IoT Implementation for Monitoring and Controlling Solar Power Plant Systems

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ABSTRACT
Solar power plants (SPP) are one of the most potential renewable energy sources that can be used as a sustainable solution to meet energy needs. However, the efficiency and reliability of SPP systems remain major challenges that need to be addressed. One way to improve the efficiency and reliability of these systems is by implementing Internet of Things (IoT) technology as a means of monitoring and controlling the operation of SPP systems. IoT can be used to remotely monitor and control the performance of SPP systems in real-time, thereby aiding in decision-making and providing system efficiency improvements.

The aim of this research is to develop a system for monitoring and controlling the operation of a solar power plant (SPP) based on IoT, which can remotely monitor and control the performance of the SPP system in real-time by implementing IoT devices. The IoT devices consist of sensors as a means of detecting the load processes in the SPP system, communication modules as wireless communication media for monitoring and controlling the load on the SPP system, and a controller device that serves as a central data processing and decision-making unit for the operation of the SPP system. The monitoring and control processes can be carried out from anywhere through a web server and can be accessed using user devices such as a PC or a smartphone. The monitoring process includes monitoring the following parameters: voltage output , electric current output , power factor, frequency, electric power, electric energy, and the payment amount in Indonesian Rupiah based on the electricity consumption. It also involves monitoring the condition of electrical equipment connected to the SPP system. The control process involves turning ON/OFF the electrical equipment connected to the SPP system based on the monitoring results.

The method used to develop a system for monitoring and controlling an IoT-based solar power plant (SPP) is prototyping, which involves the following stages: Literature review, data collection, system design, system development, and system testing.

The testing results demonstrate that the implementation of an IoT system for monitoring and controlling the load on the SPP system can be done remotely from any location using user devices. This capability improves the efficiency of both time and load management on the SPP system. The monitoring data includes measurements of electric current consumption, electric voltage, electric power, electric energy, power factor, frequency, and the amount to be paid in *Indonesian Rupiah* based on the electricity consumption. It also includes the status of the load, indicating whether it is active or inactive.

Keywords
Solar Power Plant (SPP), IoT, controller, real-time

1. INTRODUCTION
Solar power plants (SPP) are one of the highly potential sources of renewable energy that can be used as a solution for sustainable energy needs [1][2][3][4]. However, the efficiency and reliability of SPP systems still remain significant challenges that need to be addressed [5][6][7]. One way to enhance the efficiency and reliability of these systems is by implementing Internet of Things (IoT) technology for monitoring and control purposes [8][9]. IoT can be utilized to measure and control the performance of SPP in real-time, thereby aiding decision-making and providing improvements in system efficiency and reliability.

Furthermore, IoT also offers remote accessibility, providing flexibility in control and monitoring. With IoT technology in place, real-time control and monitoring become possible, aiding in addressing issues that may arise within the PLTS system.

The related research that has been carried out includes:

1. Title of the Research: "IoT-Based Monitoring System for Hybrid Grid and Solar Power Plants (PLTS)" This research focuses on monitoring the performance of a hybrid system that combines solar power plants (PLTS) and the power grid (PLN). The monitoring process involves tracking the current and voltage output of the hybrid system remotely using IoT technology [10].

2. Title of the Research: "IoT-Based Smart Home Automation Using Solar Photovoltaic System and Online Time Server" This research, conducted by C. Ghosh and his team in 2021 at the 5th International Conference on Green Energy and Applications (ICGEA) in Singapore, focuses on utilizing a solar photovoltaic system (PLTS) as the electrical source for a smart home system. In this smart home system, the IoT concept is employed to monitor the availability of water and the lighting requirements in the house. The system created automatically controls water levels and lighting needs in the rooms. The detected monitoring results are sent to a web server, in this case, [11].

3. Title of the Research: "IoT-Based Smart Solar Energy Monitoring Systems". This research, conducted by D.D. Prasanna Rani and their team, was published in Materials Today: Proceedings. The study focuses on the implementation of IoT technology for monitoring the power output of solar photovoltaic systems (PLTS). IoT technology is also used to adjust the power output of the PLTS by controlling the tilt angle of solar panels in

relation to the position of the sun. The control process is carried out remotely [12].

4. Title of the Research: "Monitoring of Solar Photovoltaic (PLTS) and Vertical Axis Wind Turbine (PLTB) with IoT-Based Hybrid System". This research was conducted by I Gusti Ngurah Wirahadi Wijaya and his team and was published in the Journal of Applied Mechanical Engineering and Green Technology in 2021. The study is related to the remote monitoring process through the application of IoT in a hybrid power generation system, which combines both solar photovoltaic (PLTS) and vertical axis wind turbine (PLTB) systems. The IoT application specifically focuses on monitoring the current output of the hybrid power generation system [13].

2. METHODOLOGI

In producing a monitoring and control system for the SPP system through the application of IoT technology, it refers to the Prototyping research method, the stages of which include data collection, hardware design, software design, hardware creation, software creation and finally system testing.

2.1 System Design

The system block diagram is a part of the system design that represents the relationship between each part that supports the work of the IoT-based SPP system monitoring and control system. The block diagram of the IoT-based SPP System Monitoring and Control system is shown in Figure 1.

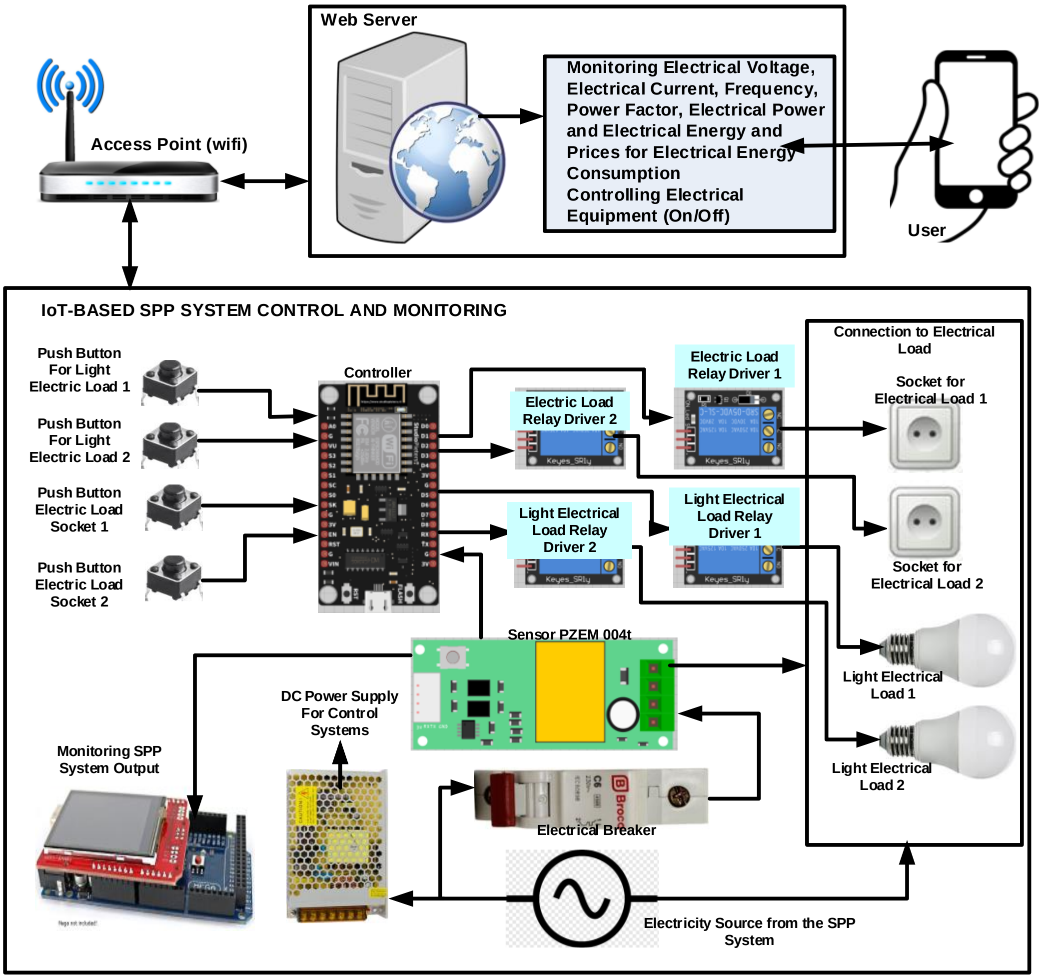

Fig 1: Block diagram system

The description of the Block diagram in Figure 1, is described as follows:

1. The controller serves as the central processing unit for input data from sensors, which includes Electric Voltage data, Electric Current data, Power Factor (Pf) data, Frequency data, Electric Power data (Watt), and Electric Energy data (KWh). Additionally, the controller is also utilized to send the processed data from the sensors to a web server and read instructions received from the web server to control the electrical load supplied by the solar photovoltaic system (SPP).
2. Driver relay functions as an ON/OFF switch for electrical equipment through outputs from the controller, including lighting loads and socket loads.
3. Sensors are responsible for detecting the values of Electric Voltage, Electric Current, Power Factor (Pf), Frequency, Electric Power (Watt), and Electric Energy (KWh).
4. Electrical disconnects are used to interrupt the electrical flow from the PLTS source to the electrical loads.
5. Push Buttons serve as switches to activate and deactivate the operation of the relay drivers, which are connected to electrical loads such as lights and outlets.
6. The monitoring output of the SPP system is utilized as a means to monitor the electrical output of the SPP system. This includes monitoring voltage output, current output, power consumption, and energy consumption.
7. The DC power supply serves as the electrical source for the Controller, Driver Relay, Sensor devices, Monitoring

output devices for the SPP system, and push buttons.

8. The Access Point (Wi-Fi) is used as an internet communication medium between the Controller and the Web Server for the data transmission process. It facilitates data transmission from the Controller to the Web Server and vice versa, serving the needs of monitoring and controlling the SPP system.
9. The Web Server functions as a user interface for monitoring the operation of the SPP system. It provides information regarding Electric Voltage, Electric Current, Power Factor (Pf), Frequency, Electric Power (Watt), Electric Energy (KWh), as well as the amount in currency to be paid for electric energy consumption. Additionally, the Web Server is utilized as a control interface for electrical equipment supplied by the SPP system. Monitoring and control processes can be carried out through user devices such as PCs, laptops, or mobile phones from any location.

2.2 Software Design

In developing IoT-based solar photovoltaic power plant (SPP) monitoring and control system operation software, the first step taken is to design the system workflow structure in the form of a flowchart. This flow diagram aims to visually represent the sequence of operations for monitoring the electricity output of the SPP system and controlling the operation of electrical loads connected to the SPP system.

2.2.1 Flow chart System (Algorithm)

Software design for system work control needs in the form of a flowchart which functions to control system work, in terms of monitoring the output of the SPP system and controlling the work of electrical equipment connected to the SPP system. The system work control flow diagram is shown in Figure 2.

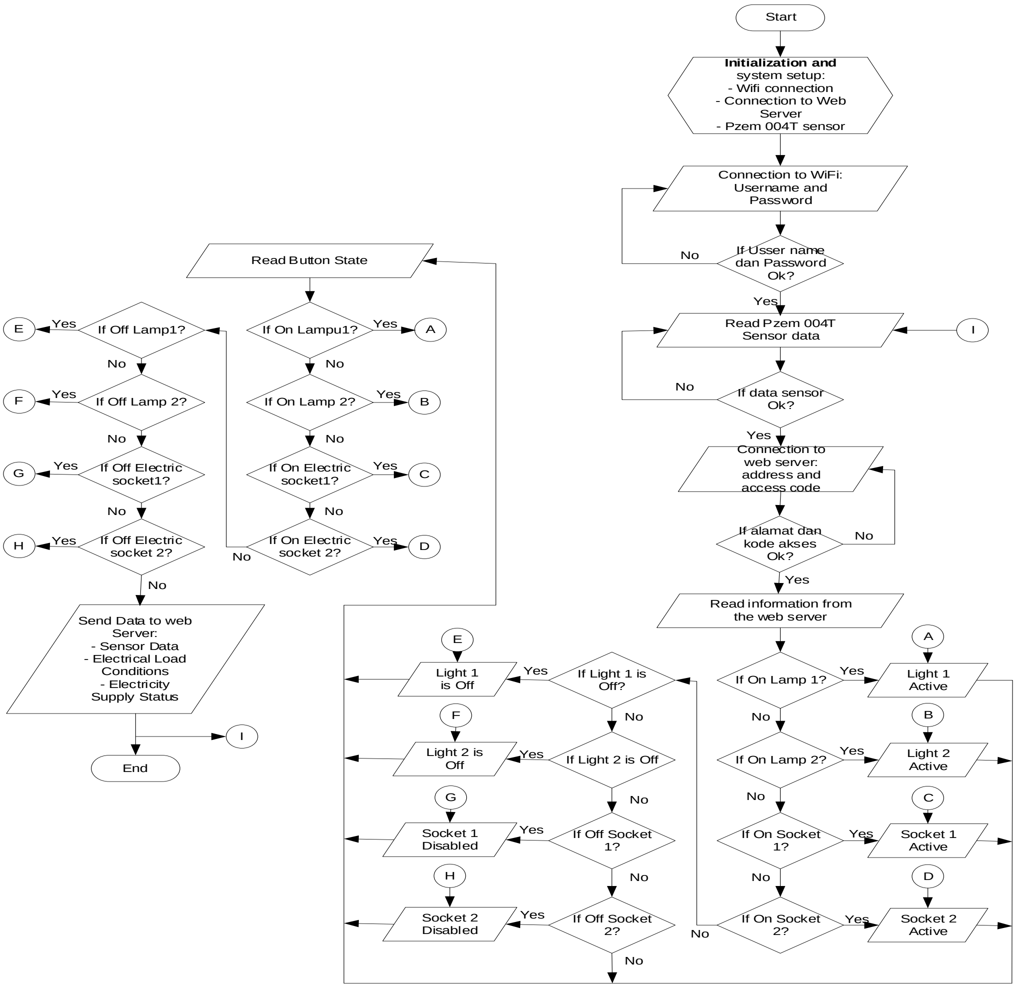

Fig 2: Flowchart system

The working principle of a flow chart is as follows:

- When the system is started (Start), the controller will execute the program section for system initialization and setup. The initialization part involves the introduction of libraries that will be used in running the system and the variables used in the program.
- After the system initialization and setup processes have been completed, the program will proceed to read data from the sensors and store the readings in the predefined libraries. If the sensor data reading process fails, the system will continuously attempt to obtain accurate data.
- Next, the controller will execute a program to establish a connection between the controller and the web server (Blynk IoT) through Wi-Fi communication. The connection process is based on access rights authenticated by the Token data to access the created dashboard. If the connection to the web server is successful, the subsequent processes will be executed. If the connection is not successful, the controller will repeatedly attempt to establish the connection until it successfully connects to

the web server.

- When the controller and web server are successfully connected, the program will proceed to read information from the web server related to the control process of electrical loads. This involves reading the status of buttons located on the web server. The buttons on the web server serve as switches for activating and deactivating electrical loads. The control process for operating electrical loads can also be carried out through the operation of push buttons (Push Button), enabling the operation of electrical loads from two directions, both from the web server and by pressing the physical buttons.
- The next step is to read the condition of the push buttons for the operation of electrical loads at the location where the SPP is installed. Each push button has the function of activating and deactivating specific electrical loads. If the status of an electrical load is active because it was activated from the web server, pressing the push button will deactivate the electrical load. Conversely, if the electrical load has been activated via the push button, the status of the button on the web server will also be active, and pressing it will deactivate the electrical load. This two-way control mechanism ensures that the electrical loads can be operated from both the web server and the physical push buttons.
- The next part of the program that is executed is the part of the program to send information to the web server.

2.2.2 Web Server Design

The web design section is carried out based on system requirements for monitoring and controlling the work of electrical equipment, which is connected to the SPP system. Figure 3 shows the design of the web server.

Description for Figure 3:

- The Volts section is for information regarding the output voltage of the SPP system.
- Ampere section for information regarding the output current of the SPP system.
- Frequency section for information regarding the output frequency of the SPP system.
- The SPP System Conditions section is a section to inform you about the condition of the SPP system, whether it is active or inactive.
- SPP Electrical Load Monitoring is a part of displaying information related to the amount of electrical power, power factor, electrical energy and payment prices in Rupiah (payment in Indonesia) based on electrical energy consumption from the SPP system.
- Electrical Load Conditions is a section for displaying information regarding the condition of each electrical load connected to the SPP system, whether it is in active or inactive condition.
- The switch section is a part that regulates (On/Off) electrical equipment connected to the SPP system.

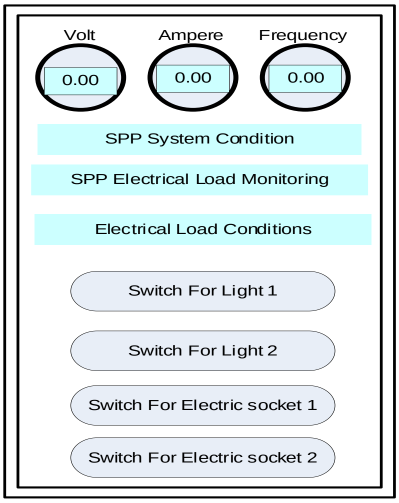

Fig 3: Dashboard Web Server

2.3 Manufacturing for Monitoring and Controlling the SPP System Work Process by Applying IoT Technology

The process of creating a monitoring and control system for the work of an IoT-based SPP system is carried out based on the design results that have been produced through the system design process (system block diagram) for hardware requirements, making software for system work based on the results of the software design in the form of flow diagrams and creating a website. server based on the Dash Board design, where the web server application uses the Blynk IoT platform. The stages of creating the system are as follows:

2.3.1 Hardware Manufacturing

Hardware manufacturing is carried out by referring to the results of hardware design in the form of a block diagram. Hardware manufacturing is done by combining modules such as:

- Controller Module as a data processing center, both monitoring data and data for the system work control process;
- PZEM 004T sensor module, which functions as an output detector from the SPP system, which includes: Electrical Voltage, Electrical Current, Electrical Power, Electrical Energy, Power Factor and Frequency;
- Relay Driver Module, which functions as a driver between the controller and electrical loads, for the On/Off process of electrical loads;
- Push Button Module, which functions as a switch that is input to the Controller Module, to On/Off electrical loads;
- LCD Display Module, which is used to display information regarding the output of the SPP system, which includes: Electrical voltage, Electrical current, Electrical power and Electrical energy, and
- DC power supply module, which functions as an electricity source for the operation of the entire control and monitoring system.

Figure 5 shows the results of making the hardware.

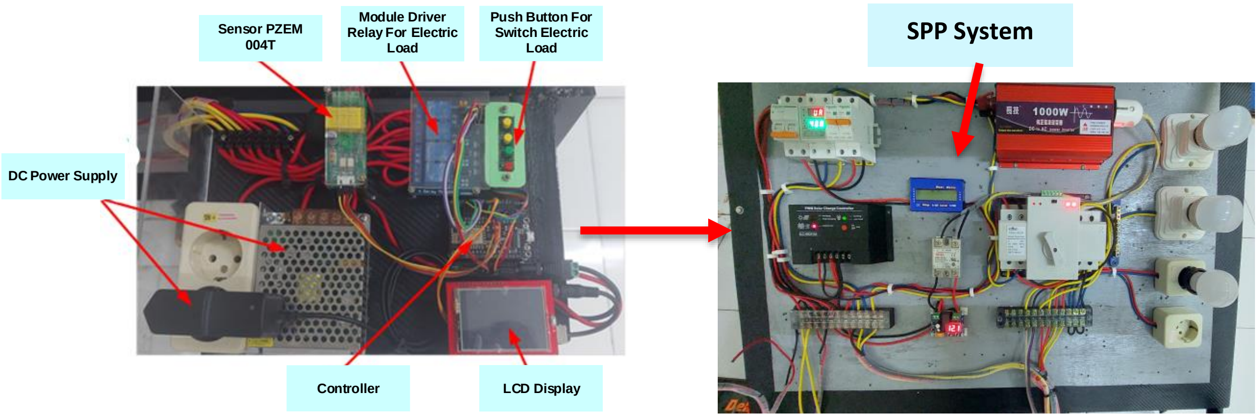

Fig 5: Control System

2.3.2 *Software Development for Controller Operations*

Making software for the work needs of controlling 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 6.

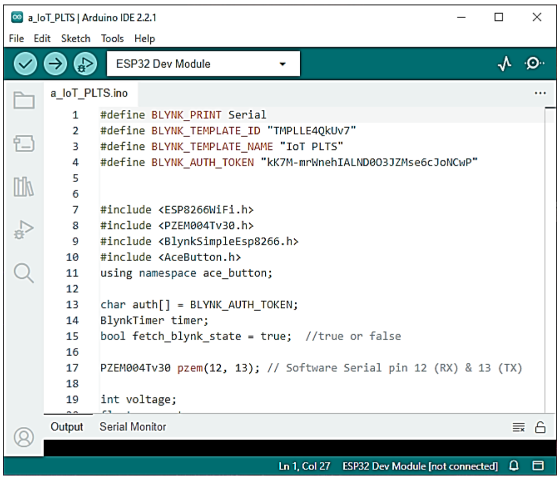

Fig 6: Software Development for controller

After the entire scratch program to operate the IoT-based solar power system monitoring and control system has been completed, the next step is the process of embedding the program into the controller, as shown in Figure 7.

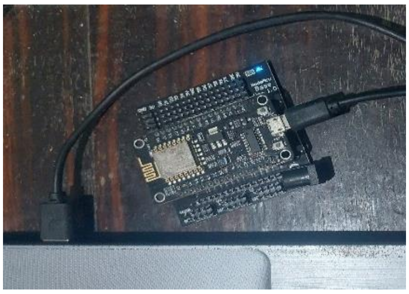

Fig 7: Embedded System

2.3.3 *Development For Web Server*

To fulfill the monitoring and control requirements for the SPP system, a web server is needed as a means to remotely monitor and control the system through smart devices equipped with the Blynk IoT application. The Blynk IoT application will be used to create a web dashboard that displays information related to the outputs of the SPP system. This information includes electrical voltage, current, power, energy, power factor, and frequency. Additionally, the web dashboard will also show information regarding the cost to be paid in Indonesian Rupiah currency, based on the electricity consumption from the SPP system. Furthermore, information about the active or non-active status of the SPP system and the status of each electrical load, whether active or inactive, will also be displayed. The process of creating the web dashboard within the Blynk IoT application will follow a pre-prepared design. Figure 8 illustrates a sample web dashboard on the Blynk IoT application for the monitoring and control needs of the SPP system.

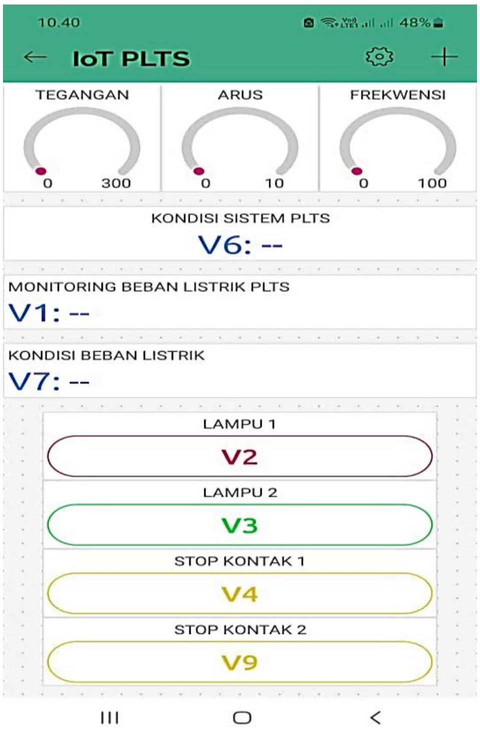

Fig 8: Server Web Development

3. RESULT AND DISCUSSION

The functional testing procedure for the IoT-based monitoring and control system applied to the SPP system for managing electrical loads is flexible and can be conducted from various locations. Users can utilize their devices, such as smartphones or PCs/laptops, to perform remote monitoring and control of the SPP system through a user-friendly interface provided by the Blynk IoT web server. Additionally, if needed, monitoring and control can also be executed directly at the SPP system's physical location. This involves using a Push Button as a switch to manage electrical loads and viewing the power supply data generated by the solar power system (SPP) on an LCD Display at the installation site.

3.1 Monitoring and Controlling Process of the SPP System Via Web Server

Once the SPP system is linked to a web server, monitoring becomes feasible directly on the SPP system itself, focusing on the system's generated outputs. The monitored outputs encompass Electrical Voltage (Volts), Electrical Current (Amperes), Frequency (Hz), Power Factor (Cos Phi), Electrical Power (Watts), Electrical Energy (Wh), the Amount Paid (in Rp), and the status of the electrical loads connected to the SPP system. Figure 9 shows the monitoring process for the operation of the SPP system via a web server.

From the results of tests carried out on the process of monitoring the output conditions of the SPP system, it can be seen that the system created can monitor the output conditions of the SPP system via user devices (Smart Phone devices) remotely, via the web server application that has been created, as shown in Figure 9.

Based on initial monitoring findings, when the SPP system was operating without load, power consumption was recorded at 4.6 watts, electric current 0.04 amperes, power factor 0.55, and electric voltage 227 volts. These readings show that the monitored electrical power actually corresponds to the power consumption of the controller device tasked with monitoring and managing the SPP system.

The process carried out by the controller in detecting electrical energy consumption in the SPP system is as follows:

- Reading electrical energy consumption data via the PZEM-004T sensor, where the data inputted via the sensor includes voltage, current, power factor, frequency, electrical power and electrical energy data,
- The data received from the sensors will be processed by the controller, and then the controller will send the monitoring data to the web server, as information on the consumption of electrical energy supplied through the SPP system.

The part of the program that is executed for this process is as follows:

```
void SendData(){
voltage = pzem.voltage();
  if(voltage != NAN){
     Blynk.virtualWrite(V0, voltage);
  } else {
     Serial.println("Error reading voltage");
  }

  current = pzem.current();
  if(current != NAN){
     Blynk.virtualWrite(V5, current);
  } else {
     Serial.println("Error reading current");
  }

  power = pzem.power();
  if(current != NAN){
  } else {
     Serial.println("Error reading power");
  }

  energy = pzem.energy();
  rp = energy*1444.7;
  if(current != NAN){
    Serial.println("kWh");
  } else {
     Serial.println("Error reading energy");
  }

  frequency = pzem.frequency();
  if(current != NAN){
     Blynk.virtualWrite(V8, frequency);
  } else {
     Serial.println("Error reading frequency");
  }

  pf = pzem.pf();
  if(current != NAN){
  } else {
     Serial.println("Error reading power factor");
  }
    Serial.println();
   Blynk.virtualWrite(V1, "PF = "+String(pf)+";  Watt =
"+String(power)+";   KWh ="+String(energy)+";   Harga
Bayar = Rp. "+String(rp));
 }
```

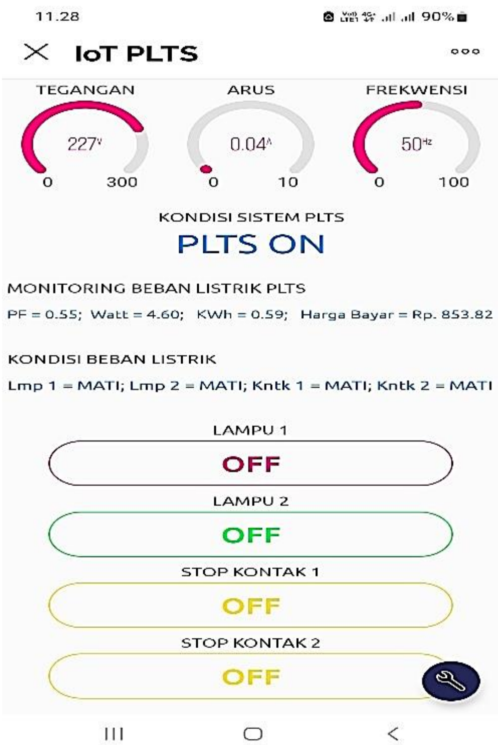

Fig 9: Monitoring process for the operation of the SPP system via a web server

Monitoring can also be extended to the status of electrical loads connected to the SPP system. These connected electrical loads comprise two lamp loads (lamp 1 and lamp 2) and two socket loads (socket 1 and socket 2). During this testing, LED lamps with a power capacity of 4 watts each are employed as the

electrical loads. The test results are presented in Figure 10 for reference.
The data obtained from the test results for the load conditions is shown in Table 1.

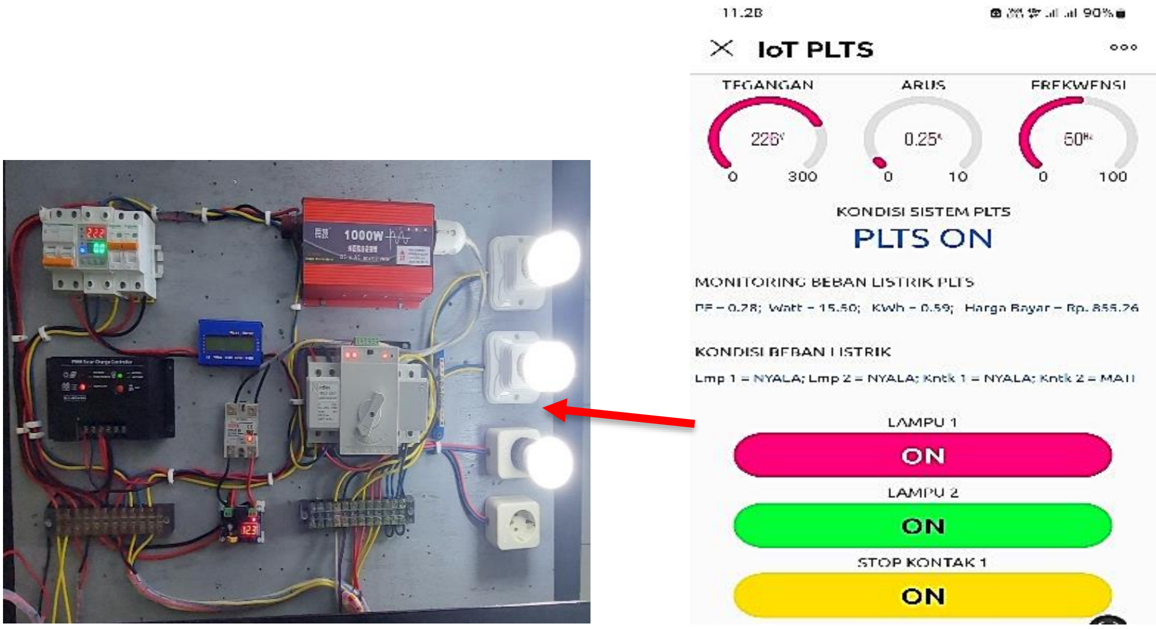

Fig 10: Monitoring load conditions via the web server

Table 1. Results of monitoring the initial conditions of the SPP system output

Electrical Load Test Conditions	Electrical Load 1	Electrical Load 2	Electrical Load 3	Electrical voltage (Volt)	Electric current (Ampere)	Power Factor (Cos φ)	Electrical power (Watt)
Condition 1	Off	Off	Off	227	0.04	0.55	4.6
Condition 2	On	Off	Off	227	0.12	0.29	8.2
Condition 3	On	On	Off	227	0.24	0.22	11.8
Condition 4	On	On	On	227	0.25	0.28	15.5

From the monitoring test data regarding the status of electrical loads connected to the SPP system, as shown in Table 1, it's evident that when all electrical loads are deactivated, the load from the SPP system is 0.04 Amperes. When one of the electrical loads is activated, such as Electric load 1, there is an increase in the current consumption from the initial value of 0.04 Amperes to 0.12 Amperes. This change in current value indicates that electrical load 1 has become active, allowing the user to discern its activation status of there is no change in the current value, even though the information received by the web server indicates that electrical load 1 has been activated, the user can deduce that there might be an issue with the load. Consequently, the user can then proceed to perform maintenance on the malfunctioning electrical load.
The process of activating the electrical load on the SPP system is carried out via a web server. Users can perform this action by pressing one of the buttons available on the application interface on the web server. For example, to activate Light 1, the user only needs to press the appropriate button, namely the Light 1 Button. After this action is carried out, the web server will send data to the controller, and then the controller will process the data to activate Light 1. After Light 1 has been successfully activated, then the controller will send information to the web server to notify the user that Lamp 1 has been activated. With Light 1 active, users can monitor its status by increasing the electric current consumption recorded on the electric current metering.
The parts of the program that are executed for the remote-control process of the SPP system, in connection with the operation of electrical loads connected to the SPP system are as follows:

```
void button1Handler(AceButton* button, uint8_t eventType,
uint8_t buttonState) {
  switch (eventType) {
    case AceButton::kEventReleased:
      digitalWrite(lampu1, toggleState_1);
      toggleState_1 = !toggleState_1;
      Blynk.virtualWrite(VPIN_BUTTON_1, toggleState_1);
      break;
  }
}
void button2Handler(AceButton* button, uint8_t eventType,
uint8_t buttonState) {
  switch (eventType) {
    case AceButton::kEventReleased:
      digitalWrite(lampu2, toggleState_2);
      toggleState_2 = !toggleState_2;
      Blynk.virtualWrite(VPIN_BUTTON_2, toggleState_2);
      break;
  }
}
void button3Handler(AceButton* button, uint8_t eventType,
uint8_t buttonState) {
  switch (eventType) {
    case AceButton::kEventReleased:
```

```
      digitalWrite(lampu3, toggleState_3);
      toggleState_3 = !toggleState_3;
      Blynk.virtualWrite(VPIN_BUTTON_3, toggleState_3);
      break;
  }
}
void button4Handler(AceButton* button, uint8_t eventType,
uint8_t buttonState) {
  switch (eventType) {
    case AceButton::kEventReleased:
      digitalWrite(lampu4, toggleState_4);
      toggleState_4 = !toggleState_4;
      Blynk.virtualWrite(VPIN_BUTTON_4, toggleState_4);
      break;
  }
Blynk.virtualWrite(V7, "Lmp 1 = "+kondisiLampu1+"; Lmp
2 = "+kondisiLampu2+"; Kntk 1 =
"+kondisiLampu3+"; Kntk 2 = "+kondisiLampu4);
}
```

3.2 Monitoring Process for the SPP System Through the Installed SPP Site

The monitoring process for the electrical output of the SPP system, including voltage, electrical current, electrical power, and electrical energy, is conducted using an LCD display. Data processing is carried out by an Arduino Uno controller based on input from a PZEM 004T sensor. The test results for the monitoring process of the electrical output from the SPP system are displayed in Figure 11 for reference.

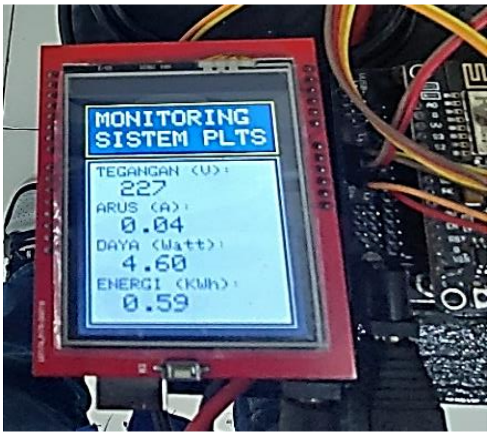

Fig 10: Monitoring the SPP system output at the installed SPP location

Based on the conducted testing, the control and monitoring system in the SPP system can effectively monitor the load conditions of the SPP system, particularly concerning its electrical output, which includes voltage, electrical current, electrical power, and electrical energy.

It's important to note that the monitoring process is specifically designed for observing the load conditions of the SPP system. If the SPP system is in the Off state (inactive), the monitoring system will not function. This limitation exists because the PZEM 004T sensor is solely utilized for monitoring the electrical output of the SPP system. Figure 4.6 displays the information presented on the LCD display when the SPP system is in the Off state, where the electrical supply is replaced by backup power via the ATS system.

4. CONCLUSIONS

Based on the conducted testing of the IoT-based control and monitoring system implemented in the SPP system, it can be concluded that this IoT-based control and monitoring system enhances efficiency. Users can monitor the status of the SPP system from anywhere, eliminating the need to be physically present at the SPP system's location. This can be achieved through user devices, particularly smartphones equipped with the Blynk IoT application and internet connectivity.
The monitoring process is linked to the SPP system's status, whether it's actively supplying power to the loads or in an off state, relying on backup power. When the SPP system is active, users can monitor the status of the loads connected to it. If a user forgets to deactivate one of the electrical appliances, they can detect it and remotely control the deactivation of the appliance using their smartphone, without needing to be at the physical location of the SPP system. This capability helps prevent electricity wastage. Users can also remotely activate electrical appliances when needed, enhancing convenience and controlling. In the future, it is hoped that the system created can be implemented in every home that utilizes solar energy, so that it can streamline electrical energy consumption by adjusting the electrical load wherever the user is located.

5. ACKNOWLEDGMENTS

Many thanks to the organizers of the International Journal of Computer Application (IJCA) who have given the author the opportunity to publish this paper, as well as to the Manado State Polytechnic for facilitating the research process.

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