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Comparative Analysis of the Performance of Monocrystalline, Polycrystalline, and Monocrystalline Solar Cells Coated with Graphene

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***Abstract*—** *Since the government promoted independent renewable power plants, especially solar energy generation, since then the development of solar energy power plants has increased very rapidly. The average annual growth rate of solar energy usage has reached 60% over the last few years. Photovoltaic (PV) solar cells are one of the most substantial technologies in renewable energy sources, which are simple and reliable for use in various purposes. Indonesia has an average global solar radiation energy potential of 4.5 to 5.5 KW/m^2/day. So that the use of solar energy with solar cell technology is an alternative to overcome the energy crisis. In the test that has been carried out for one week, several measurement results have been obtained. In the measurement of the intensity of solar radiation that has been carried out, the average solar radiation is 384.4 Watt/M^2/hour or 4612.8 Watt/M^2/Day, from the radiation measured, the average temperature is 29^o Celsius and the average humidity is 79.8%. From the daily solar radiation potential that has been measured, the potential for generating electrical energy using solar panels reaches 234.4 watts/day for polycrystalline, 227.1 watts/day for monocrystalline, and 47.2 watts/day for graphene coating on monocrystalline. From the measured results, it is concluded that polycrystalline solar panels have the best production efficiency compared to other types.*

***Keywords*—** *Datalogger, graphene, monocrystalline, polycrystalline, temperature.*

I. INTRODUCTION

Since the government has promoted independent renewable power plants, especially solar power plants, since then the development of solar power plants has increased very rapidly. The average annual growth rate of solar energy usage has reached 60% over the last few years [1]. Photovoltaic (PV) solar cells are one of the most substantial technologies in renewable energy sources, which are simple and reliable for use in various purposes [2]. Indonesia has an average world solar radiation energy potential of 4.5 – 5.5 KW/m2/day. So that the use of solar energy with solar cell technology is an alternative to overcome the energy crisis [3]. Solar Power Plants (SPS) have an important role as a source of renewable energy to overcome the energy crisis [4]. SPS has the advantages of low production costs and high efficiency, and has become an example of clean renewable energy, with polycrystalline silicon and monocrystalline silicon being the main products in the photovoltaic (PV) market. Monocrystalline solar cells are the most efficient panels, producing the highest electrical power per m2, with efficiencies of up to 15%. The weakness of this type of panel is that it does not function well at low light intensity, its efficiency will drop drastically in cloudy weather [6]. While polycrystalline solar cells are quite sensitive and able to get high energy from the sun even though the light intensity is low [7].

The latest PV technology is a type of graphene dopping semiconductor which has unique properties such as high transparency (about 97% for single layer) and high conductivity which play an important role in PV cells. Due to the characteristics of graphene oxide, it has unique superior mechanical strength, excellent thermal conductivity and chemical stability and also has low sheet resistance and high electron mobility. Therefore, graphene oxide can be used as an active layer (dopping) on monocrystalline silicon modules [8]. Of the three types of solar cells that have been described, it is necessary to test the effectiveness of the performance of a large area and the same environmental conditions, both in light and ambient temperature, so that the performance of the three solar cells can be analyzed for the best performance.

II. LITERATURE REVIEW AND RESEARCH HYPOTHESIS

Indonesia is an archipelagic country whose electrification value is still below 100%. It can be seen that there are still many islands that do not have electricity [9]. Having a lot of potential for renewable energy (RE) which is clean and environmentally friendly, does not guarantee that Indonesia is optimal in the use of RE, because the cost of generating is relatively expensive. The potential for RE in Indonesia includes 950 MW of wind energy, 11 GW of solar energy, 75 GW of water energy, 32 MW of biomass energy, 32 MW of biofuels, 60 GW of marine energy potential, and geothermal energy which is estimated to have 29 GW potential. Utilization of RE is still not optimal. Based on the records of the Ministry of Energy and Mineral Resources, the use of energy sources until 2015 was still dominated by fossil energy sources. When viewed nationally, energy sources from petroleum are still the main focus of the Indonesian people with a percentage of 47%. Followed by coal and natural gas, each of which has been utilized by 24%. The rest, which is 5%, RE contributes to the total national energy utilization [10].

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A. Solar Irradiance in Indonesia

Indonesia's geographical location is located on the equator, so Indonesia has abundant sources of solar energy with an average solar radiation of 4.5-5.5 KWh/m^2/day. The abundance of solar energy sources has potential in terms of Solar Power Plants (SEPP) which can be considered as alternative power plants [11]. This is in line with research conducted in 2014 by analyzing the radiation potential in Banda Aceh using Meteonorm 7 which is meteorological software that is connected to 8300 weather stations around the world [12]. The results of another study conducted in 2012, showed that the highest intensity of sunlight occurred between 11.00 - 13.00 hours with the value of sunlight intensity being 99,900 lux - 115,800 lux [13].

B. Photovoltaic (PV)

A solar cell or also called Photovoltaic (PV) is a semiconductor chip that can convert solar energy directly into direct current electrical energy using Si (silicon) crystals. The silicon cells are mounted in parallel-series in panels made of aluminum or stainless steel and protected by glass or plastic. Then at each cell junction given a different potential relationship that unites is called the depletion region (depletion region). When the cell is exposed to sunlight, the connection will conduct an electric current. The amount of current/electrical energy depends on the amount of light energy reaching the silicon and the surface area of the cell. All solar cells have at least two such semiconductor layers, one positively charged and one negatively charged. When light shines on a semiconductor, electrons cross the junction between the two layers causing electricity to flow [3].

C. Monocrystalline Silicon

Monocrystalline solar cells are the most efficient panels, have a performance ratio (PR) of 0.63 [3], and produce the highest electrical power per m2, with an efficiency of 15%. The disadvantage of this type of panel is that it will not function well in low light intensity, its efficiency will drop drastically in cloudy weather [6].

D. Polycrystalline Silicon

While polycrystalline solar cells are quite sensitive and able to get high energy from the sun even though the light intensity is low [7]. However, it only has a performance ratio (PR) of 0.61, which is lower than that of monocrystalline silicon [3].

E. Coated Graphene Silicon Monocrystalline

The latest PV technology is a type of coated graphene semiconductor having unique properties such as high transparency (about 97% for single layer) and high conductivity which play an important role in PV cells. Due to the characteristics of graphene oxide, it has unique mechanical superior strength, thermal conductivity and excellent chemical stability and also has low sheet resistance and high electron mobility. Therefore, graphene oxide can be used as an active layer on monocrystalline silicon modules [8].

F. Solar Cell Characteristics

The characteristic of solar cells is that the output power is influenced by the intensity of sunlight received by the solar cells [15]. The efficiency of existing solar cells is still low. But the increase in solar cell temperature is higher due to solar radiation than normal temperatures will reduce the power of solar cells [14]. Several parameters that affect the performance of solar cells such as solar radiation, ambient temperature, panel temperature, and loading power that affect the efficiency of solar cell power production and the performance ratio of solar cells to the factors that affect its performance [3].

G. Effect of Solar Radiation

Observations of solar radiation insolation in Indonesia carried out at the Muaro Jambi Climatology Station reached its highest point at 11.00-13.00 WIB with the average value of global radiation accumulation in a day reaching 4.4±1.0 KW/m^2/day [16][17]. Meanwhile, observations made in the city of Palembang average daily insolation of 4.5-4.8 KW/m^2/day. From the results of the intensity measurement, it is found that the output power of the solar panels is getting higher along with the high intensity of sunlight received by the solar cells [9][15][18].

H. Effect of Ambient Temperature

Solar radiation that is absorbed by solar cells to produce electricity of course also produces heat energy so that it raises the temperature of the solar cells. The temperature of the environment around the solar cells also has a contribution in changing the temperature of the solar cells. Due to the increase in temperature, the electrical power produced by solar cells is reduced [19]. The increase in the surface temperature of the solar cell has an impact on the decrease in the output power of the panel. For the average solar radiation above 1000 W/m^2 with an average ambient temperature of 33^o C, the surface temperature of monocrystalline solar cells is around 30.6^o C, a power loss of 2.3% occurs. Whereas in polycrystalline panels, when the surface temperature is 47.5^o C, there is a power loss of about 10.12%. The power conversion efficiency of the monocrystalline type is 11.90%, and the polycrystalline type is 9.18%. While the PR of monocrystalline and polycrystalline are 0.63 and 0.61 [3].

I. Loading Power

The working characteristics of SPS are tested through the characteristics of current to voltage (I-V) including short circuit current (ISC), open circuit voltage (VOC), and voltage to output power of PV mini-grid (P-V) [4]. The V-I characteristic of solar cells is nonlinear, changing with the intensity and temperature of the photovoltaic surface. In general, there is a unique point on the V-I curve or P-V curve, which is called the Maximum Power Point (MPP). The efficiency of the solar module based on the description above clearly changes with the working voltage. Therefore, the efficiency of the solar module is always set at its peak power [21].

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III. Research Design

A. Tool Making Process

The first process in this research is to carry out a feasibility study at the research location, the research location to be carried out is in the laboratory of the National Institute of Technology Malang. After determining the research location, the next process is making a prototype of a solar cell monitoring datalogger. The process is carried out first by making a circuit schematic in the Eagle program, after the layout drawing is complete, the printing process to the PCB layer is carried out, the drilling process, the component installation process, the sensor calibration process, the calibration process to the monitoring program creation process. The next stage after the datalogger is complete, the next process is in the manufacture of the solar panel frame / frame, the solar panel assembly process on the frame / frame, the solar panel cable installation process, the datalogger installation process, the dummy load installation process. The final stage is the process of installing solar panels at the research site, to the overall testing process for both hardware and software at the research site.

B. Data Collection Process

The data collection process was carried out in the laboratory of the Malang National Institute of Technology. The test was carried out for 1 week, on September 5 – 11, 2021, in daily weather conditions recorded on a datalogger and computer. The data recorded in the form of solar panel power, solar panel temperature, air temperature, air humidity, and sunlight intensity. The solar panels are connected to a datalogger and a dummyload. Data collection was carried out from 06.00-18.00.

IV. Empirical Analysis

The first process in this research is the process of installing solar panels at the research site (Figure 1) and testing the datlogger built from the Arduino architecture, to the overall testing process for both hardware and software at the research site (Figure 2).

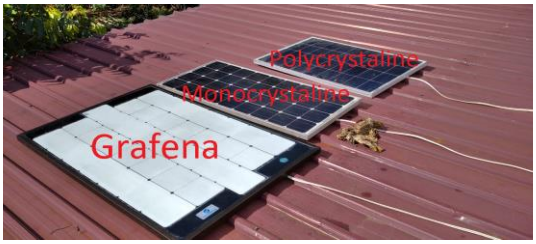

Fig. 1. Installation on research site.

Fig. 2. Installation a datalogger and test a serial communication.

The data collection process was carried out in the laboratory of the Campus II ITN Malang campus. Tests were conducted for 1 week, from September 5, 2021 to September 11, 2021, under daily weather conditions recorded on a datalogger and computer. The recorded data are solar panel power, solar panel temperature, air temperature, humidity, and sunlight intensity. The solar panel is connected to a datalogger and dummyload device. Data collection was carried out at 06.00-18.00 as shown in Figures 3 to 9.

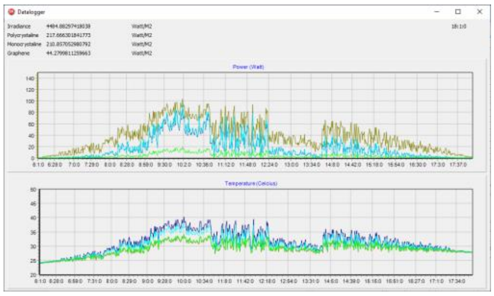

Fig. 3. Graph of Solar Panel Testing (5 Sept 2021).

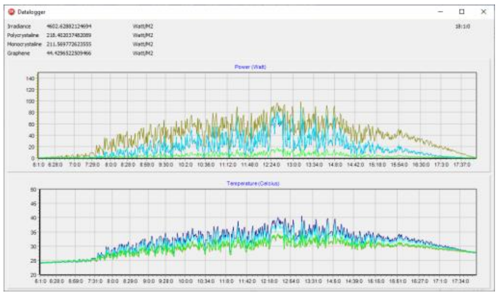

Fig. 4. Graph of Solar Panel Testing (6 Sept 2021).

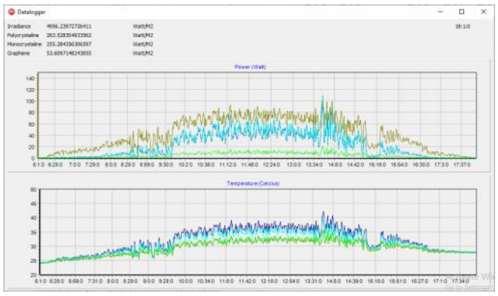

Fig. 5. Graph of Solar Panel Testing (7 Sept 2021).

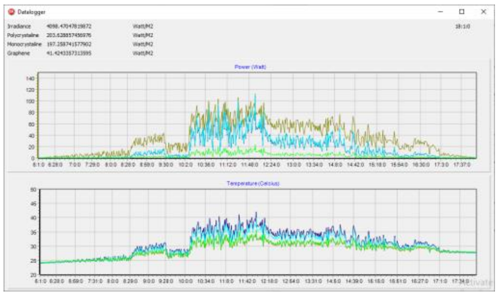

Fig. 6. Graph of Solar Panel Testing (8-09-2021).

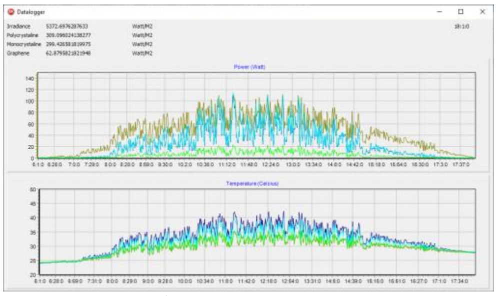

Fig. 7. Graph of Solar Panel Testing (9 Sept 2021).

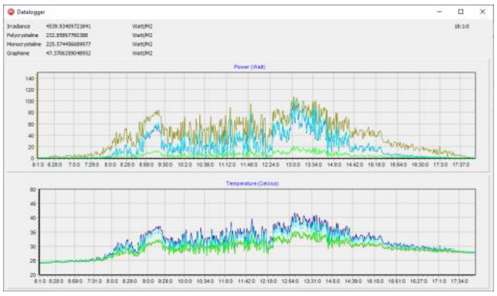

Fig. 8. Graph of Solar Panel Testing (10 Sept 2021).

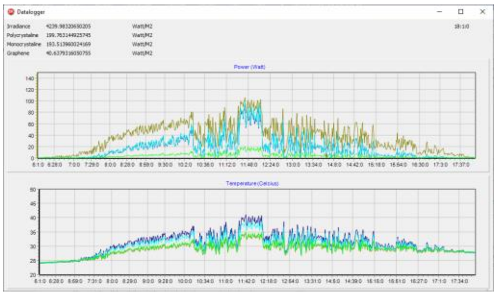

Fig. 9. Graph of Solar Panel Testing (11 Sept 2021).

Figures 3 to 9 above present graphs of Monocrystalline, Polycrystalline, and Graphene solar panel power production graphs based on the influence of sunlight intensity. The bottom section shows the temperature of Monocrystalline, Polycrystalline, and Graphene solar panels temperature graphs based on the influence of sunlight intensity and air temperature, Note: Gold Graph: Environmental measurement, Light Blue Graph: Polycrystalline, Dark Blue Graph: Monocrystalline, Green Graph: Grapenes. The test results data can be seen in Tables I to IV which present the results of solar panel testing based on light intensity, air temperature measurements and solar panel temperature measurements. Measurement of air humidity is also carried out to unify the effect of humidity on solar panels to measurement of solar panel power using a dummy.

TABLE I. Sun light intensity.

Date.	Solar Irradiance (Watt/M^2)		
	Peak Irradiance	Low Irradiance	Average
5/9/21	1050.0	0.0	373.7
6/9/21	990.0	0.0	383.5
7/9/21	1100.0	0.0	413.0
8/9/21	1100.0	0.0	341.5
9/9/21	1150.0	0.0	447.7
10/9/21	1050.0	0.0	378.3
11/9/21	1050.0	0.0	353.3

TABLE II. Air temperature measurement.

Date.	Air Temperature (º Celsius)		
	Highest	Lowest	Average
5/9/21	33.4	24.2	28.1
6/9/21	34.7	24.5	28.4
7/9/21	33.2	24.7	27.3
8/9/21	38.5	24.2	27.7
9/9/21	36.8	24.7	30.4
10/9/21	37.4	24.8	31.7
11/9/21	34.7	24.3	29.4

TABLE III. Air humidity measurement.

Date.	Relative Air Humidity (% RH)		
	Highest	Lowest	Average
5/9/21	78	75	76
6/9/21	80	78	78
7/9/21	78	76	76
8/9/21	78	77	77
9/9/21	84	83	83
10/9/21	84	83	83
11/9/21	86	85	86

TABLE IV. Solar panel power measurement table based on light intensity.

Date.	Solar Irradiance (W/M^2)	Average PV Power (W/M^2/H)			PV Total Power (Watt/Day)		
	Avg	M	P	G	M	P	G
5/9/21	373.7	17.5	18.1	3.7	210	217	44
6/9/21	383.5	17.6	18.2	3.7	211	218	44
7/9/21	413.0	21.3	21.9	4.4	255	263	53
8/9/21	341.5	16.4	16.9	3.4	197	203	41
9/9/21	447.7	24.9	25.8	5.2	299	309	62
10/9/21	378.3	18.8	19.3	3.9	225	232	47
11/9/21	353.3	16.1	16.6	3.3	193	199	40

V. CONCLUTION

In the test that has been carried out for one week, several measurement results have been obtained. In the measurement of the intensity of solar radiation that has been carried out, the average solar radiation is 384.4 Watt/M^2/hour or 4612.8 Watt/M^2/Day, from the radiation measured, the average temperature is 29º Celsius and the average humidity is 79.8 %. From the daily solar radiation potential that has been measured, the potential for generating electrical energy using solar panels reaches 234.4 watts/day for polycrystalline, 227.1 watts/day for monocrystalline, and 47.2 watts/day for graphene coating on monocrystalline. From the measured results, it is concluded that polycrystalline solar panels have the best production efficiency compared to other types.

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