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Raspberry Pi Zero Wireless Monitoring System for Analyzing Solar Photovoltaic Panel

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Abstract**: *This paper aims to explain about the implementation of a low-cost wireless monitoring and communication system for an individual solar photovoltaic panel. The proposed system continuously records voltage, current and temperature information for an individual solar photovoltaic panel. This information is used to observe the performance and operation of an individual solar photovoltaic panel. Hence, each solar photovoltaic panel is installed with a voltage-current sensor and four thermocouple sensors as a system, which is integrated with low-powered Raspberry Pi Zero Wireless. The Raspberry Pi Zero Wireless acts as voltage, current and temperature information recording system before this information is uploaded into the cloud database system. Then, from the cloud database system the voltage, current and temperature information of an individual solar photovoltaic panel is sent to phpMyAdmin database system for recording. At the phpMyAdmin, the database system allows consumers/users to monitor the performance and operational of installed solar photovoltaic panels through webpage. Hence, this paper briefly presents the operational results of the developed system.***

Index Terms**: *Data acquisition system, Internet of things, Monitoring system, Wireless sensors network*.**

I. INTRODUCTION

Solar Photovoltaic is known as one of the most promising technology, which have the greatest future to accommodate the present increasing of energy demand. Therefore, the coordination of sensed and measured data or information is very important for an effective management using the wireless communication system. In [1], ZigBee technology is integrated to remotely monitor and distribute the controlling of smart photovoltaic system. Smart photovoltaic system controls the condition monitoring, power control and data communication to connect individual module. In [2], [3], a ZigBee technology based monitoring and supervising system is proposed. The proposed system records the current and voltage originated from the photovoltaic plant, in addition, the inverter and battery temperature and humidity is also considered [4]. Similar [2], [3], different monitoring and control system are proposed in [4] using Labview software and microcontroller interfacing. Wireless sensor network is adapted for individual panels to monitor the respective photovoltaic panel's status [5]. The wireless sensor network is used to identify the efficiency, failure and weaknesses occurs during overall system functionality and operation. This system also uses the Bluetooth technology to communicate with the main controller for information sending to user interface view. In [5], smart mechanism such as wireless sensor network technology is used and integrated to proficiently monitor the solar system performances. Application of Internet of Thing (IoT) is used to detect the faulty solar panels in the solar system [3]. Having reviewed these research paper, wireless sensor network especially the Bluetooth technology is seen as one of the promising technologies being applied in solar system monitoring and controlling. In [6], an overall hardware integration and complete methodology has been explained. Also, the developed system has been tested before it is applied into real-time environment.Therefore, this paper explains the findings of an implemented wireless monitoring system to analyze the performances of solar photovoltaic panel condition. The following of this paper is organized as follows: Section 2 explains the system design and implementation of hardware. Section 3 explains the software development and implementation. Section 4 presents the performance results. Conclusion is presented in Section 5.

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II. HARDWARE SYSTEM DESIGN AND IMPLEMENTATION

Fig. 1 shows the completed hardware integration of the proposed system in reference to Table 1.

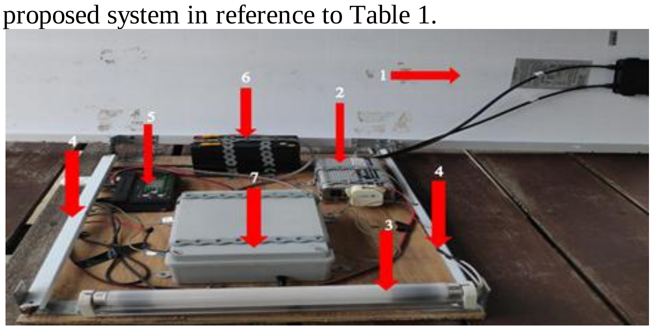

Fig. 1 Complete hardware integration – system

The listed components in Table 1 is used to design the layout shown in Fig. 1 with additional components such as the solar charger and solar power inverter.

Table. 1 Component's Hardware Number

Component's Number	Hardware
1	Solar Panel
2	Solar Power Inverter DC 12V to AC 220V
3	Lamp
4	Thermocouple Sensor K-Type (A, B, C, D)
5	Solar Charge Controller
6	12 Volt Rechargeable Battery
7	System Module

Fig. 2 and Table 2 shows the completed close-up view of the Wireless Monitoring System Module. All the sensors and Raspberry Pi Zero Wireless are arranged in one box which called as System Module. Thermocouple sensors showed in Fig. 1 is connected to MAX31855 Amplifier in Fig. 2. MAX31855 Amplifier and INA 219 DC Voltage/Current Sensor is connected to GPIO 40 pin at Raspberry Pi Zero Wireless. The Solar Charge Controller is connected to a current divider to limit output current from the solar photovoltaic panel before connecting to the INA 219 DC Voltage/Current Sensor. The high current from solar photovoltaic panel need to step down to support the characteristic of INA 219 DC Voltage/Current Sensor. In Fig. 2 the extended PCB GPIO 40 pins is required to extend the power port from the Raspberry Pi Zero Wireless.

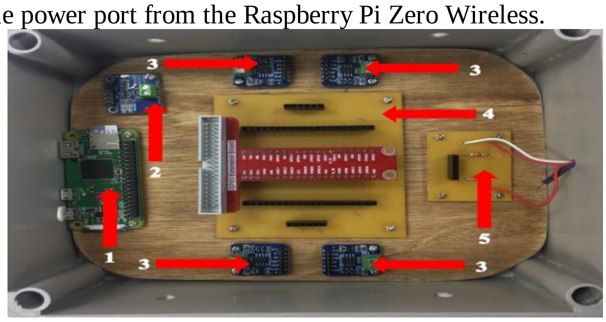

Fig. 2 Close up view of System Module

Table. 2 System Module Hardware Number

Component's Number	Hardware
1	Raspberry Pi Zero Wireless
2	INA 219 DC Voltage/Current Sensor
3	MAX31855 Thermocouple Amplifier
4	PCB GPIO 40 Pins
5	PCB Current Divider

III. SOFTWARE DEVELOPMENT AND IMPLEMENTATION

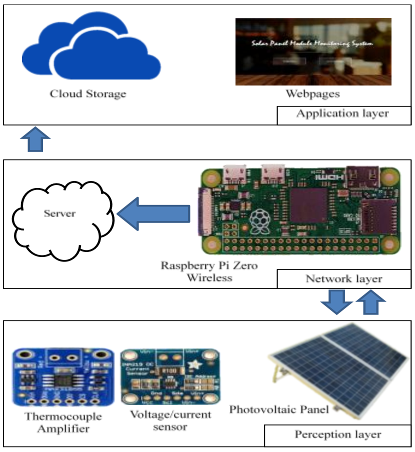

Fig. 3 Software development and IoT Architecture

Fig. 3 explain about the software development for the proposed wireless monitoring system and IoT architecture. Referring to Fig. 3, there are three-layer of architecture which are the perception layer, network layer and application layer. The perception layer includes the system integrated shown in Fig. 1 which operate to collect the data from the solar photovoltaic panel. Network layer means that Raspberry Pi Zero Wireless save the collected data from the connected sensors. Then, Raspberry Pi Zero Wireless is connected to server or Wi-Fi to send the data to cloud storage. Application layer contains the cloud storage and web page that enable the customer to monitor the performance of solar photovoltaic panel. Data from the Raspberry Pi Zero Wireless is push to cloud storage and from the cloud storage the data is publish in web page.

IV. RESULT AND DISCUSSION

This section presents the sensed and measured results for INA219 DC voltage/current sensor and thermocouple K-Type sensors. The readings in Tables 2 and 3 are taken starting at 8 am when the sun start rising and stops at 6pm in the evening during the sunset.

a) Thermocouple K-Type Sensed and Measured Reading

Table. 3 Thermocouple Sensed and Measured Readings

Hours	Degree Celsius, °C			
	TC A	TC B	TC C	TC D
8:00 AM	28.5	29.5	27.5	28.5
9:00 AM	29	30	29	29
10:00 AM	30	31	29.7	31
11:00 AM	32	32	30	31
12:00 PM	34	33	32	34
1:00 PM	33	34	33	35
2:00 PM	33	34	34	35
3:00 PM	33	35	34	35
4:00 PM	35	35	34	35
5:00 PM	34	34	33	34
6:00 PM	32	33	31	32

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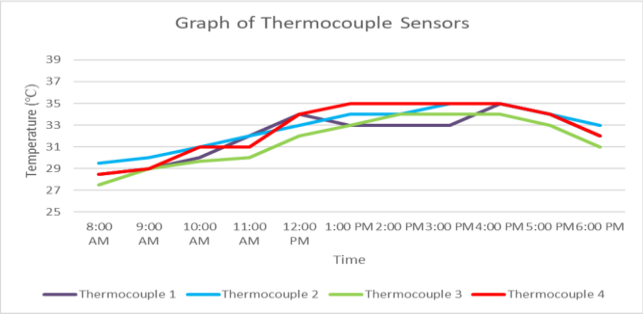


Fig. 4 Thermocouple Sensors Temperature Measurement

According to the recorded reading in Table 3 and Fig. 4, the temperature at the solar photovoltaic panel rises when the heat from the sun rises. The temperature start increased from 8 AM to 1 PM, at 1 PM to 4 PM the temperature has settled down because of the constant environment temperature. Temperature starts to decline from 5 PM to 6 PM because of sunset.

b) Current, Voltage and Power

Table. 4 Current, Voltage and Power Measurement

Hours	Voltage (V)	Current (A)	Power (W)
8:00 AM	11.5	0.80	9.20
9:00 AM	11.9	0.89	10.6
10:00AM	12.4	0.91	11.3
11:00AM	12.8	0.95	12.2
12:00 PM	13.2	0.99	14.4
1:00 PM	13.8	1.52	20.9
2:00 PM	14.4	2.02	28.8
3:00 PM	14.4	2.67	38.5
4:00 PM	14.4	2.92	42.2
5:00 PM	14.2	2.13	38.1
6:00 PM	13.6	1.50	20.4

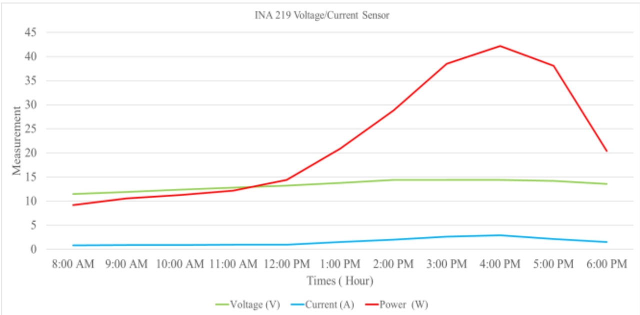
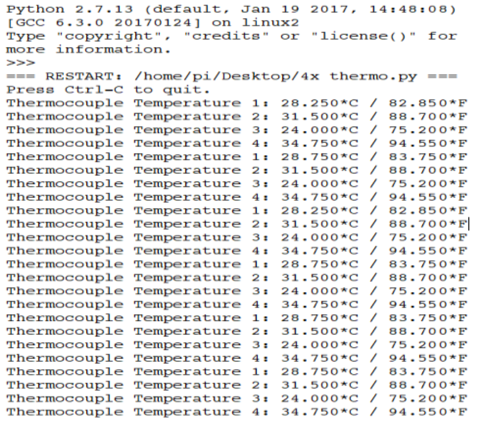


Fig. 5 Voltage, Current and Power

Table 4 and Fig. 5 shows the sensed and measure current, voltage and calculated output power at each of the solar photovoltaic panel. The output power indicates increment but eventually remain constant because of increment in the environment temperature, which affects the generated output power.

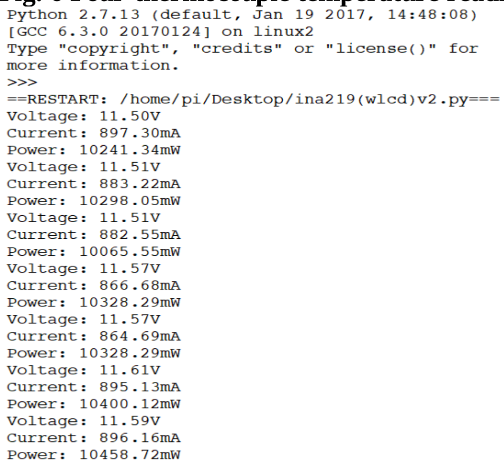
c) Result from thermocouple K-Type and DC INA 219 voltage/current sensors save in Raspberry Pi Zero Wireless

Figs. 6 and 7 shows collected data from Thermocouple K-Type and INA219 DC voltage/current sensors and save in Raspberry Pi Zero Wireless. Data from Raspberry Pi Zero Wireless then push to database in Section d.



```
Python 2.7.13 (default, Jan 19 2017, 14:48:08)
[GCC 6.3.0 20170124] on linux2
Type "copyright", "credits" or "license()" for
more information.
>>>
=== RESTART: /home/pi/Desktop/4x thermo.py ===
Press Ctrl-C to quit.
Thermocouple Temperature 1: 28.250*C / 82.850*F
Thermocouple Temperature 2: 31.500*C / 88.700*F
Thermocouple Temperature 3: 24.000*C / 75.200*F
Thermocouple Temperature 4: 34.750*C / 94.550*F
Thermocouple Temperature 1: 28.750*C / 83.750*F
Thermocouple Temperature 2: 31.500*C / 88.700*F
Thermocouple Temperature 3: 24.000*C / 75.200*F
Thermocouple Temperature 4: 34.750*C / 94.550*F
Thermocouple Temperature 1: 28.250*C / 82.850*F
Thermocouple Temperature 2: 31.500*C / 88.700*F
Thermocouple Temperature 3: 24.000*C / 75.200*F
Thermocouple Temperature 4: 34.750*C / 94.550*F
Thermocouple Temperature 1: 28.750*C / 83.750*F
Thermocouple Temperature 2: 31.500*C / 88.700*F
Thermocouple Temperature 3: 24.000*C / 75.200*F
Thermocouple Temperature 4: 34.750*C / 94.550*F
Thermocouple Temperature 1: 28.750*C / 83.750*F
Thermocouple Temperature 2: 31.500*C / 88.700*F
Thermocouple Temperature 3: 24.000*C / 75.200*F
Thermocouple Temperature 4: 34.750*C / 94.550*F
Thermocouple Temperature 1: 28.750*C / 83.750*F
Thermocouple Temperature 2: 31.500*C / 88.700*F
Thermocouple Temperature 3: 24.000*C / 75.200*F
Thermocouple Temperature 4: 34.750*C / 94.550*F
```

Fig. 6 Four-thermocouple temperature reading



```
Python 2.7.13 (default, Jan 19 2017, 14:48:08)
[GCC 6.3.0 20170124] on linux2
Type "copyright", "credits" or "license()" for
more information.
>>>
==RESTART: /home/pi/Desktop/ina219(wlcd)v2.py===
Voltage: 11.50V
Current: 897.30mA
Power: 10241.34mW
Voltage: 11.51V
Current: 883.22mA
Power: 10298.05mW
Voltage: 11.51V
Current: 882.55mA
Power: 10065.55mW
Voltage: 11.57V
Current: 866.68mA
Power: 10328.29mW
Voltage: 11.57V
Current: 864.69mA
Power: 10328.29mW
Voltage: 11.61V
Current: 895.13mA
Power: 10400.12mW
Voltage: 11.59V
Current: 896.16mA
Power: 10458.72mW
```

Fig. 7 Current, Voltage and Power

d) phpMyAdmin Database System – Current, Voltage and Temperature

Fig. 8 shows the overview of phpMyAdmin Database as the cloud storage. The collected data from the Thermocouple K-Type and INA219 DC voltage/current sensors is stored into the SD Card at the Raspberry Pi Zero Wireless, and then is pushed into the phpMyAdmin Database. Figs. 9 and 10 shows the data from Raspberry Pi Zero Wireless push to database for the monitoring system using webpage explain in Section e.

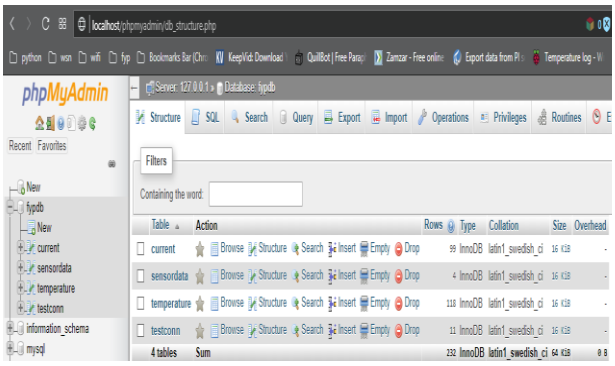


Fig. 8 Overview of phpMyAdmin Database

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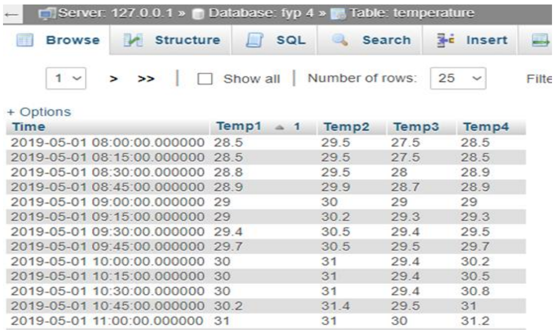
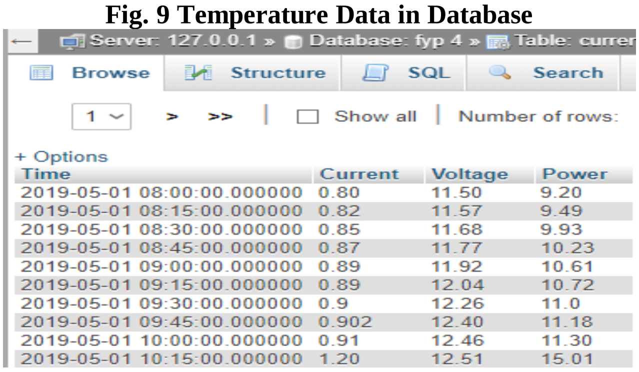


Server: 127.0.0.1 » Database: fyp 4 » Table: temperature

Time	Temp1	Temp2	Temp3	Temp4
2019-05-01 08:00:00.000000	28.5	29.5	27.5	28.5
2019-05-01 08:15:00.000000	28.5	29.5	27.5	28.5
2019-05-01 08:30:00.000000	28.8	29.5	28	28.9
2019-05-01 08:45:00.000000	28.9	29.9	28.7	28.9
2019-05-01 09:00:00.000000	29	30	29	29
2019-05-01 09:15:00.000000	29	30.2	29.3	29.3
2019-05-01 09:30:00.000000	29.4	30.5	29.4	29.5
2019-05-01 09:45:00.000000	29.7	30.5	29.5	29.7
2019-05-01 10:00:00.000000	30	31	29.4	30.2
2019-05-01 10:15:00.000000	30	31	29.4	30.5
2019-05-01 10:30:00.000000	30	31	29.4	30.8
2019-05-01 10:45:00.000000	30.2	31.4	29.5	31
2019-05-01 11:00:00.000000	31	31	30	31.2

Fig. 9 Temperature Data in Database



Server: 127.0.0.1 » Database: fyp 4 » Table: curren

Time	Current	Voltage	Power
2019-05-01 08:00:00.000000	0.80	11.50	9.20
2019-05-01 08:15:00.000000	0.82	11.57	9.49
2019-05-01 08:30:00.000000	0.85	11.68	9.93
2019-05-01 08:45:00.000000	0.87	11.77	10.23
2019-05-01 09:00:00.000000	0.89	11.92	10.61
2019-05-01 09:15:00.000000	0.89	12.04	10.72
2019-05-01 09:30:00.000000	0.9	12.26	11.0
2019-05-01 09:45:00.000000	0.902	12.40	11.18
2019-05-01 10:00:00.000000	0.91	12.46	11.30
2019-05-01 10:15:00.000000	1.20	12.51	15.01

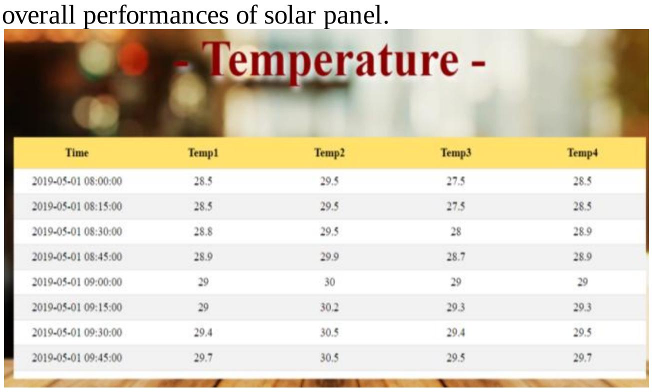
Fig. 10 Current, Voltage and Power Data in Database

e) Monitoring system using webpage

Fig. 11 shows the main interface of the webpage with the title 'Solar Panel Module Monitoring System'. There are two function buttons which are 'Temperature' and 'Current/Voltage'.

Fig. 11 Webpage Interface to Monitor the Photovoltaic Panel

Figs. 12, 13, 14 and 15 shows the tables and graphs of the temperature from the webpage to monitor the temperature performance of the solar panel. Figs. 16, 17 and 18 shows the tables and graphs of current, voltage and power from the webpage. The data in the webpage are from the database to verify that the system achieved target to send the data to cloud and publish in the webpage for user to monitor the overall performances of solar panel.



- Temperature -

Time	Temp1	Temp2	Temp3	Temp4
2019-05-01 08:00:00	28.5	29.5	27.5	28.5
2019-05-01 08:15:00	28.5	29.5	27.5	28.5
2019-05-01 08:30:00	28.8	29.5	28	28.9
2019-05-01 08:45:00	28.9	29.9	28.7	28.9
2019-05-01 09:00:00	29	30	29	29
2019-05-01 09:15:00	29	30.2	29.3	29.3
2019-05-01 09:30:00	29.4	30.5	29.4	29.5
2019-05-01 09:45:00	29.7	30.5	29.5	29.7

Fig. 12 Temperature Data for Four Thermocouple Sensors

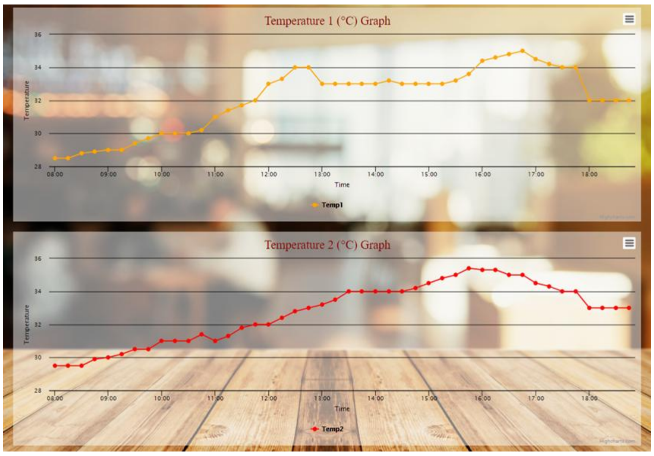


Fig. 13 Temperature Data for Thermocouple 1 and 2 Sensors

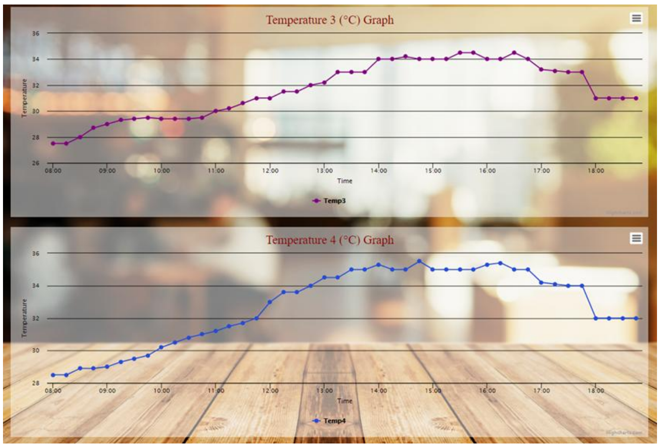


Fig. 14 Temperature Data for Thermocouple 3 and 4 Sensors

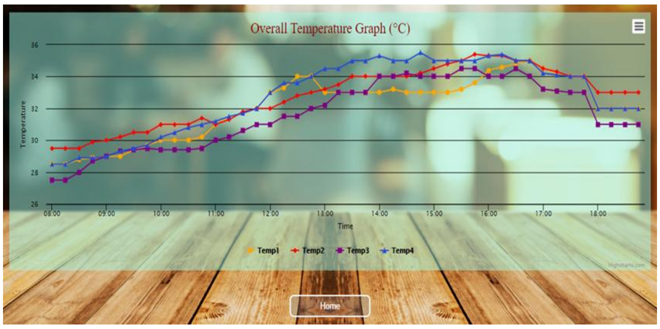
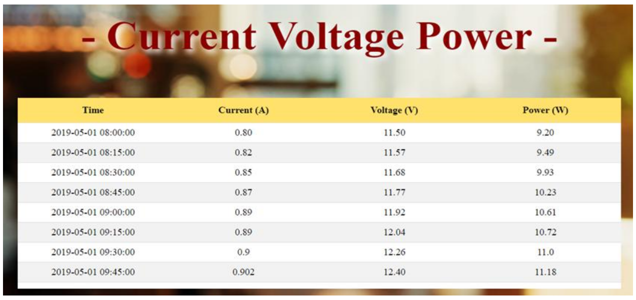


Fig. 15 Overall Temperature Data for All Thermocouple Sensors



- Current Voltage Power -

Time	Current (A)	Voltage (V)	Power (W)
2019-05-01 08:00:00	0.80	11.50	9.20
2019-05-01 08:15:00	0.82	11.57	9.49
2019-05-01 08:30:00	0.85	11.68	9.93
2019-05-01 08:45:00	0.87	11.77	10.23
2019-05-01 09:00:00	0.89	11.92	10.61
2019-05-01 09:15:00	0.89	12.04	10.72
2019-05-01 09:30:00	0.9	12.26	11.0
2019-05-01 09:45:00	0.902	12.40	11.18

Fig. 16 Voltage/Current and Power Data

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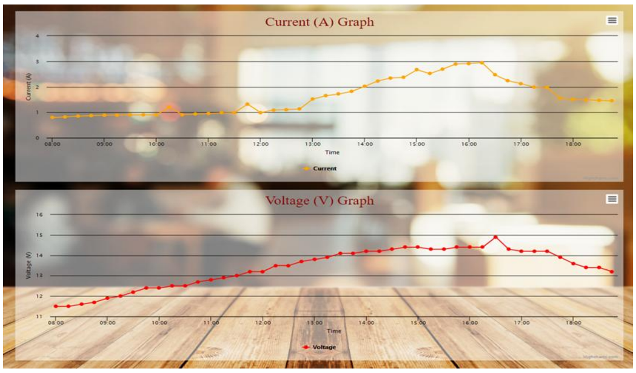

Fig. 17 Individual Data – Voltage and Current

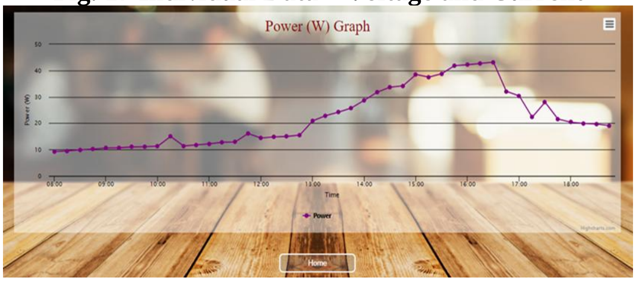

Fig. 18 Calculated Power Data

V. CONCLUSION

This paper presents the results of an implemented wireless monitoring system for solar photovoltaic panel. The captured results are presented in Section 4 and are discussed to validates the methodology used to design, developed and implement the proposed system for analyzing solar photovoltaic panel operation, which is presented in Figs 1 and 2. The cloud-based storage and monitoring system which is web based interface for consumers interaction is verified in Section 4. The information presented in the web-based system is operation information of an installed solar photovoltaic panel. The solar photovoltaic panel performance information is important to let the consumers to understand the installed solar photovoltaic panel. Hence, the information recorded in the Raspberry Pi Zero Wireless storage system and information recorded into the cloud-based storage system is validated and gives consumers basic knowledge on the installed solar photovoltaic panel performances.

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AUTHORS PROFILE

Muhammad Izzat Bin Nurdin is presently student at Faculty of Electronic Engineering and Computer Engineering, Universiti Teknikal Malaysia Melaka. He is currently an undertaking Bachelor of Electronic Engineering. This project is his Final Year Research Project.

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Dr Wong Yan Chiew is head of Micro and Nano Electronics (MiNE) research group, Universiti Teknikal Malaysia Melaka (UTeM), Durian Tunggal, Melaka. She is also a senior lecturer in Faculty of Electronics and Computer Engineering, UTeM and teaching integrated circuit design, artificial intelligence, microprocessor and computer engineering subjects. She obtained her B.Eng. and MEng (Master degree) in Universiti Teknologi Malaysia in 2005 and 2008. In 2014, she completed her PhD in Electronics Engineering, School of Engineering, The University of Edinburgh, United Kingdom. Her research work focuses on analog and mixed signal CMOS circuit design, power management system, miniature energy harvester, adaptive/artificial algorithm, reconfigurable RF circuitry and CMOS high voltage controller. Dr Wong has various scientific publications available. Most of the work is in the electronics design, wireless communication field and artificial intelligence. Her recent work focuses on the technology enhanced smart environment. She has also involved in few consultation projects. Dr. Wong participates in multiple international projects such as ARMOURS European project, Adaptive Impedance Module (AIM) SMART project and SWARM Horizon 2020 project. Locally, she involves in Demand-Driven Development (3D) project to build intellectual property (IP) for system-on-chip. She has received more than 20 awards from international or local such as ITEX, INNOVATE, IEM, EDS societies and etc. She has been able to successfully design and develop low power controller, high voltage CMOS control chips and RF circuitries. She is equipped with both design and implementation skills