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Experimental Analysis Design of Solar Panel Energy Monitoring Prototype

Abstract — Nowadays, the use of renewable energy is most discusses in energy field issues. The relation about a lack of mineral energy resources and many sources of pollutants fueled by oil and gas became a cause of it. The use of renewable energy with solar sources is a topic that considers discussing. These reasons encourage the authors to initiate research about the use of solar panels in the laboratory as a teaching aid. In this laboratory-based experiment analysis, we can use halogen lamps instead of sunlight. Energy monitoring systems using controllers in the form of PLCs and microcontrollers are several possible options. The use of this control system allows us to monitor energy regularly. In this paper, the authors use a microcontroller as a control system. Instead, the LoRa system is also equipped in this experiment to support the acquisition of data generated remotely. Besides, we can determine the best angle position to produce energy from renewable energy sources. This experimental analysis design of solar panel energy monitoring prototype paper is an initial and global discussion about solar panel energy monitoring design. This paper shows some of the current measurement and angle tilt effect on design.

Keywords— Solar panels, energy monitoring, sensors, microcontroller

I. INTRODUCTION

The renewable energy concept needs to be instilled in everybody's mind nowadays. Then, this concept can be adopted in daily life later is not only theoretical knowledge but also applied science energy concept. The energy discussed here is electrical energy. In this discussion, electrical energy produces by solar power. The energy concept discussion of this paper is future renewable energy that will immediately leave fossil-based energy that is not environmentally friendly.

Several control devices such as microcontrollers and PLCs can control renewable energy in monitoring and the system itself. In this study, the research team will combine the concept of renewable energy in the form of solar panels with a control and monitoring system using a microcontroller as energy monitoring and also conduct data acquisition of various sensed electrical parameters such as current and voltage. AT-mega microcontrollers with long-distance communication using LoRa can make us monitor the energy produced by solar panels in a distance range [15]. The prototype that can accommodate the concept of renewable energy learning and monitoring of the systems hope can be the starting gate in learning renewable energy in our institutions in particular and another community in general.

In this laboratory practicum-based design, the authors hope that the prototype of monitoring and installing tools used can represent the real conditions. This paper will discuss the installation of off-grid solar panels that stimulate by halogen lamps instead of sunlight. This initial prototype will indoors. However, the design that the author made cover the possibility to be taken outside the room because we added wheels to make it easier to move this prototype.

The resulting conditions in the energy monitoring and design of the installation can be an initial development of an energy project between monitoring and installing a solar panel later.

II. STATE OF THE ART AND THEORETICAL

A. State of The Art

Many researchers publish their papers about solar panel monitoring and installation research. Publication paper writes by Sajid Khan on entitled "IoT Enabled Real-Time Energy Monitoring for Photovoltaic Systems" can display power acquisition monitoring and compare it with the actual conditions of current and voltage using Arduino as the controller [12]. Any other research on monitoring publication paper by Saravanan entitled "Monitoring of Solar Panels Based on IoT" uses a microcontroller PIC as the controller [17]. Both sample papers use different microcontrollers as a control system. 2 In this paper, the author will use a different type of microcontroller as controller and LoRa (low-power wide-area network protocol) as long-distance communication. The differences control system and designs become a unique idea in every research concept.

Based on experimental here, the authors divide into two measurement points. They compare two measurements of the direct solar panel (DC) output and also alternating current parameter output after passing the inverter (AC). This measurement result can be compared and also analyze the inverter quality and components through two different types of currents.

In the direct current measurement, we use the ACS sensor. In this type of current, we can measure voltage and current output results. Meanwhile, for output power monitoring in alternating current, we use a PZEM sensor. This type of current measurement, an electrical parameter gain such as voltage, current, power, energy, and power factor. So the results of power measurements with some measurement instrument can be compared.

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B. Theoretical

The electrical circuit in a solar panel system draws as a closed electrical circuit that produces an energy source. In the circuit equivalent for solar panels in the figure below, we can derive the equation.

Fig. 1. Solar panel equivalnt circuit

The figure above is the 4 equivalent circuit of a solar panel where RS is the series resistance, IS the series current, where IL is the current at the load. VPV is the voltage coming out of the solar panel. As we know that the basic formula of energy is:

III.

EXPERIMENT

These conducted laboratory experiments divide into mechanical, electrical, and control design. [2] In this paper, the authors will discuss more the electrical part but will allude to a little about the general description of mechanical design and control energy monitoring.

A. Mecanical, Electrical and Control Design

The prototype design of this experiment makes in such a way that prototype users can carry out measurement and analysis of research on the off-grid solar panel output power in the form of direct current and alternating current that has been changed by the inverter. Here is a prototype design that we made.

$$P = V \times I = I^2 \times R = \frac{V^2}{R}$$

□□□

$$P = V \times I \times Cos\ ø = I^2 \times R \times Cos\ ø = \frac{V^2}{R} \times Cos\ ø \quad (2)$$

Where P = power (watts), V = voltage, I is current. The based formula on solar energy they are two energy equation that calculates, namely input energy (P-in) and energy output (P-out). Input energy depends on the location where the area to be measured because it takes into the zenith account (sun angle) of the irradiation area. P-in calculates by the equation below:

$$P.\,in = Area\ of\ Module \times E \quad (3)$$

TABLE I. AM 1.5 VALUE

The equation above is a calculation of input power. Output power also calculates by a formula in this explanation (to be compared with the measurement results of the energy meter connected to the solar panel installation). The equation below is a formula to calculate power output.

$$P.\,Max = Vmp \times Imp \quad (4)$$

The results of P-in and P-out power calculations can be a reference to determine [2] the efficiency of the solar panels that we use. The efficiency calculation of solar panels obtains by the following equation.

Fig. 2. Mechanical design of solar panel prototype

Based on the prototype mechanical design above section consists of; halogen lamps (instead of sunlight), solar panels, solar charge controllers (SCC), power meters (AC and DC), batteries, inverters, and loads (AC and DC). In this experiment, the researchers used the solar panel with the specifications listed in the following specification figure below:

5 = $P.Max$

$P.in$

(5)

In addition to the efficiency parameters of our solar panels, we can also take into account the field factor (FF) as the following equation.

Fig. 3. Solar panels spesification

$FF = P.Max$

$Voc \times Isc$

(6)

In this experiment, authors use two solar panels, which later we can assemble in series or parallel. Based on the specifications of the solar panel used, we can calculate based on the following equation.

The table below is the calculation result of the parameter owned by the solar panel. These parameters are parameters given by the industry as a manufacturer of solar panels used. The comparison results between measuring devices and data reading from the designed power meter.

TABLE II. CALCULATION POWER RESULT

No	Electrical Parameter	Theoretical Value
1	P-In (watt)	5625
2	P-Max	81.77
3	Efficiency , 5	68.79
4	Field Factor, FF	0.665

Based on the table above, the field factor (FF) of solar panels is still quite low compared to what is on the market, which often in the range of 0.75 to 0.8. It is not a significant problem for laboratory-scale experiments.

B. Machine working principles flow chart

In the conducted experiments, the prototype divides into two working principles. They are power installation and construction of the power meter. Generally, this paper will explain both. This solar panel prototype has an off-grid connection system. This system has no connection with State Electricity Company-grid as the main power. This off-grid connection is a small scale simulation that also uses batteries and DC loads. This analysis of the power results will show the results of the waves generated by solar panels. This wave has been converted into AC by the inverter. Generally, the block diagram below is the entire system design.

Fig. 4. Prototype design block diagram

As the figure on the solar panel block diagram above, the connection and regulation current and voltage through the solar charge controller (SCC) before DC and AC load connection. Previously, the power meter installs as the first energy monitor (DC) on the solar panel output. In addition to the off-grid battery charging system also control with SCC. In the SCC section, there is also a direct connection to the DC load. The authors also connect in the same terminal through to the inverter and convert into a single-phase 220V AC voltage. The electricity output from this inverter measure through a second power meter (AC).

C. Wiring Diagram

On the side of the wiring diagram itself, this paper divides into two mains wiring diagrams instead of wiring for power installation and also for the power meter. The power wiring shows in the figure below. The red and black lines are

markers for DC power lines. Meanwhile, the electricity line for the AC line uses a black marker line. The dotted line mark on the wiring is a sign of the power meter.

Fig. 5. Solar panel energy monitoring prototype wiring diagram

Based on the wiring image above, the installed power meter has two measurement points they are DC and AC measurement points. In the DC energy measurements directly conduct from the solar panel output. Meanwhile, the AC energy measurement takes from the inverter output. Despite having two different measurement points, the two power meters have located in the same box. In the diagram below, the authors give one of wiring on the AC energy meter.

Fig. 6. AC energy meter wiring diagram

In the AC energy meter, the energy sensor used to conduct sensing on the 220V single phase inverter output is the PZEM senor. PZEM will sense electrical parameters such as voltage, current, and power.

System control uses here Atmega328 microcontroller as a controller of information provided by the sensor. The microcontroller itself gets a voltage supply by a +5 VDC adapter from an AC source. The microcontroller connection to a remote communication device is connecting with LoRa module. LoRa module energizes from a 5 VDC adapter regulate a LoRa working voltage of +3.3 V DC.

IV. RESULT AND DISCUSSION

In the results and discussion section, several points will be discussed base on experiment settings. The results of experiments on current and voltage measurements at the DC output and the AC output compares at several setting of tilt angles to 2 the installation of solar panels. The results will also display readings wave on alternating power output from the inverter to compare the measurement results in a sinusoidal wave.

A. Experimental Set-up

The design results from the previous chapter produced a solar panel energy monitoring prototype which shows on the figure below:

Fig. 7. Display of solar panel energy monitoring prototype

As seen in Fig.7 above, the prototype consists of a halogen lamp as sunlight, (1). In this prototype, solar panels as a power generator that changes the energy form (2). Solar charge controller (SCC) manages the fluctuated current and voltage that solar panels gain in a day. This part of the prototype connects into the DC load grid and AC load grid (3). DC grid connects into a lamp as a load. This part also provides two contacts for external DC load (4).

An inverter works to change DC 12 V into a phase AC 220V (5). This part consists of a lamp as an AC load and provide two contacts for external connection (6). Power meter measures DC and AC electrical property in this box (7). Battery storage of the electron movement from solar panel connects into SCC (8).

B. I-V Curve result

The measurement results for the I-V curve obtained in the experiment shows in the following graphic and table below. The table shows an I-V curve value from the DC voltage source measurement output [3] of the solar panel below. Based on the figure above, the P-Max value with the existing load is 9.5 watts.

Fig. 8. I-V Curve measurement result

TABLE III. I-V CURVE MEASUREMENT RESULT

Voltage (Volt)	Current (Ampere)	Power (Watt)
0	4.40	0
2.45	1.63	4
4.34	1.20	5.2
6.56	0.98	6.4
8.67	0.83	7.2
10.23	0.73	7.5
12.56		

0.68

8.5

15.89

0.60

9.5

16.79

0.54

9

18.12

0.44

8

20.54

0

0

C. Measurement Result

The authors conduct measurements in this experiment at different installation angles of the solar panels. In the results table below will be given a measurement value for measuring point 1 (DC voltage source) and measurement value at the measurement point 2 (AC voltage source).

In the table below, the measurement results for changes in the tilt angle 3 of the solar panel installation to the energy source shows. The result presentation of measurements carried out at measuring point 1.

TABLE IV. RESULT OF POINT 1 MEASUREMENT

Based on the results of the measurement table above, the authors obtain a relationship curve between the angular arrangements of the solar panel with the power generated by solar panels. This result shows in the figure below.

Fig. 9. solar panels angle vs power generated

Based on the figure above, the change in the installation angle of solar panels does not significantly affect the energy acquisition. However, if [2] the installation of solar panels has large amounts of power will be very influential.

V. CONCLUSION

Based on the results of experiments that conduct on the laboratory, the authors obtain these following conclusions;

- The prototype of the solar energy monitoring panel is the beginning of our development of a renewable energy learning system on an off-grid system. This expected prototype is the beginning development of the concept of renewable energy.
- Based on the results of experiments and measurements in the measurement point 1, the maximum value of energy produced is 9.5 watts.
- Tilt angle measurement on solar panels installation gets a maximum result at 28o.

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