo motor based on the time of day. The process begins with defining the input and output values, where the input is the time of day and the output is the angle of the servo motor. A training dataset is then created, serving as a reference for calculations. This dataset is based on data collected over two weeks, reflecting the optimal angles for the servo motor at different times to ensure maximum solar energy absorption.

Next, the initial probabilities are calculated using the dataset, determining the likelihood of each servo angle based on the time of day. This involves analyzing the frequency of each angle in the dataset and calculating its probability. Once the initial probabilities are established, the next step is to calculate the probabilities for each time input, comparing these values to determine the most likely angle for the servo motor. This comparison helps identify the optimal angle for the servo motor at any given time, maximizing the efficiency of solar energy capture.

The final step involves programming the servo motor to adjust to the best angle throughout the day, ensuring the highest possible energy output from the solar panel. The results of this process indicate that the best angles for energy capture occur between 10 AM and 1 PM, with the peak voltage observed around noon.

Arduino IDE Programming

Arduino IDE is the software used to write and upload code to the ESP32 microcontroller, which controls the Solar Cell Tracker system. The coding process involves writing a program in a language supported by Arduino, such as C/C++, and then uploading it to the microcontroller. This code manages the data processing and system operations, ensuring that the device functions as intended. After writing the code, it is compiled and verified within the Arduino IDE to check for any errors before uploading. Once the code is successfully compiled, it is uploaded to the ESP32, allowing the system to operate according to the programmed instructions.

Web Design Using HTTP Request Protocol

The web design process begins with creating a database to store sensor data captured by the device. This database is essential for tracking and monitoring the system's performance. After setting up the database, the web interface is designed using HTML for the structure and JavaScript for dynamic features like graphs and real-time updates. The web pages are designed to display crucial information such as voltage, current, angle, time, and system status, all of which are updated in real-time.

The backend programming, developed in PHP, connects the web interface with the database, enabling seamless communication between the device and the web application. This connection allows the ESP32 microcontroller to send data to the web server, which is then displayed on the web interface. The result is a fully functional web dashboard that allows real-time monitoring and control of the Solar Cell Tracker system. Through this web interface, users can monitor system performance remotely and control the device, such as turning lights on or off, all through a Wi-Fi connection.

The overall software design, including the implementation of the Naïve Bayes method, Arduino IDE programming, and web development, ensures that the Solar Cell Tracker system operates efficiently and provides users with real-time control and monitoring capabilities.

Overall System Testing

Hardware and Web Synchronization

The hardware design for this device begins with preparing the solar panel as the primary power source. Various components are required to control the movement of the solar tracker, including the ESP32 microcontroller to manage operations, ACS712 current sensors and voltage divider resistors to monitor DC current and voltage, the LM2596 step-down module to regulate voltage, the Solar Charger Controller (SCC) to manage battery charging, the RTC module to keep time, servo motors to move the solar panel, relays to control battery charging and discharging as well as turning the load on/off, batteries as backup power sources, and an LCD to display current, voltage, time, and angle data. After gathering all the components, the next step is to assemble them on a pre-prepared mechanical structure, connect them electrically, and ensure all components are well integrated. The final step involves testing to verify performance and calibration to ensure the device operates as expected.

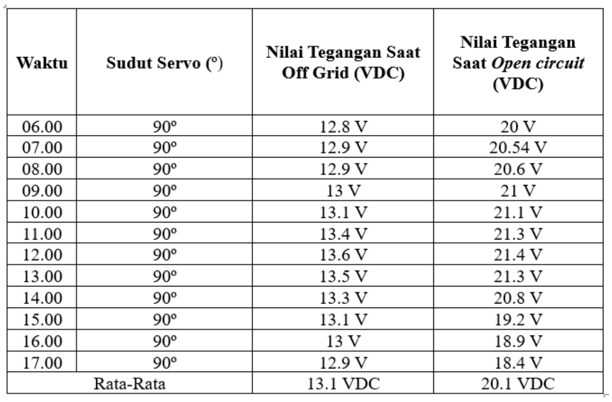
Next, the programming process is carried out using the Arduino IDE to create commands that are uploaded to the microcontroller board. The ESP32 module runs the uploaded program, processes the results, and sends them to the inputs of each sensor. Monitoring is conducted using the ESP32 as the programming brain, which instructs the sensors to send the available data, then received by the web service using the HTTP Request protocol and manually displayed on the LCD.

In this design, the Naïve Bayes method is used to enable decision-making based on historical data of the best times and angles for the solar panel movement. Parameters from the RTC sensor and servo are used as inputs for this method, which then calculates probabilities from worst to best and arrives at a final decision on the best angle to achieve optimal voltage output.

Solar Cell Fixed and Tracker Testing Results

The purpose of testing the solar cell tracker system is to compare the voltage output of solar panels without a tracker (fixed) with those using a tracker enhanced by the Naïve Bayes method. There are two types of voltage: open circuit voltage, where the solar panel operates independently without a battery, and off-grid voltage, where the battery is used. The following is an analysis of data from the overall system testing. All tests were conducted by collecting data directly from 06:00 AM to 05:00 PM over one month. Data was stored in real-time, with testing conducted at one-hour intervals. Three tables summarize the tests: static solar cell (fixed) testing under clear conditions, solar cell tracker testing under clear conditions without the Naïve Bayes method, and solar cell tracker testing with the Naïve Bayes method.

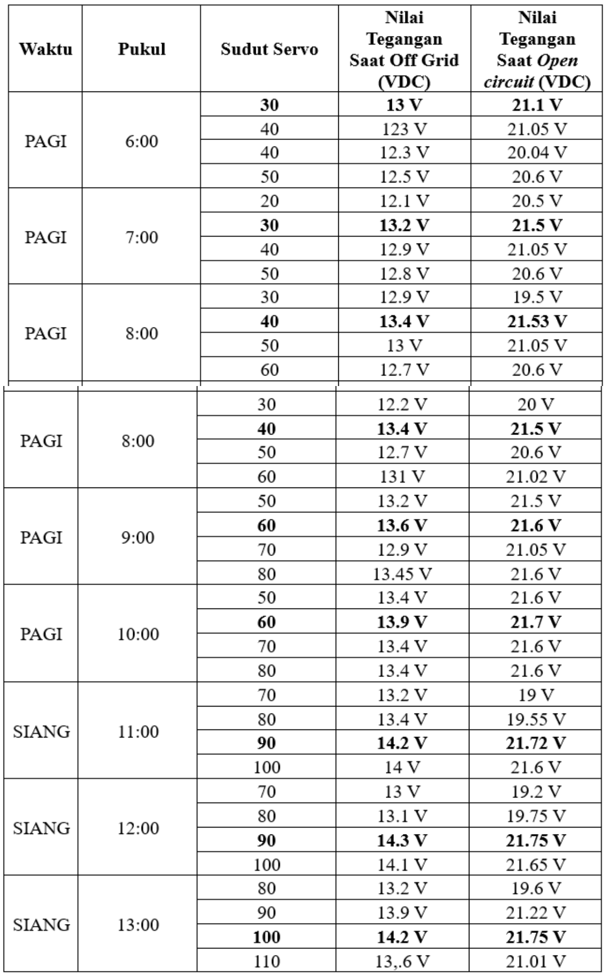
Table 1. Solar Cell Fixed Testing Data Without Naïve Bayes Method

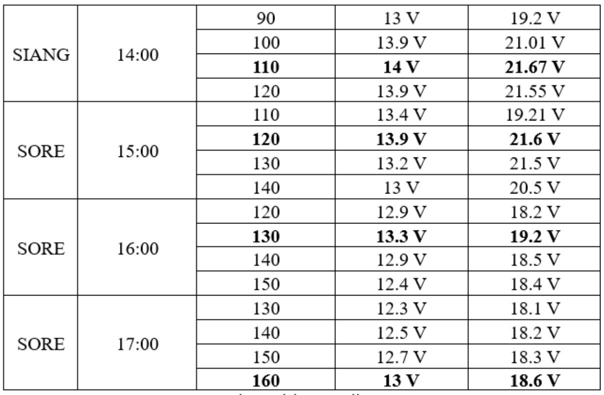


Waktu	Sudut Servo (°)	Nilai Tegangan Saat Off Grid (VDC)	Nilai Tegangan Saat *Open circuit* (VDC)
06.00	90°	12.8 V	20 V
07.00	90°	12.9 V	20.54 V
08.00	90°	12.9 V	20.6 V
09.00	90°	13 V	21 V
10.00	90°	13.1 V	21.1 V
11.00	90°	13.4 V	21.3 V
12.00	90°	13.6 V	21.4 V
13.00	90°	13.5 V	21.3 V
14.00	90°	13.3 V	20.8 V
15.00	90°	13.1 V	19.2 V
16.00	90°	13 V	18.9 V
17.00	90°	12.9 V	18.4 V
Rata-Rata		13.1 VDC	20.1 VDC

The first test was conducted statically (Solar cell fixed) without using the Naïve Bayes method during clear conditions, with the servo angle set to 90º. The highest voltage achieved was 13.6V under off-grid conditions and 21.4V under open circuit conditions. The lowest voltage was 12.9V under off-grid conditions and 18.4V under open circuit conditions.

Table 2. Solar Cell Tracker Testing Data Before Using Naïve Bayes Method

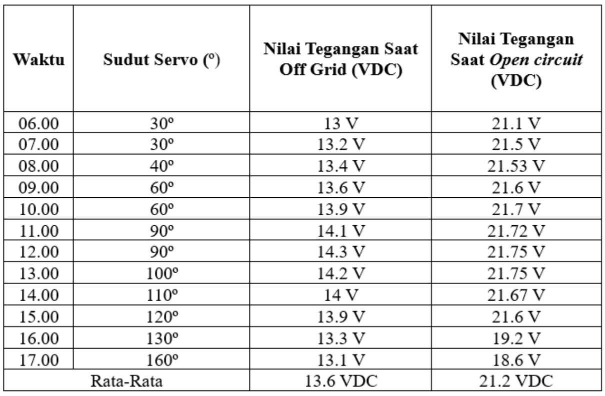




Waktu	Pukul	Sudut Servo	Nilai Tegangan Saat Off Grid (VDC)	Nilai Tegangan Saat *Open circuit* (VDC)
PAGI	6:00	**30**	**13 V**	**21.1 V**
		40	123 V	21.05 V
		40	12.3 V	20.04 V
		50	12.5 V	20.6 V
PAGI	7:00	20	12.1 V	20.5 V
		30	**13.2 V**	**21.5 V**
		40	12.9 V	21.05 V
		50	12.8 V	20.6 V
PAGI	8:00	30	12.9 V	19.5 V
		40	**13.4 V**	**21.53 V**
		50	13 V	21.05 V
		60	12.7 V	20.6 V
PAGI	8:00	30	12.2 V	20 V
		40	**13.4 V**	**21.5 V**
		50	12.7 V	20.6 V
		60	131 V	21.02 V
PAGI	9:00	50	13.2 V	21.5 V
		60	**13.6 V**	**21.6 V**
		70	12.9 V	21.05 V
		80	13.45 V	21.6 V
PAGI	10:00	50	13.4 V	21.6 V
		60	**13.9 V**	**21.7 V**
		70	13.4 V	21.6 V
		80	13.4 V	21.6 V
SIANG	11:00	70	13.2 V	19 V
		80	13.4 V	19.55 V
		90	**14.2 V**	**21.72 V**
		100	14 V	21.6 V
SIANG	12:00	70	13 V	19.2 V
		80	13.1 V	19.75 V
		90	**14.3 V**	**21.75 V**
		100	14.1 V	21.65 V
SIANG	13:00	80	13.2 V	19.6 V
		90	13.9 V	21.22 V
		100	**14.2 V**	**21.75 V**
		110	13,.6 V	21.01 V
SIANG	14:00	90	13 V	19.2 V
		100	13.9 V	21.01 V
		110	**14 V**	**21.67 V**
		120	13.9 V	21.55 V
SORE	15:00	110	13.4 V	19.21 V
		120	**13.9 V**	**21.6 V**
		130	13.2 V	21.5 V
		140	13 V	20.5 V
SORE	16:00	120	12.9 V	18.2 V
		130	**13.3 V**	**19.2 V**
		140	12.9 V	18.5 V
		150	12.4 V	18.4 V
SORE	17:00	130	12.3 V	18.1 V
		140	12.5 V	18.2 V
		150	12.7 V	18.3 V
		160	**13 V**	**18.6 V**

In this test, the angles were manually set at various samples to determine the optimal solar cell output voltage. This test did not use the Naïve Bayes method, resulting in the need for multiple servo motor movements to find the best angle and the highest possible voltage output. Excessive use of the servo motor without rest can accelerate component wear. Therefore, the Naïve Bayes method is necessary to calculate the supporting factors of achieving the best angle and optimal energy without causing damage to the existing components.

Table 3. Solar Cell Tracker Testing Data Using Naïve Bayes Method



Waktu	Sudut Servo (°)	Nilai Tegangan Saat Off Grid (VDC)	Nilai Tegangan Saat *Open circuit* (VDC)
06.00	30°	13 V	21.1 V
07.00	30°	13.2 V	21.5 V
08.00	40°	13.4 V	21.53 V
09.00	60°	13.6 V	21.6 V
10.00	60°	13.9 V	21.7 V
11.00	90°	14.1 V	21.72 V
12.00	90°	14.3 V	21.75 V
13.00	100°	14.2 V	21.75 V
14.00	110°	14 V	21.67 V
15.00	120°	13.9 V	21.6 V
16.00	130°	13.3 V	19.2 V
17.00	160°	13.1 V	18.6 V
Rata-Rata		13.6 VDC	21.2 VDC

The final test was conducted using the solar tracker with the Naïve Bayes method under clear conditions. This test displayed the servo angle changes obtained during the second data collection. The highest voltage achieved was 14.3V under off-grid conditions and 21.75V under open circuit conditions. The lowest voltage was 13V under off-grid conditions and 18.6V under open circuit conditions. The voltage generated by the solar panel remained relatively constant but increased because the solar panel received the maximum sunlight energy at the best angles accurately calculated by the Naïve Bayes method.

The testing conducted without a tracker (fixed) and with a tracker using the Naïve Bayes method was further analyzed to generate a comparison graph of the two tests. The following is the result of the percentage voltage output calculation during off-grid testing between the fixed and tracker systems.

The calculation showed that the optimization achieved by using a tracker and the Naïve Bayes method resulted in an increase of 3.81% during off-grid conditions and 5.47% during open circuit conditions.

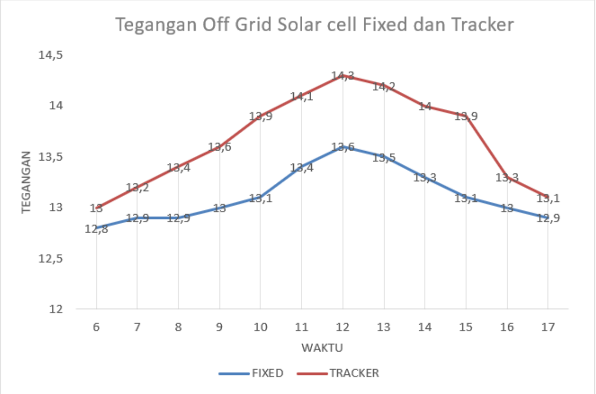


Figure 1. Comparison Graph of Solar Cell Fixed and Tracker Voltages

From the data analysis, it can be concluded that a system using a tracker can produce higher voltages than a fixed system without a tracker. The addition of the Naïve Bayes method in calculating probabilities or final decisions makes the system more optimal in finding the best angle, resulting in an average voltage of 13.6V during off-grid conditions and 21.2V during open circuit conditions. The voltage difference was 0.5V for off-grid and 1.1V for open circuit, indicating an improvement between the fixed solar cell and the solar cell tracker. Moreover, voltage optimization using a tracker and the Naïve Bayes method can reach 5.47% compared to not using a tracker.

Thus, the testing results prove that the solar tracker system using the Naïve Bayes method successfully identifies the best angle, resulting in optimal voltage output for the solar panel in generating electrical energy.

Discussion of Research Results

Advantages of the Device

Based on the overall testing results presented in Chapter IV, the advantages of the device can be summarized as follows:

1. The use of RTC ensures accurate timekeeping, enabling the solar cell tracker to precisely adjust the panel position to the optimal angle for solar energy absorption.
2. The Naïve Bayes method utilizes research data to accurately and precisely predict the sun's movement patterns.
3. The implementation of a web service-based system allows for easy control and monitoring that can be accessed from anywhere, with results recorded in real-time.
4. This system enhances energy efficiency, ultimately optimizing the overall energy output of the solar panel.

Disadvantages of the Device

Based on the overall testing results presented in Chapter IV, there are also some disadvantages of the device, as follows:

1. The web-based system relies on a stable internet connection.
2. Integrating various components such as RTC, the Naïve Bayes method, and web services requires a deep understanding of electronics and programming.
3. The initial operational costs and implementation of this system may be higher than static solar cell systems, especially when using large solar panels and high-quality electronic components.

4. CONCLUSION

Based on the discussion in the previous chapter, it can be concluded that the solar tracker system using Real Time Clock (RTC) and the Naive Bayes method was designed to optimize solar panels. The testing results show that the developed system can increase the efficiency of solar energy optimization by up to 5.47% compared to conventional tracking methods. The implementation of RTC has proven effective in accurately positioning the solar panel, while the use of the Naive Bayes method optimally predicts the sun's position based on time and the best angle data. This final project has successfully achieved its goal of developing and implementing an accurate, efficient, and effective solar tracking system, which can serve as a reference for improving the performance and efficiency of solar panels under various weather and climate conditions.

Based on the conclusion, the author offers a few suggestions. First, to enhance the accuracy of the prediction system, it is recommended to add sensors such as a lumen sensor as a determining variable. Second, in the system design, it is advisable to consider using more advanced methodologies, such as multinomial Naive Bayes, to incorporate continuous variables for more accurate predictions.

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