Real-Time Monitoring of Photovoltaic Systems and Control of Electricity Supply for Smart Micro Grid-PV using IoT

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***Abstract* – This paper aims to develop a photovoltaic (PV) performance monitoring system applied on a micro scale using the Internet of Things (IoT). Previous monitoring systems had limitations in platform flexibility, low-cost devices, hardware complexity, and stability of the data transfer process. For this reason, this research proposes an IoT architecture that uses Arduino devices, mini WIFI and an open-source platform, so that it can be easily developed further. This research also develops innovations in controlling the use of electrical energy sources from PV and utility networks. This monitoring system is applied to PV installations with a capacity of 1KW which is capable of monitoring electrical data in the form of current, voltage, power, energy and frequency obtained from PV panels, batteries, loads and electrical utilities. Monitoring data is displayed in a visual form that can be accessed via web-based and mobile applications. This research has developed an innovation in controlling the use of electrical energy sources from PV and Utility networks by using several sensors as parameters to determine the right time and condition in controlling the use of electrical resources.**

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1. Introduction

The increasing need for energy is becoming a global issue in line with the rapid growth of the world population and the need to provide adequate energy sources [1]. Currently, electrical energy sources are still dominated by fossil fuel power plants (60%), other sources come from alternative energy (30%) and the rest comes from renewable energy (10%). However, the dominant use of fossil fuels has an impact on increasing carbon emissions and global warming. Thus, many countries in the world are competing to issue various policies to reduce dependence on fossil fuel power plants and are starting to switch to the use of alternative and renewable energy.

Integration between fossil energy sources and renewable energy will be the initial stage in the overall utilization of renewable energy sources with the support of smart grid technology. The implementation of smart grids or smart micro grids (SMG) allows an increasing number of generators sourced from renewable energy and the availability of distributed and integrated energy storage units or Energy Storage System (ESS) [2]. For residential and building users, integration can be implemented between energy sources from state electricity companies and solar energy sources through the construction of solar cells. This integration will increase the role of residential and building users who are not only electricity users, but can also generate electricity from the PV systems being built.

However, environmental factors such as temperature, radiation level, weather, and photovoltaic (PV) materials will affect the performance of the PV system so that the electrical energy generated is unstable and creates uncertainty in the electricity generated.

The monitoring system can provide information on the amount of electricity produced by the PV system and the performance conditions of the PV system [3]. In addition, it can also monitor several factors that affect PV electricity production such as weather conditions, PV materials, PV panel conditions, installation methods which can also be known through this monitoring system [4].

To maintain good PV system performance, it is very important to develop this monitoring system [5], [6], [7], [8]. One of the monitoring systems previously used was Supervisory Control and Data Acquisition (SCADA). This system has a complete monitoring component so that it can carry out data acquisition, data transfer, control, and visualization of PV system performance information [9]. However, the application of SCADA has disadvantages when the number of switching circuits increases and has an impact on increasing system complexity. Besides that, SCADA requires a high frequency of Pulse Width Modulation (PWM) signals for the control process. Furthermore, the investment costs are very high to implement SCADA [10]. SCADA also requires commercial datalogger components with special software and is very expensive [11]. Therefore, it is necessary to develop a monitoring system that provides flexibility and interoperability so that it will not depend on special commercial components and of course the investment price will be cheaper. the development of the monitoring system will also be supported by high technology, such as the Internet of Things (IoT) which can manage information processing and data transfer speed so that the performance of the monitoring system is better [12], [13].

Researches [14], [15], [16] developed a PV monitoring system that provides a lower price solution, through the use of Node MCU devices as microcontroller components. Then, the system developed also uses a commercial datalogger for data transfer and data storage purposes originating from PV output electrical data and data from environmental parameters, such as radiation, temperature and humidity which are then processed into information via LABVIEW (Virtual Instrument Engineering Workbench Laboratory). However, the software used in IoT monitoring is not open source, so it has low flexibility and makes system development difficult. Researches [17], [18] developing an IoT-based monitoring system which is then applied to the process of detecting failures in PV system performance at the solar panel level. This monitoring system was developed with data communication technology using Power Line Communication (PLC). Researcher [19] developed an IoT-based solar PV monitoring system using Zigbee as a data communication protocol.

This system also uses sensors to obtain meteorological and electrical data which is then stored in a datalogger, and then sent to a computer for processing via a Zigbee communication device. However, PLC components are relatively expensive and are not suitable for implementation in micro-scale PV monitoring systems. Researcher [20] Developing an IoT-based PV monitoring system using Raspberry and also cloud-based services and dataloggers. However, the use of Raspberry has the disadvantage of complexity in the hardware used. Researchers in study [11] use 3G technology as a data communication protocol to the cloud and present information via web applications. However, 3G technology will depend on the availability of service provider stations so it will affect the performance of this monitoring system. To address it, the authors of study [21] used mini WIFI technology as a data communication protocol.

This research will propose an IoT architecture that addresses issues in previous research, namely, IoT platform flexibility, low-cost devices, hardware complexity and stability of the data transfer process and innovation in controlling the use of electrical energy sources from PV, and utility grids. Therefore, this research develops a PV monitoring system to monitor the performance of PV systems and control the use of electricity supply from PV and utility based on IoT technology. The rest of this paper is organized as follows: Section 1 provides an explanation of the introduction. Section 2 describes the IoT-based PV monitoring system model. Section 3 describes the results of the developed system. Then section 4, describes the conclusion.

2. IoT-based PV Monitoring System

The developed SMG monitoring system has the ability to determine the performance of the PV system and control the use of electricity supply from PV and Utility. The system consists of a renewable solar energy source and a suitable remote monitoring platform. The photovoltaic system is used as the RES while the IoT module serves as the data acquisition device and data communication. Some of the main features of the PV performance monitoring system are as follows:

1. Measuring electricity generated from photovoltaic modules,
2. Measuring radiation,
3. Measuring battery charge status,
4. Measuring user load,
5. Measure module and battery temperatures
6. Saving data,
7. Transmitting data to a cloud server using IoT,
8. Has a monitoring dashboard (web and mobile).

Table 1. Research tool and materials

No	Unit	Item
1	PV System	1. PV panel: 1KWp 2. Maximum Power Point Tracker (MPPT) solar charger controller 3. Off grid inverter 4. Grid tie inverter 5. Battery 1000 AH
2	Sensor	1. PV output: voltage, current, power 2. Utility grid: voltage, current, power 3. Meteorological: temperature 4. Battery: voltage, current, power 5. load: voltage, current
3	IoT Tool Set	1. Microcontroller: Raspberry Pi, Arduino 2. Relay 3. IoT tool set 4. WIFI shield 5. Cloud server
4	Visualization	Dashboard template

The solar power plant that is the research site has a capacity of I KW with the main components and equipment used as shown in Table 1. Several factors can influence and even degrade the function of a PV system.

So, it requires a PV monitoring system to improve its performance. These factors can come from the PV panel material used and from environmental factors, such as temperature, radiation, and meteorology, or weather.

An IoT-based monitoring system has several important parts, including data acquisition and preprocessing, analysis, visualization, application, and storage. In the data acquisition section, this section consists of several sensors installed at PV installation points that influence PV performance, such as PV panels, batteries, utilities, and loads. The electrical variables detected are voltage, current, and power. Apart from that, sensors are also installed in the environment around the PV installation to obtain data on weather and environmental conditions in the form of temperature, and radiation variables. Next, the data acquisition results will first be pre-processed through the A/D conversion process. Then the results will be sent to the cloud service via WIFI data communication protocol. Besides that, the data will also be stored in local storage in the datalogger. In cloud services, data will be analyzed and then visualized and can be accessed via a web service application. The proposed loT-based PV performance monitoring system can be shown in Figure 1.

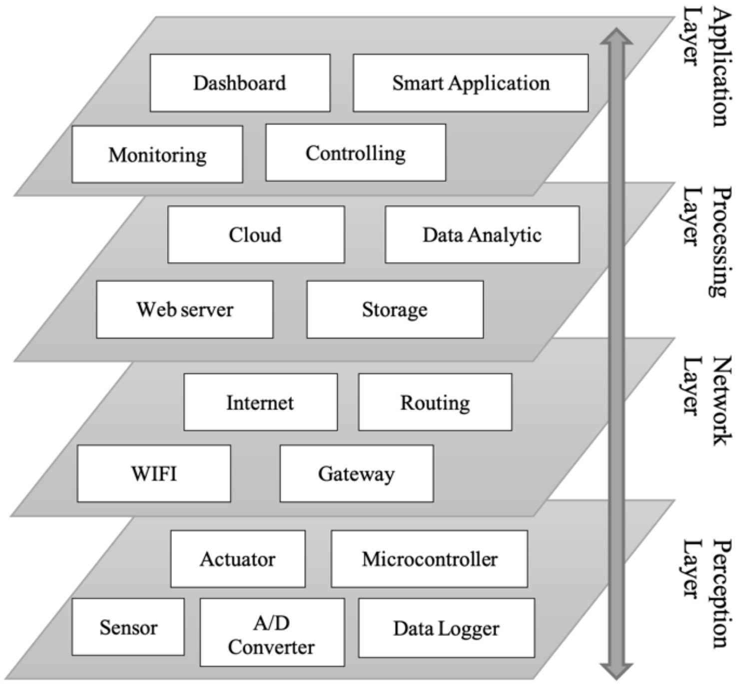

Figure 1. IoT layer of PV monitoring system

IoT-based monitoring system application as shown in Figure 1 is developed in 4 architectural layers, namely, perception layer, network layer, processing layer, and application layer [22]. The perception layer is related to sensors, actuators, A/D converters, and microcontrollers.

Sensor and actuator access is managed by the microcontroller for analog to digital conversion and preprocessing. This microcontroller becomes a node that will collect electrical data and environmental data from sensors in time intervals of every 60 seconds.

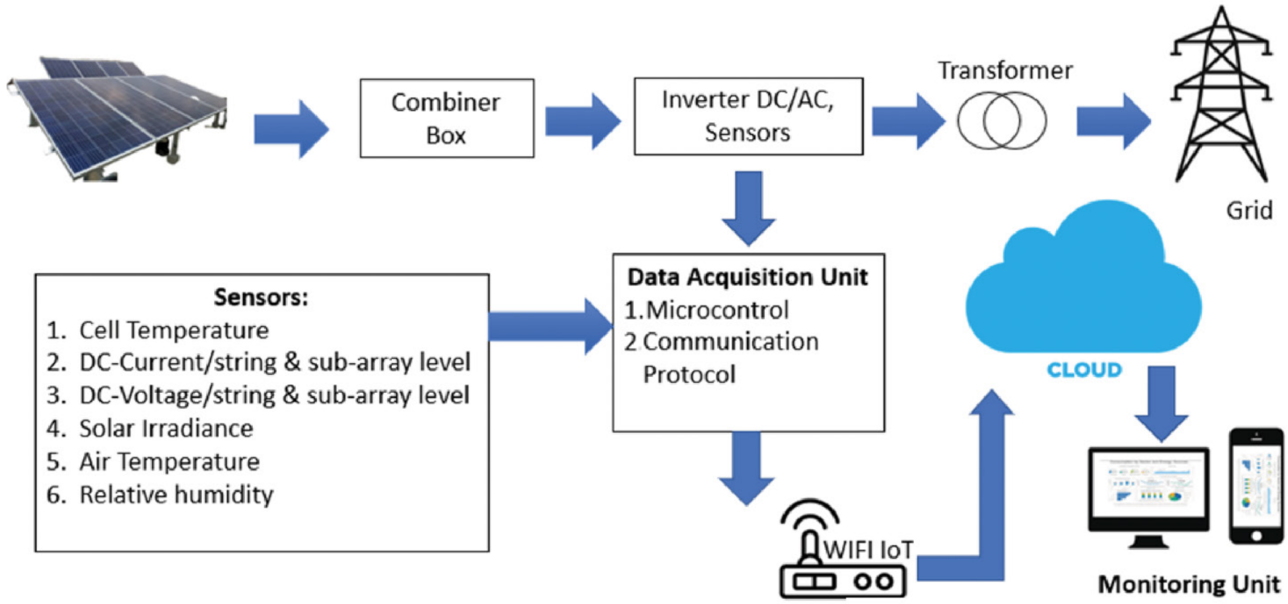

Figure 2. Proposed PV monitoring system

Furthermore, the data will be stored in the data logger and sent to the server through the network layer. This layer is used to serve data transfer using certain communication protocols, for example WIFI. Some devices in this layer such as gateway function to manage connections and routing to the server via the Internet network. In addition, the gateway also functions as a hub that connects nodes to the Internet network. The processing layer is used to process the information received using data analysis methods and store the results on cloud storage. This data analysis process will be used in making decisions in several applications in the application layer.

Hardware development consists of the physical parts that make up the proposed system, namely the IoT monitoring platform, photovoltaic system, and load. In this research, the development of physical devices is more focused on the IoT monitoring platform which consists of sensors, IoT modules, microcontrollers, data loggers, and relays as shown in Figure 2. In the PV system, the PV array produces electrical energy from the conversion process of solar radiation from each solar cell.

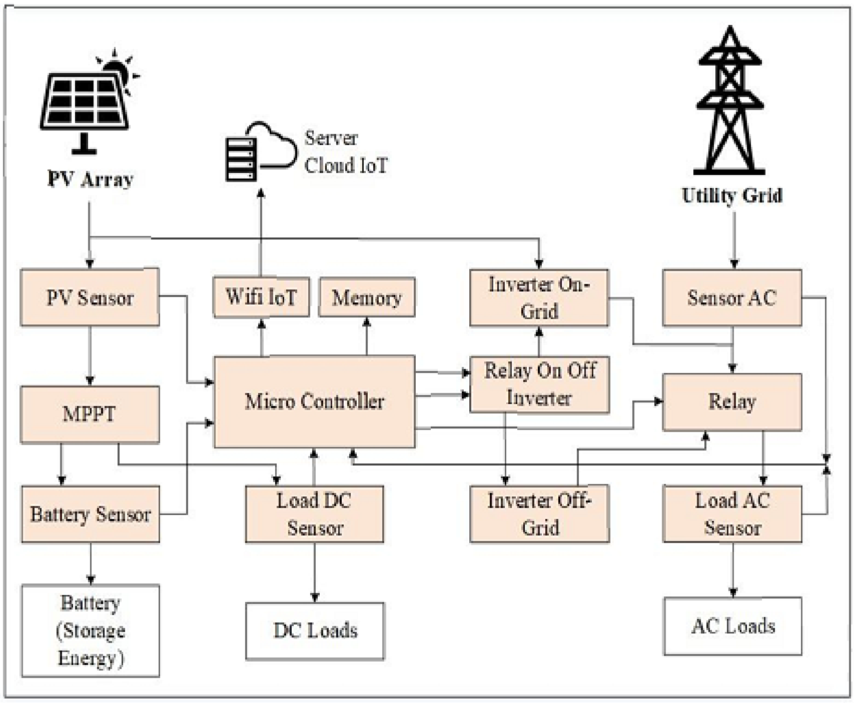

Figure 3. Workflow of PV performance monitoring system

Some PV system equipment includes PV array, MPPT, inverter, and load. Inverters can be both on grid and off grid. Furthermore, loads can be batteries, direct current (DC loads), and alternating current (AC) loads. In PV systems, the electrical energy generated can be used directly by DC type electrical equipment and can also be stored in batteries. MPPT devices are used in the process of storing electrical energy in the battery, so that the charging process will be at a safe limit. On grid and off grid inverter devices are useful for the process of using electrical energy in AC type electrical equipment originating from PV arrays and batteries.

Furthermore, in the PV performance monitoring system as shown in Figure 3, there are several sensors that support the monitoring process which include battery sensors, AC load, and DC load sensors, PV sensors, and utility sensors. The data obtained by the sensors become parameters which are then processed by the microcontroller section as shown in Table 2.

Some of the processes carried out in the microcontroller section are analog-digital converters, sending data to the IoT cloud server via a WIFI connection and controlling relays for inverter operation on grid and off grid and relays for utility grid operation.

Table 2. PV monitoring system parameters

Type	Sensor	
PV Array	Voltage Current Power Irradiance (PV Array) Temperature	*V* *A* *W* W/m^2 ^oC
Utility Grid	Voltage Current Power	*V* *A* *W*
Load	Voltage Current Power	*V* *A* *W*
Battery	Voltage Current Power	*V* *A* *W*

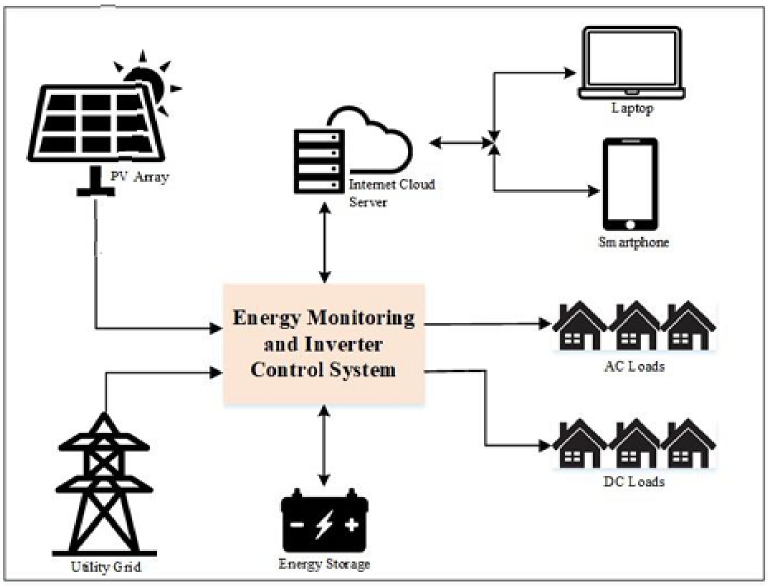

Figure 4. IoT application of PV performance monitoring system

Software development aims to build a cloud application that is used to manage data obtained from sensors on the PV unit via IoT to be analyzed into useful information for users. Figure 4 shows the monitoring system application and inverter control system on the cloud server. This application processes data from sensors installed in the PV system, utility grid, battery, AC/DC load. The processing results in PV performance monitoring information and control commands that are sent back to the relays in the microgrid via IoT. Furthermore, this monitoring application can serve many customers and can be accessed by users via web and mobile. Some of the software modules developed include:

1. IoT platform,
2. Cloud server,
3. Cloud data logger,
4. Monitoring application.

The development of the IoT platform is carried out on the microcontroller and server devices, so that the data obtained from sensor devices can be processed and sent to the cloud server and processed into information that can be accessed by users, as shown in Figure 5. Vice versa, feedback data from users will be processed by the cloud server and then sent to the microcontroller through the IoT platform to be processed into commands to actuators/relays.

Figure 6 below shows the stages of the IoT platform process from the user in the form of feedback to the actuator.

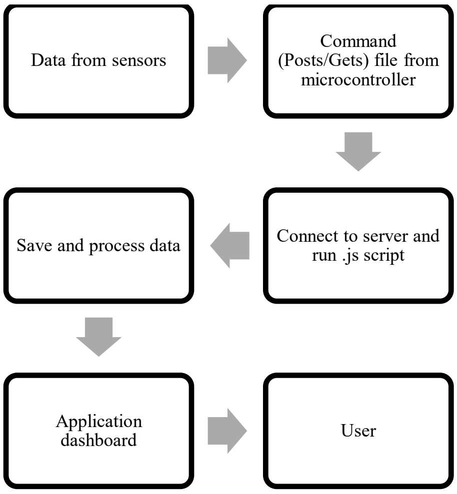

Figure 5. The process of data transfer on IoT platform from sensors to information for users

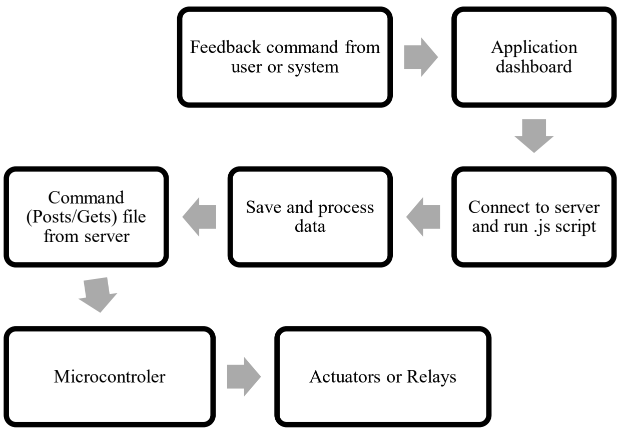

Figure 6. The process of data transfer on the loT platform from the user in the form of feedback commands to the actuator

Cloud server services consist of 3 types, namely Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). The development of the SaaS model allows cloud-side computing for data analysis to produce decisions that will be used in user applications. Furthermore, the process and the cloud computing results will be stored in the cloud data logger. The monitoring application includes a backend part that functions to run programs for data processing and a front-end part that can be web or mobile that allows information to be accessed by end users.

3. Experiment and Results

The PV system in the smart micro grid uses a capacity of 1000 wp, consisting of 10 solar panel modules with a capacity of 100 wp each. Figure 7a shows the PV array installed on the roof of the building and Figure 7b shows the panel box which contains PV system devices and IoT devices. Furthermore, In Figure 8a, there are several PV system devices, including MPPT, inverter and IoT modules, relays, and sensors. The MPPT device is useful for controlling the battery charging process. This device has a specification of 100A/47 VDC. The inverter device is in the form of grid tie and off grid. Grid tie inverters are useful for converting DC power from solar panels to AC power so that it can be consumed by AC loads. This inverter has a specification of 2000W/24VDC. Next, an off-grid inverter is used to convert DC power from the battery to AC power. This inverter has a specification of 2000W/24VDC.

a)

b)

Figure 7. Installation of PV system on micro grid

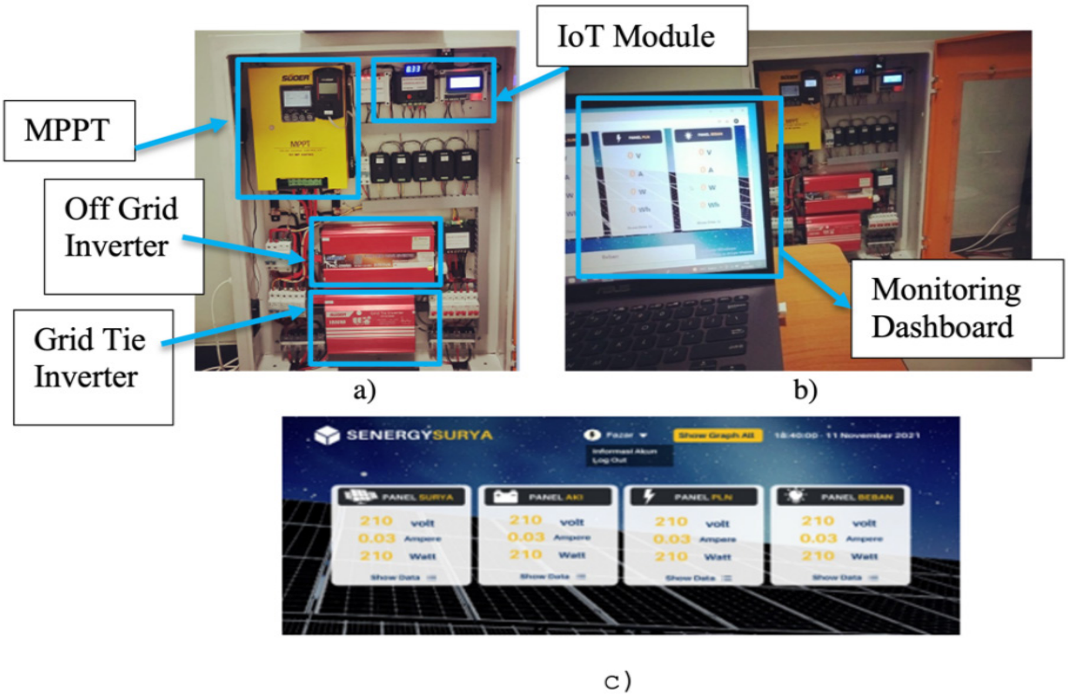

Figure 8. Installation of component micro grid (MPPT, Inverter Switch Breaker, IoT Module)

WIFI as a data communication protocol is used to transmit sensor acquisition data to a cloud server via the IoT module. The A/D converter section on the Arduino will convert the data obtained from the sensors installed on the PV system which is still in the form of analog data into digital data. Furthermore, there is a monitoring dashboard that contains monitoring information in the form of electrical data of solar panels, battery, PLN, and load. Figure 8 (c) shows the monitoring system dashboard which contains PV system performance information. The information displayed is from the parts of the PV system unit that are equipped with sensors, including: solar panel parts, inverter, load, utility, environment around the PV system. Data is taken from each part in a time period every 10 seconds.

Figure 9. Installation of CT sensor on PZEM module

The process of data acquisition and transfer to the cloud server is carried out by the IoT module. Data acquisition uses several sensors including DC 200A and DC 0-24 V as DC current sensors and DC voltage sensors which are used to measure current and voltage in PV panel output cables, DC loads and batteries. Next, the 0-225V AC current and voltage sensor is used to measure current and voltage on AC loads, utilities and inverters. Other components in the IoT module include RTC DS 1302, Node MCU, Arduino, WIFI, and data logger. The data acquisition process is carried out by split core PZEM Current Transformer (CT) sensors to measure voltage, current, and power placed on cables in PV panels, batteries, DC loads, AC loads, and PLN grid as shown in Figure 9. The PZEM module is then connected to the Arduino Mega microcontroller using RS485 serial communication with Modbus RTU protocol and UART TTL converter. On the microcontroller, the data obtained from several sensors will be displayed to the LCD, stored in the data logger, and sent to the cloud via the WIFI IoT module. Then, information on the PV system monitoring results will be displayed on a dashboard application which can be accessed using the web and mobile as shown in Figure 10.

Figure 10. Solar PV system monitoring dashboard

The information displayed is in the form of electrical values from solar panels, batteries, utility grid and loads consisting of voltage, current, power and electrical energy.

Furthermore, other information is the radiation and temperature values. Apart from that, there are also features for controlling loads, inverters, and Automatic Transfer Switch (ATS). Through this ATS, the use of electricity sources from PV, batteries, and utility grid will be controlled automatically.

Figure 10 shows information on the results of monitoring PV system performance from each section. This information includes PV panel performance data in the form of output power in the form of current, voltage and energy which is measured in a time period every 10 seconds as shown in Figure 11. The power generated from solar panels depends on the availability of solar radiation it receives. As seen in the figure, the effective time for the power produced ranges from 7.00 AM to 04.00 PM.

Figure 11. Panel data includes voltage, current, power

In Figure 12, detailed data for each component being monitored can be seen. From this feature, users can directly observe electrical information which can be arranged based on certain time periods.

Furthermore, it can also be downloaded in file form for further processing and can also be visualized in graphic form as shown in Figure 13.

Periode dd/mm/yyyy - dd/mm/yyyy Cari Show graph Kembali

Show 25 entries Copy CSV Print Excel PDF Column visibility

No	Tanggal	Jam	Tegangan	Arus	Daya	Kwh	Kg
2551	2023-09-18	07:05:27	88.45	0.65	57.45	181652	151
2552	2023-09-18	07:05:37	88.45	0.65	57.45	181652	151
2553	2023-09-18	07:05:47	88.43	0.65	57.45	181652	151
2554	2023-09-18	07:05:57	88.42	0.65	57.45	181652	151
2555	2023-09-18	07:06:07	88.4	0.645	57	181652	151
2556	2023-09-18	07:06:17	88.38	0.645	57	181652	151
2557	2023-09-18	07:06:27	88.32	0.64	56.5	181653	151

Figure 12. Detailed information in the form of graphs based on period settings

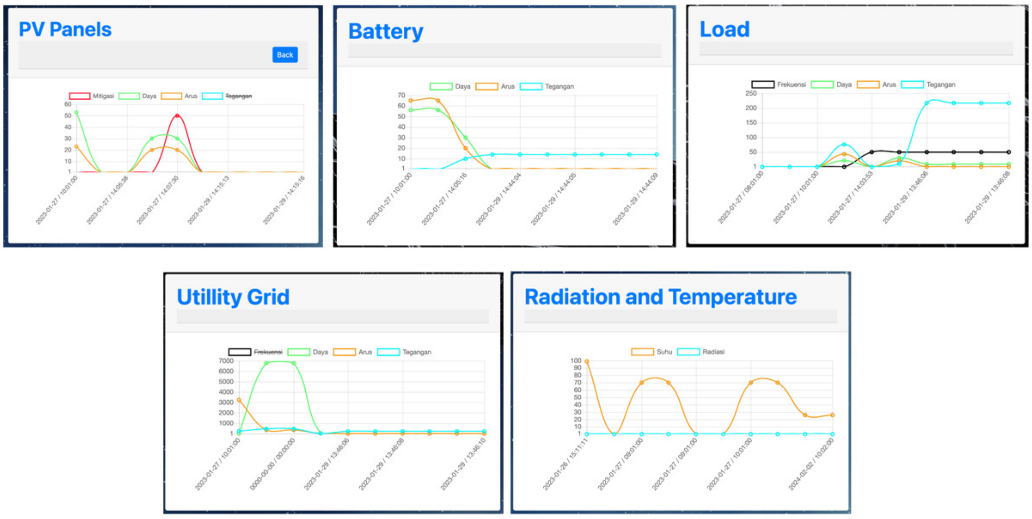

Figure 13. Visualization of panel, battery, load, utility grid radiation and temperature data

4. Conclusion

The development of the SMG monitoring system on solar PV has helped in improving the performance and maintenance of the grid so that it can maintain the stability of electricity supply to users. This monitoring system has been equipped with sensors, loT modules using WIFI, and web-based monitoring applications that allow the monitoring process to be carried out remotely by users. Data storage of monitoring results using data loggers and cloud in real-time with 5 data variables in each part of the PV panel, battery, load, and utility grid. The 5 variables include current, voltage, power, energy, and frequency data. This IoT-based SMG monitoring system has been applied to a micro grid installation system with a capacity of 1KW and runs well in real-time. The advantages and novelty of this monitoring system are in the ability to manage the supply of electrical power sourced from solar PV, batteries, and utility grid. The next research needs to be further developed on the implementation of artificial intelligence in improving the performance of the solar PV SMG monitoring system.

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