Fault Detection System and Smart Power Utilization Using IoT Monitoring for Photovoltaic System

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Abstract. Solar photovoltaic (PV) systems are the most widely renewable technologies used to generate power. In this paper, smart monitoring and fault detection on the off-grid solar system is proposed and designed to improve the solar PV system's operation more effectively. Environmental conditions, equipment interference, and changes in existing parameters normally cause problems in the system. A real-time monitoring system is required to monitor the performance of the solar PV system circuit. The internet of things (IoT) is used in this project to directly observe the energy in the system via an application platform. Also, this paper discussed solar PV system faults detection based on the difference in voltage and current values measured during usual and unusual periods based on parameters value. This project will reduce the time and effect in searching for faults in the solar system. The results show several categories, including open circuits and short circuits, are classified as faults in this system. In general, the fault detection system and smart power utilization using IoT monitoring for the photovoltaic system is the focus of this project's development.

INTRODUCTION

In the last decade, photovoltaic power generation has grown to become a significant power source. Even though solar PV systems have no moving parts and require low maintenance, the solar panel module, batteries, wiring, and other components are susceptible to failure. In a large PV array, it may become difficult to properly detect or identify a fault, which can remain hidden in the PV system until the whole system breaks down [1]. However, faults in a PV system's direct current side, such as open-circuit and short-circuit, are often difficult to avoid and result in system energy loss or even severe safety concerns. Hence, the development of a fault detection method for the solar PV system is particularly significant for improving the energy conversion efficiency of the PV system and reducing time faults searching area [2].

Previously conducted research identified methods for detecting faults such as comparing real-time operating parameters, using artificial intelligence algorithms, and analyzing mathematical models [3]. The SIM 900 GSM method detects and identifies faults by logging and monitoring data and transmitting it to the Internet via mobile networks [4]. Additionally, this system is capable of notifying the user via SMS. Besides that, a Human Machine Interface (HMI) screen was used as a monitoring platform for displaying real-time measurements from a solar photovoltaic (PV) system. To control the system's input and output data, the author utilized a CompactRIO module as the controller [5]. This technology is frequently found in high-performance embedded controllers.

The Internet of Things (IoT) enables communication and data collections among multiple devices, systems, and services, without human interaction [6]. Solar photovoltaic systems aren't far behind in utilizing IoT systems to improve performance and generate energy more efficiently [7]. Monitoring and fault detection can be easily detected using an IoT system and a direct monitor via an internet platform. This system works by using the Wi-Fi module to receive data from the microcontroller connected with various sensors via the internet. The received data can determine a normal and abnormal performance in a solar photovoltaic system. This paper proposes a fault detection method in solar PV systems based on the difference between the parameter value detection and the measurement of the components. The developed methods have been tested on an off-grid solar system under real fault conditions for performance testing purposes that include open circuit faults and short circuit faults.

SYSTEM DESIGN AND CONSTRUCTION

A block diagram is used to represent the layout and structure of the involved system. The design of the project will be described in Figure 1**.** This system consists of an IoT system, a monitor system, and PV system parts. ESP32 is the main microcontroller in this project system as intermediaries between provided and received signals. The ACS712 current sensor, the voltage sensor, and the temperature sensor (DS18B20) are used and powered by 5V DC power supplies. The sensors are installed between each component to measure the voltage and current in the solar circuit.

To trigger faulty in the solar system in this project 5V relay module has been used. The faults are identified based on the parameter's value that has been determined. The Blynk application serves as an IoT platform for storing and displaying data from sensing devices. Via a smartphone application connected to a Wi-Fi network, ESP32 data able be accessed. From that, the user of this smart system can monitor and notice if faults occur in the solar PV system when operating. The pop-up notification interface has been created when faults are detected on the wiring circuit. This project used the Arduino IDE software to create the code program for this system function.

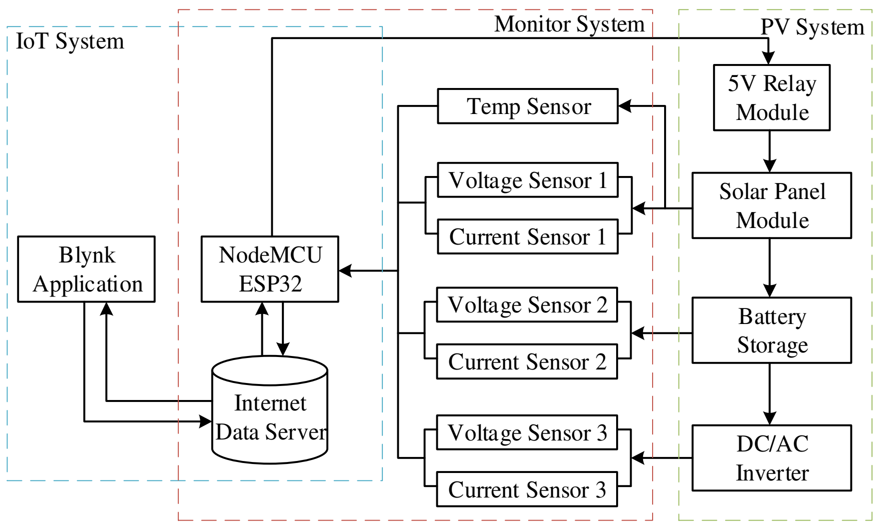

FIGURE 1. The block diagram of the project system

System Monitoring and Fault Detection Process

The flow chart of the Monitoring System and Faults Detection in the solar PV system for this project is shown in Figures 2 and 3, respectively. This flow chart illustrates how the solar PV system operates once the hardware is implemented.

The project flow chart are described based on two parts which are monitoring and fault detection. First, an ESP32 microcontroller module is connected to the Blynk app through Wi-Fi. The solar PV system's sensors send data to the microcontroller's analogue inputs, which read it and display it on the Blynk app and OLED display—the ESP32 communicates with the monitor system via serial connection.

The sensor reading data is kept in the Blynk data server and can be exported and examined on a computer using Microsoft Excel. The storage data is used to construct a graph chart to monitor the performance of solar PV systems. Besides, the frequent internet connection between the ESP32 and Blynk applications interrupted this data collection process, causing inconsistent data results.

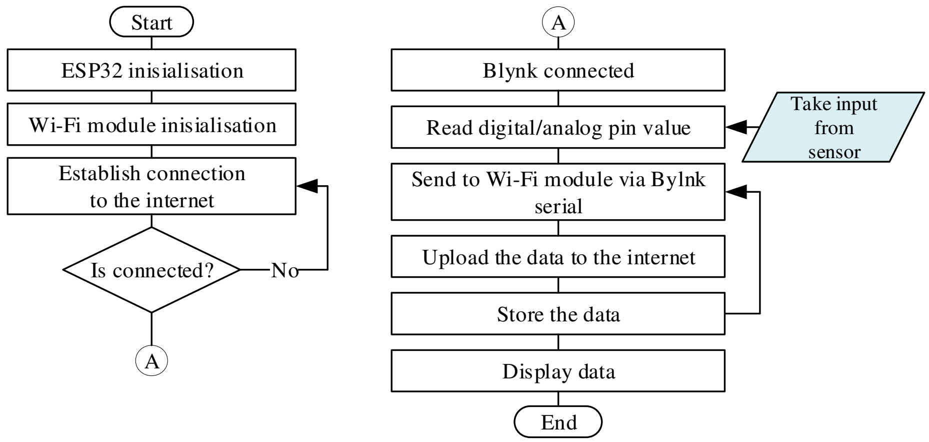

FIGURE 2. Monitoring Flowchart.

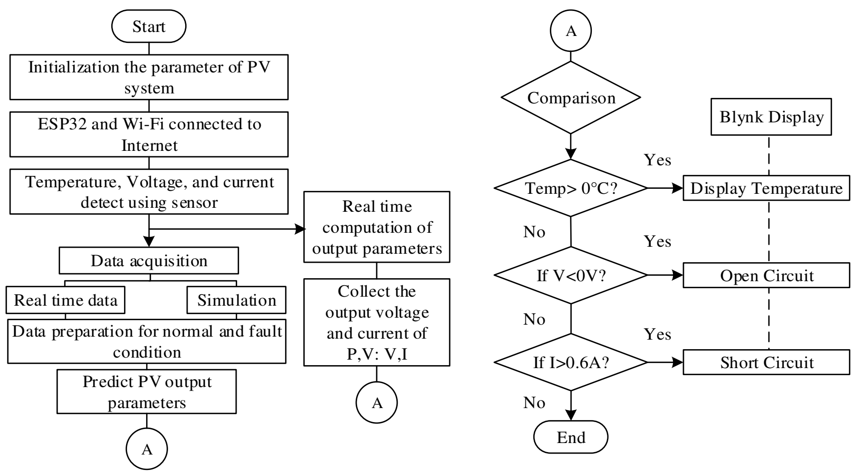

FIGURE 3. Flowchart of fault detection.

TABLE 1. List of components

Component	Item	Description
Off-Grid Solar	Solar Panel Module	10W, 18V, Poly
	Battery	12V, 7Ah
	DC MCB	1 Pole
	Inverter	PWM DC/AC
	Charge Controller	12V, 10A
Electronic Component	Microcontroller	NodeMCU ESP32
	Current Sensor	ACS712, 5A
	Voltage Sensor	0V-25V
	Relay	5V
	Display	OLED 128x64
	Temp Sensor	DS18B20
	Switch	Push Button

Hardware Development

The list of components for electrical and electronic parts of the system are tabulated in Table 1. The components include two parts for the off-grid solar system and electronic components to monitor the solar functioning. A DC circuit breaker is used to protect electrical devices that use direct current (DC) to make the solar system safer.

The Off-Grid solar wiring diagram is illustrated in Figure 4. A 10W, 18V solar panel is connected to a 10A charge controller in this wiring circuit, along with a 12V, 7Ah battery storage. Additionally, the solar charger controller featured USB ports and a 12V DC output compatible with direct current loads [8]. This controller purpose is to prevent overcharging or discharging the battery. This charger controller was straightforward and suitable for this project because it is easy to use in terms of setting and installation.

Additionally, the DC breaker served as a safeguard against component damage. This project utilized an off-grid photovoltaic solar system that usually requires a battery to store energy, allowing the system to operate without using an alternating current. The prototype's designation project was created to ensure that each electronic device is correctly connected and the prototype is able to perform as expected after the development process.

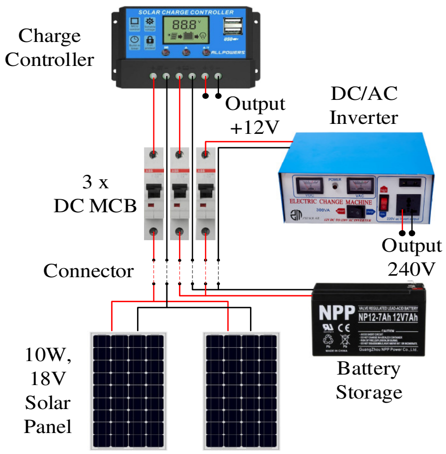

FIGURE 4. Off-Grid solar wiring diagram.

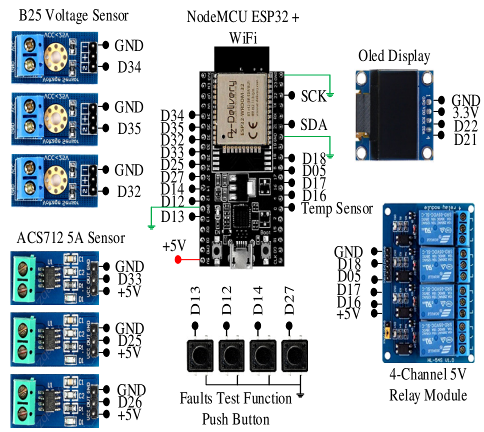

FIGURE 5. Off-Grid solar wiring diagram.

The connection diagram for the photovoltaic solar system is shown in Figure 5, which includes the ESP32 with B25 voltage sensor, the ACS712 current sensor, a push-button, a 5V 4-channel relay module, and an OLED screen display. This circuit is used to monitor and control the photovoltaic system's circuit. Additionally, the push-button acts as a fault-testing function.

Overall Design Circuit

Figure 6 shows the design circuit of the off-grid solar PV system with monitor and fault detection system. The monitoring and fault detection system is made up of numerous components which are ESP32 microcontroller, voltage, current, temperature sensors, and a 4-channel 5V relay module. The ESP32 receives a voltage and current signal from the solar panel, battery, and inverter and a control signal from a 5V relay module attached to the live component wire.

The coding programme activates the relay using the sensors and push-button (fault test function). The ESP32 interfaces with the Blynk app, monitoring the PV system's sensors. This application displays the types and locations of defects in the solar PV circuit. This application makes users more aware of the state of the solar operating system and as a result, the solar system is safer and more efficient.

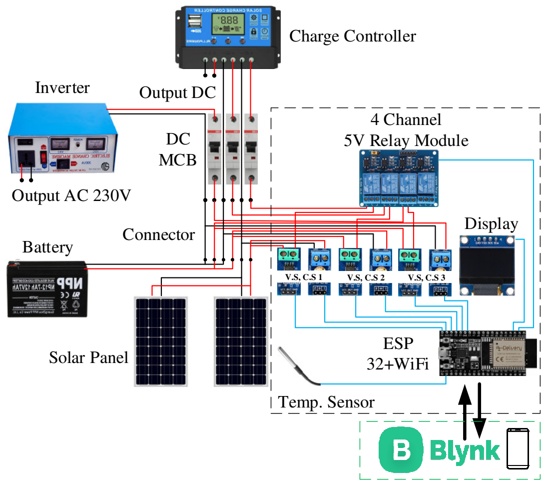

FIGURE 6. Design circuit of the project system

Software Development

Software development is required to be a part of this project to collect the data and information during the operating condition of the solar system. The software used in this project is Arduino software (IDE) and the Blynk application. The Blynk app provides the interface for monitoring and fault notification for users, while the Arduino IDE is required to construct and design the programming code. Figure 7 shows the interface of solar PV system monitoring and fault detecting with the Blynk application.

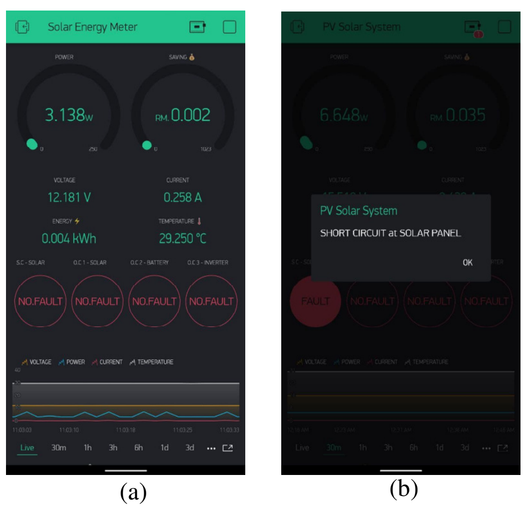

FIGURE 7. Blynk application interface (a) Monitoring parameter, and (b) Fault notification

Prototype Design and Setup

This hardware development began with installing an off-grid solar system, including a solar panel module, charger controller, DC miniature circuit breaker (MCB), battery storage, and PWM inverter. The push-button function for manually switching the 5V relay module from normally closed to normally open condition makes it easier to simulate short and open-circuit faults as fault tests in the solar PV system. The hardware's functionality was tested to ensure that it worked as expected and to show that the objective had been achieved. Figure 8 shows the final hardware development of the solar PV system.

Figure 9 shows the electronic components for monitoring and faults detection circuit using ESP32 microcontroller module. This circuit comprises voltage and current sensors that measure the voltage and current flowing from the solar panels, battery, and inverter line. These sensors measure the value from the components as an input signal to the ESP32 to display data on the Blynk application and OLED display using the serial communication method. A 4-channel 5V relay module is installed to trigger faults and disconnect the solar panel if a short circuit fault occurs to protect other components from damage.

FIGURE 8. Final design of the project

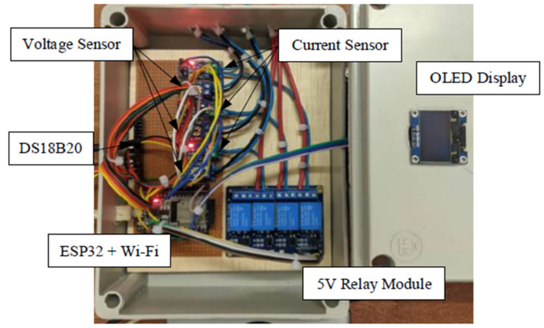

FIGURE 9. Display and control box

The faults parameter on the code program has been determined based on the comparison between normal state parameters to identify the type of faults in the operation system. At the same time, the Blynk application interfacing with the operating of the circuit. A notification from Blynk will appear informing users that faults have occurred in the solar PV system.

RESULTS AND DISCUSSION

The PV solar systems collected data results are taken for a few days at Kolej Kediaman Pagoh, UTHM, from 10 a.m. to 8 p.m. to monitor the solar system's performance. The real-time voltage and current readings are compared to the average state parameter values to classify the types of faults in the circuit system using the data collected during system operation. Figure 10 shows a photovoltaic (PV) solar system tested in direct sunlight.

FIGURE 10. Outdoor solar system testing

Normal State Solar Panel Chart

Based on the testing condition in Figure 10, the testing results are illustrated in Figure 11. Can be seen that the sun's irradiance might be one of the differences between these systems due to cloudy and sunny days while testing a solar PV system. Thus, the measured results may not be as accurate to compare when the current sensor and ESP32 had an issue with the current scale, offset current, and pins analog problem. This issue can be solved by modifying the scale value on the calculation function at the programming code level.

Using the Blynk application, the reading should be the same as manually measured using a multimeter, at the solar panel module. The results displayed the reading value for the solar photovoltaic system's operation data on the solar panel components. The user can export the data stored on the Blynk server into MS Excel format using a computer and then construct the graph chart.

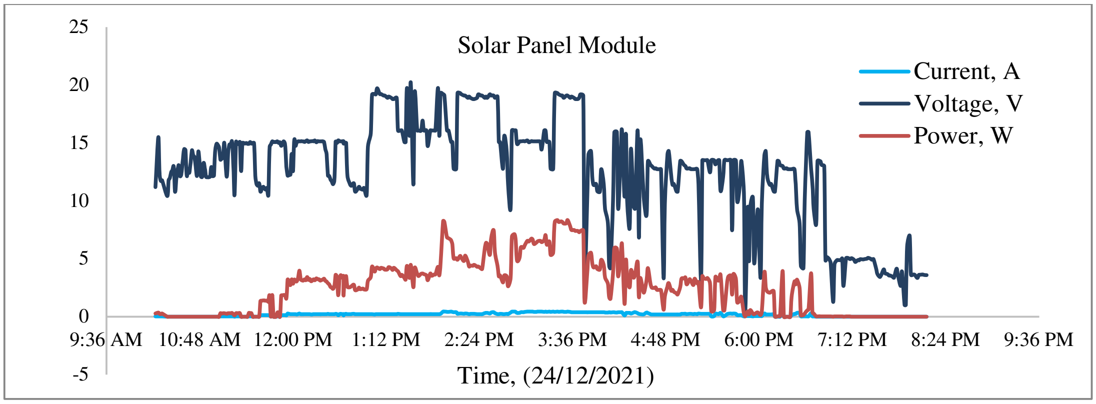

FIGURE 11. Voltage, current and power measured from solar panel

Table 2 shows the parameter value identified based on the testing that has been done to determine the maximum operating point of this system. The code program function will use this parameter as a reference to classify the faults. The tolerance of this solar panel was ±6% according to the datasheet of this panel specification. The graph in Figure 11 shows that power able started to generate around 12.30 a.m. to 4.00 p.m., and recorded the maximum power of 8W that day.

TABLE 2. Parameter of PV solar system

Parameter	Spec. Model	Value
Maximum Power (Pmax)	10W	8W
Voltage at Pmax (Vmp)	18W	21V
Current at Pmax (Imp)	0.55A	0.43A
Short-Circuit Current (Isc)	0.6A	0.6A
Power Tolerance	±6%	±6%

However, unstable current affects the power reading measure due to the ACS712 current sensor issue. The maximum current recorded in the system is 0.43A since the high solar radiation generates at the noon periods. In theory, the higher the irradiance, the higher the maximum voltage and current obtained [9]. The voltage of the solar panel is easier to measure than the current because voltages can flow over longer distances than currents due to lower resistive losses. The current value generated by the solar panel is too small, causing the current sensor to be unstable and not read the exact value. As a result, method improvements are necessary for future implementation.

Normal State Battery and Inverter Chart

Figure 12 shows the voltage measure readings from the battery storage and the inverter. The battery voltage value based on its specifications is 12V, 7Ah, but after conducting tests, it can reach a maximum of 13.50V. Similarly, the inverter's voltage should be the same as the battery's voltage because the inverter's power is dependent on the battery power since they are connected in parallel. The maximum voltage measure reading by the Blynk app is 12.94V, while the maximum reading of the inverter is 12.78V.

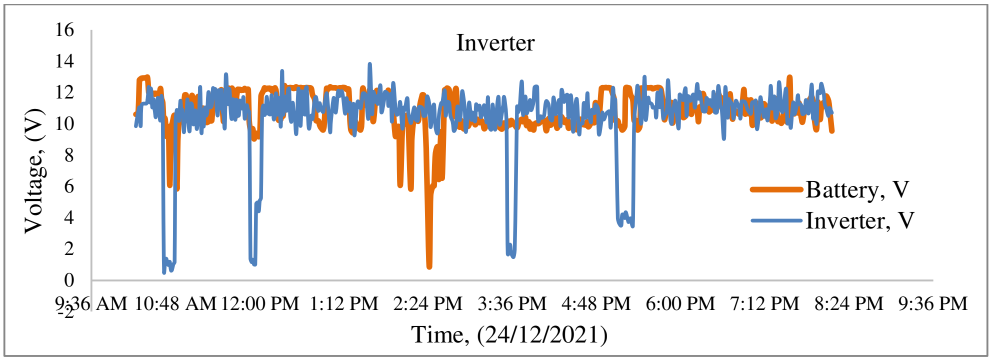

FIGURE 12. Voltage reading on battery and inverter

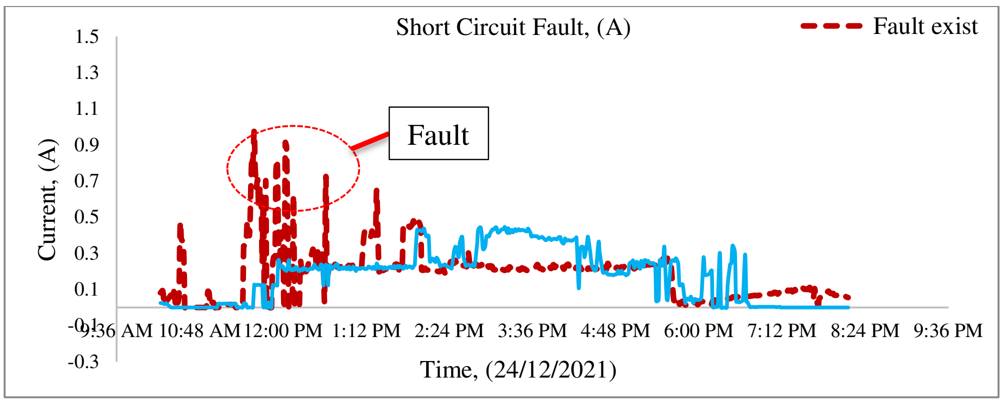

FIGURE 13. Short circuit current (fault) occur at solar panel module part

Short Circuit Fault

Figure 13 shows the current flowing through a solar panel module during a short circuit. When the current value exceeds 0.6A, which is greater than the current parameters defined in the code programme, a fault occurs. This could be because solar panels received a high amount of solar radiation and heat during that period. Additionally, the push-button was used to switch the relay, simulating this fault by shorting the positive and negative terminals, as waiting for it to occur naturally is more difficult.

The higher current sensor recorded was 0.97A when a short circuit happened. Figure 14 shows the interface of the Blynk app when faults happened in the solar circuit. The pop-up notification will appear on the mobile screen showing "SHORT CIRCUIT at SOLAR PANEL". The widget also turns red when a notice fault occurs in the solar system.

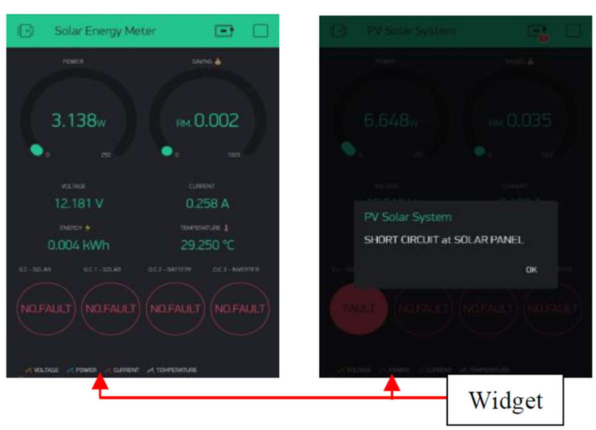

FIGURE 14. Short circuit fault on Solar Panel notification via Blynk interface

Open Circuit Fault – Testing on Solar Panel Fault

Figure 15 shows the difference between two voltage graphs measured by the solar panel's voltage sensor. This fault occurred when the solar panel module did not receive enough irradiance to generate power. Otherwise, the voltage becomes 0V when push-button (fault test function) is used to simulate the fault as observation for the solar PV system functionality.

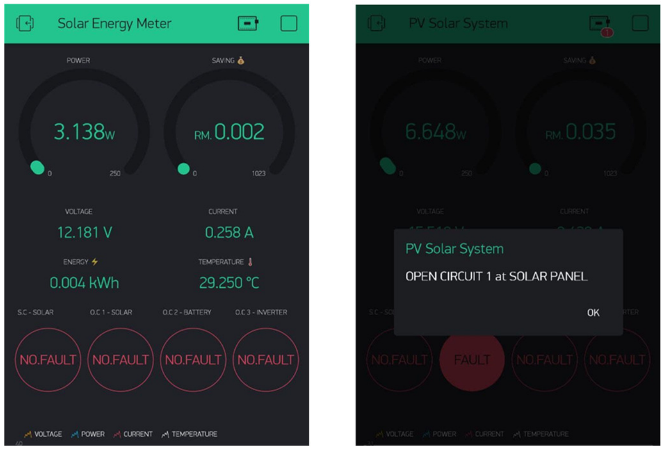

FIGURE 15. Open-circuit fault at Solar Panel notification via Blynk application

The real-time reading graph must be lower than the normal reading in sunny weather. The graph shows, the longest faults happen between 1.30 p.m. and 3.00 p.m. and several times afterwards. When the faults happened, the voltage was 0V because the solar system could not operate efficiently due to a fault. The interface of the Blynk app is shown in Figure 16. The text "OPEN CIRCUIT 1 at SOLAR PANEL" will appear on the mobile screen, indicating a fault in the solar circuit.

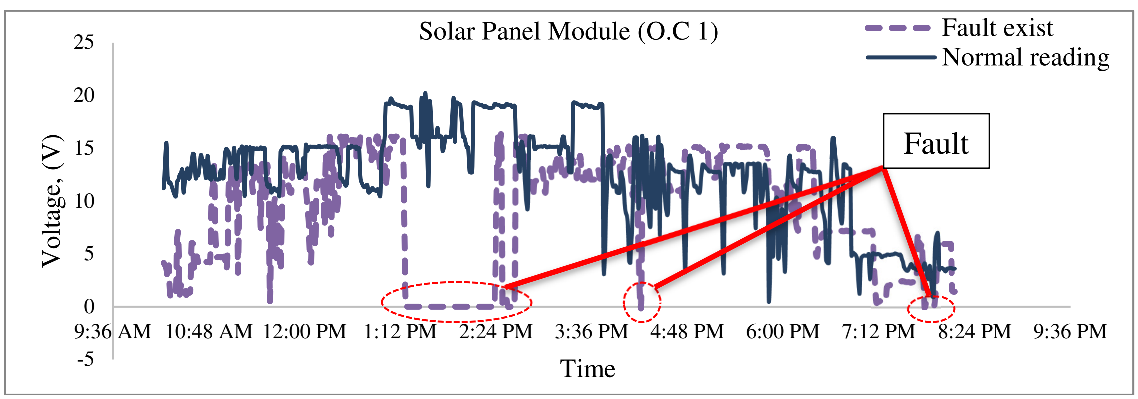

FIGURE 16. Open-circuit graph occur at Solar Panel module part

Open Circuit Fault – Testing on Battery Fault

Generally, using a single battery reduces the risk of this part failing due to the lack of a complicated connection. However, the connection between the batteries may cause a fault, as a connection fault or a poor connection at the battery terminals may result in the solar system failing to function properly. When the battery is fully charged, short circuits on the battery side can damage another component, resulting in excessive voltage and current. The relay module and the battery are wired in series.

When the voltage falls below 0 volts, the relay switches from a normally closed to a normally open state, activating the fault function. This is due to the voltage difference between real-time measurements and the parameter setup value.

When this fault occurs, the battery charging time is temporarily stopped because the voltage reading on that moment is 0V.

A pushbutton has been added to test for this fault that signals the relay module to change its state. The relay will automatically disconnect the battery from the wiring circuit of the solar photovoltaic system and cause the open-circuit fault.

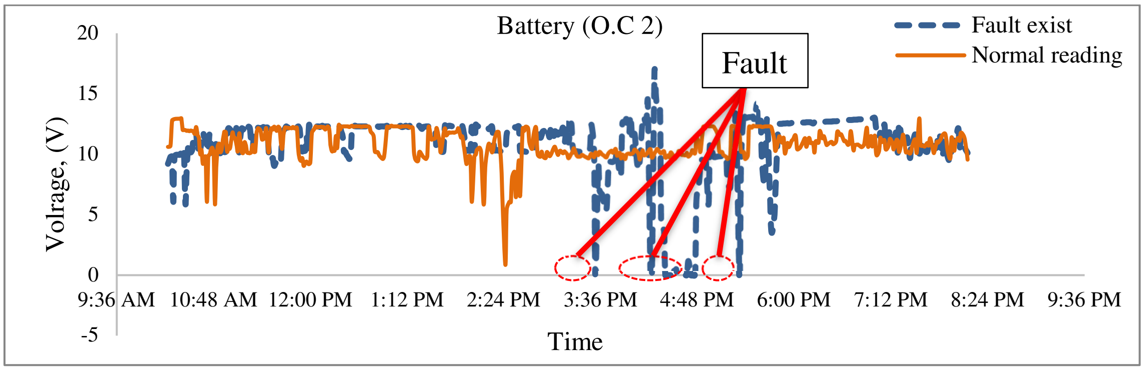

FIGURE 17. Open-circuit graph occur at Battery part

Figure 17 and Figure 18 show the battery voltage graph measuring between the normal and fault existing in the solar circuit system and the notification screen from the Blynk application showing "OPEN CIRCUIT 2 at BATTERY".

Open Circuit Fault – Testing on Inverter Fault

This project used an inverter to convert 12V DC to 230V AC power. The chances of a fault occurring are the same as the battery because the inverter is directly connected. The voltage received by the inverter is the same as the voltage by the battery. A faulty connection between the inverter and the battery was demonstrated using push-button (test fault function). Thus, the result shows voltage change on the inverter becomes 0V because the power source from the battery has been disconnected.

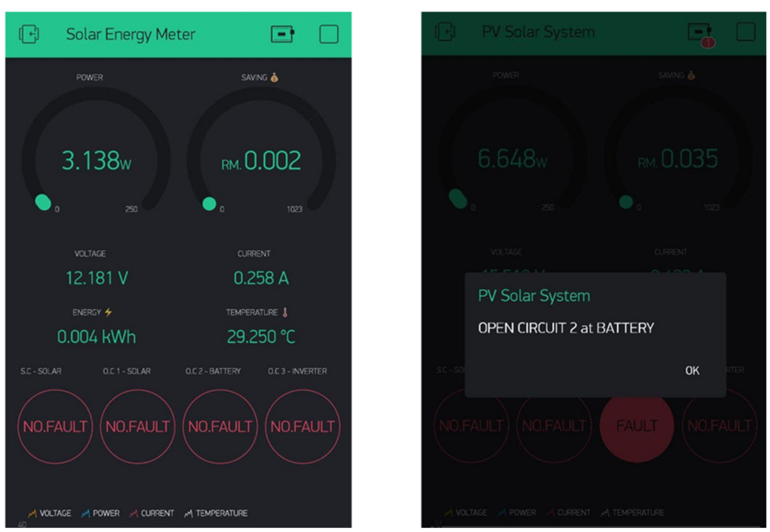

FIGURE 18. Open-circuit 2 fault at Battery notification via Blynk application

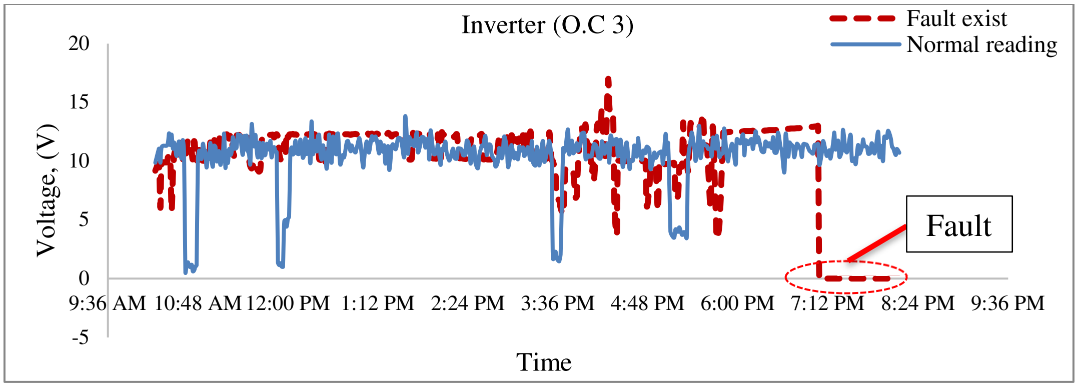

FIGURE 19. Open-circuit graph occur at Inverter part

Thus Figure 19 shows the graph reading of the open circuit fault on the inverter, and Figure 20 shows the Blynk app notification fault that occurs at the inverter part showing "OPEN CIRCUIT 3 at INVERTER".

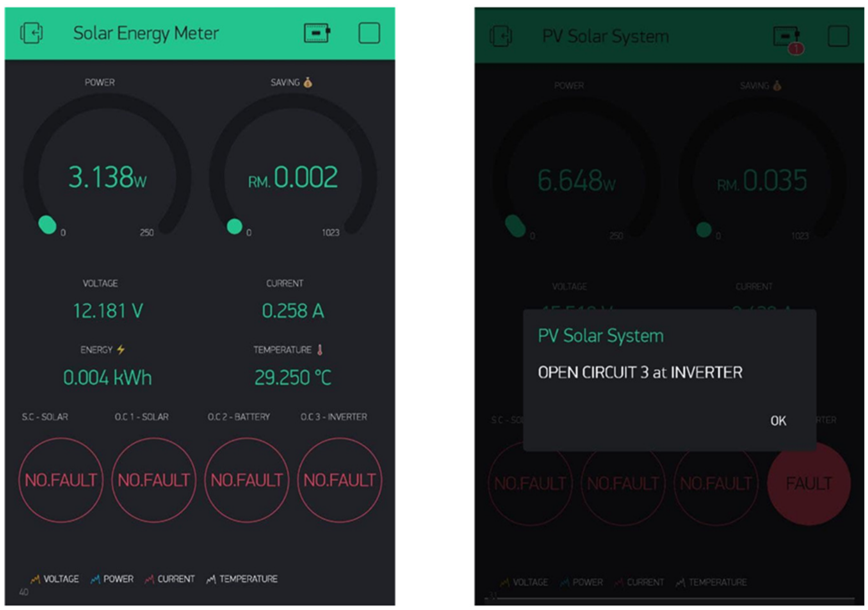

FIGURE 20. Open-circuit 3 fault at Inverter notification via Blynk application

CONCLUSION

In conclusion, a Fault Detection System and Smart Power Utilization Using IoT Monitoring for Photovoltaic Systems has been developed successfully. This project has been chosen as the primary focus for developing an effective solar photovoltaic (PV) system. A fault detection method based on voltage and current observation and comparison has been employed to identify faults of the solar PV system. Results show that this method can detect different fault types for the solar PV system. Although the proposed method met the expected fault detection objective, an improved fault detection method will be required when the photovoltaic system's parameter values change over time.

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