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Development of IoT Based Monitoring System for Small Scale Photovoltaics Electricity Generating System

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Abstract

The usage of non-renewable energy resources to meet the global energy demand has left its impact on the environment such as global warming, pollution and climate change. Countries worldwide are now shifting their focus towards utilization of renewable energy sources. In Malaysia, one of the more prominent initiatives is the integration of small scale, photovoltaics based, solar electricity generating system (PVSEGS). This initiative aims to propel the usage of PVSEGS in the country. However, there is noticeable lack of monitoring system available for small scale PVSEGS. A monitoring system is a crucial element especially when it comes to power generating system. A monitoring system will allow users to track the performance of the PVSEGS to make sure it is fully functional. This project focuses on designing and fabricating a Internet of Things (IOT)-based monitoring system for PVSEGS. The monitoring system logs data from the PVSEGS and will then upload the data to a cloud-based service via Wi-Fi network. The data can be viewed via mobile devices and web browsers. This will enable users to monitor their PVSEGS anytime and anywhere.

Keywords: Cloud, Internet of Things, Microcontroller, Monitoring, Photovoltaics, Solar

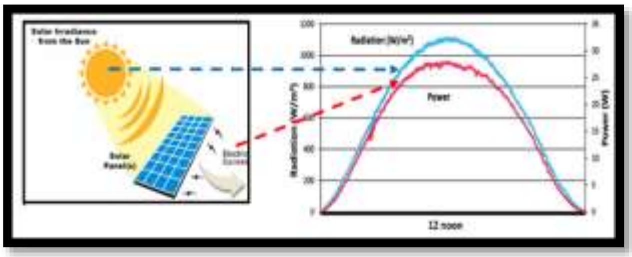
Introduction

At the turn of the century, there was a global shift towards the utilization of renewable energy sources, especially for electricity generation. This shift is predominantly driven by the rise in the impact on environmental and economical volatility as a result of over relying on fossil fuels as mankind's primary source of energy. The major consequences of the over exploitation of fossil fuels are global warming as well as critical ecological concerns such as pollution and the threat of extinction of certain flora and fauna species. The highly volatile prices of fossil fuels and its negative impact on the environment have raised the awareness amongst Malaysians for the need to migrate towards utilizing renewable energy sources, especially for electrical power generation.

Renewable energy is a type of energy that is reaped from renewable sources such as the sun and wind [1]. These sources of energy will not deplete when they are utilized to generate electricity, as compared to the fossil fuel-based electricity generating system. In recent times, the solar energy sector has expanded rapidly with countries like China and Germany competing to manufacture the latest and most advanced solar based electricity generation technology. Many countries are now setting up solar farms to supply electricity to their respective national grids. These solar farms mainly use solar panels that utilize the photovoltaics (PV) effect to generate electricity. Malaysia has the potential to generate large amount of solar power as it is located significantly close to the equatorial region. This means the country receives abundance of sunshine all year long, at an average of 1643kWh/m^2 of radiation yearly. However, the utilization of solar power is still low. The Malaysian government has put in lots of effort to boost the penetration of solar PV electricity generation by introducing various initiatives and policies. According to [2], between the years 1998 to 2002, a total of six solar farms were setup as a pilot project. In 2005, the total electricity generation via on-grid solar power system was 470kW peak and the off-grid system solar power capacity was 3MW peak. In order to increase the share of solar power in the local energy mix, the government launched the Malaysia Building Integrated Photovoltaic (MBIPV) project. The goal of the MBIPV project was to install or retrofit PV modules onto buildings. The project managed to install modules at over 17 sites nationwide. The government also introduced the Feed-in-Tariff (FiT) program in 2011 and an updated version of it, the Net Energy Metering (NEM) [3] scheme in January 2019. A program known as Small Renewable Energy Power (SREP) [4] program was also conceived to encourage the development of small scaled renewable energy power plants that would eventually feed into the national grid.

In July 2019, the government announced that they are formulating a new policy which will push real estate builders to incorporate PV based solar electricity generation system (PVSEGS) on newly constructed building. According to [5], this new policy will utilize the spaces on rooftops to install PVSEGS. These systems might be small scaled but will eventually contribute to the gradual reduction of the country's dependency of fossil fuels. Malaysia is blessed with abundant sunshine throughout the year, but there is a need to deal with the intermittent nature of the incoming solar irradiance. The intermittent levels of incoming solar radiation cause the output from PVSEGS to fluctuate, as shown in Figure 1.

The true performance of the installed system cannot be determined easily, and it needs to be continuously monitored as the intermittent levels of solar irradiance, local meteorological conditions and surface cleanliness affects the PV output. There are PVSEGS monitoring systems available, but the reliable ones are designed to track the performance of large scale PVSEGS that are usually costly and complex to be used for domestic purposes. Due to these issues, the purpose of this project is to design a simple, intelligent and inexpensive PVSEGS monitoring system. The need to ensure optimum conversion of sunlight to electricity is rather critical, as sunlight is available between 7:30 a.m. to 6:30 p.m. daily in Malaysia. Besides that, the weather also plays a crucial role in determining the levels of solar radiation as the irradiance magnitude can drop up to 40% during cloudy days in Malaysia. This project will also take advantage of the Internet of Things (IoT) platform by developing a cloud-based monitoring system which will enable the monitoring system to transmit real time data from the PVSEGS to the cloud. Owners and authorized personnel will be able to access relevant performance data anytime, anywhere and will be useful for preventive maintenance.



Distribution of the output power of the solar panel and the solar radtiation in a single day.   .

LITERATURE REVIEW

Solar Energy in Malaysia

Malaysia heavily relies on non-renewable sources of energy to generate electricity. According to [3], data collected in 2013 states that over 88 percent of the electricity generated originated from fossil fuels sources such as coal and natural gas. Despite the implementation of various policies and schemes, the utilization of renewable sources for electricity generation is alarmingly low. Hydroelectric power is the largest contributor of electricity from renewable sources, at over 11 percent. Other renewable resources only account for 0.2 percent of the electricity generation. Malaysia is also the largest emitter of carbon dioxide in the Southeast Area region with the power sector contributing close to 55 percent of the emissions. The years of inordinate exploitation of non-renewable energy sources has led to heavy pollution as well as contributing to global warming and climate change [2]. This pushed the Malaysian government to ratify the Paris Agreement in 2016 where it vows to achieve its goal of reducing 45% of its greenhouse gas emission relative to 2005 by the year 2030. Since then, the ruling government has been pushing to implement renewable energy sources into its electricity generation.

The government has put its focus on PVSEGS as Malaysia is located near the equator and receives abundant sunlight all year long with the annual average solar irradiance of 1643 kWh/m^2. As of July 2019, the initiatives to incorporate PVSEGS into the national grid include the Net Energy Metering (NEM) scheme, Small Renewable Energy Power (SREP) [4], and an in-works policy for real estate developers to install small scale PVSEGS on new buildings [5]. At one point, the Malaysian government expects solar PV to be the main supplier of renewable energy by 2020, and it will supply at least a third of the nation's electricity by 2050. Based on a study conducted by [3], small scale PVSEGS installed on rooftops nationwide can contribute up to 8.57 GW of power generation. There is potential for small scale PVSEGS system in Malaysia with the implementation of the various schemes and policies. However, it is heavily under-utilized. Statistics reveal as of April 2017, the utilization of the Feed-in-Tariff (FiT) scheme had only expanded to generate 314MW of power. On the flip side, the introduction of FiT scheme successfully brought down the cost to setup a PVSEGS by 23 percent. This paved the way for more large-scale solar farms getting constructed nationwide [2]. For the rural parts of Malaysia, private as well as government bodies are working on setting up small scale, standalone, PVSEGS. This type of system is suitable for rural and isolated settlements as these settlements have trouble obtaining power from the national grid. The output of the PVSEGS will be stored into a housing containing batteries and it can provide either DC or AC output depending on the specifications of the system.

Utilization of Cloud based Systems in Renewable Energy

Cloud computing is the utilization of a system of remote servers that are hosted on the internet which provides users with the ability to manage, process and store data which can be accessed from any device and anywhere, although this is dependent on the type of cloud services that is being used. According to [12], there are three types of cloud computing services:

- Public cloud
- Private cloud
- Hybrid cloud

The utilization of cloud services can be cost saving as all the data obtained is stored on a remote server. The user does not need to invest in hardware such as Hard Disk Drives to store data. The other benefit is security. The data stored in clouds are usually encrypted and requires special and complex security keys to access it. The other advantage is mobility as the data can be accessed anywhere and anytime. This feature is crucial for this project as this feature can be utilized for monitoring of PVSEGS installed in isolated locations. Since cloud-based systems use the internet, devices are not required to install plugins or update their operating systems to gain access to the stored data. Although mobile devices may require installation of local apps, generally the data stored can be accessed via cloud service website [12]. Currently, most large-scale monitoring system such as SCADA, the data that is logged by the monitoring system is stored in local servers at the plant. Due to the large size of the plant, the volume of data is extremely high, and companies must resort to either deleting old data or investing in new hardware periodically to meet the demands of the data monitoring system. These data cannot be accessed from locations other than the plant [9].

For a small scale PVSEGS monitoring system, sensors record down important and critical information such as output voltage, output current and solar irradiance. These data would then be transmitted via internet connection to the cloud services. Users can monitor these data at their convenience from any location and any time.

Integration of Arduino and Cloud Computing for PVSEGS Monitoring System

Arduino is a company that designs and manufactures open-source microcontrollers and provides open-source software for the public usage. The company has a strong user community that designs and fabricate projects using the Arduino IDE software and microcontrollers. Arduino has designed its products to be low cost and it is easy for professionals as well as novices to fabricate projects [13]. These projects can be as simple as displaying a message on an LCD screen to as complex as a cloud based PVSEGS monitoring system.

Arduino microcontroller boards are equipped with ATmega328 AVR microcontroller, digital input output pins with Pulse Width Modulation (PWM) capabilities, and analog input pins. The Arduino board can connect to the internet by utilizing a Wi-Fi shield which will allow it to connect to Wi-Fi networks and upload data to cloud-based services. One of the cloud-based services that is excellent for data logging is Blynk. Blynk is an open-source web-based cloud service that can read and store data from the Arduino. Users have an option to either view the said data in numerical form or graphical form such as in gauges and graphs. The nature of its graphical output makes it engage as it makes it simpler for users to collect and analyze data. Users have an option to access the data either by the Blynk mobile application or via a third party web application. This means that users can monitor the PVSEGS system anytime and at any location if they have stable internet connection. Since Blynk is open source, users do not need to pay for the services.[14]

Monitoring Systems for Small Scale PVSEGS

Since the early 2010's, there have been countless attempts to design and fabricate monitoring systems for small scaled PVSEGS. In 2014, a team of researcher from University of Jaén, Andalucía, Spain designed a small scaled, Arduino based monitoring system for PVSEGS. This system was designed to collect irradiance and voltage data. The testing of the prototype was carried out for a six-month period at the South of Spain. The prototype was tested alongside another data logger whose type remains undisclosed. The prototype was tested on a standalone PVSEGS system and on a micro-grid tied PVSEGS. While the system was able to carry out the datalogging process, it lacked diagnostic and cloud computing capabilities [15].

In 2015, the Department of Electronic, Faculty of Science and Technology Constantine University, Algeria and the Institute Microelectronics, Materials and Nanosciences of Provence Aix Marseille University, France collaborated on a project to design on a monitoring system. The Arduino based monitoring system was designed to trace the current-voltage curve of PV modules under natural conditions based on the LabVIEW software. The parameters from the PV module that were recorded and calculated are the module's open circuit voltage, short circuit current and max power max power, short-circuit current, open-circuit voltage. This system however lacks cloud computing features as well [16].

A similar attempt in designing a small-scaled monitoring system was conducted in 2017 by personnel from Department of Control & Instrumentation, National Institute of Technology, Jalandhar, India. The team designed a monitoring system that would record voltage reading from the solar panel and send the data to Lab View. This system too lacked cloud computing features and it only records the output voltage from the PV modules, which is insufficient for full performance monitoring [17].

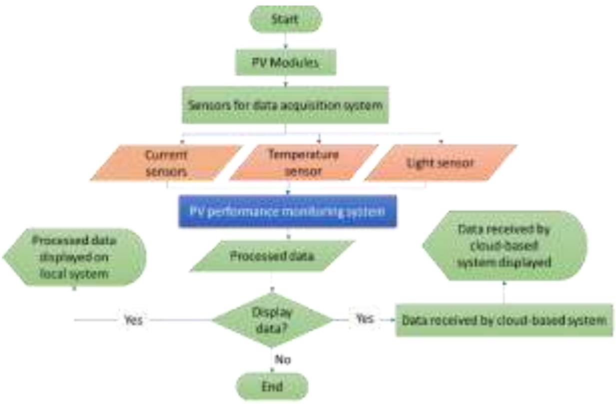
In 2018, a team from the Department of Electrical Engineering, Universitas Bangka Belitung, Indonesia and the Department of Information System Universitas Muhammadiyah Gorontalo collaborated and successfully fabricated a small-scaled monitoring system utilizing Arduino and cloud computing without the integration of any diagnostics system [18]. In 2019, a Korean researcher designed a control system to control the temperature of PV modules. This system measures and records the temperature of the PV modules and could not carry out full performance monitoring [19]. The outcomes from all these initiatives to develop monitoring systems for a small scale PVSEGS are as given in Table 2.1 where all the attempts made to design and fabricate a monitoring system for small scaled PVSEG together with their weaknesses are highlighted. There is clear evidence for the need to design and develop a cloud-based system that can monitor and analyze the performance of small scaled PVSEGS, in line with the objectives of this project work.

List of existing monitoring systems

Author/Year	Title	Findings	Weakness
M. Fuentes, M. Vivar, I. Burgos, J. Aguilera, and J. Vacas/2014	• Design of an accurate, low-cost autonomous data logger for PV system monitoring using Arduino that complies with IEC standards	• The team designed a monitoring system that was abled to record data from PVSEGS	• It does not have cloud computing features
C. Rachid/2015	• Tracing current-voltage curve of solar panel Based on LabVIEW Arduino Interfacing	• A system that could record the output voltage and current and plot the I-V characteristics using LabView	• It does not have cloud computing features
S. Mandal and D. Singh/2017	• Real Time Data Acquisition of Solar Panel Using Arduino and Further Recording Voltage of the Solar Panel	• The team designed a monitoring system that would record voltage reading from the solar panel and send the data to Lab View	• It does not have cloud computing features • It only records output voltage, not sufficient for full performance monitoring
R. F. Gusa, W. Sunanda, I. Dinata, and T. P. Handayani/2018	• Monitoring System for Solar Panel Using Smartphone Based on Microcontroller	• The team developed a microcontroller based monitoring system that utilizes cloud computing	• The system lacks diagnostic capabilities
H.-J. Kim/2019	• Solar Panel Temperature Control System Using IoT	• Designed a IoT based monitoring system to monitor the temperature of solar panels	• Only measures and records the temperature of the solar panels • The system lacks diagnostic capabilites

IOT BASED PV PERFORMANCE MONITORING USING A MICROCOMPUTER

This paper focuses on the designing and fabrication a prototype that is capable of monitoring small scaled, photovoltaics based, solar electricity generation systems (PVSEGS). The prototype utilizes cloud computing technology as part of its monitoring system. The utilization of cloud-based technology will enable the consumer to monitor the condition as well as functionality of the PVSEGS. The monitoring system comprises of two main components: the hardware components and the software components. The hardware components are designed to read various forms of data from the PVSEGS and transmit said data to a cloud-based platform. Sensors such as current sensors, temperature sensors and light sensors will read their respective data and send it to the microcontroller. The microcontroller accepts the input from the sensors, process the data and transmit them to a cloud-based platform in real time. The software components are the integrated development environment which is used to program the microcontroller and the cloud-based platform which receives, stores, and displays the data collected from the sensor. Users can access the stored data anytime and anywhere without having to physically be at the PVSEGS. The complete working of the prototype is fully illustrated in Figure 2.



Flowchart of System

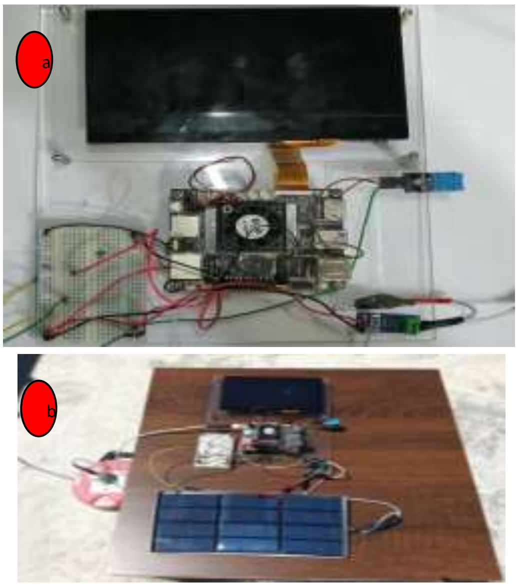
After fabricating the prototype, it is taken out for a field test. The monitoring system is connected to a 4.5 Watts, 36 Volts string of solar panel to measure its output. The prototype is tested for its ability to measure the output power from the solar panel as well as other information such as light intensity and temperature, and its ability to connect to a wireless network and transmit the data to a cloud server. A solarimeter was used alongside the prototype throughout the testing period. The solarimeter function was to record down the solar irradiance data which will then be matched to the output power collected by the prototype. This is done to ensure the fluctuation of the output power is like the fluctuation of solar radiance throughout the testing period. Data from the test are tabulated and analyzed. From the analysis, if there are any issues with the prototype or there are potential for improvement, changes will be made to improve the overall performance of the prototype.

RESULTS & DISCUSSION

The list of hardware and software that were used for the design and fabrication of this prototype are listed in Table II.

Hardware & Software used

No	Hardware
1	ACS712 current sensor
2	DHT11 temperature and humidity sensor
3	LM 35 temperature sensor
4	Light Dependent Resistor
5	LattePanda Windows Microcomputer
6	Arduino Leonardo (built-in with LattePanda)
7	Capacitive Touch Screen Display
8	Arduino IDE
9	Blynk mobile application
10	Blynk Third Party Web app



Prototype of monitoring system(a) and the the protoype that is connected to a string of solar panels during its field test(b).

The prototype reads the output voltage and current of the solar panels via the current sensor. The current sensors utilize a set of Hall Effect sensors to obtain the output voltage and through an equation coded via the Arduino IDE, it will provide the output current. The voltage and current values are then used in the calculation of the output power of the solar panels. The current sensor detects current magnitude up to 25 amperes. The DHT11 temperature and humidity sensor is used to obtain the environmental temperature and humidity while the LM35 temperature sensor is attached to the string of solar panels in order to obtain temperature of the surface of the solar panel. The LDR is used to obtain light intensity. The output of the sensors is read by the analog pins of the Arduino Leonardo microcontroller, ATmega32u4. The analog values are then converted to the respective values of each measured parameters via equations that are coded via Arduino IDE. The data is then transmitted to the cloud-based servers of Blynk via the Wi-Fi network. The data from the performance monitoring system can be viewed in real time via the Blynk mobile application or via Blynk third party web app. However, that is a subject to the availability of the internet connection at the location of the prototype. The performance data can also be view locally on the LattePanda. Since the LattePanda is a microcomputer that supports Windows 10 operating system and its respective applications, the Blynk web application can be utilized for local monitoring. Figure 4 illustration the view of the performance data in the Blynk application and its web application

Figure 5 illustrates the performance data being viewed across multiple platforms. The platforms in Figure 5 are Windows laptop, LattePanda and a smartphone.

Fig 4. Performance data displayed on the mobile application (a) and on the web application (b)

Fig 5. Performance data viewed across multiple devices.

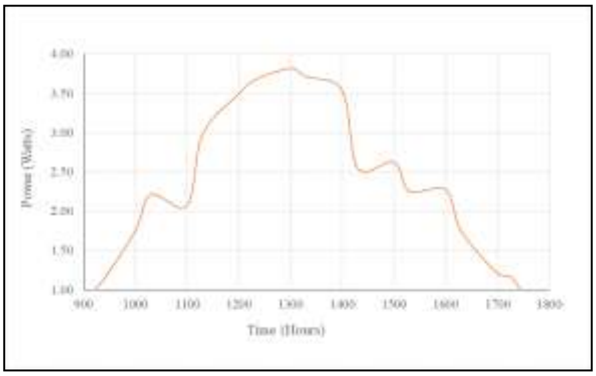


Fig 6. Data collected from the monitoring system.

The testing of the prototype began immediately after its fabrication. A string containing 3 solar panels was used for the testing. The same type of solar panel was used for consistency of data. The string of solar panels can give an output power of 4.5 Watts and 36 volts at peak solar radiation. The panels are also connected to power resistor which acts as a load for the system. The setup is as in Figure 3. The solar panels were placed in the east-west orientation to be in the path of the sun for optimum exposure and data was collected between 9 a.m. to 6 p.m., as shown in Figure 6. Data was collected and tabulated. The fluctuating power curve shown in Figure 6 is consistent with the intermittent nature incoming solar irradiance.

The LattePanda has the specifications that is comparable to a budget laptop. It is equipped with USB ports, HDMI ports, Wi-Fi, Bluetooth 4.0, 4 gigabytes of RAM and 64 gigabytes of flash storage and a built-in Arduino Leonardo. It only requires a regulated power supply of 5 volts and 2 amperes [20]. Its compact nature, relatively high processing ability, and low power requirements allows the prototype to be installed in any location which is convenient for the consumer when they use the product. Not only that, the utilization of LattePanda opens up to the possibilities of adding improvements include developing a diagnostic software or upgrading hardware. The summary of the results is tabulated in Table III.

Summary of results

	Summary of Results
	•Fully functional prototype designed and fabricated using LattePanda with Windows 10 as operating system and built-in Arduino Leonardo to interface with sensors •Use of Blynk as cloud server •7” touch screen for direct monitoring on site •Prototype has an independent Blynk web client that will allow for local monitoring. •The prototype is able to read sensor data accurately and transmit the data to the cloud for it to be viewed across multiple devices.

conclusion

This objective of this research project is to design a simple, intelligent and inexpensive prototype for monitoring of PVSEGS has been achieved. The prototype that was designed and fabricated is fully functional and capable of monitoring the performance of PVSEGS where data acquisition is done continuously at a set time interval. The prototype has the capability to upload the logged data to a cloud based Blynk server via Wi-Fi network. The data can be viewed via mobile devices and web application, which allows for the performance of PVSEGS to be monitored anytime and anywhere. The performance data can also be monitored locally on its capacitive touch LCD display that is attached to the prototype. Any abnormal variations in the recorded parameters such as output voltage would allow for fault detection in the PVSEGS. The detection would allow the fault to be rectified instead of going undetected and disrupt the performance of PVSEGS.

The next step would be to upscale the components to so that it can be tested on PV panels with higher power rating. This will allow the researchers to be able to understand how the components at a higher power interact with the ATmega32u4 microcontroller.

Once the upscaled components have been successfully integrated into the system, the next step would be to begin research into developing a diagnostic system. Since the microcomputer runs on Windows and has computing power of a budget laptop, there is an opportunity to create a diagnostic software that is able to read the sensor data and determine the health of the PVSEGS. The software could alert the consumer if the performance of the PVSEGS is below optimal range.

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