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Online Monitoring of Grid Connected Residential Photovoltaic System using Zigbee and Web Server

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Abstract

The paper presents grid-tied PV monitoring system using wireless sensor networks. The temperature and humidity parameters were measured using DHT22. While ACS 712 5A current sensor and Arduino voltage sensor modules were used to measure photovoltaic output current and voltage respectively. Web application has been developed in the base station using PHP programming web server to access the sensor nodes through Zigbee wireless data communication. The user can access the HTML web interface of Photovoltaic monitoring system through local Ethernet or Wi-Fi connection. The residential 1.25 kWp grid connected photovoltaic system used to test the developed monitoring system. The data received exactly same as data sensed from remote area with average delay time 3 to 4 seconds. The result shows the photovoltaic power generation caracteristics under clear sky, cloud cover, and rainy weather conditions. The power 608.12 Wp has been generated by the solar panel from 7.00 am to 6.00 pm or 6.7 kWh per day during clear sky. During intermittent cloud covered the photovoltaic power graph have shown fluctuation power profile and energy conversion were decreased as well as in raining weather condition. The electrical power has been generated by photovoltaic for almost 12 hours per day in tropics area, but energy conversion is highly influenced by weather conditions, especially cloud cover, overcast and rainy.

Keywords*: Online monitoring, Photovoltaic, Zigbee sensor network and Web server*

1. Introduction

The utilization of communication technology, computer, and information to operate the power system is one of the interested topics in the development of smart grid future study. Implementation of smart monitoring and control on the operation of new power plants and renewables will improve the efficiency and reliability as well as reducing operation cost [1][2]. Among renewable energy sources, solar energy is the most alternative has been developed and reliable [3]. The Indonesian government supports the utilization of solar energy resources including supporting industries in order to achieve the target share of renewable energy is higher in the national energy mix, which is by 23% in 2025 and 31% by 2050 as mention in Indonesian Energy Policy No. 79 Year 2014 [4].

The One important aspect after the construction of solar power station, especially for isolated mini grid system is the need of monitoring equipment and control systems are adequate. The monitoring system will be designed to be able to display the important parameters of solar panels and detect early failures and provide the right trip command to the breaker. Many wired and wireless monitoring and data collecting systems have been proposed and developed in the past. The main task of these systems is to monitor and collect data concerning the performance of the photovoltaic (PV) plant.

The wired monitoring of small scale photovoltaic proposed in [5] using LabVIEW graphical interface via RS232 serial communication. The wired monitoring of 1.72 kW photovoltaic system reported in [6] which the sensor nodes connected to monitoring system via a serial RS485 link. The wired monitoring system provides reliable solution in data transmission but suffers from several limitations [7] such as have physical constraints during laying of the data cables, increases installation and maintenance. The outdoor application may reduce lifespan, because of continuous exposure to sun light and rains [8].

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Wireless networks can be used for communication between sensors, actuators with a local server. The advantages of this system does not take some extra cost and maintenance for data communication cable [8]. A wide variety of wireless communication technology have been reported. The GSM-based monitoring and control of photovoltaic power generation proposed in [9]. These systems have high operating costs, which requires users to pay for services of data transmission. Bluetooth and Wi-Fi are another alternative technology in wireless communication [10]. Bluetooth support simple wireless networking but only cover short distances. Wi-Fi has high data transfer rate and supports star topology but the cost of Wi-Fi device is relatively higher compared to Bluetooth.

Another proposal of PV monitoring are reported in [7] [11] [12] using Zigbee based devices. ZigBee can be implemented in mesh networks larger than it is possible with Bluetooth [13]. The paper described in [11] focus on monitoring devices management suitably placed. PV power station monitoring system based on wireless sensor networks (WSNs) and cloud to handle big data have been built [14]. While how to select and measure PV operation in real-time and sensors used not discussed. The monitoring using Zigbee sensors network also report in [12]. The system architecture of hardware and software components are presented in detail in the paper [12]. However, the parameters measured only environmental condition for general application.

The aim of this paper is to present results obtained from PV monitoring system based on Zigbee and web server. It is expected the PV generation system can operate even during overcast and rainy days with lower operating costs. The prototype of monitoring system of PV power generation results of this study are expected can be implemented in isolated systems of mini grid which are spread throughout Indonesia.

This paper is organized as follows. The introduction has been presented in section 1. In section 2, the PV monitoring system including Zigbee sensor networkand web server and test system are explained. The implementation results and discussion are presented in section 3. Finally, section 4 concludes the paper.

2. Research Method

2.1. Online PV Monitoring System

The proposed online residential scale photovoltaic monitoring system using Zigbee sensor networks [15] and web server. The Zigbee is a wireless communication technology with low power consumption and low data transmission rate based on IEEE 802.15.4 standard. Zigbee device is built to support sensor networking-based applications which utilize radio frequency. They are designed for simple and lightweight wireless networks. Zigbee’s transmission ranges are up to 200 m indoor and 3 km outdoor. The temperature and humidity parameters were measured using DHT22. While low cost ACS 712 5A current sensor and Arduino voltage sensor modules were used to measure PV output current and voltage.

The Arduino voltage sensor module with voltage dividers have been used to measure the PV output voltage. This module is based on resistance points pressure principle, and it can make the input voltage of red terminal reduce 5 times of original voltage. Because the Arduino AVR chip 10 bit analog to digital converter or have returns values between 0-1023, so this module resolution is 0.00489 V (5V/ 1023), and the input voltage of this module maximum range be 0.00489 V x 5 = 0.02445 V. The voltage divider have been used to measure higher voltage. The PV voltage then calculated using equation (1). The voltage divider with 6.5 ratio have been used to measure PV voltage:

$$V_{PV} = (5/1023) * V_{out} * 5 * VD \tag{1}$$

Where V_{PV} is PV output voltage, Vout is analog read between 0 – 1023 and VD is voltage devider rasio.

The ACS712 current sensor module have been used to measure the PV output current. The ACS712 sensor read the current value and convert it into a relevant voltage value. The sensor power supply is 5V and the middle sensing voltage is 2.5V when no current. Therefore the PV current then calculated using equation (2).

$$I_{PV} = \frac{(5/1023)*V_{out} - 2.5}{0.185} \quad (2)$$

Where I_{PV} is PV load current

Four sensor node are connected to Arduino Mega and Zigbee tranceiver i.e. the Xbee module in remote area. The Xbee module on the remote station is configured as router and the Xbee module on local station is configured as coordinator. The Real Time Clock (RTC) S1307 Arduino compatible have been used to provide the accurate time and date for this application. The RTC chip uses internal battery, which keeps the time and date even though the power is off. The measurement time of local station refer to remote station time is created by RTC.

The visualization of sensors and interpretation of their data has a great importance, without it data has basically no meaning. Visualization helps in conveying useful and effective information to the users regarding real time sensor data. The main objective of the web server is to achieve these tasks in easy and straightforward way. Web server turns your computer into a ready-to-use personal web hosting server. Web application, MySQL database server, and PhpMyAdmin database management can be used to perform these tasks.

The PHP web programming is responsible for interpreting results from the database which contains information from the local station to the user in a graphical interface. A Phpmyadmin was used to set up the MySQL database to do the tasks. Then user can access the HTML web interface through Ethernet or Wi-Fi connection within the local area network or from anywhere on the Internet when configured appropriately on the router by using IP addresses http://10.28.139.242/site in the client's browser. The screen snapshot of wireless data logger for photovoltaic monitoring displays in local station is as shown in Figure 1.

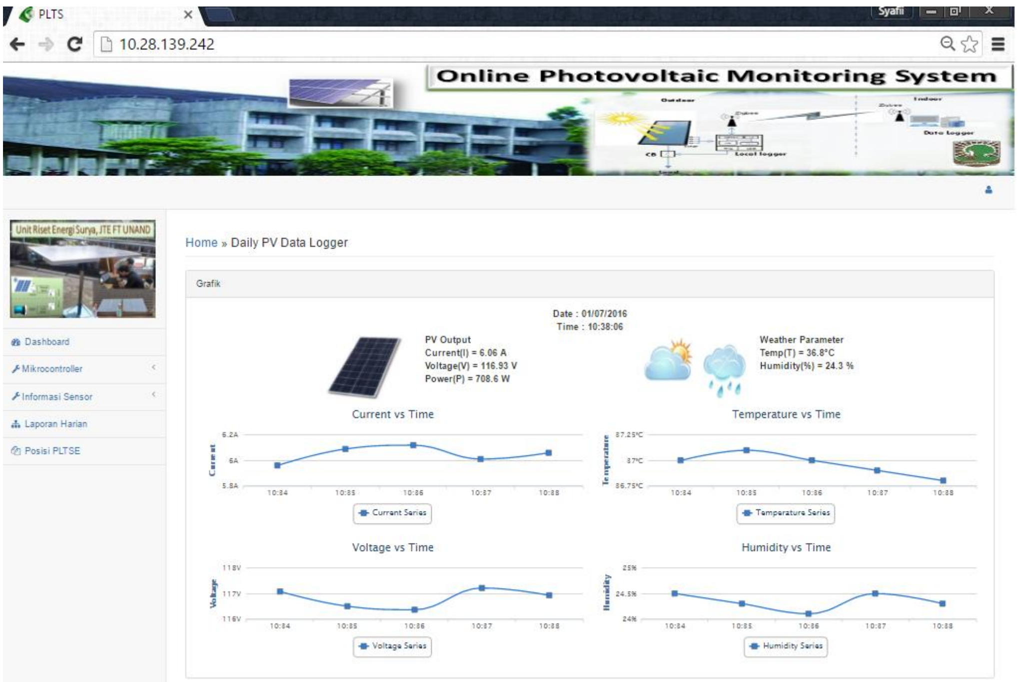


Figure 1. Grid-Tied PV monitoring system.

Web application have been developed on the base station using the PHP programming web server to access the sensor nodes through Zigbee wireless data communication. The data received exactly same as data sensed that measured and sent from remote area. The real time values display in the form of graphs in web site developed as shown in Figure 1 for fourth parameters monitored. The data monitored are recorded at sampling rate per second, while the refresh rate of web display is set to be 1 min. A Phpmyadmin was used to set up the MySQL database to recorded and evaluated PV power generation by send to user via email regularly for every one hour intervals. The user also can access the HTML web interface of Photovoltaic monitoring system through local Ethernet or Wi-Fi connection.

2.2 Description of Test System

In this research, a monitoring system has been installed for residential scale 1250 Wp PV System. The PV system is located on the 4rd floor of Electrical Engineering Building, University of Andalas in Padang, West Sumatera, Indonesia. The solar panel was used IPV250P polycrystalline silicon type which maximum power in STC 250 Watt, 31.2 Volt. Therefore, five units of solar panel have been used and PLN grid connected through grid tied inverter 2kW with MPPT SNV-GT-2001SM type. Figure 2 shows the overall setup of the system, as well as the sensors and devices available on each location.

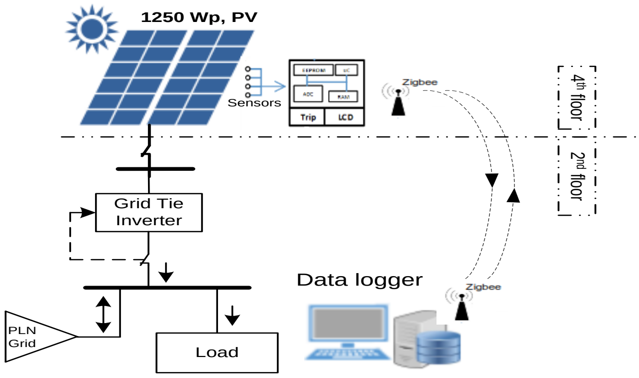


Figure 2. PV local and remote data logger

The load will supply from photovoltaic and PLN grid. However, during high radiation intensity and minimum load demand, the overload power from photovoltaic can be injected to PLN grid. In contrast during power from photovoltaic not enough to supplied load demand, the PLN grid will supply the load. The DC photovoltaic energy conversion and thr weather condition monitored in reat-time in PC based local station.

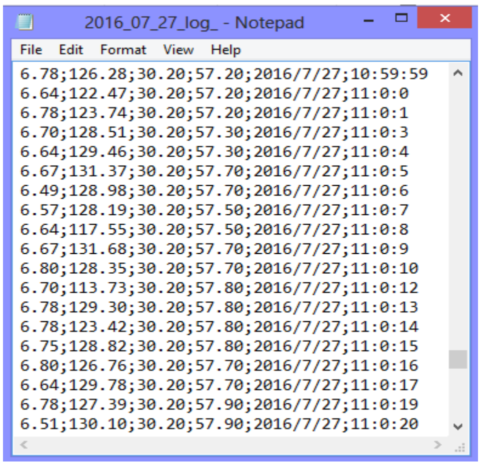
3. Results and Analysis

The Zigbee sensor network measurement firstly validated through the individual sensing and compared to real measurement equipment. The temperature and humidity sensors reading are then validated with digital LCD temperature humidity meter and a digital mini Volt/Amp meter for PV electrical output. The average different reading of DHT 22 compared to HTC-2 digital temperature and humidity meter is around 0.5°. The average different reading of current sensor and voltage sensor compared to mini digital Volt/Amp meter are around 0.5 Volt and 0.2 Amp. The voltage divider with 6.5 ratio have been used to measure PV voltage.

The PV masure paramenters sequence that records which download to arduino mega is state:

```
void get_data(){
  get_current();
  Serial.print(";");
  get_voltage();
  Serial.print(";");
  get_temp();
  Serial.print(";");
  get_humidity();
  Serial.print(";");
  get_rtc();
  Serial.println("");
}
```

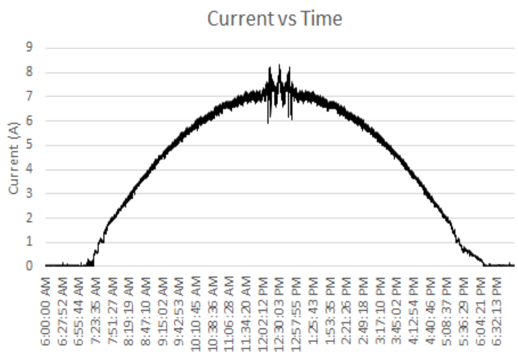
The PV parameters which have been read sequentially display for current, voltage, temperature, humidity, date and time. The current measure in Ampare, voltage in volt, temperature in °C and humidity in %. There were 145,132 data logged for two days August 1-2 2016. A part of collected data is shown in Figure 3. The Figure 3 shows that the monitoring system logs the current, voltage, ambient temperature and humidity for every seconds.Then the real-time recorded data sent to base station through wireless Zigbee communication system. The data received exactly same as data that sent from remote area and the time delay received by coordinator Xbee in base station is around 3 to 4 seconds.


2016_07_27_log_ - Notepad
File Edit Format View Help

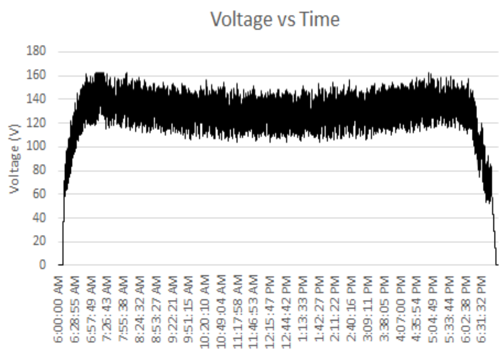
```
6.78;126.28;30.20;57.20;2016/7/27;10:59:59
6.64;122.47;30.20;57.20;2016/7/27;11:0:0
6.78;123.74;30.20;57.20;2016/7/27;11:0:1
6.70;128.51;30.20;57.30;2016/7/27;11:0:3
6.64;129.46;30.20;57.30;2016/7/27;11:0:4
6.67;131.37;30.20;57.70;2016/7/27;11:0:5
6.49;128.98;30.20;57.70;2016/7/27;11:0:6
6.57;128.19;30.20;57.50;2016/7/27;11:0:7
6.64;117.55;30.20;57.50;2016/7/27;11:0:8
6.67;131.68;30.20;57.70;2016/7/27;11:0:9
6.80;128.35;30.20;57.70;2016/7/27;11:0:10
6.70;113.73;30.20;57.80;2016/7/27;11:0:12
6.78;129.30;30.20;57.80;2016/7/27;11:0:13
6.78;123.42;30.20;57.80;2016/7/27;11:0:14
6.75;128.82;30.20;57.80;2016/7/27;11:0:15
6.80;126.76;30.20;57.70;2016/7/27;11:0:16
6.64;129.78;30.20;57.70;2016/7/27;11:0:17
6.78;127.39;30.20;57.90;2016/7/27;11:0:19
6.51;130.10;30.20;57.90;2016/7/27;11:0:20
```

Figure 3. PV data logger

The output current and otput voltage of residential PV system are shown in Figure 4.a and Figure 4(b) respectively. The PV power can be obtained by multiplied PV output current and output voltage as shows in Figure 5. The PV output power is increased same as the PV current increased. The PV power generation is adversely affected by weather conditions, especially cloud cover, overcast and rainy. During intermittent cloud covered the PV power show an irregular profile. The power 608.12 Wp has been generated by the solar panel from 7.00 am to 6.00 pm or 6.7 kWh per day. Therefore the electrical power can be generated by photovoltaic for almost 12 hours per day in in Padang area, West Sumatera as one of tropics area.



(a) PV output current



(b) PV output voltage

Figure 4. Output current and voltage of PV system under clear sky weather

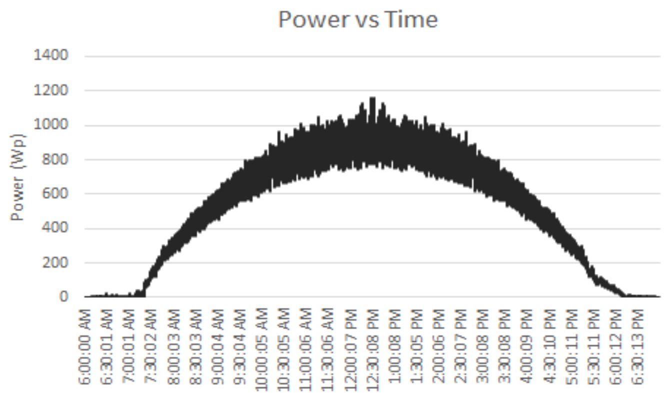


Figure 5. Daily variation of PV power generated under clear sky weather

Daily variation of PV output current, voltage and power when raining and overcast weather condition (1/8/2016) and intermittent cloud covered (2/8/2016) are shown ini Figure 6 and Figure 7. During rainy and overcast sky the PV current decreased and disconnected earlier before sunset. However, under normal day or clear sky day, the PV system connects to grid early hours after sunrise and disconnect to grid late hours during sunset. Therefore, the average power that can be converded 127.53 Wp or the energy that can be generated about 1.53 kWh per day during the rainy weather. While cloud cover weather conditions, the average power that can be raised is 451.36 Wp or equal to 5.42 kWh of energy. Therefore the weather conditions greatly affect the size of the electrical power that can be generated.

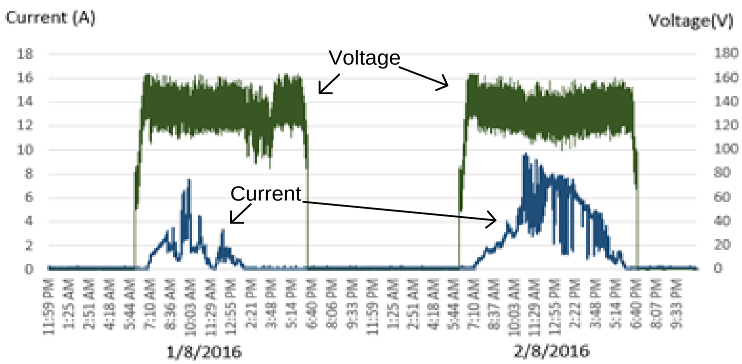


Figure 6. Daily variation of PV current and voltage

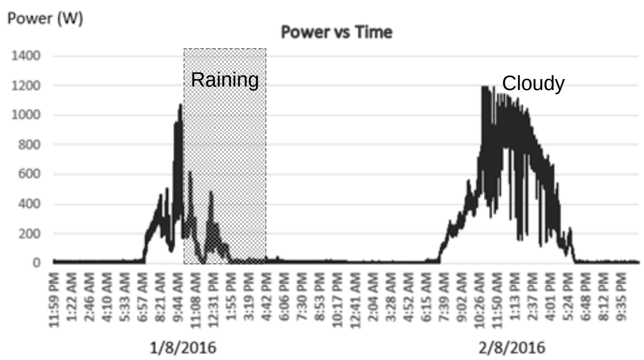


Figure 7. Daily variation of PV module power generated

Figure 8 and Figure 9 shows daily variation of PV module temperature and humidity. The temperature has been increased during clear sky and decreased when cloud covered and overcast. However, the humidity has been decrease during clear sky and increased when overcast and rainy. The temperature of the PV station varied between 21.2ºC at 16:00:40 on 1/8/2016 and 42.7ºC at 13:30:41 on 2/8/2016 and the humidity varied between 110% toward evening and 26.9% at noon 02:22 PM on 2/8/2016.

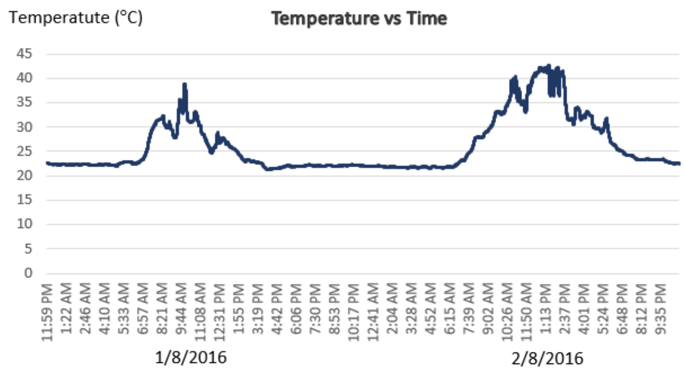


Figure 8. Daily variation of ambient temperature of PV system

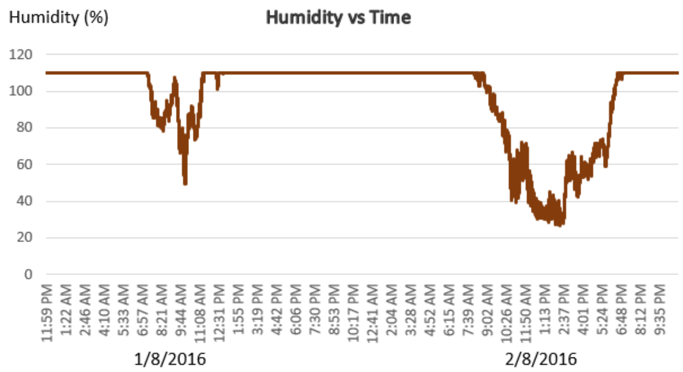


Figure 9. Daily variation of ambient humidity of PV system

By using Zigbee sensors network and web server, PV power and energy supply have been recorded. This information can be used for performance and energy saving analysis of PV system. Based on the results obtained, the developed monitoring system have provided low cost and effective solution for wireless monitoring of grid connected photovoltaic generation system.

4. Conclusion

The online data logger for PV monitoring system have been build and presented. The recorded data sent to base station through wireless Zigbee communication system. The data received exactly same as the data sensed that sent from remote area. The time delay between Xbee transceiver and received around 3 to 4 seconds. During sunny day, the PV system connect to grid early hours after sunrise and disconnect to grid late hours during sunset. During rainy and overcast sky the PV current decreased and disconnected earlier before sunset. The PV power can be obtained by multiplied PV current and voltage. The PV power output is increased as the PV current increased. During intermittent cloud covered the PV power curve show an irregular profile. The average power 608.12 Wp has been generated by the solar panel from 7.00 am to 6.00 pm or 6.7 kWh per day during clear sky. During intermittent cloud covered the photovoltaic power graph have shown fluctuation power profile and energy conversion were decreased as well as in raining weather condition. The temperature of the PV station varied between 21.2ºC at 04:00 PM on 1/8/2016 and 42.7ºC at 01:30 PM on 2/8/2016 and the humidity varied between 110% almost all night and 26.9% at 02:22 PM on 2/8/2016.

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