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Development of An IoT-Enabled Photovoltaic-Battery Renewable Energy System

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Abstract: Solar energy is considered as a prominent source of renewable energy, mainly due to the vast abundance of sunlight and rapid advancements of photovoltaic (PV) technology. The performance, reliability and lifespan of PV systems are severely affected by numerous environmental factors and fault occurrences, which include: (1) extreme swing in the operating temperature; (2) low solar irradiation levels which appear undetected in PV systems, resulting in energy losses and degradation of PV panels; and (3) non-homogenous shading and accumulation of dirt on PV panels, causing thermal imbalance and hotspots on the panels. Therefore, it is important to monitor the operating temperature and homogeneous detection of sunlight on the PV modules to guarantee efficient energy production. In this paper, we present the development and demonstration of a sensor-assisted Internet of Things (IoT)-based photovoltaic-battery renewable energy system. The adoption of the IoT solution for monitoring the real-time variations in environmental factors and system performance is discussed here. For the PV-battery hardware module, solar panels along with rechargeable batteries are constructed to supply the system. Inverters and controllers are used to synchronize the voltage level and transformation of AC power from DC power. In the design of the IoT system, the Arduino Mega microcontroller and ESP32 TTGO board are used along with sensors for recording the temperature, presence of dust/dirt, and voltage and current levels. The working prototype enables real-time data to be captured and sent to the cloud database for data collection, performance analysis, and diagnosis/detection of faults in the proposed system.

Keywords: *Internet of Things (IoT), renewable energy, photovoltaic systems, solar panels, microcontroller*

1. Introduction

The sun provides more than enough energy to the earth in a single day to meet the planet's total energy requirements for a year [1]-[2]. Solar energy has been stated to be the most promising in Malaysia [3]-[4]. Solar photovoltaic (PV) systems are a promising way to produce electricity from Malaysia's renewable energy resources [1]. The system that absorbs sunlight and transforms it into electricity is known as a PV panel. Solar panels create an electrical wave that allows photons to interfere with electrons that have broken free from their atoms. It comprises several smaller units known as photovoltaic cells. PV cells transform sunlight into electricity [5]. Renewable energy equipment is becoming more affordable due to technological advancements, allowing for large-scale solar photovoltaic installations.

Solar energy is solar radiation and absorbed by a PV plate. When the Sun's radiation hits the Earth, it generates isolation energy, enabling solar power to be produced. Heat and other radiation, such as UV, are produced by the Sun's electromagnetic wave. In Malaysia, the entire population could use solar energy to generate electricity instead of gas, hydroelectric, or fossil fuels [6]. The strength of solar light hitting every area of Earth varies as our world rotates around the Sun. The Sun emits a massive amount of radiation into the surrounding environments, including the Earth. The radiation constant of the Sun is calculated to be 1353 W/m^2 [7]-[8]. Diffused radiation is the name assigned to dispersed radiation. The radiation that is reflected by the field is referred to as reflected radiation. The total amount of radiation in the world can be calculated by combining three different forms of radiation: diffused, beam, and reflected. According to several recent studies [8], the highest radiation is about 1000 W/m^2. It is possible to see it on a clear day.

Recently, PV systems have been common contributors to renewable energy, according to authors in [9]. One of the solar's challenges is uncontrolled environmental effects such as dust and sand. Regular checks on the solar panel indicate the cleanliness of solar cells. Different types of sensors deployed, such as light intensity, voltage and current sensors, to keep track of parameters and take readings as microcontroller inputs. The microcontroller was then used to upload cloud service information and data [9]. Wireless

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Fidelity (Wi-Fi) module eventually sends the sensed data to the cloud. The system proposed includes an Arduino to serve as microcontroller, sensors to monitor dust, current, and voltage.

In another relevant work [10], Mubashir *et. al* proposed a wireless solar panel monitoring system, which enabled voltage, current, temperature and heat measurements to be monitored and captured remotely using the Arduino. The proposed system adopted the concept of IoT, General Packet Radio Service (GPRS) module, and

cloud computing to assist users in planning schedules for tracking.

In [11], Babu *et. al* proposed a device which consists of a controller with a Node MCU and an LDR sensor. The controllers check for predetermined conditions, detect dust coming from the output voltage, and issue alerts to users or maintainers. It also uses the stuff talking cloud to display the sensor's data and the graphical user interface (GUI) to monitor it.

Hudedmani, M., [12] mentioned a device mounted on a PV panel that includes a weight sensor that measures dust thickness on a regular basis in terms of the panel's weight difference. The Arduino microcontroller instructs the electrostatic precipitator (ESP) to clean if the weight of the dust reaches a certain threshold. The PV solar panel's tare weight should be entered using the Arduino controller as a reference.

Alugam Akhil [13] use of LoRa technology for transmission is a characteristic feature of this method of monitoring. The LoRa can transmit over large distances over an inexpensive energy budget, which would enable us to build more efficient IoT networks than is currently possible. In this journal, the system uses an integrated Web server based on the Arduino Nano microcontroller. A voltage sensor for each solar panel is used for tracking the voltage. This voltage sensor helps to detect the voltage levels of the solar panel. This is going to be handled by the Arduino board.

The remainder of this paper is structured as follows: Section II describes the proposed methodology of our work, where the design, configuration and building blocks of our proposed system are presented here. Next, Section III highlights and discusses the key results and observations from the project implementation, which is then followed by a detailed cost analysis in Section IV. Finally, our concluding remarks are highlighted in Section V.

2. Proposed Methodology

2.1. System Design and Configuration

In this paper, a monitoring system will be designed by considering the following factors: temperature, light intensity, voltage, and surface dust accumulation. Then, all the information is processed and sent online to the IoT platforms in the microcontroller. In this case, the Arduino TTGO ESP32 and Adafruit.io is the platform that is being used.

Arduino reads the parameters through the sensors, sends all the data, and upload to the IoT platform, Adafruit.io. Then, Arduino executes actions such as turning on/off the LED alarm light, sending message notifications to notify the user based on the information read by the sensors. The first step is to determine the amount of dust deposited on the surface

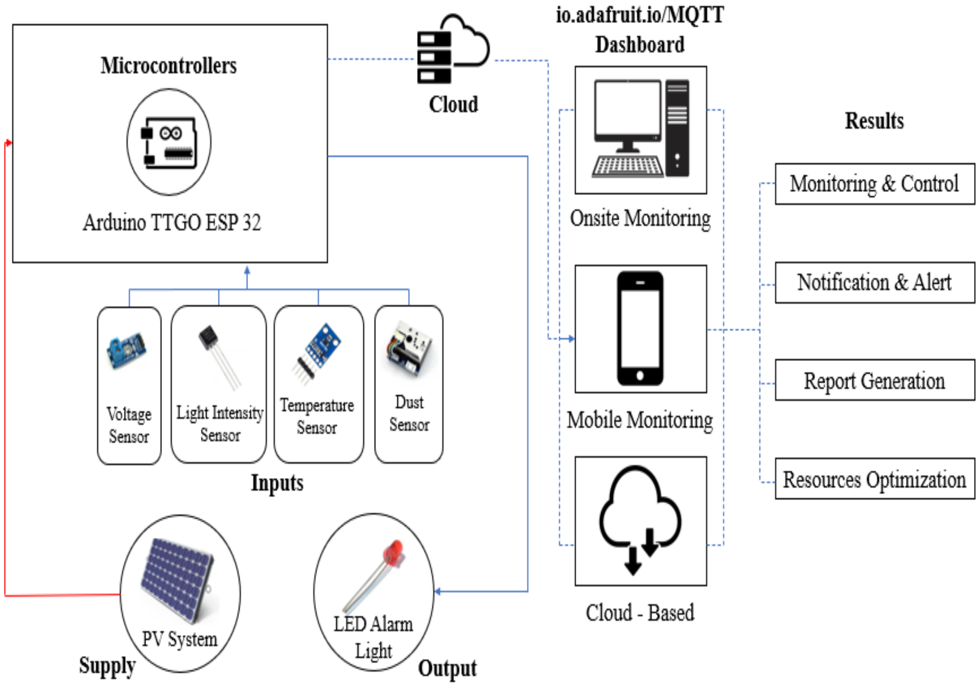

Fig. 1. Overall architecture of the IoT-enabled photovoltaic-battery system.

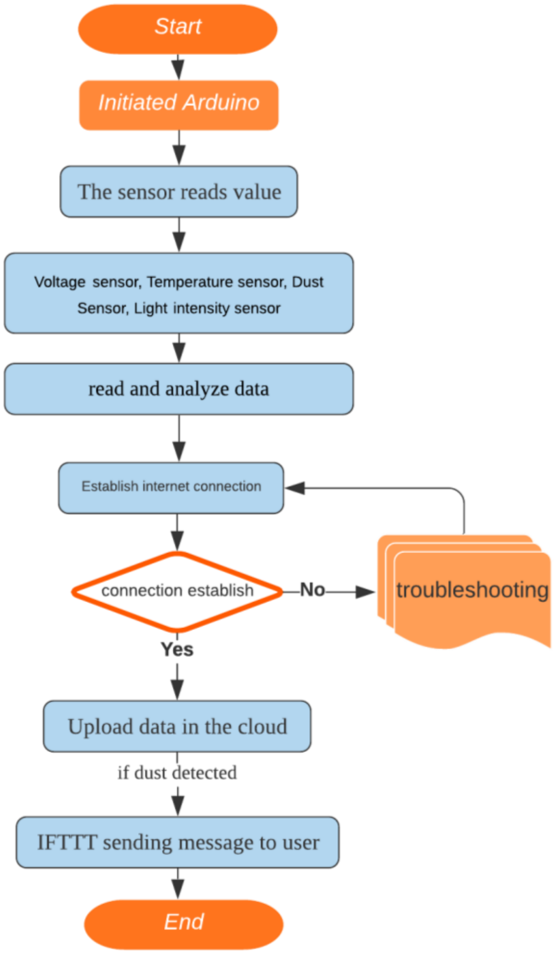

Fig. 2. Flow chart depicting the mechanisms of the proposed system involving the IoT technology.

of the PV panel and to give operators a head's up-to-date notice. The effects of a dusty environment were tested on sensors and microcontrollers. In addition, there is a light-dependent resistor sensor connected to the microcontroller to monitor the light intensity of the solar panel.

Arduino obtains the remaining parameters from the sensors as soon as it gets powered up. This begins with the reading of the LM35 sensor, which records the solar panel's temperature continues with the voltage sensor and LDR sensor. During the reading process, Arduino reads and stores its data. Next, Arduino triggers the LED to light on when the dust is detected by the dust sensor and continues to perform the rest of the actions through If This Then That (IFTTT) platform, sending a message to the user to clean their PV panel. Finally, Arduino sends the complete set of data as an array. The ESP32 microcontroller uploads the data as a final step to Adafruit.io and MQTT application, displaying the data on computers/tablets and phones user-friendly.

An internet connection will be established. If the connection is successfully established, the system proceeds to upload data, or else the system will enable manual troubleshooting if the connection fails. The input taken from the solar panel is accessed by sensors attached to the panel and then inputted to Arduino microcontroller. The initial information is processed and transmitted over the cloud by Adafruit.io and IFTTT. These parameters are displayed and uploaded to the cloud on the LCD/Tablet, and users can access this information via mobile application.

There will be two sets of experiments that have been conducted. In the first set of the experiment, the solar test panel is under optimum condition considering any factors that have been mentioned. While the second set of the experiment will include all those factors, and the results for both sets will be captured.

2.2. Hardware Development

2.2.1. Arduino Module

Arduino has an open platform that is one of the most commonly used platforms. This means all the codes written for the program for hardware will be loaded on Arduino ESP32.

2.2.2. LM35 Temperature Sensor Module

The LM35 is a temperature sensor that measures the temperature using a thermistor. The LM35 temperature sensor is a low-cost option, which is widely used in embedded projects.

2.2.3. Voltage Sensor Module

This physical signal then assists in measuring the difference in voltage between two points. This allows the analog input to monitor voltages that are much higher than it can be detected.

2.2.4. LDR Sensor Module

A light sensor is used to monitor and measure the quality or strength of the amount of light. The module has a dual output mode, digital output, and analog output to achieve greater reading accuracy.

2.2.5. Dust Sensor Module

Sharp Optical Dust sensor is the dust sensor used. By sensing reflected light, it detects dust in the air. The dust particle counter can be used to determine the quantitative particle density, which can detect particles larger than 1 m. The heater creates an airflow into the sensor.

2.3. Online IoT Platform

Io.Adafruit is an end-to-end IoT solutions provider which can remotely monitor, control, and automate actions using the microcontroller. The data may be displayed and stored online for further analysis and action. It also can send a text message and email to send data to a particular device without any cost.

2.4. PV-battery renewable energy

Error! Reference source not found. shows the setup of the PV-battery charging module. The process starts with the PV panels absorbing the sunlight and converting the solar energy into a DC energy. The Maximum Power Point Tracking (MPPT) Solar Controller balances the power and extract the maximum power from the PV panels and transfer it to both batteries and the inverter. The inverter converts the DC power coming from both batteries and MPPT solar controller to AC supply suitable for standardized equipment rated around 230V in Malaysia. The inverter is connected to the grid supply, Tenaga Nasional Berhad (TNB) in Malaysia, with no power supply from panels no batteries.

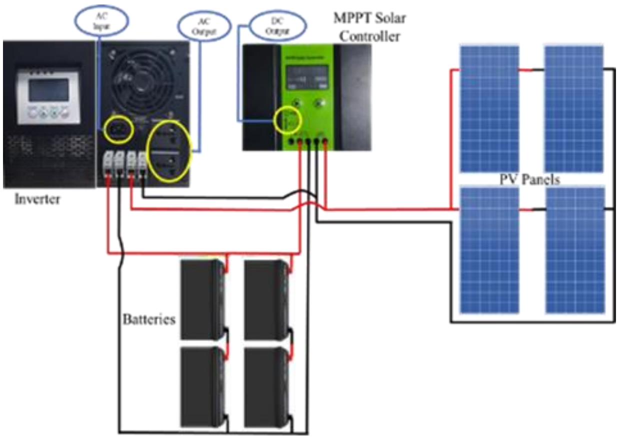

Fig. 3. Setup of the PV-battery charging module.

2.5. PVsyst Software and simulator

The PVsyst software widely used in the industry by engineers and by researchers in the academia. It contains a database of components encompassing PV panels, inverter, batteries, and others. It is used for sizing and data analysis when designing a PV system. It could be used for grid-connected, stand-alone, pumping, and DC-grid. The software includes metro data such as Meteonorm 7.1 and NASA-SSE of solar irradiation. To choose the optimum positioning of the PV panels, PVsyst software was used in this project.

3. Results and Discussions

3.1. RSA Testing

Experiment is done to test ESP32's connectivity to Wi-Fi. The ESP32 prints the Received Signal Strength Indicator (RSSI) to display the Wi-Fi Strength in both dBm and percentage unit. Smartphone Wi-Fi strength is used for reading comparison. For-loop is used in the ESP32 coding to obtain the average RSSI from 100 reading since it always fluctuates. It can be concluded that the ESP32 shows decent performance throughout the entire rooftop. System fits the purpose to promote solar monitoring for the users with decent internet connection. Used in system to refer for Wi-Fi connectivity, but ultimately cannot be used for geographical positioning.

Table 1. RSSI testing result at the rooftop

ESP32 reading	*Percentage (%)*	*Phone reading*	*Percentage (%)*
-51dBm	88	-33dBm	100
-48dBm	100	-30dBm	100
-54dBm	82	-37dBm	100
-48dBm	100	-33dBm	100
-42dBm	100	-39dBm	100
-30dBm	100	-37dBm	100
-54dBm	100	-37dBm	100
-48dBm	100	-35dBm	100

3.2. Final Setup

Fig. 3 shows the equipment and the sensors placed on the solar panel. Equipment such as solar panel (represented a real solar panel in the industry) and actuators such as Light-Emitting Diode (LED) alarm light.

Fig. 5. The hardware setup.

3.3. Voltage Characteristics of the PV Panel

As it can be seen from Fig. 3, the output voltage curve for the dusty solar panel is non-linear even though no external variables were changed during the first experiment, indicating that fluctuation occurs. The performance readings would gradually decrease over time as dust accumulates on the solar panel's surface, covering some of the cells in the panel, as shown by the results of the second experiment. The graphs show that a gradual decrease in the output voltage can reach a value between 10% and 15% due to the dust effect.

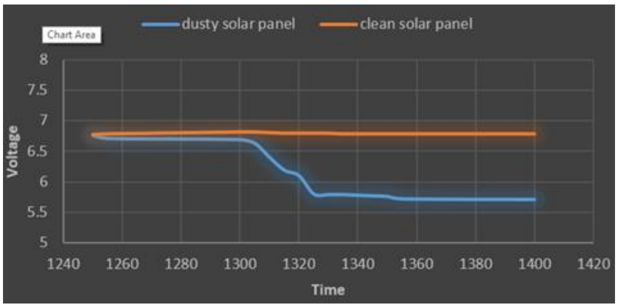

Fig. 3. Open-circuit voltage versus time graph.

3.4. Temperature Characteristics of the PV Panel

The lines describing the temperature show that the temperature fluctuates, despite no external variables modified during the first experiment. The performance readings would gradually increase over time as dust accumulates on the solar panel's surface, blocking some cells in the panel, as shown by the results of the second experiment. Because of the dust impact, a gradual rise in temperature of 1 to 5 degrees Celsius can be inferred from the graphs obtained.

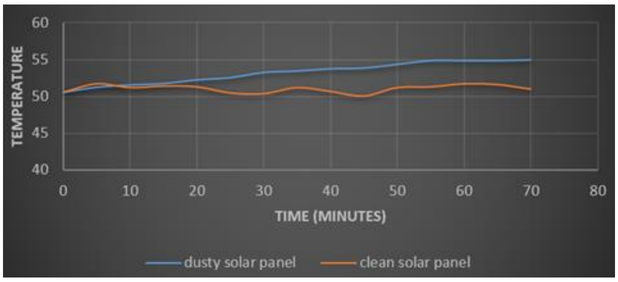

Fig. 4. Temperature versus time graph.

3.5. Light Intensity Characteristics of the PV Panel

The lines defining light intensity indicate that fluctuation occurs during the first experiment, as seen from the findings. The results of the second experiment show that as dust accumulates on the solar panel’s surface, covering some cells, light intensity readings will gradually decrease over time. The dust accumulation process is simple; it begins with a single layer that accumulates until it covers the entire surface.

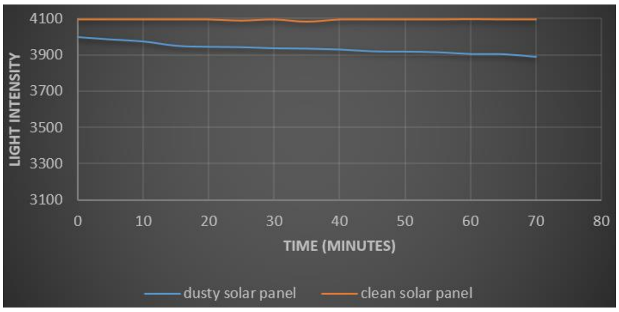

Fig. 5. Light intensity versus time graph.

3.6. Testing Environmental Impacts on Dust Sensor

The PV panel was coated with flour in the second scenario. It represents the situation of dirty solar panel or the solar panel, which is not clean. Thus, the accumulation of dust can be observed. Figure 8 shows the PV panel was covered by flour with all the sensors attached. When dust is detected, the IFTTT detects the value from the dust density sensor is greater than 0.1; then, it will send a notification through a message to the user of the PV panel.

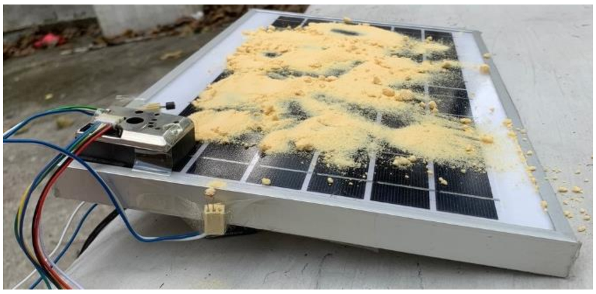

Fig. 6. The dirty solar panel testing.

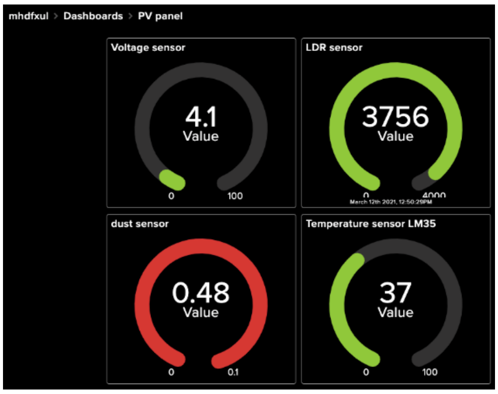

Fig. 7. io.Adafruit dashboard (dirty panel).

Fig. 8. The IFTTT sends notification.

3.7. PV-Battery Renewable Energy System with A Working Battery Charging Module Implementation

To optimize the power input from the solar panels, a study was done using PVsyst software. Cyberia Smart house rooftop was used to set up the panels and the rest of the module’s components and batteries. Therefore, an angle of 8 degrees is chosen as Loss concerning optimum, and FT is not affected by this tile and remain 0% and 1(100%), respectively. The losses are minimum regarding the maximum point from 4 to 6. From Figure 4.40, the optimum azimuth is from 1° to 16°. Therefore, a degree of 1 was chosen. Once the above was done, it was proceeded to install the panels on the rooftop of D22A.

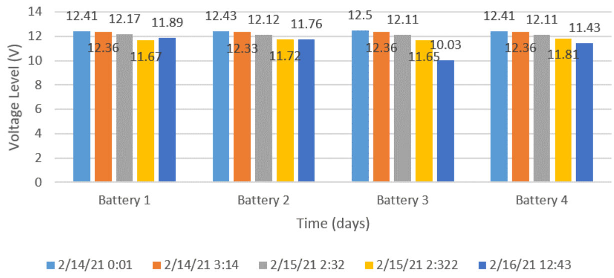

Fig. 9. Power consumption by the system.

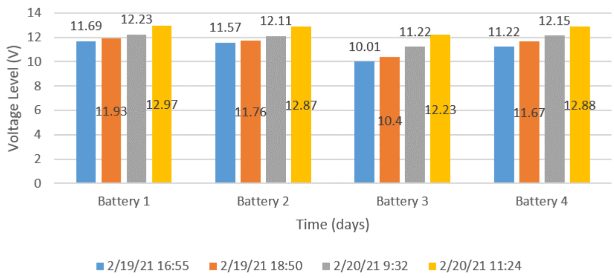

Fig. 10. Power input by the PV panels.

4. Cost Analysis

The solar module system cost about RM 6,000 for 1kWp. However, if the system is increasing, the price will rise but not at the same rate. If the device increased, only the number of panels and batteries will increase, but not the number of MPPT solar controllers or inverters, as only one of them is required. Table 2 displays the cost analysis of the installed device. In contrast, KWTBB which is related to the Renewable Energy Fund, supports the growth of electricity generation from renewable energy sources. ICPT and KWTBBB are considered costs for regular customers, while Renewable Energy companies are deemed profitable. The solar module system is expected to last for approximately 25 years.

Table 2. Tabulation of financial modeling

Commercial Cash Flow Model Analysis	
Total DC System Size	1.0 kWp
Price Per kWp	MYR 6,000
Total System Price / Cost of Investment	MYR 6,000
Daily Specific Yield	4.38 kWh/kWp/Day
Annual Specific Yield	1,598 kWh/kWp/Year
Annual Generation	1,598 kWh/Year
Average Monthly Generation	133 kWh/Month
Tariff Per kWh	MYR 0.3945
ICPT Per kWh	MYR 0.026
KWTBB Rate Per kWh	MYR 0.006
Year-1 TNB Savings	MYR 672
Average Monthly Year-1 TNB Savings	MYR 56
Average Yearly O&M Cost	MYR 262
Total 25 Years O&M Cost	MYR 6,561
Total 25 Tax Savings/Exceptions	MYR 2,880
Total 25 Years Savings	MYR 20,951
Total 25 Years Net Savings	MYR 11,270
Payback Period	6.54 Years

Table 3. Commerical cash flow model analysis

Of Years	System Performance	Solar Generation (kWh)	TNB Tariff (MYR)	TNB Bill Savings (MYR)	KWTBB Savings (MYR)	Tax Savings From ITA (MYR)	Tax Savings From CA (MYR)	O&M Annual Fees (MYR)	Yearly Net Savings (MYR)	Accumulate Net Savings (MYR)
0	100.00%	1,598							(6,000)	(6,000)
1	100.00%	1,598	0.4060	649	10	1,440	490	(180)	2,408	(3,592)
2	97.50%	1,558	0.4060	633	9		202	(180)	664	(2,928)
3	96.80%	1,547	0.4060	628	9		202	(180)	659	(2,269)
4	96.10%	1,536	0.4060	623	9		202	(198)	636	(1,633)
5	95.40%	1,524	0.4608	703	11		202	(198)	717	(916)
6	94.70%	1,513	0.4608	697	11		144	(198)	654	(262)
7	94.00%	1,502	0.4608	692	10			(218)	485	223
8	93.30%	1,491	0.4608	687	10			(218)	480	702
9	92.60%	1,480	0.5230	774	12			(218)	568	1,270
10	91.90%	1,469	0.5230	768	12			(240)	540	1,810
11	91.20%	1,457	0.5230	762	12			(240)	534	2,345
12	90.50%	1,446	0.5230	756	12			(240)	528	2,873
13	89.80%	1,435	0.5936	852	13			(264)	601	3,474
14	89.10%	1,424	0.5936	845	13			(264)	595	4,069
15	88.40%	1,413	0.5936	839	13			(264)	588	4,657
16	87.70%	1,401	0.5936	832	13			(290)	555	5,212
17	87.00%	1,390	0.6738	937	14			(290)	661	5,873
18	86.30%	1,379	0.6738	929	14			(290)	654	6,526
19	85.60%	1,368	0.6738	922	14			(319)	617	7,143
20	84.90%	1,357	0.6738	914	14			(319)	609	7,753
21	84.20%	1,346	0.7647	1,029	16			(319)	726	8,479
22	83.50%	1,334	0.7647	1,020	16			(351)	685	9,164
23	82.80%	1,323	0.7647	1,012	16			(351)	677	9,841
24	82.10%	1,312	0.7647	1,003	16			(351)	668	10,509
25	81.40%	1,301	0.8680	1,129	18			(386)	761	11,270
-		37,502		20,635	316	1,440	1,440	(6,561)	11,270	

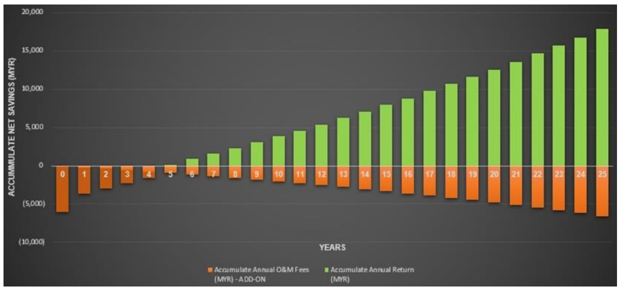

Fig. 11. Return of investment – cash model.

It can be estimated that the return of investment period is 6.54 years. This applicable to bigger system as well. For bigger systems, the return period is even shorter as the cost per kWp is cheaper compared with a bigger system.

5. Conclusions

In a nutshell, the objective of this project is to design IoT-enabled photovoltaic battery renewable energy systems. It has been discovered that solar panels exposed to sunlight with dust accumulation resulted in higher open-circuit voltage. The solar panel with dust has a slightly higher temperature compared to the clean solar panel. Other than that, the light intensity becomes lower when it was discovered that the solar panel is covered with dust. The system was improved by exposing the PV panel with a dust sensor that will detect dust, then automates the light while sending a notifications message to alert the users. Solar radiation is one of the most renewable and clean sources of energy available in Malaysia.

Reliable performance monitoring and surveillance system are some technologies that will help increase the solar power generation systems' efficiency. With the help of sensors and actuators, the solar panel monitoring system can be automated, thus reducing human effort for checking and cleaning the dust and optimizing the resources. Using the PV-battery charging module system, 1kWp will be sufficient to supply power to the system (battery), leading to lower carbon emission and, in the long run, cost-effective.

6. Future Work

The current application used by the system is the io.adafruit and MQTT Dash application, and the recommendation would be creating its database because all the data collected can be monitored easily and has administration right on the interface. Arduino comes with limitations, especially when it comes to multiprocessing. Therefore, using Raspberry pi is more functional if considering upgrading the setup to execute more actions, store data locally, and, optionally, monitor the system more systematically. Foundations for a dust detection system using microcontroller had been achieved. Improvements can be made via different feature extraction and classifying methods. All the sensor need to be covered up with a case. The casing of the system should be made from a material that is durable and waterproof. This is to prevent all the system's electric component from damage due to rain, mud, dust and others.

Author contributions

Mohamad Hafizul Ikhwan bin Ridzuan: Hardware, Software, Field Study, Writing-Original Draft Preparation **It Ee Lee:** Conceptualization, Methodology, Investigation, Data Curation, Writing-Original Draft Preparation **Eng Eng Ngu:** Validation, Writing-Reviewing and Editing **Gwo Chin Chung:** Visualization, Data Curation **Wai Leong Pang:** Validation **Chitra Dhawale:** Writing-Reviewing and Editing

Conflicts of interest

The authors declare no conflicts of interest.

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