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Analysis of the Effect of Two Types of Solar Panels on the Basic Design of a 9 kWp Rooftop Solar Power Plant on the Pusenlis Building Using Pvsyst

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Abstract-Nowadays, pollution is increasing, the most common pollution that causes global warming is air pollution. The increasing air pollution in Jakarta creates a less friendly environment. Many things cause air pollution in Jakarta, and the primary source of air pollution is the coal-fired steam power plant. Therefore we need an environmentally friendly power plant or reduce air pollution in Jakarta. Environmentally friendly power plants are known as new and renewable energy power plants. New and renewable energy power plants are environmentally friendly because they use energy sources from nature that can be regenerated freely and renewed continuously and indefinitely. Examples of renewable energy power plants are solar power plants, called PLTS in Indonesia. PLTS power source is a generator that uses solar to generate electricity. PLTS is a power plant that converts solar energy into electrical energy. PLTS in Indonesia generally uses two types of solar panels, namely monocrystalline and polycrystalline types. The monocrystalline module has higher efficiency than polycrystalline. On the other side, the production cost of monocrystalline is higher than the polycrystalline module. Whatever the solar power plant material, this is very suitable to be built in Jakarta. In Jakarta, there is a lot of high building, so that this generator can be placed on the roofs of office buildings in Jakarta. Having solar power plants on the tops of buildings in Jakarta will help reduce air pollution caused by coal-fired steam power plants. Therefore, in this research, a nine kWp rooftop solar power plant will be designed using simulation conditions at the Pusenlis building using PVSyst software. With a higher efficiency value, losses can be reduced to work more efficiently, marked by a high system performance ratio value.

Keywords- *Solar Power Plant, PVsyst, Monocrystalline, Air Pollution*

I. INTRODUCTION

Solar power plants need to be built in Jakarta to reduce pollution caused by coal-fired steam power plants. Because around the Jakarta area, there are a lot of coal-fired power plants that make the air in the Jakarta city environment unhealthy. Coal-fired steam power plants cause approximately 10% of SO_2 and NO emissions in Jakarta. In addition, the city of Jakarta has hot air, and the average land has been lost due to the construction of high buildings. Because this situation exists, there is a need for a better power solution. PLTS has become one of the solutions of alternative energy sources. PLTS doesn't need a large area like a PLTU. PLTS can use the solar cells that could be placed on the roofs of buildings in the city of Jakarta. Because there are many high buildings in Jakarta, a cluster of PLTS could support and, in the future, substitute the coal power plant [1].

PLTS is a generator that uses solar power to generate electricity. Electricity generation can be done in two ways: directly using photovoltaics and concentrating solar energy. Photovoltaic systems use solar cells to convert solar photon radiation into electrical energy. The concentration of solar energy uses a lens or mirror system combined with a tracking system to focus solar energy to a single point to drive a heat engine [2].

Monocrystalline and polycrystalline solar panels are commonly used in solar power facilities in Indonesia. Although monocrystalline modules have greater efficiency, their production costs are still greater than those of polycrystalline modules. By choosing the right type of solar panel, it can produce optimal electrical energy [3].

In this research, a PLTS with a capacity of 9 kWp will be designed in Jakarta, more precisely in the Pusenlis building using the PVSyst software. The design of PLTS with nine kWp is due to the limited land area in the Pusenlis building. Pusenlis building has a 50 m^2 land area on the roof of the building. This land will be used as a PLTS that produces electrical energy with a good efficiency and performance ratio. Pusenlis uses electrical sources from PLTS as alternative energy for the activity inside the building, which could help in reducing air pollution in Jakarta caused by coal-fired power plants [4].

The topic of discussion in this research is the design of a nine kWp rooftop solar power plant using PVSyst software. The primary purpose of this research is to analyze the effect of two types of solar panels on the performance of a Rooftop Solar Power Generation System with a Capacity of nine kWp.

II. THEORETICAL FRAMEWORK

A. *Solar Energy*

Solar energy is the energy obtained by converting solar thermal energy through specific equipment into other forms of power. The solar energy generated for the entire mainland of Indonesia, which has an area of 2 million km^2, is 4.8 kWh/m/day or equivalent to 112,000 GWp distributed. Indonesia has only utilized about 10 MWp. There is still a lot of need and construction PLTS potentially in the territory of Indonesia to be able to produce electricity. Fig. 1 shows the solar atlas in the Indonesia region.

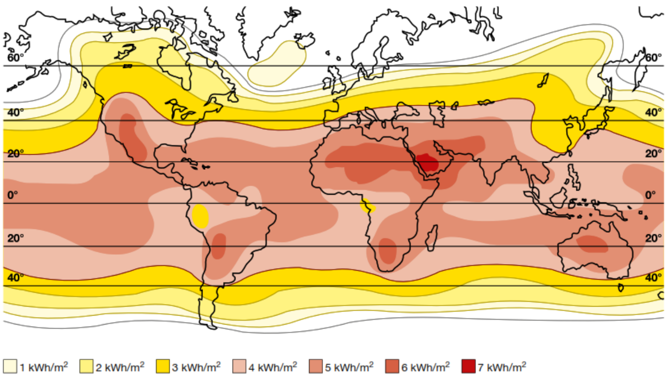

Figure 1. Solar Atlas

Based on solar radiation data collected from various locations in Indonesia, it shows that solar energy resources in Indonesia can be grouped by region, namely the western and eastern regions of Indonesia. Indonesia's solar energy resources by region are as follows (IEO 2010):

1. Western Indonesia (KBI) = 4.5 kWh/m2/day, monthly variation is around 10%

2. Eastern Indonesia (KTI) = 5.1 kWh/m2/day, monthly variation around 9%

3. Indonesian average = 4.8 kWh/m2/day, monthly variation is around 9%.

B. *Solar Power Plant*

PLTS is a power plant that uses sunlight through solar cells (photovoltaic) to convert solar photon radiation into electrical energy. Solar cells are thin layers of pure silicon (Si) semiconductor material and other semiconductor materials. PLTS utilizes sunlight to produce DC electricity, which can be converted into AC electricity when needed; therefore, even if the weather is cloudy, as long as there is light, PLTS can still generate electricity. Fig. 2 shows the solar cell example application on the rooftop.

Figure 2. Solar Cell Application

PLTS is a power supply and can be designed to supply small to significant electricity needs, either independently or hybrid (combined with other energy sources), either with the decentralized method (one house, one generator) or with the centralized approach (distributed electricity). PLTS is a renewable energy source, where sunlight is an inexhaustible energy source; besides that, PLTS is an environmentally friendly power plant without any rotating parts, does not cause noise, and does not emit exhaust gases or waste.

C. *Working Principle of Solar Cells (Photovoltaic)*

Sunlight has tiny particles called photons. When exposed to sunlight, the photon hits the silicon semiconductor atoms of the solar cell. Solar cells generate enough energy to separate electrons from their atomic structure. The separated electrons and negatively charged (-) will be free to move in the conduction band region of the semiconductor material. Atoms that lose electrons will create vacancies in their structure. These vacancies are called "holes" with a positive (+) charge.

This semiconductor region with free electrons is negative and acts as an electron donor. This semiconductor region is called an N-type semiconductor. While the semiconductor area with a positive hole and acts as an electron acceptor is called a P-type semiconductor. At the junction of the positive and negative regions (PN junction), there will be energy that pushes electrons and holes to move in opposite directions. Electrons will move away from the negative concentrated area, while the holes will move away from the positive region. Electric current will appear when there is a load of electrical devices at this positive and negative junction (PN junction). Fig. 3 shows a layer of solar cells that contains a PN junction.

Silicon which is the material of the PN junction, is a four-valent semiconductor material. The advantages of silicon are that it has a very high resistivity of up to 300,000 Ωcm and is widely available in nature. However, the drawback is the very high cost of producing silicon wafers. Silicon with high purity is needed to get good solar cell performance, above 99.9%. The development of low-cost photovoltaic is required to get more excellent power resources with minimal cost.

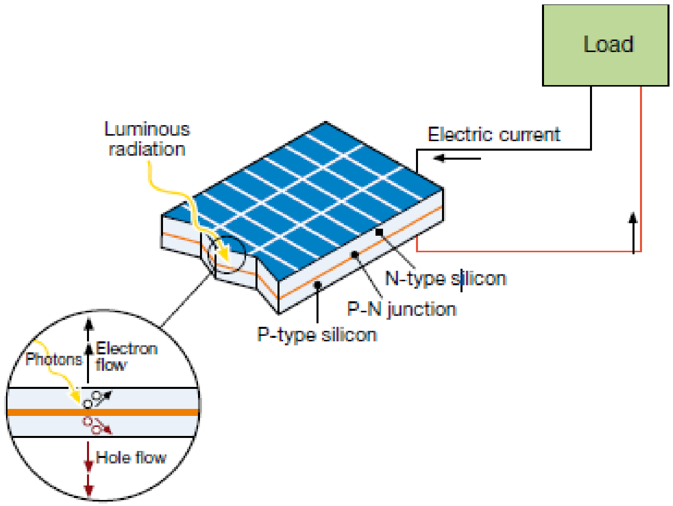

Figure 3. A layer of the Solar Cell

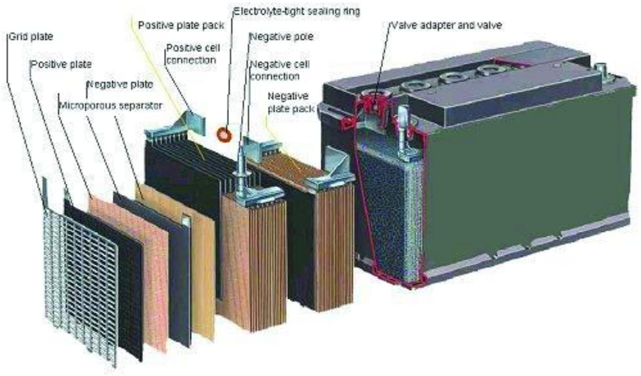

Figure 4. Battery as storage of electrical energy

Batteries are generally charged at a voltage of 14 - 14.7 Volts. 12 Volt solar panels / solar cells typically have an output voltage of 16 - 21 Volt. So without a solar charge controller, the battery will be damaged by over-charging and voltage instability. Fig. 5 shows the solar charge controller that controls the charge condition based on the strength of solar radiation.

Figure 5. Solar charge controller

D. *Solar Power Plant Component*

Photovoltaic is a device that can convert sunlight directly into electricity. The word photovoltaic is commonly abbreviated as PV [4]. Semiconductor materials such as silicon, gallium arsenide, cadmium telluride, copper, and indium diselenide, are usually used as raw materials. Solar cells are typically made from crystalline. There are two kinds of crystalline commonly used in practice: monocrystalline and polycrystalline.

1) *Monocrystalline*

Monocrystalline uses pure silicon produced by a relatively complicated crystal-growth process with about 0.2 - 0.4 mm. thickness. The efficiency is relatively high, ranging from 13-19%.

2) *Polycrystalline*

Polycrystalline, sometimes referred to as multi-crystalline, solar panels made from polycrystalline cells are cheaper, and their efficiency is still below that of monocrystalline, ranging from 11 to 15%.

The battery or battery is a store of electrical energy when the sun is not there. Batteries are distinguished by application and construction. The battery is determined for automotive, marine, and deep cycles based on the application. Meanwhile, the batteries are divided into wet, gel, and AGM (Absorbed Glass Mat) types in construction. AGM-type batteries are usually VRLA (Valve Regulated Lead Acid). The battery suitable for PV is a deep cycle lead-acid battery that can accommodate a capacity of 100 Ah, 12 V, with an efficiency of about 80%. Battery charging time for 12 hours - 16 hours. Fig. 4 shows the battery as storage of electrical energy and its layer.

Solar charge \controller is an electronic device used to regulate the direct current charged to the battery and taken from the battery to the load. The solar charge controller controls overcharging (the battery is 'full') and excess solar panel / solar cell voltage. Overvoltage and charging will reduce battery life.

There are two types of technology commonly used by solar charge controllers:

1) *PWM*

Pulse Wide Modulation as the name suggests, uses the pulse width of the electrical on and off, thus creating a sine wave electrical form.

2) *MPPT*

Maximum Power Point Tracker is more efficient in converting DC to DC (Direct Current). MPPT can take maximum power from PV. The MPPT charge controller can store excess energy that is not used by the load into the battery, and if the power required by the load is greater than the power generated by the PV, then the power can be drawn from the battery.

In PLTS, the inverter functions as a power condition and control system that converts direct current (DC) generated by the PV module into alternating current (AC) electricity. The inverter is a device that functions to convert DC into AC. The inverter will control the quality of the electrical power issued to be sent to the load or power grid.

The load is equipment that consumes the power generated by the resource. These loads, for example, such as lights, fans, electronic devices, etc. In the whole system, the total power is the sum of all the active and reactive power used by the equipment that uses electrical energy.

E. Solar Power Generation System (PLTS)

A stand-alone PV system or Centralized Solar Power Generation System (PLTS Centralized) is an alternative power generation system for remote/rural areas that are not covered by the PLN network. Fig. 6 shows a solar power plant with the off-grid scenario.

A grid-connected PV system or interconnected PLTS is a green energy solution for housing and offices urban residents. This system uses a solar module (photovoltaic) to generate environmentally friendly and emission-free electricity. This system will reduce household electricity bills and add value to the owner. As the name implies, grid-connected PV, PLTS, operates and is directly connected to the Existing Electricity System without any combination with storage. Or in other words, PLTS On-Grid is included in the category of intermittent generators. Power harmonic stability is the primary problem of the PLTS On-Grid. Fig. 7 shows the scenario and design of the On-Grid power plant.

A hybrid system is a system that involves two or more power generation systems; generally, the power generation systems that are widely used for hybrids are generators, solar power, micro-hydro, and wind power. Fig. 8 shows a solar power plant with a hybrid scenario.

F. PVSyst

PVSyst is a software package used for the learning process, measurement (sizing), and data analysis of the complete PV mini-grid system. PVSyst was developed by the University of Geneva, which is divided into a grid-connected system, a stand-alone system, a pumping system (pumping), and a direct current network for public transportation (DC-grid). PVSyst is also equipped with a database of comprehensive and diverse meteorological data sources and data on PV mini-grid components [8].

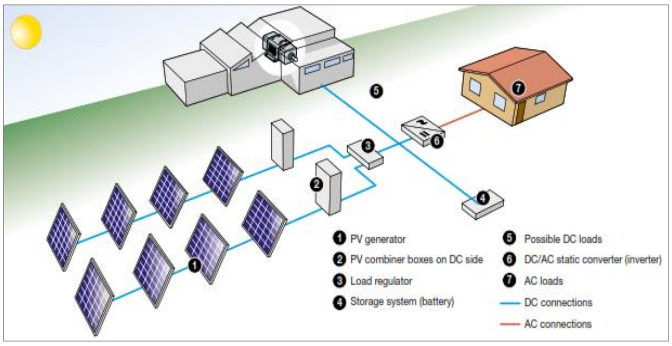

Figure 6. Solar Power Plant with Off-Grid Scenario

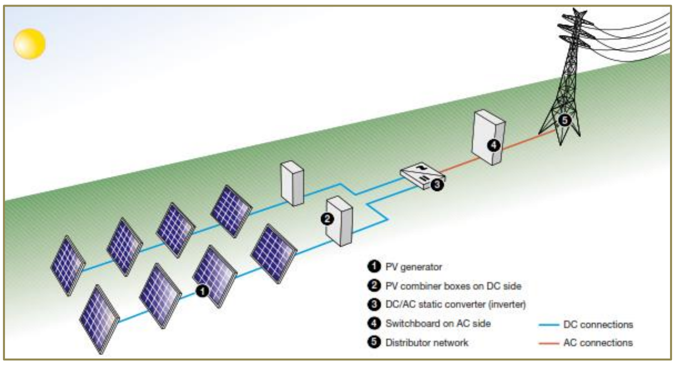

Figure 7. Solar Power Plant with On-Grid Scenario

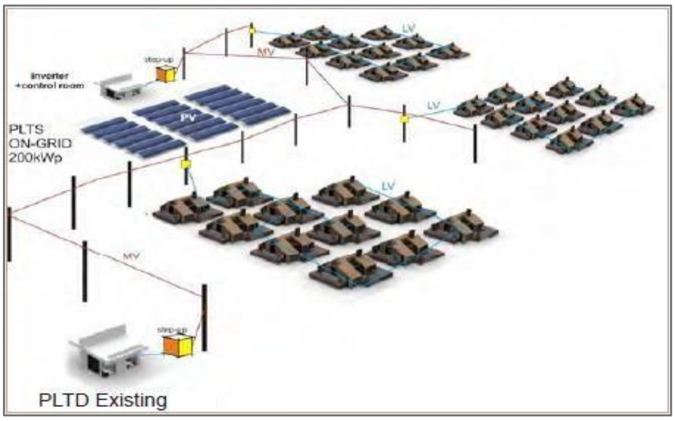

Figure 8. Solar power plant with Hybrid Scenario

III. RESULT AND DISCUSSION

A. Rooftop Solar Power Plant

The rooftop solar power plant is a solar power generation system where PLTS operates parallel with the grid of the State Electricity Company (PLN) network intended to save PLN / grid electricity consumption. It is called a rooftop because, generally, solar panels are placed on the roof of the building (house/building). Fig. 9 shows a rooftop solar power plant.

Figure 9. A rooftop Solar Power Plant

The main components of the rooftop solar power plant are solar module or PV array, grid inverter, kWh meter export-import, and conventional kWh meter. PLTS rooftop On-Grid (PLTS roof or solar roof or solar rooftop) uses an AC coupling system. PLTS is run in parallel with the PLN network/grid without batteries. In the AC Coupling system, the output of the solar inverter is connected to the PLN / grid electricity network and simultaneously serves the load. The power produced by PLTS is a priority to reduce electricity consumption from the PLN / grid. An electricity bill reduction scheme can transfer excess energy to the PLN network (feed-in/export). The rooftop solar power plant is designed according to the space on the roof. So if the open space on the top is getting bigger, we can make a giant solar power plant.

B. Basic Design of an On-Grid Rooftop Solar Power Plant with a Variety of Monocrystalline and Polycrystalline

PVSyst is software used for the learning process, measurement (sizing), and data analysis of the complete PV mini-grid system. For the basic design of a solar power plant that will be made on the roof of the Pusenlis building. On the rooftop of the Pusenlis building, there is an area of 50 m^2. Therefore the land can be used to make a solar power plant with a capacity of nine kWp. Fig. 10 shows a Pusenlis building's view.

Figure 10. Pusenlis Building

In the picture above is a view of the rooftop of the Pusenlis building that will be made an on-grid Solar Power Plant with a capacity of 9 kWp. At the initial stage, we open the Pvsyst application, then we select the location of the PLTS rooftop, which will be made as follows. Fig. 11 shows the area on the geolocation map for the Pusenlis building. Pusenlis building was located more precisely in the city of South Bambu. We can adjust the tilt and azimuth of the solar panel so that the PLTS will produce maximum electrical energy.

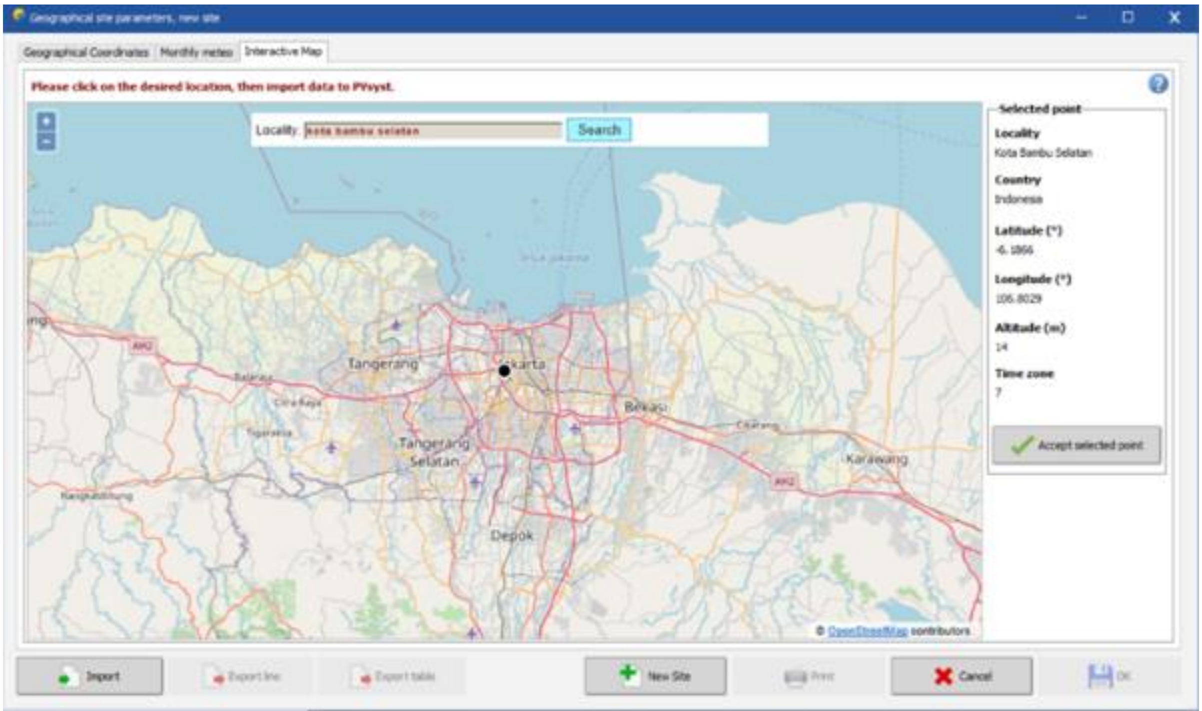

Figure 11. Pusenlis Building Location

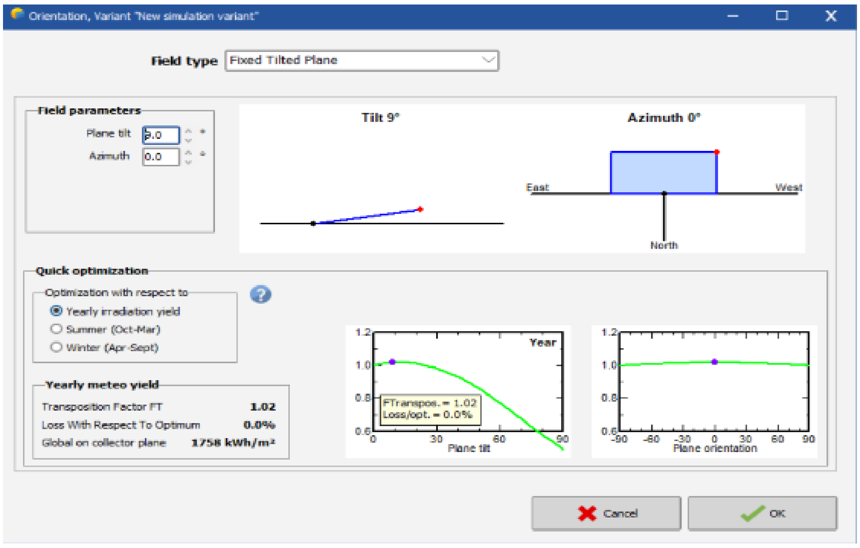

Figure 12. The input of Azimuth and Tilt

Fig. 12 shows that the tilt position must be in the 9º position, and the azimuth position is 0º. At that position, the solar panel will produce maximum electrical energy with a loss following the picture, which is 0.0%. Then after adjusting the tilt and azimuth. The next step is to choose a solar panel and inverter suitable for use at a predetermined location. If we have set the angle and azimuth, the next step is to determine the components to be used as follows.

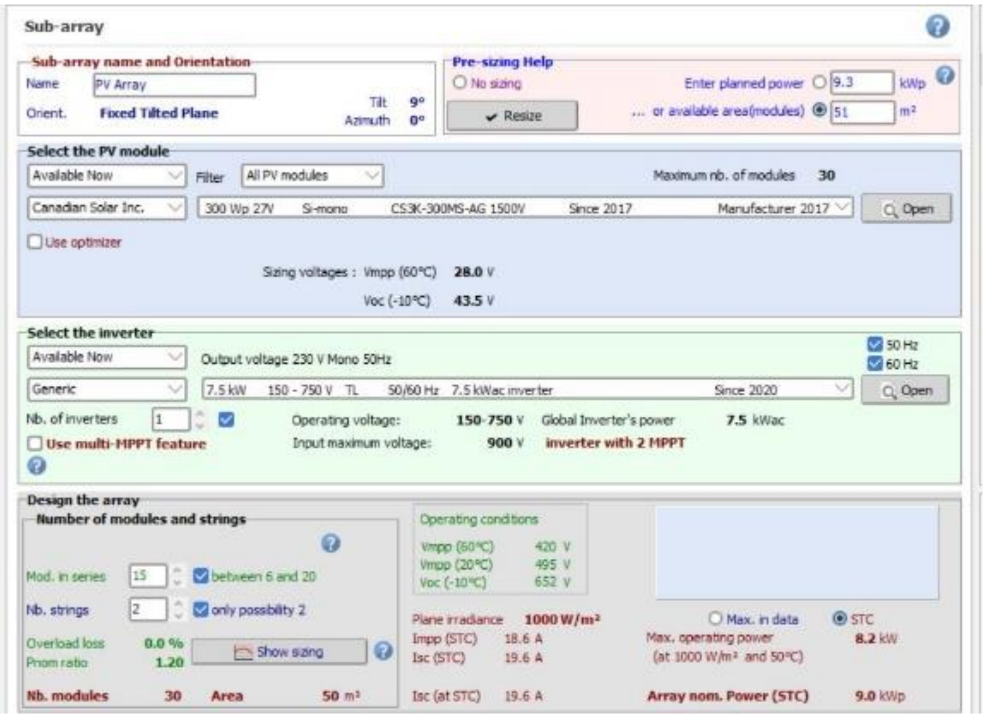

Figure 13. Determine the type of solar module and the type of inverter

Fig. 13 shows the type of solar module used is a monocrystalline solar module with a capacity of 300 Wp, which amounts to 30 units to produce 9 kWp. This type of inverter is a generic inverter with a capacity of 7.5 Kw. This rooftop solar power plant also uses an MPPT module to optimize energy capture. After choosing the type of solar panel and inverter used, we can view reports that match the data entered at the beginning of the design. It can be run, and we will get the results in the reporting section.

C. *Comparative Analysis of Simulation Results of Designing a nine kWp Rooftop Solar Power Plant with Variations of Two Types of Solar Panels*

Based on the simulation results, the following comparison is obtained. Table 1 shows a complete comparison from the report gained in PVSyst software. There is a parameter that could be acquired after the direct simulation. The main concern is an efficiency comparison and losses of each material.

TABLE I. SIMULATION COMPARISON OF TWO SOLAR PANEL DESIGN

Parameter	Variation 1 Solar Panel Monocrystalline	Variation 2 Solar Panel Polycrystalline
Model	CS3K-300MS-AG 1500V	CS3K-300PB-AG
Module Efficiency	20,48 %	20,36%
PV Module Dimension	1,675 m x 0,992 m	1,696 m x 0,992 m
PV Module surface area	1,661 m2	1,682 m2
PV Module Array	30	30
Nominal Power	9 kWp	9 kWp
Module Configuration	2 strings x 15 series	2 strings x 15 series
Total Surface Area of PV Module	50 m2	50 m2
Output Power of PV Array (Pmpp)	8,17 kWp	8,17 kWp
Voltage of PV Array (Umpp)	439 V	444 V
Current of PV Array (Impp)	19 A	18 A
Result of Main Simulation		
PV Module Efficiency in the Standard Test Condition	18,07 %	17,85 %
Losses of PV Array from the temperature effect	9,84 %	9,88 %
Energy which injected to (E_Grid) overal year	13,22 MWh	13,18 MWh
Performance Ratio	83,8 %	83,6 %

Fig. 16 shows that the PLTS design has an excellent performance. Monocrystalline has dimensions of 1.675 m x 0.992 m, so the total area of Solar panels needed to make PLTS is 50 m2. The nominal value of the STC power as planned is nine kWp. Simulation results of Variation 1 with Monocrystalline Solar Panel resulted in a system performance ratio of 83.8%. Based on the simulation that has been done, it is also known that the effective irradiation in the PV array is 1731 kWh/m2.

The conversion of Solar Panels produces an array of nominal energy per year of 13.22 MWh by considering the efficiency value of Monocrystalline Solar Panels at STC conditions of 18.07%. The most significant losses occurred due to the influence of temperature on the PV Array, which reached 9.84 %. System losses are affected by the inverter, which converts power from DC to AC with a specific efficiency. Conversion results in a loss of energy during the conversion from AC to DC. The efficiency curve depends on the inverter used. The inverter used in this experiment is a generic brand with a capacity of 98% inverter efficiency. The value of the operating efficiency losses of the inverter used is 1.90%. After PVSyst calculates by considering the value of the losses above, it is found that the value of energy that can be injected into the grid per year reaches 13.22 MWh.

Variation 2 with Polycrystalline Solar Panels is arranged in 15 strings x 2 series. With this configuration, there are 30 PV Modules in the Array. Monocrystalline Solar Panels have dimensions of 1.696 m x 0.992 m, so the total area of Solar Panels needed to make PLTS is 50 m2. The nominal value of the STC power as planned is none kWp.

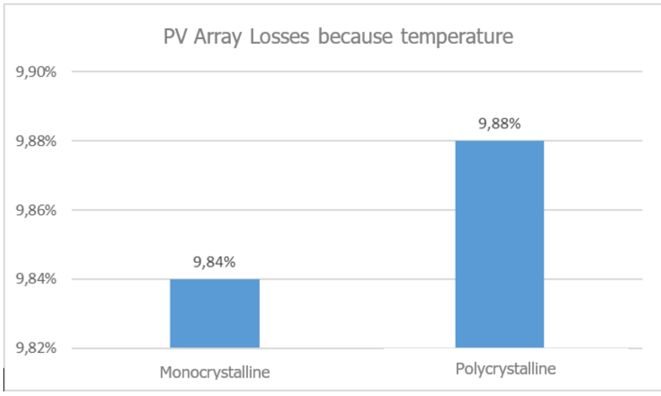

Figure 14. Comparison of PV Losses because of temperature

Simulation results of Variation 2 with the Polycrystalline Solar Panel resulted in a system performance ratio of 83.6%. Fig. 16 shows that the PLTS design has an excellent performance. Based on the simulation that has been done, it is also known that the effective irradiation in the PV array is 1719 kWh/m2.

The conversion of Solar Panels produces an array of nominal energy per year of 13.18 MWh by considering the efficiency value of Polycrystalline Solar Panels at STC conditions of 17.85 %. System losses are affected by the inverter, which converts power from DC to AC with a specific efficiency. Conversion results in a loss of energy during the conversion from AC to DC. The most significant losses occur due to the influence of temperature on the PV Array, which reaches 9.88%.

The efficiency curve depends on the inverter used. The inverter used in this experiment is a generic brand with an efficient value of 98%. The value of the operating efficiency losses of the inverter used is 1.89%. After PVSyst calculates by considering the value of the losses above, it is found that the value of energy that can be injected into the grid per year reaches 13.18 MWh.

Fig. 15 shows the graph of the comparison of PV Array losses due to the influence of temperature. Variation 1 with PV Module Efficiency of 18.07% has losses of 9.84%, while

Variation 2 with PV Module Efficiency of 17.85% has smaller losses of 9.88%. The most significant losses in these two variations occur in the PV array caused by temperature. So it can be concluded that the principle of efficiency is inversely proportional to lose. In other words, if the module's efficiency is more significant, it can reduce the loss factor, making the system work more efficiently.

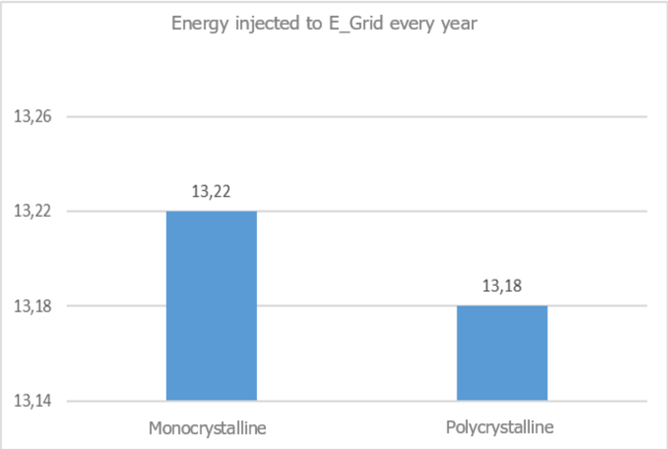

Figure 15. Energy Comparison Graph injected into the grid (E_Grid)

The energy injected into the grid (E_Grid) in one year for Variation 1 is 13.22 MWh, and variation 2 is 13.18 MWh. The difference in the value of E_Grid is due to the difference in PV module efficiency under STC conditions. For example, Variation 1 has a PV Module Efficiency of 18.07%. E_Grid generated for Variation 1 is the largest in a year. Therefore, it can be concluded that the PV Module Efficiency at STC conditions is directly proportional to the energy injected into the grid (E_Grid) per year.

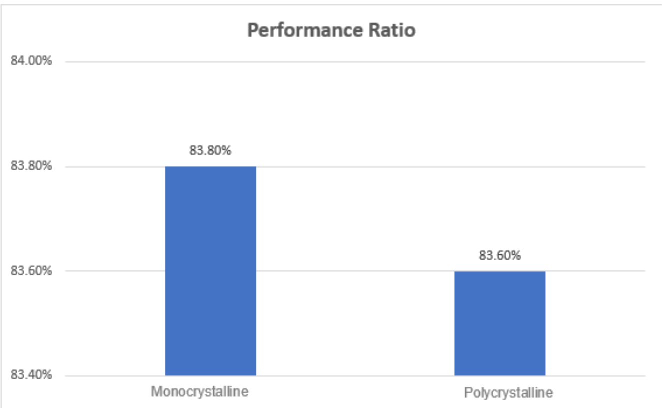

Figure 16. Comparison of Performance Ratio Graph

The comparison graph of the Performance Ratio can be seen in the image above. Based on the chart, Variations 1 and 2 have excellent system Performance Ratio values, only slightly different, namely Variation 1 of 83.80% and variation 2 of 83.60%. The difference in the value of the Performance Ratio is due to the difference in PV Module Efficiency. For example, Variation 1 has the best PV Module Efficiency, 18.07%. The resulting performance ratio for Variation 1 is the largest. Therefore, it can be concluded that the PV Module Efficiency is directly proportional to the System Performance Ratio (PR).

Based on the comparison of the parameters above for the various types of Solar panels, it can be concluded that the efficiency of the PV Module dramatically affects the system losses that arise. With a higher efficiency value, the loss factor can be reduced to make the system work more efficiently, marked by the high E_Grid value and system Performance Ratio (PR).

IV. Conclusion

In the research on the analysis of types of solar panels in the basic design of a nine kWp on-grid Rooftop Solar Power Plant at the Pusenlis Building using PVsyst software, the following conclusions were obtained:

1. Many stages are carried out before a power plant is operational. These processes are Site Scoring, Pre-Feasibility Study, Feasibility Study (FS), Design Engineering, Bid Document, HPE, Procurement to Contract, Engineering Supervision, and Commercial Operation Date.

2. Solar Power Plant is a power plant that uses sunlight through solar cells (photovoltaic) to convert solar photon radiation into electrical energy.

3. There are two types of solar panel technology often used in Indonesia, namely Monocrystalline (mono c-Si) and Polycrystalline (poly c-SI). Monocrystalline solar panels have the highest efficiency. On the other side, the production costs are still higher than polycrystalline solar panels.

4. PVSyst 7.1 software is commonly used in calculating and planning the use of PV mini-grid in an industry or region. This software can be used for the learning process, measurement (sizing), and data analysis of the complete PV mini-grid system.

5. Simulation of the Basic Design of 9 kWp rooftop PLTS On-Grid in the Pusenlis building with variations in the types of solar panels aims to determine the effect of solar panel efficiency on overall system performance.

6. There are three main factors affecting system performance: PV Array losses due to the influence of temperature, then energy injected into the grid. (E_Grid) Per Year, and lastly is the performance ratio

7. Based on the PV Array Loss factor due to temperature, a higher PV Module Efficiency Value can reduce the PV array loss factor.

8. Based on the Energy factor injected into the grid (E_Grid) Per year, the most significant value in variant 1 with energy injected into the grid of 18.22 MWh. It can be

concluded that the efficiency of the PV module under STC conditions is directly proportional to the fuel injected into the grid (E_Grid) per year.

9. Based on the Performance Ratio factor, it can be concluded that the PV Module Efficiency is directly proportional to the System Performance Ratio (PR).

10. Based on the Comparative Analysis of the Simulation Results of Designing a nine kWp Rooftop Solar Power Plant with Variations of 2 Types of Solar Panels, it can be concluded that selecting a solar panel with high efficiency will affect the system losses later. A higher efficiency value can reduce the loss factor so that the system works more efficiently, characterized by a high-Performance Ratio and E_Grid value.

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