Research Article

Performance Evaluation Of Hybrid System Monitoring Solar Panels Based On WSN Case In Smart Regional Drinking Water Company (PDAM)

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Abstract: This research is to design and build a wireless sensor network system to monitor the performance of the Regional Drinking Water Company (PDAM) smart solar module on the network server using the DS18B20 temperature sensor and the INA219 sensor. Of course, the use of solar panels also greatly reduces costs for consumers, so the design of this tool is a combination of switching methods between solar panels, batteries, and the State Electricity Company (PLN). There are still many obstacles to using solar panels such as: how effectively they absorb solar energy, and this can contribute to or reduce damage to digital meters not working. The working principle of this tool uses the Wireless Sensor Network (WSN) method so that the designed tool is placed on several solar panel modules on the Smart PDAM so that the sensor sends data to the network and technicians can control it in real-time. Data collection techniques use observation techniques and documentation to obtain test data. This research uses quantitative descriptive analysis techniques that are inductive, objective, and scientific, with data obtained in the form of numbers or statements that are evaluated and analyzed. The results of this study with the PDAM PCB board testing scenario with an average of 320.2 measurements with a multimeter showed an average result of 322.8 with a relative error of 2.6%. The test results with Smart PDAM components showed an average power consumption of 1789.2 mW. The observations of the two panels gave an average result of 887.1 on panel 1 and an average result of 908.7 on panel 2. The results of the DS18B20 temperature sensor comparison test showed an average error of 0.5%. The result of a switching scenario with 20 experiments, resulted in 9 switching operations to the battery and 11 switching operations to the solar panel. Monitoring the solar module with the INA219 sensor, 277 voltage, current, and power data were determined with an average of 17.1 V, 513.9 mA, and 481.5 mW. The calculation results use the exponential moving average formula to predict the 278th data with an exponential moving average of 20 based on sensor data showing a value of 294.7 mA while using a simple moving average is 590.1 mA.

Keywords: Wireless Sensor Network; Monitoring; Solar Panels; Smart PDAM; Switch; INA219; DS18B20.

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1. Introduction

Clean water is one of the resources needed by the community for consumption and daily activities [1]. PDAM (Regional Drinking Water Company) is one of the regionally owned business units engaged in distributing clean water to the community. In general, the PDAM system currently mostly uses a manual recording system which of course is still prone to fraud and inconsistency in measuring water use. Smart PDAM is one of the latest technologies that can be used as an investment if managed professionally by BUMDes (Village-Owned Enterprises).

This technology can measure the discharge of water integrated with telemetry systems for wireless transmission of sensor data [2]. Smart PDAM can reduce the occurrence of fraud at the time of recording and of course, is more efficient because it can be monitored via the web.

The digital meter is one part of the smart PDAM that functions to record water use by consumers. [3] This device works using a digital sensor device so it requires a source of electrical energy for its operation. Currently, PDAM's smart energy source comes from a combination of PLN (State Electricity Company) electrical energy and solar panel modules and batteries. The combination of the two is a solution to extreme problems that can occur during the operation of digital water meters on smart PDAMs [4]. The use of electrical energy sourced from PLN has a disadvantage because digital meters depend on sources of electrical energy.

The use of solar panel modules as a solution to problems [5] minimizes the operational cost of digital meters. The use of energy sources from PLN causes additional costs from the consumer side. The use of solar panel modules can minimize the operational costs of digital meters. Environmental conditions that are always changing over time also lead to variations in the performance of solar panels. The use of solar panels still has many obstacles such as [6] the effectiveness of solar energy absorption and there can be damage to parts of solar panels, of course, it can have an effect or can be detrimental to making the device unable to function if there is damage to smart PDAM [7]. Seeing the potential of this solar power plant has a disadvantage, namely, if the solar panels do not work, it can result in the system not working properly, this can certainly be detrimental from the business aspect so this study proposes monitoring solar panels using WSN [8]. In the research, techniques or monitoring will be adopted by developing the performance of solar panels, Battery Management Systems (BMS), batteries, and controllers to ascertain which parts there are problems and preventive measures can be taken immediately so that this system can work continuously.

The alternatives that have been proposed on this issue have been widely studied by previous researchers such as research on solar panel monitoring that has been carried out previously by [9]. with a data acquisition system that integrates with Excel spreadsheets using the PLX-DAQ application and memory cards as data storage, but in the study there are still disadvantages, namely in the readings of solar radiation sensors so that not so efficient and the use of micro SD as data storage is certainly not so good and the actuator thruster lever used cannot drive the 90 solar panel so it cannot position the solar panel in the direction of the sun. Further research by [10] used a website-based solar panel monitoring system, but in the study, there are still shortcomings, namely in monitoring through the website, of course, the place must have an internet network so that in places where there is no internet network, of course, it cannot monitor solar panels. Further research by [11] using an IoT-based solar panel current and voltage monitoring system using the Thingview application to monitor voltage and current remotely, but this study had a time lag of 15 seconds to store data on the thingspeak database and the use of a 16x2 LCD to display data.

From these problems, researchers take the initiative to optimize and develop previous research [12] that can monitor smart PDAM components; solar panels, and battery management systems (BMS), batteries from the monitoring can find out which parts have problems that eventually occur, namely the diagnosis of damage to the solar panel electrical system [13]. The working principle of this tool is to utilize the method from WSN, so the designed tool is placed on several smart PDAM solar panels so that the sensor will send data to the Web server and is stored then displayed on a website page so that it can be monitored in real-time by technicians and can monitor with the Wireless Sensor Network system which displays the data read on the PDAM smart solar panels.

2. Literature Review

2.1 Smart PDAM

The meaning of the word SMART in the English–Indonesian dictionary is smart, smart, wise. Meanwhile, PDAM stands for Regional Drinking Water Company, a regionally owned business entity that distributes clean water to the community. PDAMs exist in every province, district, and municipality throughout Indonesia. *Smart* PDAM is the latest form of technology for providing clean water to professionally managed communities and a computational recording system that minimizes the occurrence of fraud [14]. *Smart* PDAM is a form of work between Makassar State University and Village-Owned Enterprises (BUMDes) from *Mongcongloe Bulu village*, Maros Regency. This smart PDAM technology utilizes solar panels as one of the power sources that can reduce electricity use from *smart* PDAMs.

2.2 Solar Panels

A solar panel is a device consisting of solar cells that convert light into electricity. They are called solar or salami solar because the sun is the most powerful light source that can be used [15]. Solar panels are often also referred to as solar cells, solar energy can be interpreted as "electric light". The effect of solar energy itself is the release of positive and negative charges of solid materials through light. The intensity of light thus indirectly affects the power in the form of current and voltage.

2.3 Wireless Sensor Network

A wireless sensor network or WSN (Wireless Sensor Network) is a group of nodes managed within a network. [16] Each node in this WSN is typically equipped with a radio transmitter module, a mini microcontroller, and a power source (battery) that has many applications such as environmental information collection, node monitoring scenarios, and security monitoring.

Moreover, WSN is known as a low-cost, small, easy-to-implement, and highly powerful technology as well as a useful technology for various applications. This makes it possible to monitor and control the surrounding environment with high accuracy and can be applied to agriculture, health care, public security and military systems, industry, and transportation systems [17]. According to [18] WSN consists of smaller components of wired networks and can be applied to a wide range of applications. The main components of WSN are sensing, processing, communication, and power sources (batteries). According to [19] the WSN device is small but has outstanding functionality. Having the ability to receive data, manage data, and send data, WSN can also monitor a large area because it is supported by networks and other devices. there are several advantages to applying WSN technology.

3. Method

This research was designed because of the needs of Village-Owned Enterprises (BUMDes) from *Muzzleloe Bulu village*, Maros Regency to prepare a clean water supply program for villagers. The source of water from the use of Muzzleloe residents is used by BUMDes for the provision of clean water. The PDAM system is now still a manual recording system that is prone to fraud and inconsistency in measuring water use. The PDAM system offered is in the form of water discharge measurements, electronic valves, and water pressure measurements integrated with the previously carried out telemonitoring system and the use of solar panels as a power source from meter devices [20]. So that the design made is intended to replace the need for electricity in the area to minimize operational costs and clean water is well controlled, a design model is designed that allows monitoring in real-time.

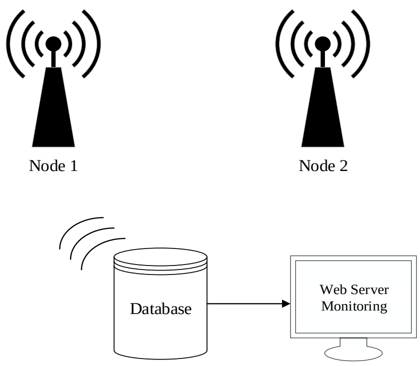


Figure 1. System Environment

The system architecture in Figure 1 at this stage describes the solar panel output monitoring system on the web server utilizing several technologies, namely Wireless Sensor Network (WSN), NodeMCU ESP32, and Database. Wireless Sensor Network (WSN) is a cluster of nodes in the form of sensors, NodeMCU ESP 32, temperature sensors, and INA219 sensors used for data retrieval commonly referred to as WSN Node, data retrieval is carried out every 2 seconds, these retrieved data are sent to a Sink Node connected to a database to carry out data processing.

Each sensor's device will send the latest data on solar panels and lithium batteries, namely the DS18B20 temperature sensor and the INA219 sensor in open space. The sensor becomes an algorithm for establishing the status of the panel, after which the ESP32 NodeMCU reads the amount of data received from the sensor to the ADC port, which is converted into digital data transmitted over a wireless network. The information received from the sensor is displayed in real-time in the form of data and the condition of the panels is stored in the database on the server.

```
Declaration:
 IF ( current_mA < 100) {
   Request_Code process;
     "main source of battery device"
 ELSE {
     "The main source of solar panel
 devices"
 END LOOP
```

Figure 2. Pseudocode Switch

Figure 2 is a Smart PDAM power *switching flowchart* from the solar panel if the INA 219 sensor has a current value of ≤100 mA, then automatically the 5V relay will switch to the battery, then the battery becomes the main power source if the sensor value is met for *switching*.

3.1 Data Collection Technique

The trial scenario in this study was carried out to find out how the condition of the solar panels on the monitoring web and the condition of the battery at the time of charging by the solar panels. This trial is to collect data from each sensor then the data is sent via WSN to the database then the results of the data are displayed on the web server.

Table 1. Observation of Monitoring on Solar Panels

No	Observation Of Monitoring Solar Panel Variable		Unit
	Monitoring Web	Use a Multimeter	
1	Voltage	Voltage	V
2	Current	Power	mA
3	Power	Power	mW
4	Average	Average	%

In Table 1 trials conducted on solar panels using a multimeter and monitoring data on the web server will then be compared between web monitoring and the use of a multimeter on solar panel measurements how big the difference in measurements of the two then the results of these measurements will be analyzed again after testing.

Table 2. Data Collection Grid on Solar Panels

No	Observation Variables	Unit
1	Voltage	V
2	Temperature	°C
3	Current	mA
4	Power	mW

In Table 2 conducted trials on solar panels will receive output to find out how much power the solar panels produce by looking at the magnitude of the value of the INA 219 sensor and DS18b20 temperature sensor can then be analyzed.

3.2 Switching Parameters

Furthermore, Table 3 is the grid for switching parameters of the main source of *smart* PDAM from the solar panel to the battery with a predetermined current value. If the current value has been met, it will automatically switch the main source of the *PDAM smart* device.

Table 3. Switch Parameters

No	Current Value		Switch to	
	< 100	>100	Battery	Solar Panels
1	Current (mA)	Current (mA)	Yes/No	Yes/No
2	Current (mA)	Current (mA)	Yes/No	Yes/No
3	Current (mA)	Current (mA)	Yes/No	Yes/No

4. Result and Discussion

In this study, quantitative *descriptive* data analysis techniques are *inductive, objective,* and scientific where the data obtained is in the form of numbers or statements that are valued and analyzed. The data analyzed are data obtained from the test results [21] of the PDAM *smart* solar panel *output* monitoring system and the results are the overall conclusions. In equation 1, n is the amount of data, $\bar{x}$ is a sample of average, and x is a data to n.

$$\sqrt{\frac{\Sigma(\bar{x}-x)^2}{n-1}} \quad (1)$$

This study also used the data analysis technique *Exponential Moving Average* (EMA), according to monitoring from photovoltaics (PV) can predict the power generated from *exponential moving average* calculations because usually PV is only equipped with a basic mapper that does not provide the use of environmental parameters to evaluate the beginning of energy performance PV plant. A Simple Moving Average (SMA) is a moving average for example, n in the data in the time series data is not weighted because the time series data has the same weight. Forecasts are based on moving average estimation data series[23]. A statistical analysis method is used to estimate the trend of data movement over a certain period using the average of the data in that period [24]. In monitoring the output of *smart* PDAM solar panels that can be affected due to changeable weather or anomalies [25] therefore it is difficult to evaluate whether the performance of the solar panels is optimal or not. Based on equation 2, A1 is Data early, An is Data last, and n is an Overall data.

$$SMA = \frac{(A1+A2+\cdots+An)}{n} \quad (2)$$

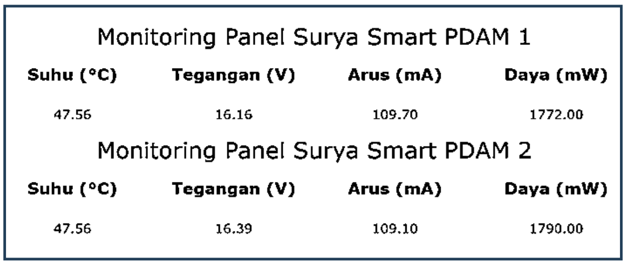
$$EMA = (C-P)\times\frac{2}{n+1}+p \quad (3)$$

Based on equation 3, C is a current data point, P is an exponential moving average of the previous period, *n* is the amount of data, and *p* is the Last Data Point.

The results of this study examine the application of *wireless sensor networks* in the web server-based smart PDAM solar panel *output* monitoring system. The system will monitor the main resource of the digital meter device, namely solar panels, and can be viewed on the *web server* later. This study is limited to testing the ability of the system to monitor the output of the solar panel design and switch the main power source from the solar panel to the battery as a backup power source if the *output* of the solar panel can no longer supply electrical energy to the digital meter device.
The author designed a prototype solar panel output monitoring system that can be used to determine the output of solar panels. This prototype applies the concept of WSN and *web server* as a monitoring system for the solar panels. This study uses the INA 219 sensor and the DS18B20 temperature sensor to find out the output produced by solar panels, where the sensors can send voltage, current, power, and temperature data then the data can be seen on the web display.

4.1 Observations on Solar Panel Web Monitoring

This stage is a stage of web testing designed on the coding of the previous system. The data stored on the MySQL database is then displayed on the web page in tabular form according to the output of each sensor. The results of this web test can be seen in Figure 3.



Monitoring Panel Surya Smart PDAM 1

Suhu (°C)	Tegangan (V)	Arus (mA)	Daya (mW)
47.56	16.16	109.70	1772.00

Monitoring Panel Surya Smart PDAM 2

Suhu (°C)	Tegangan (V)	Arus (mA)	Daya (mW)
47.56	16.39	109.10	1790.00

Figure 3. View On Web Monitoring

Moreover, Figure 3 monitors the output of solar panels using the INA 219 sensor and the DS18B20 temperature sensor then displayed on the web page. From the test results of pre-designed devices, the output results can be seen in the following Figure 4 where the web page can display the values of the DS18B20 temperature sensor and INA 219 sensor.

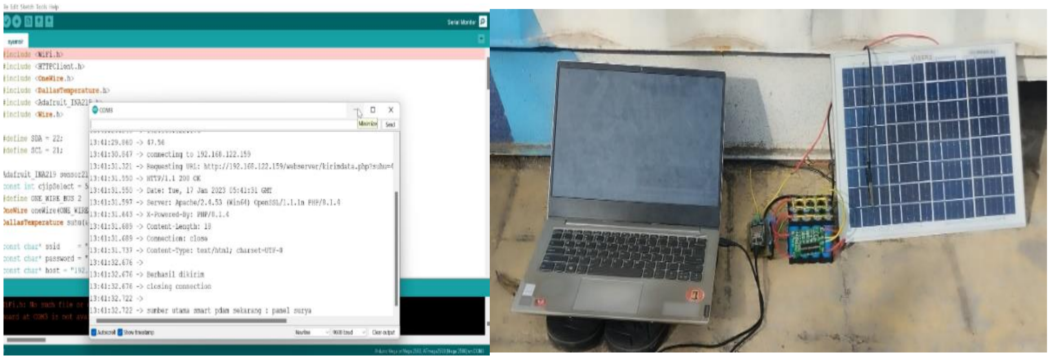


Figure 4. Overall System Test Results

In the observation of solar panel monitoring with PCB experiments of digital water meters as a load to obtain current and power values. Moreover, Table 4 shows the results of solar panel monitoring by displaying on the web page the results of the INA 219 sensor and then measuring it using an RD701 multimeter. The data obtained from the results of trials and measurements obtained a relative error of 2.584%.

4.2 Power Consumption in Operation

Table 4. Observation of Solar Panel Output Monitoring

No	Monitoring By System			Use a Multimeter (Manual)		
	Voltage (V)	Current (mA)	Power (mW)	Voltage (V)	Current (mA)	Power (mW)
1	17.3	121.5	118	17.1	270	4.617
2	17.4	134.6	132	17	272	4.624
3	17.3	118	114	16.9	270	4.563
4	17.6	122.1	118	16.9	270	4.563
5	17.6	124.3	122	16.9	268	4.529
6	17.5	121.6	118	16.9	268	4.529
7	17.4	134	132	16.8	270	4.536
8	17.4	144.6	138	16.8	270	4.536
9	17.4	171.4	150	16.8	270	4.536
10	17.3	130.9	168	16.7	270	4.509
Average	17.4	132.3	131	16.8	269.8	4.554

This observation is intended to determine the power that will be used by smart PDAM devices with solar panel resources. In this test, several components from smart PDAM devices are used, namely: ESP32, Water Flow Sensor, LM2596 Regulator, and Solenoid. More detailed test data is presented in Figure 5.

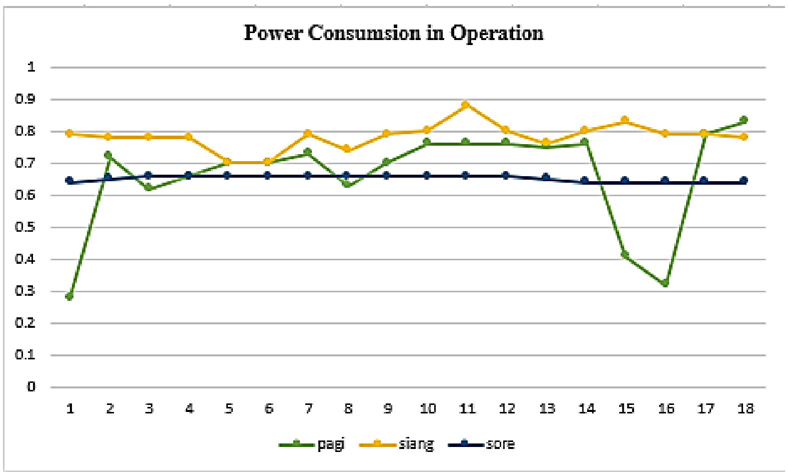


Figure 5. Observation of Solar Panel Monitoring with PDAM Smart Components

Figure 5 is the result of observing solar panels with several components from smart PDAM *devices* when operating. In this observation, using the INA219 sensor and DS18B20 temperature sensor, the results of which are then displayed on the monitoring web, power consumption results are obtained if the components of the digital meter are operating with an average power *consumption* value of 1789.2 mW.

4.3 Energy Harvest by Solar Panel

In this observation using the INA 219 sensor and the DS18B20 temperature sensor, which had previously been carried out functional testing on the two sensors, results were obtained of 2.6% relative error on the INA 219 sensor and 0.5% obtained error measurement error on the DS18B20 temperature sensor. to observe the energy produced by solar panels, two solar panels are needed to monitor the energy generated from the solar panels.

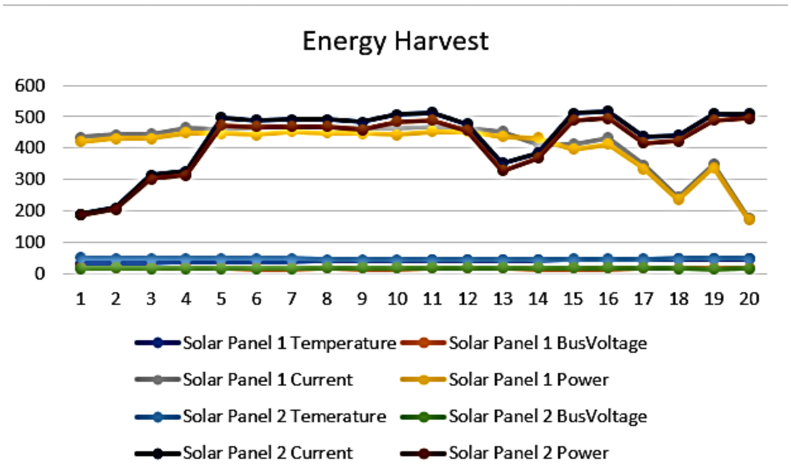


Figure 6. Observation of Two Solar Panels

Figure 6 is a graph of the results of monitoring 2 solar panels to find out the energy obtained using a temperature sensor and an INA 219 sensor with an average temperature of 40.3 °C, the average power of the sensor is 403.1 mW.

4.4 Testing Hybrid System

In the following test scenario find out whether the parameters that have been determined in the INA219 sensor coding have been successful or not. The solar panel will automatically switch to the battery. More detailed test results on.

Table 5. Switch Test Scenario

No	INA 219 sensor			Switch to battery		Switch to Solar Panel	
	Voltage (V)	Current (mA)	Power (mW)	Yes	No	Yes	No
1	18.5	177.8	170			✓	
2	18.6	178.9	180			✓	
3	18.4	179	180			✓	
4	18.4	179.6	180			✓	
5	18.5	180.1	180			✓	
6	18.6	16.8	20	✓			
7	18.4	44.4	40	✓			
8	18.3	83.6	80	✓			
9	18.2	72.4	70	✓			
10	18.6	54.2	50	✓			
11	18.4	50.2	50	✓			
12	18.6	43.1	40	✓			
13	18.5	48.1	50	✓			
14	18.3	45.9	50	✓			
15	18.5	102.8	40			✓	
16	18.4	178.5	100			✓	
17	18.5	177.8	170			✓	

No	INA 219 sensor			Switch to battery		Switch to Solar Panel	
	Voltage (V)	**Current (mA)**	**Power (mW)**	**Yes**	**No**	**Yes**	**No**
18	18.4	178.9	180			✓	
19	18.3	179	180			✓	
20	18.2	179.6	180			✓	

In Table 5 of the test scenario of switching to a battery with 20 test switches with a current parameter of ≤100 mA, it will automatically switch to the battery which is a backup power source from the *smart* PDAM if the solar panels can no longer produce maximum power. Figure 7 is a display on the Arduino ide COM which notifies that the switch test was successful.

```
Bus Voltage:   0.95 V
Current:       540.30 mA
Power:         0.51 W
sumber utama smart pdam sekarang : panel surya
Bus Voltage:   0.96 V
Current:       539.00 mA
Power:         0.52 W
sumber utama smart pdam sekarang : panel surya
Bus Voltage:   0.96 V
Current:       539.90 mA
Power:         0.52 W
sumber utama smart pdam sekarang : panel surya
Bus Voltage:   18.19 V
Current:       0.10 mA
Power:         0.00 W
sumber utama smart pdam sekarang : baterai
```

Figure 7. Solar Panel Observation Switch

4.5 Predictions EMA Solar Panels

In this observation, it uses a 10WP solar panel and an INA219 sensor to get *the current* and *power* values on the solar panel. This observation uses a serial monitor from Arduino Ide to find out the magnitude of its value.

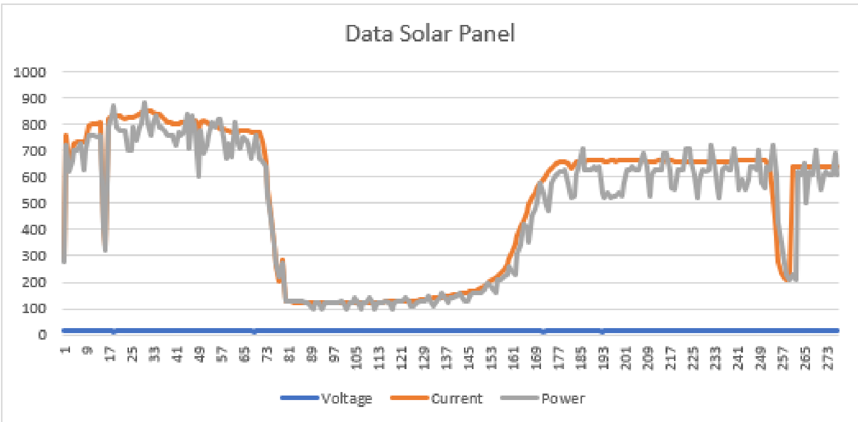


Figure 8. Solar Panel Observation Chart with INA219

Figure 8 is a graph of the observation of solar panels with the INA219 sensor as much as 277 times the data received has an average *current* of 513.9 mA and an average *power* output of 484.6 mW. Based on the results of solar panel observations with INA 219 sensors, it can predict *the current results* of the *exponential moving average* calculation with the following formula:

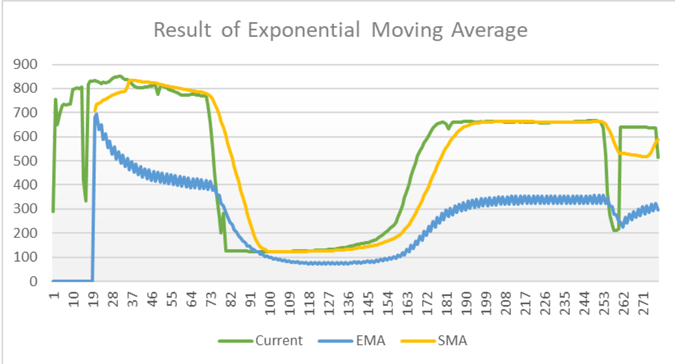


Figure 9. Exponential Moving Average Calculation Results

Figure 9 is the result of calculating the exponential moving average to predict the value of the 278th *current* data on the solar panel with an exponential moving average of 20 based on the data sent by the sensor to the serial monitor. The EMA (exponential moving average) *current* result is 294.7 while the SMA (*simple moving average)* calculation result is the *current* value that gets 590.1.

5. Conclusion

Based on the results of the research and discussion, there are conclusions. [1] The power generated from solar panels is erratic due to several factors such as environmental conditions that always change from time to time and also cause variations in the performance of solar panels. The use of solar panels itself still has many obstacles. [2] Based on the results of research the temperature of the solar panels does not affect the power generated by the solar panels themselves. Solar panels work optimally if the absorption of solar energy is not disturbed. [3] This research is further by creating a distance maintenance system to monitor Smart PDAM devices and making actuator levers for solar panels so that the absorption of solar energy can be maximized by paying attention to the State of Charge (SoC) and State of Health (SoH).

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Author contributions: All authors are responsible for building Conceptualization, Methodology, analysis, investigation, data curation, writing—original draft preparation, writing—review and editing, visualization, supervision of project administration, funding acquisition, and have read and agreed to the published version of the manuscript.

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