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Design of a 20 wp solar panel DC power monitoring system based on the internet of things

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Abstract: The role of solar panels is to transform solar energy into electrical energy. The process of monitoring solar panel output is still done in the traditional manner, which takes a lot of time and produces less reliable data. In order to solve this issue, a system that can track data produced by solar panels in real time and remotely via an application has been developed. With the help of the Internet of Things (IoT), this monitoring system, which makes use of a 20 WP solar panel, will show data in the form of readings of light intensity, voltage, current, and applications made with MIT App Inventor that use real-time databases on Firebase and the ESP32, and that are powered by DC power. Several tests were run on sending data to customers in this study while looking for the delay value. The solar panel's output voltage is measured against the greatest value for sunshine intensity, and output is also measured with and without a 12V DC lamp load on the battery. With an average time of 18.01 seconds, the data monitoring results were obtained to inform consumers. The highest value occurred at 12.00 WIB with an intensity of 54,588 lux and a solar panel output voltage of 20.01 volts. When the battery's output is measured without a load, it averages 12.56 volts, 0.02 amps, and 0.2 watts; when the battery's output is measured with a 12 volts direct current light load, it averages 11.98 volts, 0.40 amps, and 4.8 watts. Real-time monitoring of solar panel dc power is substantially facilitated by this monitoring method.

Keywords: Solar panel; INA219 sensor data; ESP32 microcontroller; Internet of Things; Mit App Inventor

1. INTRODUCTION

By using solar energy, solar panels, a renewable energy source, can lower the rise in CO2 output [1]. The role of solar panels is to transform solar energy into electrical energy. The amount of energy produced by solar panels depends on environmental factors such light intensity, temperature, sunlight direction, and spectrum. The output power of solar panels changes over time as a result of the ever-changing environmental circumstances [2]. Direct monitoring of a solar panel's output parameters, such as voltage, current, and power, can be used to assess how well it performs in a given environment [3][4]. Effective supervision and monitoring of solar panel DC power systems are crucial for maximizing the use of solar energy. Typically, using a multimeter at the place where the solar panels are located, monitoring and measuring the parameters produced by solar panels is done in a conventional manner. As a result, this approach is less effective, laborious, and unable to obtain data under the required circumstances [4]. The Internet of Things (IoT) has emerged as one of the most alluring approaches to effectively link and monitor gadgets thanks to advancements in communication and network technology [5].

The objective of this research is to increase the functionality and connectivity of the constantly connected internet [6]. Aim to provide an IoT-based panel DC power monitoring system that can deliver precise, real-time monitoring of solar panel performance through a mobile application [7].

IoT-based solar panel monitoring systems have been covered in a number of earlier studies. Previously, webpages, Telegram applications, and Blynk applications were used for monitoring. The online system functions effectively and can use a web server to display current, voltage, and power in real time, according to research titled Solar Panel Monitoring System [8]. However, they continue to use the website to display the data, making it less adaptable for new users to view measurement data. In accordance with a study titled Design and Build of Current and Voltage Monitoring in PLTS

Internet of Things (IoT) Based on Grid Systems Using the Telegram Application. To monitor the current and voltage in the PLTS system, the system is already in operation [9]. However, it is done as part of the process of measuring the current and voltage values in accordance with the calling order. As a result, the read data is sent after a delay. A Prototype Current and Voltage Monitoring System for IoT-Based Solar Panels is the result of subsequent research. Through the use of the Blynk Application, the system is capable of displaying data in real time [10]. The free version of the Blynk program can only be used with a certain number of devices per project. As a result, adding users to the monitoring system is challenging.

Many have used the Internet of Things (IoT), but the blynk application is still used to monitor the power produced by solar panels, according to many surveys. There are only a few devices utilized in one project and this application still relies on the blynk website.

In this study, a monitoring system was created using MIT App Inventor to create a smartphone app with the name "20 WP Solar Panel DC Power Monitoring System Based on the Internet of Things (IoT)" that can provide accurate and real-time performance data tracking. a solar cell. System owners can access the data required to monitor light intensity, voltage, current, and dc power generated and be able to identify issues or damage to solar panels to maximize energy efficiency by integrating sensors installed on solar panels and sending data via the internet network.

2. METHOD

The approach taken in this study is to create a prototype tool while conducting a literature review on studies pertinent to the tool being created. Following the acquisition of various literature studies, the hardware and software for the system were designed and manufactured. Start the testing from the system, hardware, and software after the hardware and software devices have been created. Collect data and perform a test analysis of the data that has been received if the entire system has been tested, as shown in **Figure 1**.

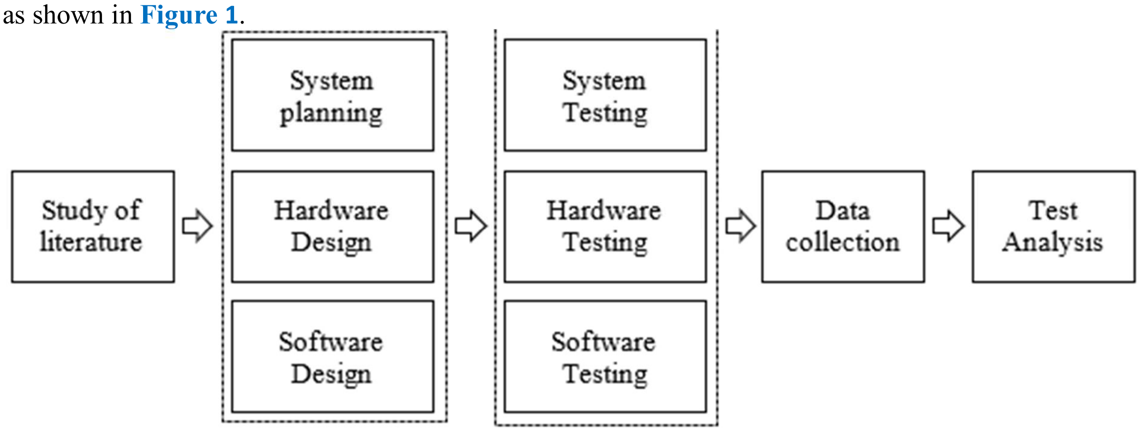

Figure 1. Research execution strategy

This study was carried out in an open space, such as a field, where solar panels can receive sunlight unhindered. This study was carried out between 8:00 and 17:00 WIB. The 20 WP Solar Panel DC Power Monitoring System Based on the Internet of Things investigation used the following materials and equipment:

a. 20WP solar panel
b. Digital volt-amp meter
c. Light intensity sensor module (BH1750)
d. Current and voltage sensor module (INA219)
e. ESP32 microcontroller module
f. PWM SCC (Solar Charge Controller) Module
g. Deep cycle battery
h. Smartphones
i. Application designed by MIT App Inventor
j. Google firebase platform as cloud

2.1 System design

Figure 2 block diagram, which is used to explain the system design of the "20 WP Solar Panel DC Power Monitoring based on IoT" in detail, seeks to make it simpler to comprehend how the monitoring system functions. Three distinct components, input, process, and output, make up this system block diagram. Each component and component in the diagram play a part in how this tool functions.

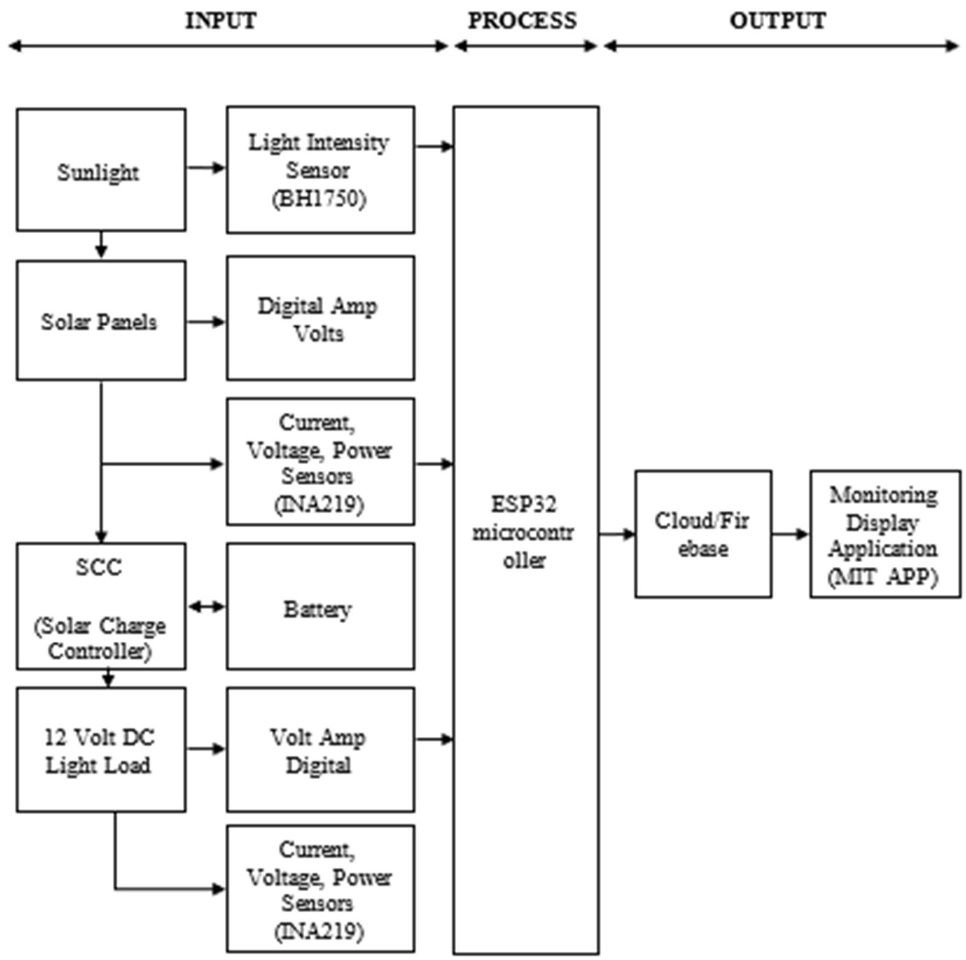

Figure 2. Block schematic of an Internet of Things-based 20 wp solar panel dc power monitoring system.

Figure 2, the input portion includes a light intensity sensor to measure the amount of sunlight that the solar panel receives, two power sensors to measure the voltage that the solar panel produces as an output, and voltage, current, and power utilized both when there is no load and when a 12 volt dc lamp load is present. The ESP32 microcontroller serves as the system's processing input for sensor data, and after the data has been processed, the sensor sends the processed data to Firebase, which receives real-time data on sensor readings. The MIT App application serves as the system's output, receiving sensor data and displaying it on a smartphone in real-time.

2.2 Hardware design

The hardware architecture for the IoT-Based 20 WP Solar Panel DC Power Monitoring System is depicted in **Figure 3** as an outline. where solar panels will later transform solar-generated light energy into electrical energy. Sensors will measure the electrical energy, including voltage, current, and power, and send the information to the smartphone after being processed by the microcontroller. The smartphone will show solar panel monitoring data, including light intensity, voltage, current, and power.

Each component of the pin utilized in the circuit for the IoT-Based 20 WP Solar Panel DC Power Monitoring System is described in detail in **Figure 4**. On solar panels, there is a sensor (BH1750) that measures light intensity. This sensor operates with a 3.3 volt operating voltage [11] This will be derived from the voltage supplied on the ESP32 microcontroller's output pin while delivering digital data via the SCL and SCA pins to the microcontroller to send data about light intensity. In order to monitor voltage, current, and power, a digital volt-amp meter and an INA219 sensor that is mounted in parallel with the positive and negative poles of the solar panel are connected to the SCC PWM. The solar panel will gather solar energy from the sun and convert it into electrical energy.

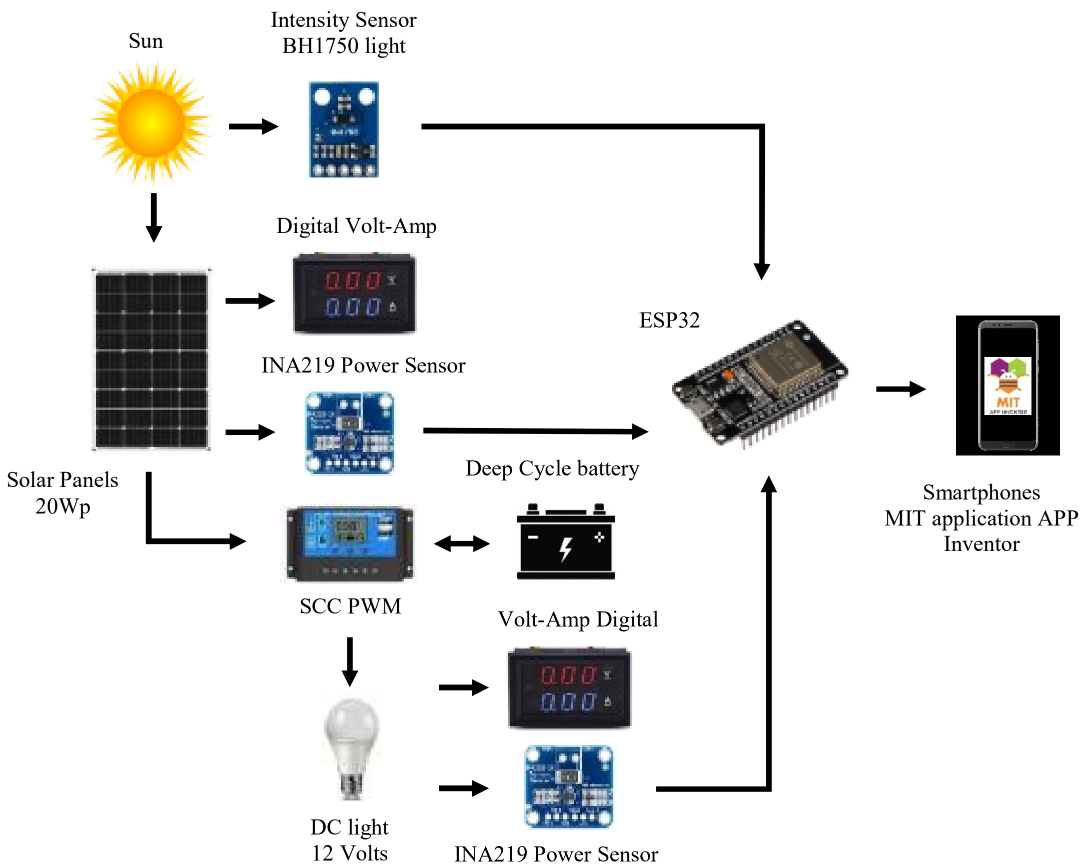

Figure 3. Design for a 20 watts solar panel dc power monitoring system based on the internet of things

Solar Charge Controller Pulse Width Modulation is referred to as SCC PWM. The solar panel controller (SCC PWM) controls the solar panel battery's current to prevent sudden drops in battery voltage and to prevent reverse current, or, to put it another way, acts as a safeguard against solar panel overcharging [12]. The INA219 sensor operates at a voltage of 5 volts, which is supplied by the EPS32 microcontroller. Sensor data is sent to the ESP32 using digital signals via the SCL and SDA pins [13]. The positive and negative poles of a 12 Volt battery will be connected to the SCC PWM in order to store the energy produced by the solar panels. Deep cycle batteries, which have thick interior plates, are the kind of battery that are used. Step-down dc is used to reduce the voltage from 12 Volts to 5 Volts so that the 12 Volt battery can power the ESP32 microcontroller, which requires a working voltage of 5 Volts, as well as 12 Volt dc light loads. A digital volt-amp meter and the INA219 sensor, which uses the same methodology as measuring the voltage generated by solar panels, will be used to monitor the voltage, current, and power consumed in the 12 Volt light load.

The ESP 32 microcontroller was used in the creation of this tool since it has various features with minimal power consumption and already has Wi-Fi and Bluetooth minimal Energy (BLE) installed on the board [14][15][16].

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An IoT-based 20 WP solar panel DC power monitoring system hardware design flowchart is shown in Figure 5. It begins by determining whether the solar panel is operational. The next step is to determine whether the hardware of the monitoring system is linked to the internet whether it is operating properly. The sensor data collection operation will continue while it waits for an internet connection.

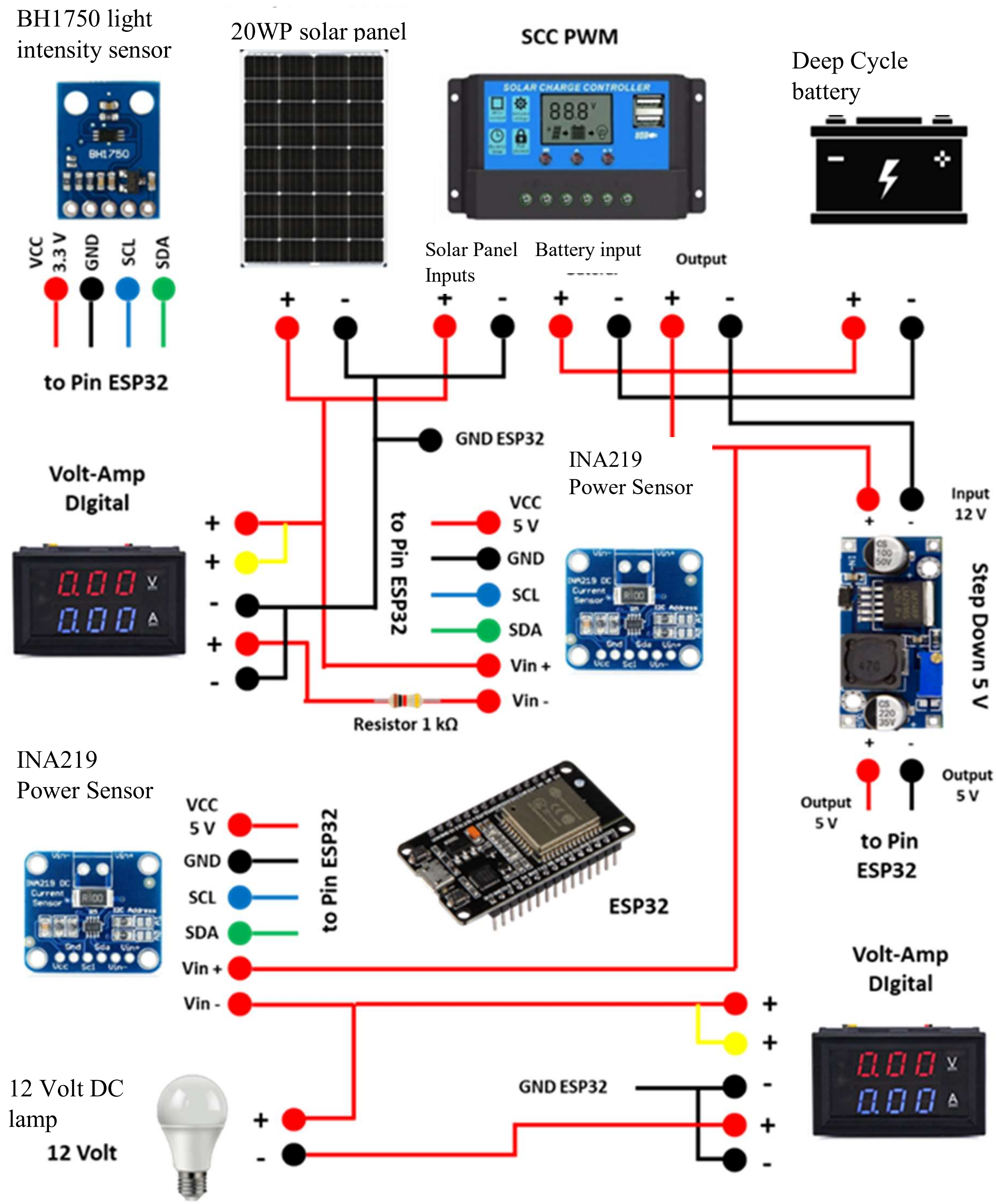

Figure 4. Details of the IoT-based 20 wp solar panel dc power monitoring system circuit

The Arduino IDE v2.0.0 was used to develop the software code that the system used automatically to do the sensing procedure. Voltage, current, power, and light intensity measurement data are first received by the microcontroller and then sent to Firebase via the API address to the Firebase real-time database.

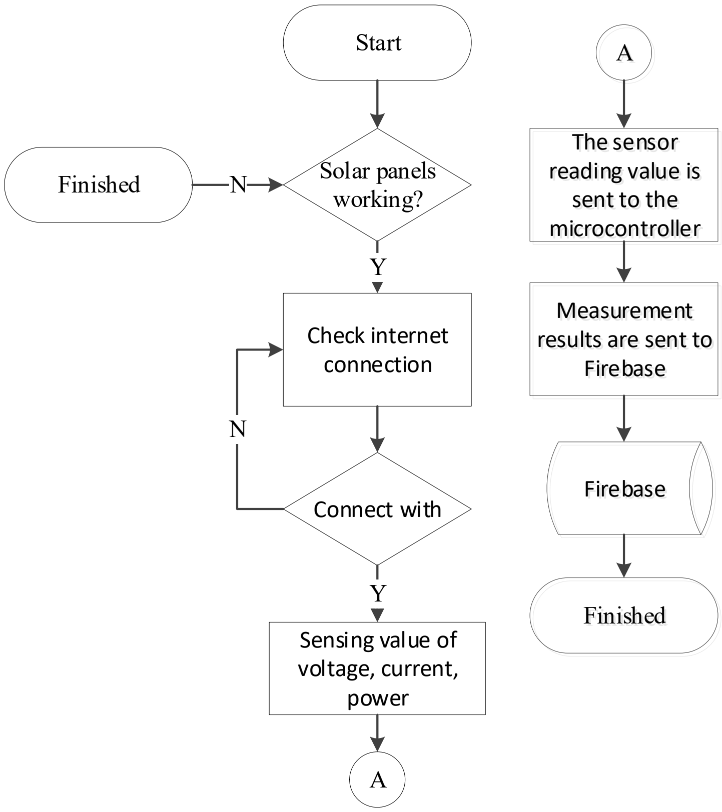

Figure 5. Flowchart of IOT-based 20 wp solar panel dc power monitoring system hardware design.

2.3 Software design

To obtain real-time data, software design is carried out by building a real-time database on the Firebase platform. A real-time database linked to the internet is shown in **Figure 6** together with a microcontroller. Firebase will appear in that location in accordance with the required output as specified by the program in the Arduino IDE.

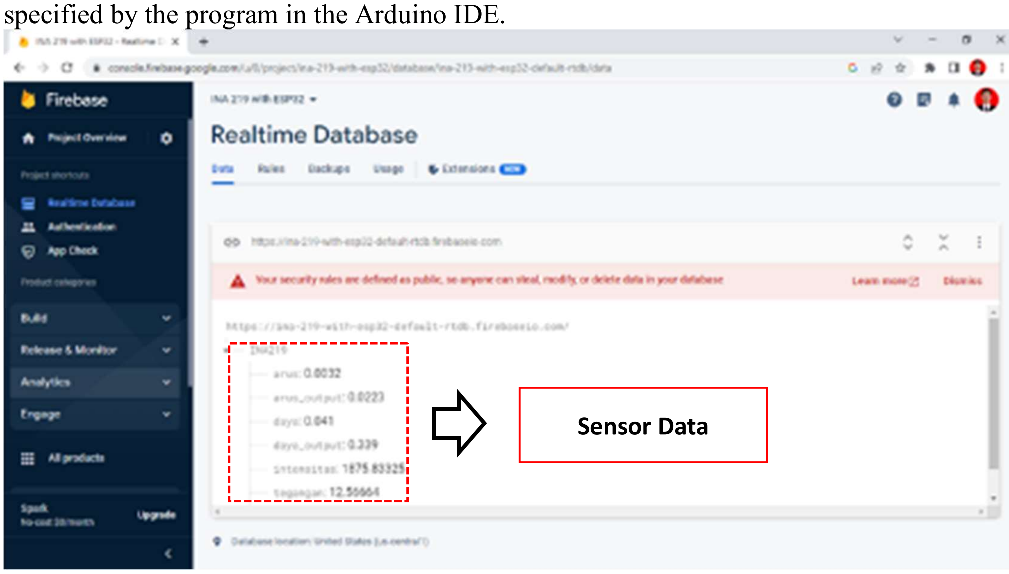

Figure 6. Making a firebase realtime database

Token codes and linkages to real-time databases that will be programmed in ESP32 and the MIT App Inventor program are available through Firebase. in order for the MIT App Inventor application to show firebase real-time output [17].

Figure 7 illustrates a project for creating a smartphone interface using the MIT App Inventor platform. This design is developed specifically to meet the user's demands and preferences for the display of the monitoring application later. In this monitoring application, monitoring of voltage, current, power, and light intensity on solar panels is displayed visually. For later presentation of real-time sensor measurement data, the MIT App Inventor program connects to the Firebase real-time database via the internet.

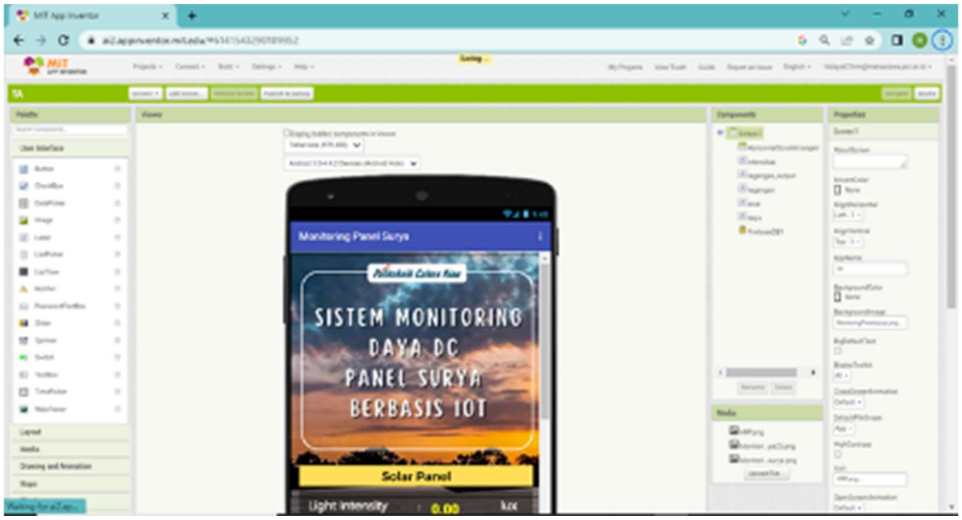

Figure 7. Making the MIT App Inventor interface design

On the MIT App Inventor platform, programs are composed of logically connected program blocks that alter output in accordance with design specifications. Voltage, current, power, and light intensity values are retrieved from real-time Firebase by display program blocks created in the MIT App Inventor application.

In the past, plans were made to add Firebase, the token code, and the Firebase connection throughout the interface design process. The data will be presented in the text box in accordance with the initials of each sensor when the application calls the firebase data. Programming is done in program blocks to display data that can change and is programmed to display a 2-digit value after the comma since the sensor data that is called will always change. This feature makes the application's display as large as possible later.

A software design flowchart is shown in Figure 8 and begins with initializing Firebase to create a project on the Firebase platform. After initializing, the process checks to see if the data on Firebase has been read; if not, it waits until Firebase receives a value; and if it has, MIT App Inventor calls Firebase Realtime Data Value and displays it in the MIT App Inventor application.

Testing the performance of the created tools is necessary once all hardware and software designs have been put together and thoroughly examined. The energy sources (solar panels) are tested for current and voltage.

Once all of the hardware and software designs have been assembled and thoroughly reviewed, it is vital to test the functionality of the developed tools. Current and voltage measurements are made on the energy sources (solar panels):

a. Measures the delay in sending data from sensors to the MIT App Inventor application.
b. Measuring solar panel voltage using the INA219 sensor and light intensity with the BH1750 sensor. At various intervals, measurements of solar panel voltage and light intensity are made.
c. Using the INA219 sensor to measure voltage, current, and power at the battery output without a 12V DC lamp load. Without a 12V DC lamp load, measurements of voltage, current, and power at the battery output were made using the INA219 sensor at various time intervals.

INA219 sensor measurement of voltage, current, and power at battery output with a 12V DC lamp load At various time intervals, the INA219 sensor with a 12V DC lamp load measures voltage, current, and power at the battery output.

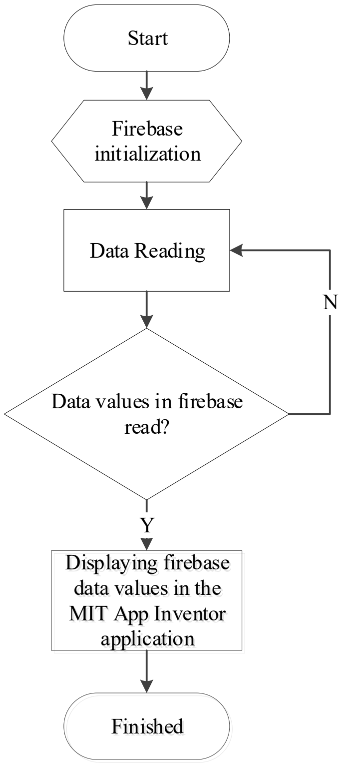

Figure 8. Software design flowchart

This research was conducted away from home in order to test the tools and collect the data. The "Internet of Things (IoT)-based Solar Panel DC Power Monitoring System" research produces outputs such as current, voltage, and light intensity.

3. RESULTS AND DISCUSSION

3.1 Hardware and software implementation

An IoT-based solar panel monitoring system tool prototype is shown in **Figure 9**, and it is made to be portable to make data gathering and the demo process easier. By displaying monitoring data on a smartphone application, this tool aims to determine how well a 20 WP solar panel performs when converting solar energy into electricity between the hours of 8:00 and 17:00.

Figure 9. Prototype of an IoT-based solar panel monitoring system tool

The solar panel monitoring system makes use of a battery with a 12 V 7 A capacity and a 20 WP solar panel. **Figure 10** illustrates how hardware components are implemented on the PCB.

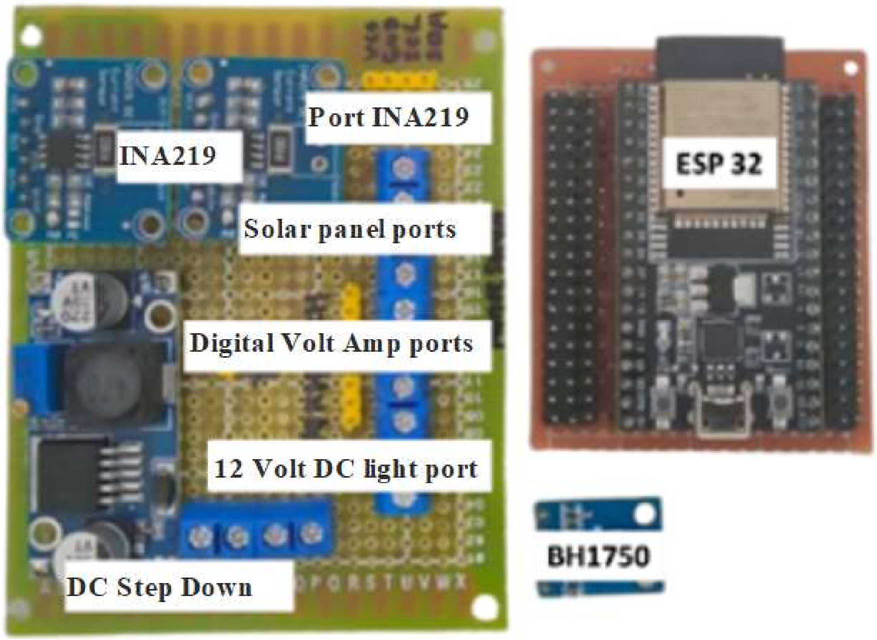

Figure 10. Hardware implementation on PCB

Figure 11 shows the interface display for the MIT App Inventor-based "IoT-based DC 20 WP Solar Panel Power Monitoring System" application. Whereas the battery section of the application will display voltage, current, and power, and the solar panel section will display statistics on light intensity and output voltage. Users can simultaneously track values measured in real-time on solar panels and batteries through this display.

Figure 11. Solar panel monitoring interface application using MIT App Inventor

3.2 System and device testing

3.2.1 Measures the time it takes for sensors to communicate data to the MIT App Inventor program.

In this test, we determined how long it took for data to be sent from Firebase's real-time database to the MIT App Inventor application. where the test is run to keep track of the user's average delay value.

Table 1. Delivery time monitoring

Testing	Network Connected	Database Validation	Submission to MIT App Inventor	Total Activation Time
Number 1	10,16	4,66	3,98	18,8
Number 2	9,23	4,3	3,91	17,44
Number 3	10,29	4,2	3,95	18,44
Number 4	8,51	4,68	3,88	17,07
Number 5	7,66	4,52	3,85	16,03
Number 6	11,32	4,76	4,03	20,22
Number 7	8,56	4,41	3,76	16,73
Number 8	11,95	4,55	3,86	10,36
Number 9	10,09	4,61	3,93	18,63
Number 10	8,32	4,42	3,77	16,51
Average	**9,6**	**4,51**	**3,89**	**18,01**

Table 1 contains data gathered ten times from the time to connect to the network, database validation, and sending databases to MIT App Inventor obtained for an average duration of 18, 01 sec. This data is used to test the time of transferring data from sensors to the MIT App Inventor application. It can be observed from the test results on data linked to the network that a large time difference is achieved that affects the overall activation time, thus for an average total sending value of 18.01 seconds, this is a typical period where this will influence the internet network when it is used.

3.2.2 Monitoring of Light Intensity Using the BH1750 Sensor and Solar Panel Output Voltage using the INA219 Sensor

The BH1750 sensor and INA219 sensor are used to monitor light intensity and solar panel voltage. While the monitoring data are shown in **Table 2**, different monitoring operations were carried out at various times.

Table 2. Monitoring of light intensity using the BH1750 sensor and solar panel voltage using the INA219 sensor

Testing Time	Sunlight Intensity	Solar Panel Output Voltage 20 WP		
		Voltage	Current	Power
	Lux	V	A	W
08.00	5.742	16,94	0,01	0,17
09.00	10.798	17,02	0,01	0,17
10.00	22.778	17,89	0,02	0,36
11.00	29.142	19,21	0,01	0,19
12.00	54.588	20,01	0,01	0,2
13.00	25.412	18,39	0,01	0,18
14.00	24.223	18,15	0,01	0,17
15.00	5.557	16,02	0,02	0,32
16.00	3.152	15,75	0,01	0,16
17.00	1.834	15,34	0,01	0,1315
Average	18.322	17,47	0,01	0,21

The highest light intensity and voltage values are recorded at 12.00 WIB with a light intensity of 54,588 lux and a voltage of 12.56 volts, while the average voltage produced is 17.47 volts, according **Table 2** of monitoring data for light intensity and voltage output of a 20 WP solar panel conducted from 08.00 to 17.00. This might speed up the process of charging the battery with a 12 volts capacity.

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3.2.3 Monitoring the current and voltage at the battery output using the INA219 sensor without light load

The INA219 sensor is used to monitor voltage, current, and power at the battery output without light load. While the monitoring outcomes are shown in **Table 3**, these monitoring actions were carried out at various times.

Table 3. Monitoring of solar panel current and voltage at battery output using the INA 219 sensor without lamp load

Testing Time	No-Load Battery Output Voltage V	Current A	Power W
08.00	12,55	0,02	0,25
09.00	12,58	0,01	0,13
10.00	12,56	0,02	0,25
11.00	12,54	0,02	0,25
12.00	12,57	0,01	0,13
13.00	12,55	0,02	0,25
14.00	12,54	0,01	0,13
15.00	12,56	0,01	0,13
16.00	12,58	0,02	0,25
17.00	12,54	0,02	0,25
Average	12,56	0,02	0,2

Table 3 for battery output monitoring data using the INA219 sensor without load, the average value of voltage, current and power measurements is obtained at the time range from 08.00 to 17.00 as follows:
Average Battery Output Voltage = 12.56 volts
Average Battery Output Current = 0.02 amperes
Average Battery Output Power = 0.2 watt

3.2.4 Monitoring the current and voltage at the battery output using the INA219 sensor with a light load.

The INA219 sensor is used to monitor voltage, current, and power at the battery output without light load. The findings of this monitoring activity, which was conducted over two days, are shown in **Table 4**.

Table 4. Monitoring the current and voltage of the solar panel at the battery output using the INA 219 sensor with a light load.

Testing Time	Battery Output With 12 Volt DC Light Load Voltage V	Current A	Power W
08.00	11,97	0,4	4,8
09.00	11,98	0,4	4,79
10.00	11,97	0,4	4,79
11.00	11,99	0,4	4,8
12.00	11,98	0,4	4,8
13.00	11,98	0,4	4,79
14.00	11,97	0,4	4,79
15.00	11,99	0,4	4,8
16.00	11,97	0,4	4,8
17.00	11,98	0,4	4,79

Average	11,98	0,4	4,8

Table 4 for battery output monitoring data using the INA219 sensor without load, the average value of voltage, current and power measurements is obtained at the time range from 08.00 to 17.00 as follows:
Average Battery Output Voltage = 11.98 volts
Average Battery Output Current = 0.40 amperes
Average Battery Output Power = 4.80 watts

3 CONCLUSION

After conducting this research, it can be said that an IoT-based 20 WP Solar Panel DC power monitoring system has been successfully developed. This system uses apps made with the MIT App Inventor platform that use real-time databases on firebase platforms to provide realtime solar panel and battery data information. The average time needed for system activation as a whole is 18.01 seconds, and the average response time for sending from ESP32 to the database to the MIT App Inventor program is 3.89 seconds. Using the BH1750 sensor to measure light intensity and the INA219 sensor to measure the solar panel's output voltage, the peak readings of 54,588 lux and 20.01 volts were recorded at 12.00 WIB. The average voltage, current, and power of the battery when it is operating with no load is 12.56 Volts; 0.02 Amperes; and 0.2 Watts. When the battery is operating with a 12 Volt dc lamp load, the average voltage, current, and power is 11.98 Volts; 0.40 Amperes; and 4.8 Watts. It is planned that in the future, additional research will focus on determining the temperature in the vicinity of the solar panel in order to determine whether temperature affects how much solar energy is absorbed by the device.

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