Solar panel performance monitoring using Wireless Sensor Network in State Polytechnic of Malang

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Abstract. The electricity supply used in State Polytechnic of Malang (Polinema) is still fully supported by PLN by utilizing the electricity source of the Electric Steam Power Plant (PLTU) with coal as a fuel. As the use of electricity in Polinema’s environment is very large, this has an impact on the expensive cost that must be incurred every month. The use of solar power as a new source of electricity that utilizes the nature of renewable energy can be used as an alternative electricity in Polinema. Supported by the use of solar panels with relatively affordable price and can be used as a long-term investment, it is expected that the use of electricity from PLN can be replaced by this solar power plant (PLTS). In this research, a prototype of electrical energy monitoring device produced by solar panel using several sensors connected in one network or commonly called Wireless Sensor Network (WSN) was designed and made. WSN was built using ESP32 microcontroller which is assembled with a voltage and current sensor which then the readings from the sensors will be sent wirelessly to the router to proceed to the server with internet facilities. Information from the sensors are continuously stored and monitored, so user can see the results of WSN reading from any location connected to the internet (real time).

1. Introduction

Currently, the need for electricity use in the Malang State Polytechnic (Polinema) is very high especially used for activities in the classroom, practicum activities in the laboratory and also office activities from morning to evening. Until now, the electricity needs in Polinema are fully supported by PLN by utilizing a power source from the Steam Power Plant (PLTU) in Paiton [1].

The use of PLTU itself has its drawbacks, that it still requires fuel of coal, whose availability can be exhausted, expensive investment and also requires a lot of cooling water, so it must be placed in a location close to many water sources [2].

The use of solar power as a new source of electricity that utilizes the nature of renewable energy can be used as an alternative to electrical energy in Polinema. Being in the equatorial region, the potential for solar energy in Indonesia reaches an average of 4.8 kilowatt hours per square meter per day (kWh/m²/day), equivalent to 112,000 GWP [3]. With an average sun shining 6 to 8 hours per day, it can meet the needs of electricity production in solar panels, which the ideal length of irradiation is 4 to 5 hours per day [4]. Supported by the use of solar panels at a relatively affordable price and can be used as an investment in the long term [5-6], it is hoped that the use of electricity from PLN can be replaced by Solar Power Plant (PLTS).
However, the design of PLTS cannot be done carelessly, but must meet several factors that determine the performance of solar panels. The amount of output power generated from the conversion of sunlight energy into electrical energy is determined by several environmental conditions such as sunlight intensity, temperature, direction of sunlight and the spectrum of sunlight. Environmental conditions that always change every time can cause the output power of the solar panels to also fluctuate [7].

In this research, a prototype of a monitoring tool for electrical energy produced by solar panels will be designed and built using several sensors connected in a network or commonly called a Wireless Sensor Network (WSN) which is then connected to a microcontroller to obtain data such as voltage and current as well as take advantage of the Wi-Fi facility available as a medium for sending and receiving the data in real time. The performance of solar panel can be determined by monitoring its output parameters such as voltage, current, power and efficiency output. If the results of these monitoring are known, the appropriate energy consumption and electrical load can be well planned.

2. Methods

This research applies the Wireless Sensor Network (WSN) concept to monitoring the solar panel parameters such as voltage and current values generated from the solar panel and also the temperature around. WSN itself at least consist of node sensor to get data from the environment, gateway or sink to collect the data from node sensor and base station to store the data. The topology used in the WSN system is a star topology, means each node sensor is directly connected to the sink.

Every sensor node is sensing or monitoring the environment, in this research sensor nodes are sensing the voltage and current value from solar panel and also temperature around solar panel. These monitoring results are sent to sensor gateway/sink. After several times, sink will deliver the monitoring result data to the base station. At the base station, the data will be processed into another data desired by the user.

2.1. Solar panel monitoring system

Based on WSN architecture above, here is in Figure 1 shown the architecture of solar panel monitoring system implemented in this research:

![Figure 1. Architecture of solar panel monitoring system.](image_url)

Note:

a. Node Sensor = Voltage Sensor and Current Sensor ACS712 connect with ESP32μC
b. Node Sensor = Temperature Sensor BME280 connect with ESP32μC
c. Gateway/Sink = ESP32μC
d. Base Station = Server (http://niaja.id)
Figure 1 explains the overall research diagram that consists of node sensor around solar panel for sensing voltage, current and temperature sensor. Node sensor send the data to sink through Wi-Fi. Sink also send the data to base station or server through Wi-Fi. At base station, these data will be performed in number and also in chart, so user can access it from mobile phone or laptop anywhere in real time.

ESP32μC is a single 2.4 GHz Wi-Fi-and-Bluetooth combo chip designed with the TSMC ultra-low-power 40 nm technology. It is designed to achieve the best power and RF performance, showing robustness, versatility and reliability in a wide variety of applications and power scenarios. ESP32μC is designed for mobile, wearable electronics, and Internet-of-Things (IoT) applications. It features all the state-of-the-art characteristics of low-power chips, including fine-grained clock gating, multiple power modes, and dynamic power scaling [8].

From research diagram shown in figure 1 above, the system is implemented as shown in Figure 2, Figure 3 and Figure 4 as follow:

**Figure 2.** Configuration of node sensors: power sensor (a) and temperature sensor (b)

From Figure 2 above, node sensor (a) consists of voltage sensor and current sensor that connected to ESP32μC. This node sensor is used to retrieve voltage and current data generated by the solar panel. Node sensor (b) consists of temperature sensor that also connected to ESP32μC. This sensor is used to retrieve temperature data around solar panel. Temperature around solar panel is important to monitor because higher temperature around can decrease the solar panel efficiency about 0.055% /ºC [9].

**Figure 3.** Configuration of sink  

**Figure 4.** Configuration of solar panel monitoring system.

From Figure 3 above, we also can see that sink is also using ESP32μC so the communication between node sensor and sink can be done more easily, by utilizing the MAC address on each ESP32 board. After node sensors send the power and temperature data to sink, sink will collect all data and then send them to base station or server through Wi-Fi.

In Figure 4, the whole system is shown. The solar panel is connected to a battery with a capacity of 12 mAh, so the electrical energy obtained from the sunlight can be stored in the battery.
3. Results

The monitoring results from sensors can be accessed at address http://niaja.id/esp-data-daya.php for power and efficiency of solar panel, http://niaja.id/esp-data-temp.php for temperature around solar panel and also http://niaja.id/esp-chart.php for every data in chart. Here in Figure 5 (a), (b) and (c) show the all result of monitored data:

| No. | Sensor | Current(A) | Voltage (V) | Power | Efficiency | Time        |
|-----|--------|------------|-------------|-------|------------|-------------|
| 6980 | Power  | 3.12       | 13.03       | 40.45 | 0.66       | 2020-07-29 07:25:45 |
| 6959 | Power  | 2.87       | 12.97       | 37.21 | 0.55       | 2020-07-29 07:24:44 |
| 6958 | Power  | 3.06       | 13.00       | 39.76 | 0.66       | 2020-07-29 07:23:43 |
| 6957 | Power  | 2.82       | 12.95       | 36.55 | 0.55       | 2020-07-29 07:21:41 |
| 6956 | Power  | 2.99       | 12.98       | 38.79 | 0.66       | 2020-07-29 07:20:40 |
| 6955 | Power  | 2.86       | 12.97       | 37.67 | 0.55       | 2020-07-29 07:19:39 |
| 6954 | Power  | 2.83       | 12.92       | 36.58 | 0.55       | 2020-07-29 07:18:38 |
| 6953 | Power  | 2.99       | 12.82       | 37.00 | 0.55       | 2020-07-29 07:17:37 |
| 6952 | Power  | 2.61       | 12.80       | 33.35 | 0.55       | 2020-07-29 07:16:37 |
| 6951 | Power  | 1.88       | 12.68       | 23.79 | 0.30       | 2020-07-29 07:15:55 |
| 6950 | Power  | 1.57       | 12.57       | 19.77 | 0.30       | 2020-07-29 07:14:34 |
| 6949 | Power  | 1.35       | 12.51       | 16.84 | 0.20       | 2020-07-29 07:13:33 |

(a) Monitoring result: Power and Efficiency data

| No. | Sensor | Location | Humidity(%) | Temperature(°C) | Altitude(m) | Time        |
|-----|--------|----------|-------------|----------------|-------------|-------------|
| 5742 | Temp   | FY16WP   | 39.50       | 38.31          | 470.05      | 2020-07-29 11:33:56 |
| 5741 | Temp   | FY16WP   | 38.95       | 38.51          | 470.71      | 2020-07-29 12:52:30 |
| 5740 | Temp   | FY16WP   | 38.69       | 38.55          | 470.96      | 2020-07-29 13:51:41 |
| 5739 | Temp   | FY16WP   | 38.50       | 38.60          | 470.80      | 2020-07-29 13:40:34 |
| 5738 | Temp   | FY16WP   | 38.43       | 38.66          | 469.85      | 2020-07-29 13:29:29 |
| 5737 | Temp   | FY16WP   | 38.73       | 38.64          | 470.95      | 2020-07-29 12:28:22 |
| 5736 | Temp   | FY16WP   | 39.15       | 38.28          | 470.31      | 2020-07-29 12:17:15 |
| 5735 | Temp   | FY16WP   | 37.83       | 31.01          | 470.06      | 2020-07-29 11:26:08 |
| 5734 | Temp   | FY16WP   | 38.95       | 38.50          | 469.67      | 2020-07-29 11:25:01 |
| 5733 | Temp   | FY16WP   | 38.57       | 38.55          | 469.59      | 2020-07-29 11:23:54 |
| 5732 | Temp   | FY16WP   | 39.39       | 38.43          | 469.48      | 2020-07-29 11:22:47 |

(b) Monitoring result: Temperature data

Figure 5. All results of monitored data.

From the Figure 5 above, it is shown that the maximum power voltage generated by the solar panel is 14.63 V, while the specifications of the solar panel said that the maximum power voltage at normal temperature (25°C) is 16.8V [9]. This difference is due to measured temperature around the solar panel is around 31°C. This is in accordance with the characteristics of the solar panel that higher the temperature around the solar panel will decrease the voltage value. The efficiency of solar panel is about 12%, by using incident radiation flux about 1000W/m².

4. Testing and analysis

Testing process was carried out to ensure that the results obtained by WSN were correct, this includes voltage testing, current testing, temperature testing and communication between nodes and sink. Voltage and current testing were done by measure the voltage and current value using digital multimeter, so the result between multimeter and node sensors can be compared. Here in Figure 6 shows the voltage testing:
From the Figure 6 above, voltage data from digital multimeter has higher value about 0.15 – 0.21 V than value from voltage sensor, with percentage error is about 0.91%.

Temperature testing was also done by measure the temperature value using digital thermometer, so the result between thermometer and node sensor can be compared. Here in Figure 7 shows the temperature testing:

From the Figure 7 above, temperature data from digital thermometer has different value about 1.62° – 1.83° lower than value from temperature sensor, with percentage error is about 1.73%.

Communication between node and sink testing was done through serial monitor using IDE Arduino, shown in Figure 8 below:
From Figure 8 above, connection between node and sink is successfully done and after that nodes send the data to sink through Wi-Fi. About 16 seconds after, sink successfully received the data.

5. Conclusion
From the results of testing and analysis in this research, several conclusions can be drawn as follows: 1) Wireless Sensor Network are successfully configured to monitoring the efficiency of solar panel. 2) Sensor nodes that consist of voltage, current and temperature sensors are able to sensing data but the data taken has different values measured manually (still in normal value). 3) Sensor nodes are able to communicate with sink by utilized their MAC address. 4) Data taken form Wireless Sensor Network are real time and can be accessed from anywhere.

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