Automatic Solar Panel Cleaning and Cooling System based on IoT

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ABSTRACT
The growth of the renewable energy industry, particularly solar panels, has become a major focus in efforts to reduce dependence on conventional energy sources. However, improving the efficiency and productivity of solar panels requires optimal maintenance of panel surfaces and proper temperature regulation. Accumulation of dirt and dust on the panel surfaces, as well as uncontrolled temperatures, can reduce electricity generation efficiency. Therefore, the development of a system that can automatically clean panel surfaces and regulate panel temperature becomes crucial in optimizing solar energy-based electricity generation.

This research aims to design and build an automatic system that can periodically clean the surface of solar panels and regulate panel temperatures to enhance the efficiency and productivity of electricity generation based on IoT. The system is expected to optimize the performance of solar panels by reducing the negative impact of dirt accumulation and temperature fluctuations. An experimental approach will be used in this research to design and build a surface cleaning system and temperature regulator for solar panels. The system development will utilize sensors to detect the level of dirt on the panel surfaces and to monitor panel temperature. In addition, microcontrollers and actuators will be used to automatically control the system's operations, ensuring the solar panel surfaces are cleaned and the temperature is adjusted according to the panel's conditions.

With the implementation of the proposed system, it is expected to significantly improve the efficiency of solar panel electricity generation by reducing the negative impact of dirt accumulation and temperature fluctuations. Additionally, this system is anticipated to reduce the need for manual maintenance costs and extend the operational lifespan of solar panels. Thus, this research will provide a valuable contribution to the development of more efficient and sustainable renewable energy technology.

Keywords
Cleaner, Temperature Conditioner, Solar Power Plant (PLTS), Optimization

1. INTRODUCTION
In recent years, the global shift towards renewable energy sources has increased, driven by the need to reduce dependence on fossil fuels and mitigate the effects of climate change [1]. Among the various renewable energy technologies, solar power has emerged as one of the most promising solutions due to its abundance and sustainability [2]. Photovoltaic (PV) systems, commonly known as solar panels, are at the forefront of this transition, converting sunlight into electrical energy. However, despite their great potential, the efficiency of solar panels is often hindered by external factors that affect their energy conversion capabilities [3].

One of the main challenges faced by solar panels is the accumulation of dirt, dust, and other particles on their surface. This layer of dirt can block the amount of sunlight reaching the photovoltaic cells, thus reducing the overall efficiency of energy generation [4]. Research has shown that even a thin layer of dust can significantly decrease energy output. In addition to cleanliness issues, the operational temperature of solar panels also plays a crucial role in determining their efficiency. When solar panels are exposed to sunlight for extended periods, their surface temperature rises, which can reduce energy conversion efficiency due to the characteristics of photovoltaic materials [5]. Excessive heat can also accelerate the degradation of panel components, thus shortening their operational lifespan.

Traditional maintenance methods, such as manual cleaning and cooling of solar panels, are not only time-consuming and labor-intensive but also come with several drawbacks. These methods often require temporary system shutdowns, resulting in lost productivity. Additionally, frequent manual intervention, particularly in large-scale solar power plants (PLTS), can increase operational costs and may cause wear and tear on the panel components. To address these limitations, innovative solutions are needed to ensure optimal panel performance without the shortcomings associated with manual maintenance.

In response to these challenges, this research aims to develop an automatic solar panel cleaning and cooling system that can operate periodically to maintain the panels in optimal condition. This system will be designed to detect dirt buildup on the panel surface and monitor panel temperature in real-time using a network of sensors. When certain thresholds are reached, the system will activate cleaning mechanisms to remove the dirt and cooling systems to regulate panel temperature.

This automatic system is expected to offer several key benefits. First, it will improve the efficiency of solar energy generation by ensuring that the panels are consistently free of dirt and operate within optimal temperature ranges. Second, it will reduce costs associated with manual maintenance, as the system will function independently without requiring frequent intervention. Third, by minimizing the wear and tear caused by manual cleaning and excessive heat, the system will extend the operational lifespan of solar panels, thereby enhancing the economic and environmental benefits of solar power systems.

This research will adopt an experimental approach to design, develop, and test the automatic cleaning and cooling system. Various components such as sensors, microcontrollers, and actuators will be integrated to monitor and control the system's functions. The results of this research are expected to make a significant contribution to the development of renewable energy technology by enhancing the efficiency, reliability, and sustainability of solar power systems.

Here are the previous studies related to the research being conducted:

1. **Research Title:** Control System for Solar Panel Cleaner Using Rolling Brush and Wiper with Scheduled Method This study discusses how to design a solar panel cleaning system using a rolling brush and wiper. The cleaning system uses a scheduled method to clean the surface of the solar panels to optimize solar energy absorption. This system employs Arduino as a microcontroller connected to a Real-Time Clock (RTC) to determine the cleaning schedule for the solar panels, activating four motors that control the rolling brush and wiper, along with a water pump via a relay. The analysis results show that the cleaning system with the wiper and rolling brush can increase voltage output by 4.42% in the morning and 4.91% during the day [6].
2. **Research Title:** Prototype Design of Solar Panel Cleaning Device with Automation Movement System This research focuses on designing a prototype of a solar panel cleaning device and evaluating its performance with an automation system. The design operates using an automation control system, specifically Arduino. When the device is activated, the water pump sprays water, and upon pressing a push button, the device begins cleaning the solar panel. A distance sensor activates the motor driver to move in the opposite direction. Cleaning the solar panel once requires 98.571 cm³ of water, and the robot requires a speed of 3.75 cm/s for one cleaning cycle [7].
3. **Research Title:** Analysis of the Effect of Surface Temperature Increase on Solar Cell Power Output This study examines how the rise in temperature of solar panels affects power output by comparing water-cooled solar cells to those without cooling. The cooling process involves circulating water beneath the panel. The power output of the solar cell can be measured using current and voltage with a multimeter. The test section comprises two solar cells with a capacity of 50 WP from a monocrystalline brand specifically designed for this purpose. The results indicate that with a temperature increase to 50.92 °C, the output power decreases to 42.51 watts for the uncooled solar cell, while the water-cooled solar cell generates 45.36 watts at a surface temperature of 34.36 °C under the same solar intensity [8].
4. **Research Title:** Implementation of the Internet of Things in Optimal Monitoring of Solar Panel Performance This study focuses on optimizing solar panel performance by creating a monitoring system that implements the Internet of Things (IoT) to track important variables in real-time. In this research, IoT serves as a remote communication tool utilizing the internet to function as a monitoring system for optimal solar panel performance. The monitored variables include dual-axis panel movement, four LDR sensors measuring light intensity, dual-axis movement angle, position and weather conditions of the solar panel, as well as the voltage, current, and power generated by the solar panel [9].
5. **Research Title:** IoT Based Smart Home Automation Using Solar Photovoltaic System and Online Time Server This research utilizes the solar power generation system as an electricity source for a smart home system. In the smart home system, the IoT concept is applied for monitoring water availability and lighting requirements in the house. The system performs automatic control of water levels and lighting needs in the rooms. The monitoring results detected will be sent to a web server, in this case, Blynk [10]
6. **Research Title:** Design and Implementation of Current and Voltage Monitoring on On-Grid Solar Power Systems Based on IoT Using Telegram Application This study pertains to the application of IoT technology in monitoring the voltage and current generated from solar panel electricity generation, where monitoring is conducted using the Telegram application through the transmission of monitoring data from the controller device [11]
7. **Research Title:** Design and Implementation of Solar Power Meter Data Acquisition System Based on IoT This research focuses on measuring the radiation flux density of sunlight needed for solar power systems to convert it into electrical energy. Monitoring can be conducted remotely via a web server utilizing IoT technology [12]
8. **Research Title:** IoT-Based Smart Solar Energy Monitoring Systems This research relates to the application of IoT technology as a monitor for the output power of solar power systems. IoT is also utilized for controlling the output power of solar power systems by adjusting the tilt angle of the solar panels relative to the sun's position, with remote control performed from a distance [13].
9. **Research Title:** Application of Solar Power Generation with IoT-Based Control to Meet Electricity Needs in Lo'ang Village - Kojagete, Sikka District, East Nusa Tenggara This study focuses on the utilization of solar energy as a power generation source (solar power plant) implemented in the coastal area of Kojagate village in NTT, where the solar power system can be monitored remotely for its electricity generation results, utilizing IoT technology [14].
10. **Research Title:** Internet of Things (IoT) in Photovoltaic Systems This research involves a study of the utilization of the Internet of Things (IoT) for the long-distance monitoring needs of solar power system performance and remote control of solar power system operations. Through the utilization of IoT in monitoring and control systems, real-time conditions of solar power systems can be detected, allowing for direct diagnosis of the solar power system's performance, even if the solar power system is installed in remote areas [15].

2. METHODOLOGI

In producing the model of an automatic solar panel cleaning and cooling system, it refers to the prototyping research method, where the stages include data collection, hardware design, software design, and system simulation testing to obtain data related to the system's performance in the cleaning and cooling process.

2.1 System Design

In the hardware design stage, it is important to have an overview of the system that will be built to facilitate the author's design process. The description of the system to be developed is presented in the form of a block diagram that illustrates the entire system. Figure 1 displays the Design of an Automatic Solar Panel Cleaning and Cooling System and in Figure 2, it shows the block diagram of the control system for the automatic solar panel cleaning and cooling system.

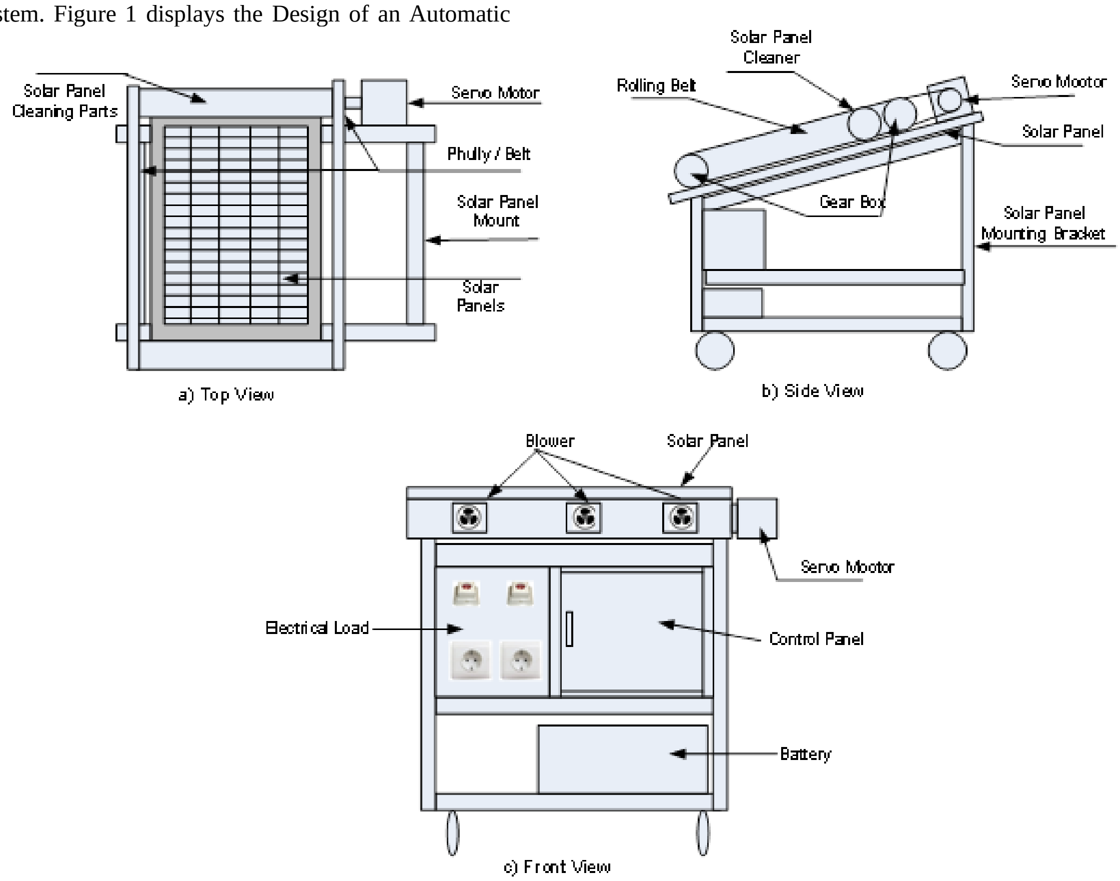

Fig 1: Design of an Automatic Solar Panel Cleaning and Cooling System

Materials and equipment used for the production of an automatic prototype system that can periodically clean the surface of solar panels and regulate their temperature to enhance efficiency and productivity of IoT-based electricity generation include:

1. Solar Power System (PLTS) consisting of solar panels as the medium for converting sunlight into electrical energy, a solar charge controller that functions as the control medium for charging DC current from the solar panel to the battery and from the battery to the electrical load, batteries that serve as storage for the electrical energy produced by the solar panels, an inverter that acts as a medium to convert DC electricity to AC for electrical equipment needs, a Low Voltage Disconnect (LVD) that provides battery protection during the discharging process, and short circuit protection.
2. Solar Panel Surface Cleaning System which includes: light sensors to detect sunlight intensity, DC motors that act as the driving mechanism for the surface cleaning section of the solar panels.
3. Solar Panel Temperature Conditioning System consisting of: temperature sensors, current sensors, and voltage sensors, along with blowers for cooling the solar panels.
4. Microcontroller Module as the central processing unit for data based on the output detection from the solar power system through current and voltage sensors, as well as outputs from temperature and light sensors. The detection results will be processed by the microcontroller module to make decisions regarding the condition of the solar panels, whether they are clean or dirty, and to detect if the panel temperature is normal or exceeds normal conditions. This information will be displayed via an LCD screen installed on-site and sent to a web server for user monitoring as data regarding the condition of the solar power system, accessible through user devices (Laptop/PC or smartphone).
5. PZEM-004T Sensor, which is used to measure: electrical current, voltage, frequency, power factor, electrical power (watts), and electrical energy (KWh). The output detection results from the solar power system are obtained through this sensor.
6. Relay Driver, which functions to activate and deactivate the operation of the solar panel cleaning system and the solar panel temperature conditioning system, as well as to activate and deactivate the respective electrical loads connected to the solar power system.
7. Access Point (Wi-Fi), serving as a medium for internet communication between the controller and the web server for data transmission from the controller to the web server and receiving data from the web server back to the

controller for monitoring and controlling the solar power system.

8. Web Server, which acts as the storage medium for the data sent from the controller and serves as a monitoring platform for the solar power system's condition, including electrical current, voltage, frequency, power factor, electrical power (watts), and electrical energy (KWh), related to the loading process of the solar power system, the surface cleaning process of the solar panels, the temperature conditioning process of the solar panels, and controlling the electrical loads connected to the solar power system.
9. User Devices (Laptop/PC and Smartphone), which are used to monitor the condition of the solar power system and as a remote control for switching ON/OFF the electrical loads connected to the solar power system.
10. DC Power Supply 5 Volt as the electrical power source for the control system, which is implemented as the monitoring and controlling medium for the solar power system.

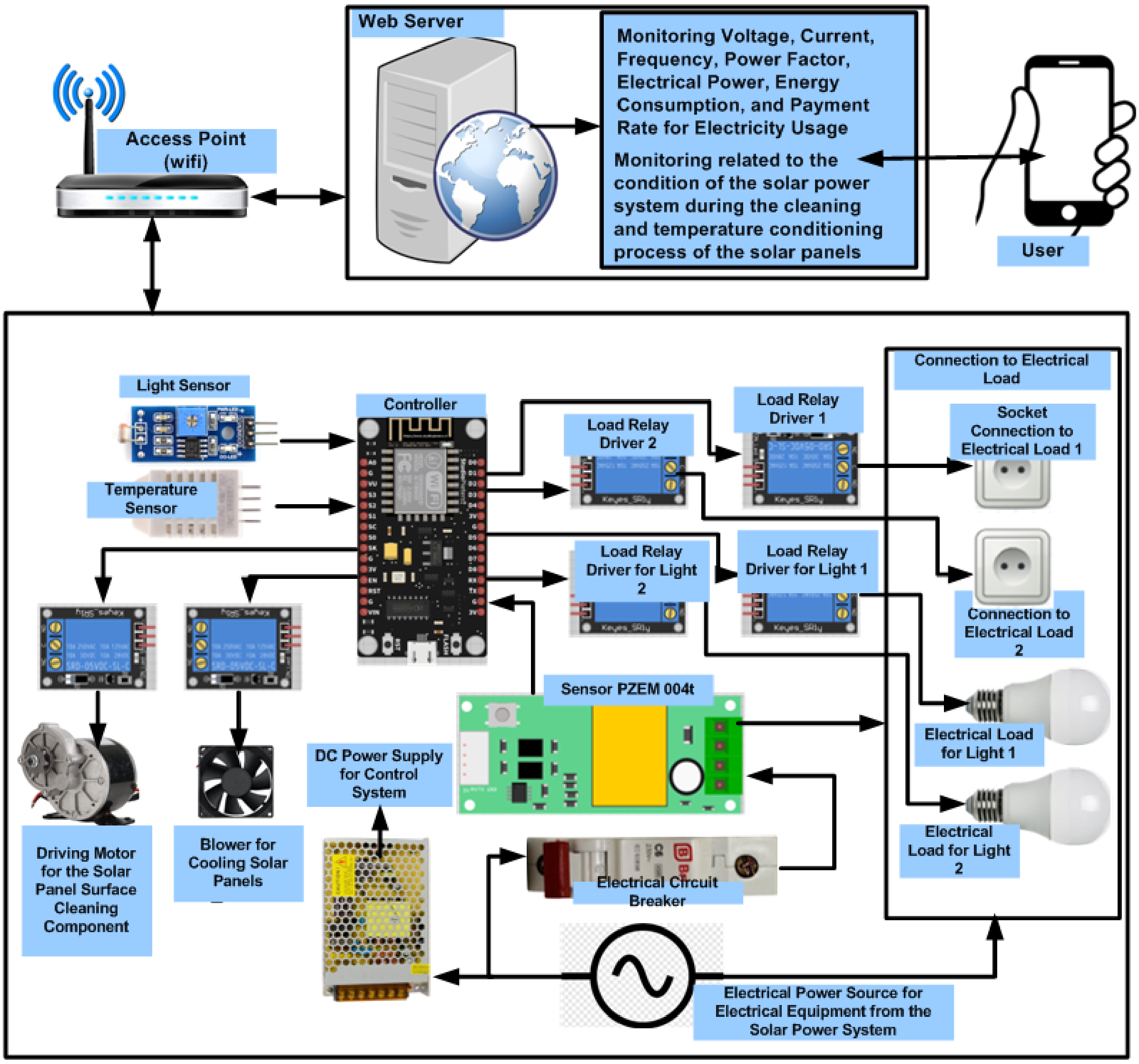

Fig 2: Block diagram of the control system for the automatic solar panel cleaning and cooling system

2.2 Flow chart System (Algorithm)

In producing software for the operation of the solar panel cleaning and cooling system, the initial step is to design the system's workflow structure in the form of a flowchart. This flowchart aims to represent the sequence of operations of the system for monitoring the cleaning and cooling processes of the solar panels, which can be monitored from anywhere through the application of IoT technology. The monitoring process includes checking whether the temperature and cleanliness of the solar panels are in a normal state or not. The flowchart for the solar panel cleaning and cooling system is shown in Figure 3

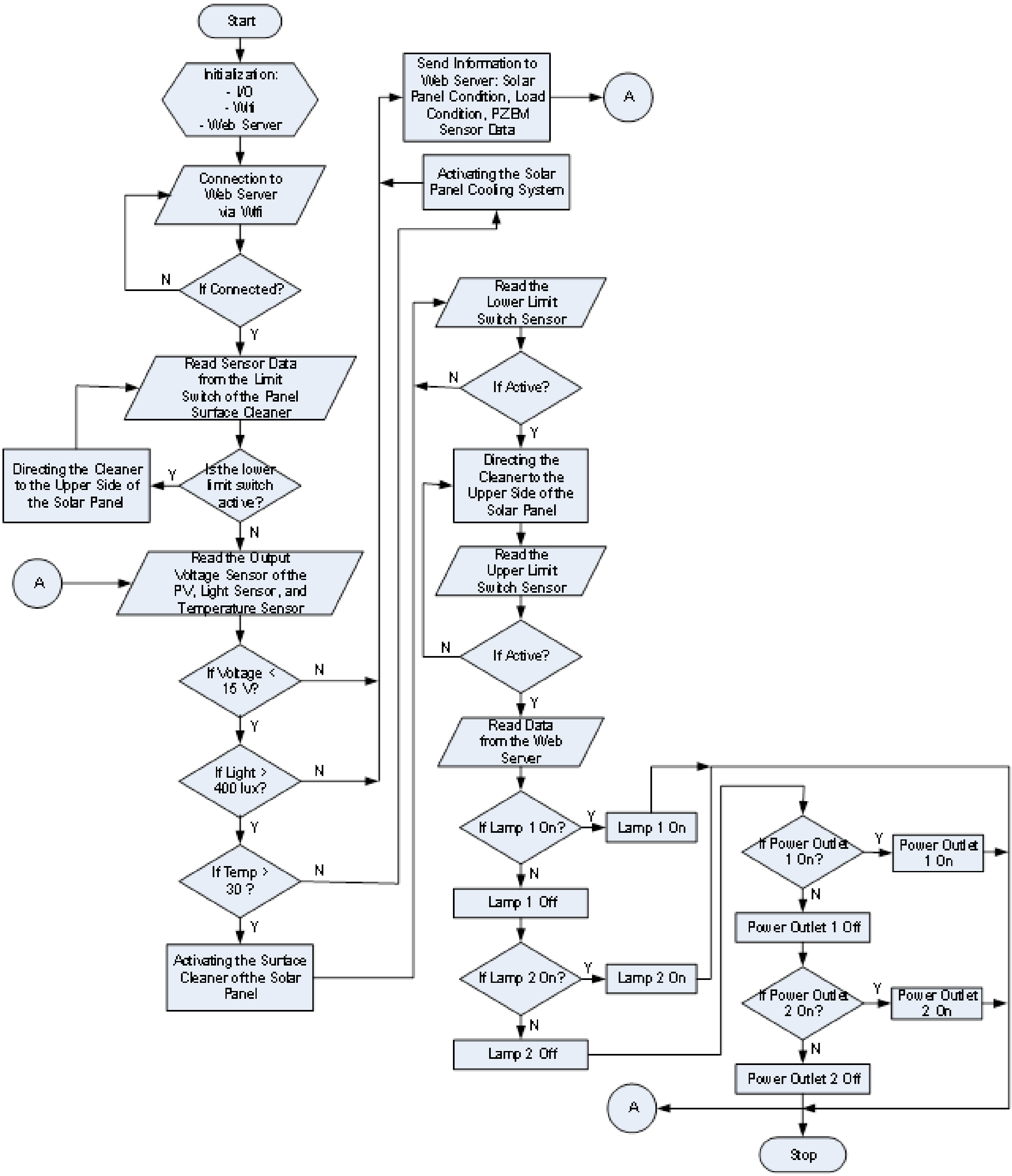

Fig 3:Flowchart system

Image Caption Figure 3:

1. When the system is started, the controller will execute the part of the program for system initialization and setup. The initialization process involves recognizing the libraries that will be used to run the system and the variables used in the program. The libraries used consist of:
   - A library for WiFi, which is used for connecting to the web server.
   - A library for the type of controller used, in this case, the ESP32 controller.
   - A library for the web server, where the web server used is Blynk IoT.
   - A library for sensors, which includes voltage sensors, current sensors, and light sensors.

The variables used in the program consist of:
   - Variables to hold sensor data.
   - A variable to hold the Token data as access rights to the web server.
   - Variables for the username and password for WiFi connection.
   - Other variables needed in the program to operate the system.

The setup section functions to configure the variables used in operating the monitoring process for the cleaning and cooling system of the solar panel. The setup includes:

- Configuration of the function for each GPIO pin of the ESP32 controller, both as input and output as required.
- Configuration of access functions, both for WiFi and the web server.

2. Next, the controller will run the program to connect the controller to the web server (Blynk IoT) via WiFi communication. The connection process between the controller and the web server is based on access rights through Token data authentication to the created dashboard. If the connection to the web server is successful, the next process will be executed; if the connection has not been established, the controller will repeatedly attempt this connection until it is connected to the web server.
3. When the controller and web server are connected, the next program executed is the working system for the Cooling and Cleaning of the Solar Panel and monitoring the load in use. The procedure is as follows:
   - Detect whether the position of the cleaner is at the bottom of the solar panel surface or at the top of the solar panel surface. If it is at the bottom, the system will activate the motor to move the cleaner to the upper position of the solar panel surface. If the position of the cleaner is at the top of the solar panel surface, the next process is to read sensor data, including PZEM sensor data and the voltage output from the solar panel.
   - If the voltage sensor detects a drop in the output voltage from the solar panel below 15 volts, the next process is to detect the Light Intensity level. If the light intensity value is detected below 400 lux, the system will decide that the drop in output voltage from the solar panel is caused by a decrease in light intensity, and the system will send information to the web server regarding that condition. If sunlight intensity is detected to be > 400 lux, the next process is to detect the temperature of the solar panel to decide whether the drop in output voltage from the solar panel is due to a dirty solar panel surface or if the solar panel's temperature has risen above normal conditions (temperature > 30°C).
   - If the solar panel temperature is detected to be less than 30°C, the decision made is that the solar panel surface is dirty, leading to a drop in output voltage from the solar panel. The system will automatically activate the surface cleaner of the solar panel. The procedure is as follows: a. Activate the electric motor to drive the cleaner, configured to rotate in the clockwise (CW) direction to move the cleaner from the top position of the solar panel surface to the bottom position for cleaning the solar panel surface. b. Detect the position of the solar panel surface cleaner to see if it has reached the bottom position. If not, the movement of the solar panel surface cleaner from the top to the bottom will remain active. If the lower limit switch is detected as active, the system will deactivate the electric motor and configure its rotation to counterclockwise (CCW). This is done to direct the cleaner back to the upper part of the solar panel surface for the cleaning process. The motor driving the cleaner will be configured to move back to the bottom of the solar panel surface when the system detects the activation of the upper limit switch. This condition will continue until an increase in output voltage from the solar panel is detected. If this occurs, the system will deactivate the surface cleaner and the system will return to normal operation.
   - If the solar panel temperature is detected to be greater than 30°C, the decision made by the system is that the drop in output voltage from the solar panel is due to the solar panel's temperature rising above its normal temperature (25°C). Therefore, the system will automatically activate the solar panel cooling system by turning on a fan used as a blower. This condition will continue until the output voltage from the solar panel is detected to be above 15 volts.
4. For controlling the electrical load connected to the solar power system, the electrical loads include: Lamp 1, Lamp 2, Outlet 1, and Outlet 2. The procedure is as follows:
   - When the data received by the controller from the web server is data to activate Lamp 1 (data 1), the controller will turn on Lamp 1.
   - When the data received by the controller from the web server is data to deactivate Lamp 1 (data 0), the controller will turn off Lamp 1.
   - When the data received by the controller from the web server is data to activate Lamp 2 (data 1), the controller will turn on Lamp 2.
   - When the data received by the controller from the web server is data to deactivate Lamp 2 (data 0), the controller will turn off Lamp 2.
   - When the data received by the controller from the web server is data to activate Outlet 1 (data 1), the controller will turn on Outlet 1.
   - When the data received by the controller from the web server is data to deactivate Outlet 1 (data 0), the controller will turn off Outlet 1.
   - When the data received by the controller from the web server is data to activate Outlet 2 (data 1), the controller will turn on Outlet 2.
   - When the data received by the controller from the web server is data to deactivate Outlet 2 (data 0), the controller will turn off Outlet 2.
5. For monitoring the load, the PZEM is used to read the voltage and current in use, which is then converted to watts and subsequently converted to kWh to determine the cost in Rupiah. The procedure is as follows:
   - Read data from the PZEM sensor and send the data to the web server as information regarding: Electrical Voltage, Load Current, Load Power, Frequency, and Electrical Energy.

2.3 System Manufacturing

In producing an automatic solar panel cleaning and cooling system based on IoT, the process refers to the system design results, which in this case include the system block diagram and the system working algorithm that have been developed. The stages of the production process are as follows:

2.3.1 Hardware Manufacturing

The hardware assembly is carried out by integrating modules such as: input components to the controller, which include: solar panel output voltage sensor, light sensor, temperature sensor, PZEM sensor, lower limit switch sensor, and upper limit switch sensor. As for the output components from the controller, they include: the solar panel surface cleaning system (relay driver connected to the motor driving the cleaning part, which can operate in reverse for the solar panel surface cleaning process), the solar panel cooling system (relay driver connected to three fans for the solar panel cooling process), and the On/Off control for electrical devices (Lamp 1 and Lamp 2, Outlet 1 and Outlet 2). The control system is shown in Figure 4.

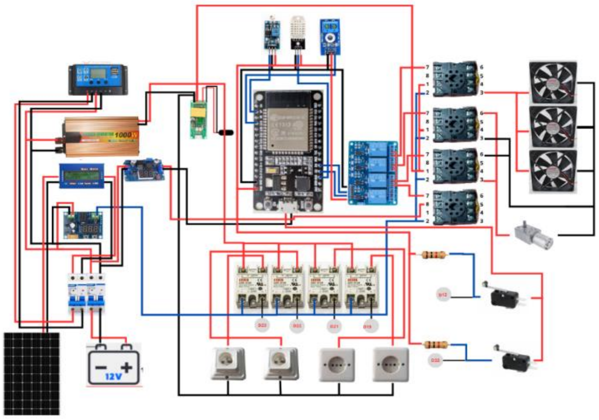

Fig 5: Control System

After producing the integrated hardware, the next step is the packaging process. The results after the packaging process are shown in Figure 6.

Fig 6: The packaging process

2.3.2 Software Development For Controller Operations

Making software for the work needs of controlling the of the system which will be embedded into the controller is made based on the results of the software design, with reference to the stages of the algorithm in accordance with the flowchart made. The process of making software for system work operations using the Arduino IDE as shown in Figure 7.

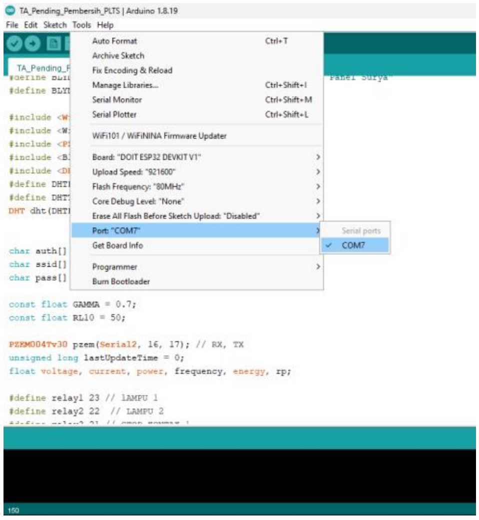

Fig 7: Software Development for controller

2.3.3 Develompent For Server

The creation of an IoT-based user interface for monitoring the condition of the solar panel cleaning and cooling system, as well as for remotely controlling the electrical devices connected to the solar power system, is achieved by utilizing one of the available applications as an IoT platform, in this case, Blynk IoT. The results of the user interface creation through Blynk IoT are shown in Figure 8.

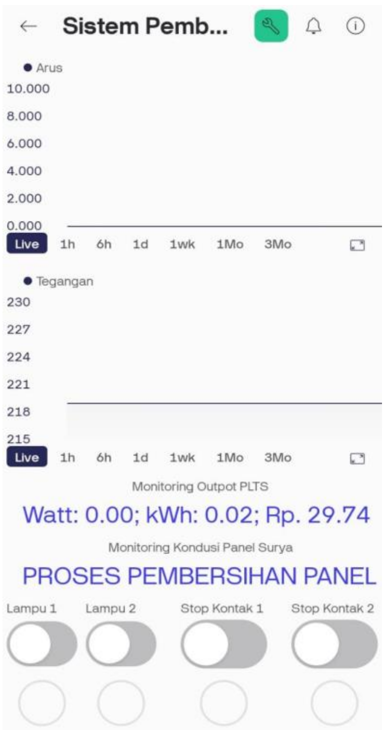

Fig 8: Web Server Development

3. RESULT AND DISCUSSION

The testing process for the operation of the Solar Panel Cleaning and Cooling Monitoring System is conducted using the Black Box method by performing functional tests on the system's functionality, focusing on the flexibility of the cleaning and cooling monitoring process and control of the load that can be done remotely, by applying IoT technology through user devices. In addition to testing the system's performance, tests are also conducted on the efficiency of the solar panel cleaning and cooling system, as well as in supplying electricity to the electrical load.

When the controller detects a decrease in the output voltage from the solar panel through the voltage sensor, where the output voltage of the solar panel is detected to be less than 15 volts, the controller will then measure the sunlight intensity through the LDR sensor. If the sunlight intensity is detected to be less than 400 lux, the decision made by the controller is that the solar panel is in normal condition, as the decrease in output voltage is caused by the reduced sunlight intensity, which means that the cleaning and cooling system for the solar panel will not be activated. This information will also be sent to the web server as an update on the condition of the solar panel, with the monitoring results displayed in Figure 9.

Fig 9: The solar panel is in normal condition.

From the test results shown in Figure 9, it can be seen that the information received on the web server indicates that the solar panel is in a normal condition, labeled "Normal Panel Temperature and Cleanliness." When the sunlight intensity is detected to be greater than 400 lux, the controller will measure the solar panel's temperature using the temperature sensor. If the temperature sensor value is detected to be greater than 30°C, the decision made by the controller is that the decrease in the solar panel's output voltage is caused by the solar panel temperature being above normal. Consequently, the controller will activate the solar panel cooling system by turning on the fan, which functions as a blower, to dissipate excess heat from the solar panel.

With the activation of the solar panel cooling system, the controller will also send information to the web server, which will be relayed to the user device (smartphone) in the form of a notification regarding the solar panel's condition, specifically indicating that the solar panel cooling process is underway. The activation of the cooling system and the notification about the solar panel cooling process are illustrated in Figure 10.

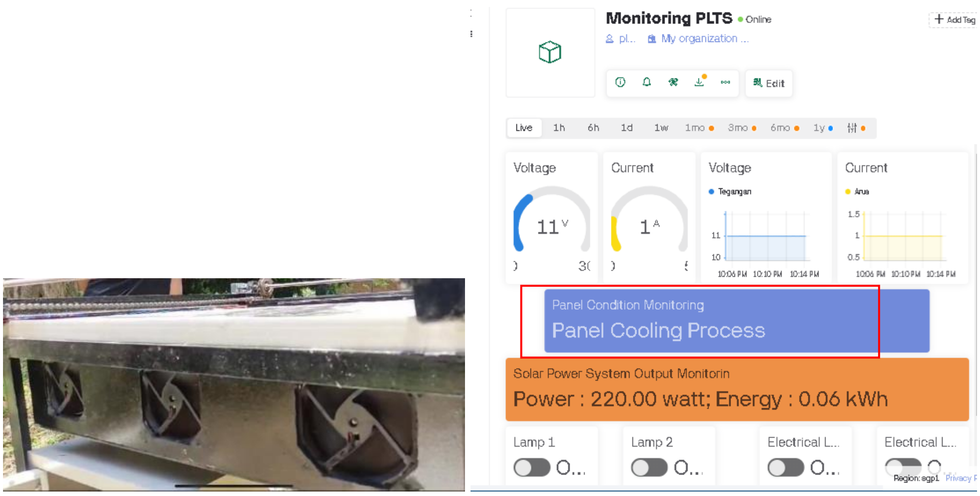

Fig 10: Solar Panel Cooling Process.

If the solar panel temperature is detected to be below 30°C, the controller will determine that the decrease in the solar panel's output voltage is due to a dirty panel surface. The controller will automatically activate the solar panel surface cleaning system, where the cleaning process involves activating the electric motor that drives the solar panel surface cleaning mechanism. The motor is configured to rotate clockwise (CW) to move the cleaning mechanism to the lower part of the solar panel surface. The cleaning mechanism will stop moving when the lower limit switch sensor detects that the cleaning mechanism has reached the bottom of the solar panel surface.

Next, the motor will rotate counterclockwise (CCW) to guide the cleaning mechanism back to the top of the solar panel surface. This process will continue until the controller detects an increase in the solar panel's output voltage. If the cleaning mechanism is detected to be at the bottom, the controller will reposition the cleaning mechanism back to its initial position at the top of the solar panel. The solar panel surface cleaning process and the information received by the web server are shown in Figure 11.

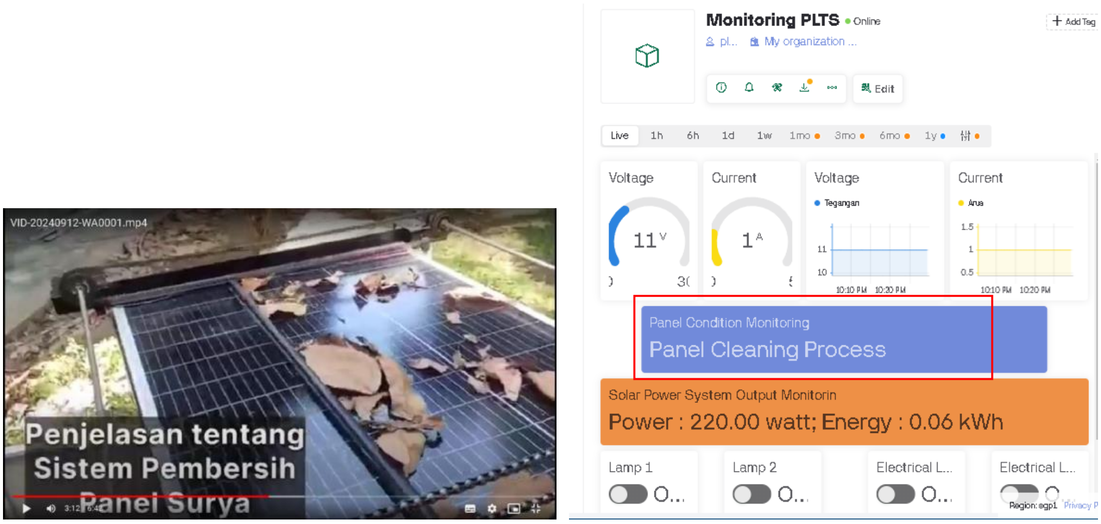

Fig 11: Solar Panel Surface Cleaning Process.

The system created can also perform remote control processes for the electrical loads connected to the solar power system, where the control process is related to turning electrical devices on and off, specifically Light 1 and Light 2, Outlet 1, and Outlet 2. For example, to activate the electrical device Light 2, the user can do this through a smartphone that has the Blynk IoT application installed. In the user interface, the user can activate Light 2 using the switch for Light 2.

When this action is taken, the activation data for Light 2 will be sent to the controller via the web server, and the controller will respond by activating Light 2. To verify whether Light 2 has been turned on, the controller will send information about the change in electric current due to Light 2 being activated to the web server, informing the user that Light 2 has been turned on. Figure 12 shows the process of turning on Light 2 through the user device (smartphone).

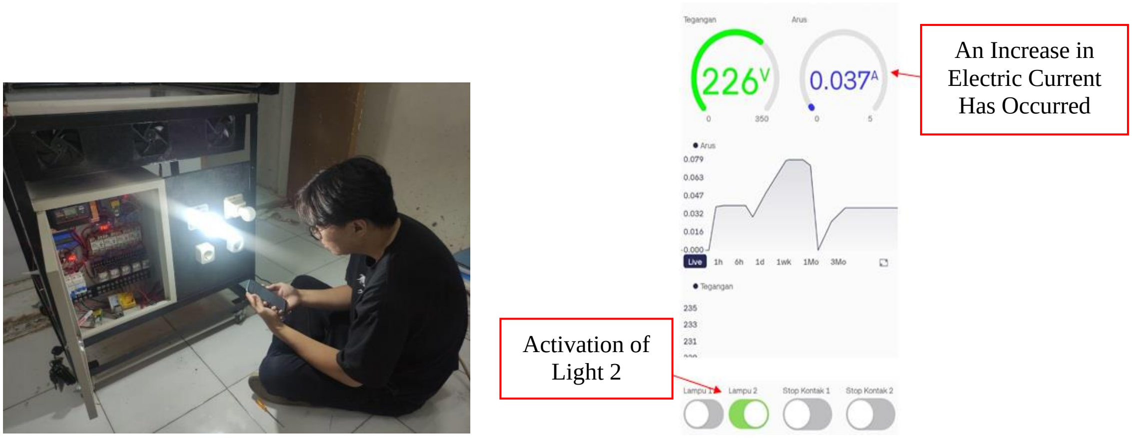

Fig 11: Solar Panel Surface Cleaning Process.

If there is no increase in electric current in the current information (current metering) when Light 2 is activated, the user can conclude that there is an issue with Light 2, and it is likely that it has malfunctioned. Therefore, the user can proceed to replace the faulty light.

4. CONCLUSIONS

Based on the test results conducted on the automatic solar panel cleaning and cooling system based on IoT, it can be concluded that the system can operate automatically in terms of cleaning the solar panel surface when it is detected to be dirty and cooling the solar panel when its operating temperature exceeds the normal temperature. When the output voltage sensor of the solar panel detects a value below 15 volts, the sunlight intensity is detected to be above 400 lux, and the solar panel temperature is below 30°C, the system's decision is to initiate the solar panel surface cleaning process. If the solar panel temperature is detected to exceed 30°C, the system's decision will be to activate the solar panel cooling process.

The condition of the solar panel can be monitored from anywhere the user is located through the application of IoT technology, where the monitoring process is related to the solar panel's condition, whether it is currently undergoing the solar panel cooling process or the solar panel surface cleaning process. Through the application of IoT technology, users can also control the electrical devices connected to the solar power system.

5. ACKNOWLEDGMENTS

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