Analysis of The Effectiveness of Household Scale Smart Window Panel as a New Renewable Energy Source Using PVsyst Software

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***Abstract*— Increasing electrical energy consumption causes problems because it produces greenhouse gas emissions. The problem is that the fuel used so far is not renewable. Carbon emissions can trigger global warming. Global warming causes the temperature on earth to increase, causing icebergs in the polar regions to melt and sea levels to rise. Efforts can be made to minimize this problem by transitioning to alternative energy, such as solar panels. Using solar panels as an energy source has an excellent opportunity to be implemented because Indonesia gets sunlight throughout the year. However, solar panels have drawbacks, such as surfaces that are difficult to clean, depending on location and weather conditions, and their installation requires a large area. Therefore, this research was conducted by designing smart window panels that are easy to apply on a household scale so that their effectiveness is known when implemented. The method used in this study is a simulation method using the PVsyst software. The simulation was carried out with a variable angle of installation of the smart window panel, 0°,30°,45°,60°, and 90°. The results showed that the best results were obtained from modules with an installation angle of 90° because the EfrGrid value was 19168 Kw/year and E_Solar was 104.28 Kw/year. Increasing the number of modules used can be done by using suitable inverters so that optimizing the use of smart window panels on the household scale can be done to reduce carbon emissions and achieve energy security in Indonesia.**

***Keywords*—Efrgrid, E_solar, Pvsyst, Mounting angle seismic, Smart window panel**

I. INTRODUCTION

The rapid population growth in Indonesia is in line with the increase in electrical energy consumption, most of which comes from fossil fuels. The production of electricity produces greenhouse gas emissions and non-renewable that cause global warming. Based on greenhouse gas inventory data from the Ministry of Energy and Mineral Resources in 2015, steam power plants using coal produce emissions of 122.5 million tons of CO_2e. The increase in emissions is predicted to double in 2028 to 351.3 million tons of CO_2e [1]. Carbon dioxide (CO_2) gas is a greenhouse gas with the smallest global warming index but the most significant concentration after water vapor, so it contributes the most to temperature changes compared to other greenhouse gases such as N_2O, CFCs, HFCs, CH_4, and SF_6 [2]. Carbon dioxide gas is closely related to global warming events. Global warming is caused by increasing greenhouse gases in the troposphere, which, if too much, will have negative impacts, such as increasing the earth's temperature and causing icebergs in polar regions to melt. As a result, sea levels will become high and low-lying islands will sink [3]. The magnitude of the impact caused by CO_2 gas on climate change encourages the Indonesian Ministry of National Development Planning to commit to reducing CO_2 gas emissions by 26%. Therefore, to achieve this commitment, various efforts to develop alternative energy are carried out to meet energy needs and overcome climate changes, one of which is using alternative energy, such as solar panels [4].

Using solar panels as an energy source is an excellent implementation opportunity. Solar panels have developed a lot since they were discovered. As for material development, initially, solar panels were made from polycrystalline or monocrystalline silicon. The development of technology gave rise to various new materials such as gallium arsenide [5], basic organic materials such as Moringa leaves [6], and perovskite, which can produce an efficiency of up to 29.15% [7]. Solar panel design has also undergone many developments. Innovations emerged in terms of solar panel design. Such as transparent solar panels [8] that can be applied as windows. Developments in terms of design continue beyond there, and there are also flexible solar panels that can be applied on the surface of various shapes, such as on planes, cars, drones, or buildings [9]. The results of Ugli's (2019) research show that solar panels have several areas for improvement, such as the surface that must always be

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cleaned of dirt or dust. There are some hard-to-reach parts to clean in a vast solar panel plant. Then, solar panels that are too hot can also reduce their effectiveness, so they must be installed with cooling. Also, several challenges and shortcomings must be faced in its implementation. For example, installing solar panels depends highly on site and weather conditions [10]. Extreme temperature and wind speed [11], and humidity also affect the performance of solar panels [12-13]. In addition, the understanding of the Indonesian people regarding solar panels is also uneven [14].

Smart window panels are innovative solar panel technologies that are installed in windows. Some of the technologies used in smart windows include silicone gel or organic transparent panels. The results of Giucastro et al. (2018)show that using graphene in smart windows has several advantages, such as higher energy performance, and the technique of making graphene panels is easy to do in the industry without changing production lines and significant investment [5]. Then, research on the efficiency of smart window panels was carried out by Fathi et al. (2017); Martina et al. (2017) Abu-Bakar et al. (2015); Huang et al. (2012); Mallick and Eames (2007); which produce power outputs of 4.8W, 18.85mW, 0.050W, 20.94mW and 70W respectively [15-19]. Y. Niu et al. (2022) have also conducted other research on smart window panels, which resulted in a photoelectric conversion efficiency of 18.24% [20]. From this research, no one has used the installation angle as a variable simulated using PV system software taken from environmental conditions in Indonesia. Therefore, this study develops smart windows by designing smart window panels that are easy to apply on a household scale to know the effectiveness of smart window panels when implemented based on the variable angle of installation.

A. Smart Window Panel

Smart window panels are solar panels fastened in a window that can integrate the material used for increasing efficiency. Since the material used in organic perovskite is graphene, it has high electrical conductivity. It allows for efficient charge transport within solar panels with the movement of electrons, reducing energy losses and improving the overall conversion efficiency of solar cells [21]. Besides electron transfer, graphene has a transparent characteristic that can be used as a window plantation. The implementation used the angle, height, and layer thickness parameters to maximize output efficiency.

B. Parameters

1. Angle and Height

The angle of solar panel plantation aims to maximize the solar panel's energy output throughout the year. For fixed-tilt solar systems, the optimal tilt angle is typically determined based on the latitude of the installation site. However, for adjustable or tracking systems, the tilt angle can be adjusted dynamically to track the sun's position throughout the day, optimizing energy generation. It ranges from 0-90^o depending on the installation place, so the height and mounting can be adjustable on fastened [22].

2. Layer Thickness

The thickness of transparent conductive layers, such as transparent electrodes, can affect the reflection and transmission of light. Thicker conductive layers may cause more reflection, reducing the amount of light that reaches the active layer and decreasing overall efficiency. Thin conductive layers can help minimize reflection losses and maximize light transmission. The layer of sandwich structure from the electron transport layer (ETL), hole transport layer (HTL), perovskite transport layer (PTL), and organic perovskite can be adjusted in the material used and the type of manufacturing process [8].

II. METHOD

This smart window panel research was conducted using a simulation method to determine the effectiveness of smart window panels from the electrical energy produced. The simulation process is carried out with the flow according to Figure 1.

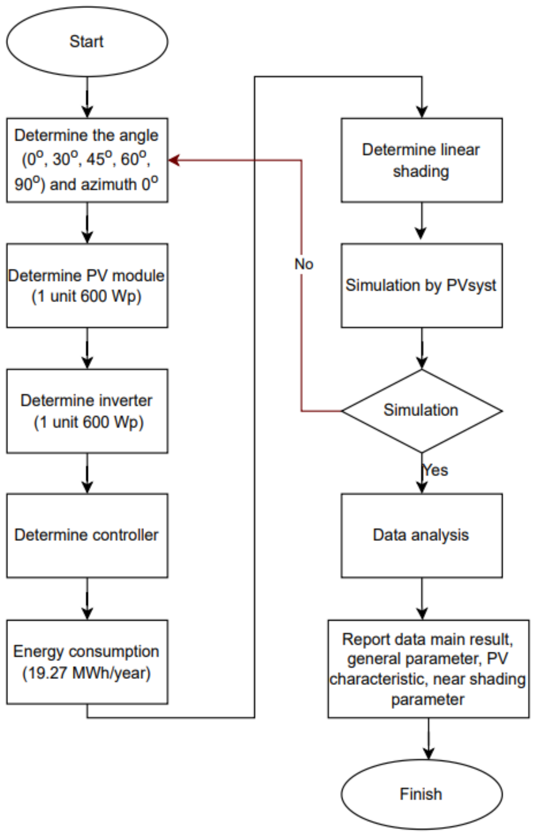

Figure 1. Flowchart of the smart window panel simulation process with PVsyst

The materials used in smart window panels, graphene oxide, polyethyleneimine ethoxylate, and metallic counter, are shown in Table 1.

TABLE 1.
MATERIAL USED FOR SMART WINDOW PANEL

Parameter	Material	Result
Efficiency GlassGO	Graphene oxide (GO)-grafted	11.5%
Efficiency ETL	Polyethylenimine ethoxylate (PEIE) in ETL for PTB7:PC71BM,	8.21%
Efficiency HTL	Graphene oxide (2 nm thick) untuk effective HTL	16.5%
Efficiency PTL	Metallic counter	>11%
Efficiency Cathode	Graphene oxide (2 nm thick) untuk effective HTL	16.5%
	Total	**12.742%**

The simulation was carried out using PVsyst with smart window panel specifications according to Table 2.

TABLE 2.
SPECIFICATION OF A SMART WINDOW PANEL

Parameter	Result
Irradiance	4,8 kWh/m^{2}day
Plant Tilt	0, 30, 45, 60, 90
Azimuth	South and North
Energy used	2200 VA
Inverter capacity	2200 VA/1440W
Controller	600W/25A
Area in plant	6 x 8 = 48m^2
Power Panel	611,616~600 W

A. Electron Transporting Layer

Electron Transporting Layer (ETL) is a component in the manufacture and design of perovskite solar cells that serves to facilitate the transfer of electrons formed in the perovskite screen toward the electrode so that it can produce electrical energy. PTAA is an effective organic material used to manufacture ETL because the level of electron mobility is high, stable, and durable. The material can be placed as a thin layer through techniques such as spin-coating. PTAA effectiveness of 24.5% when used in perovskite solar cells as an ETL layer. The disadvantage of PTAA is that the origin of PTAA made from organic materials has a high degradation rate and installation and repair prices [7].

B. Organic Perovskite

Organic perovskites have a crystal structure similar to mineral perovskites, but organic molecules are at the center of the structure. The most well-known metal ion with organic perovskites is methylammonium lead iodide ($CH_3NH_3PbI_3$). Methylammonium lead iodide has the potential to be used as an organic perovskite because its ability to absorb light is very high and low in price. Before organic perovskite, the materials used were silicon and thin films. The material has a high level of efficiency, but the price and scalability of the material are problems. Meanwhile, organic-inorganic materials have low costs and can be produced easily. The efficiency of methylammonium lead iodide-based solar cells is 25.2% [9].

In order to find out the power and efficiency generated by the smart window panel, a calculation is made (length value = 120 cm, width = 100 cm, and A = 1.2 m^2) with the following formula:

$$\eta_{total} = \frac{\sum(\eta_{GO}+\eta_{ETL}+\eta_{HTL}+\eta_{PTL}+\eta_{CATHODE})}{5} \quad (1)$$

$$\text{Efficiency} = \frac{\text{Power (watt)}}{\text{Length}\times\text{Width (m)}} \times 100 \quad (2)$$

This study's two most relevant algorithms regarding the normalized performance index and performance ratio. Concerning the Normalized Performance Index, this indicator relates to GlobInc's incident energy in the collector field. It is normalized by the Pnom = Array of nominal installed power at STC as given by the PV module manufacturer [kWp]. Therefore, they are independent of array size, geographic situation, and field orientation. This definition expresses the yield energy as [Wh/KWp/day]. In other words, these quantities are numerically equal to the equivalent operating time under constant radiation of 1 kW/m²; that is, they can also be expressed as [Hours/day] when working at one kW/m², or [kWh/m²/day]. The following quantities are stated and defined:

Yr = Yield Reference System (kWh/m²/day).
Ya = Yield array (kWh/KWp/day)
Yf = System Yield (kWh / KWp / day)
Lc = Collection Loss = Yr – Ya
Ls = System Losses = Yes – Yf

The second algorithm used in this comparison and the more relevant one is the performance ratio. Performance Ratio is the energy effectively produced (used) with respect to the energy produced if the system continued to run at its nominal STC efficiency. In a typical Grid connected system, the available Energy is E_Grid. In a stand-alone system, the PV energy is effectively delivered to the user, i.e., E_User – E_Backupsystem. The potential energy generation under STC conditions is the same as Globinc* PnomPV, where PnomPV is the STC installed power (manufacturer nameplate value). This equality is explained by the fact that at STC (1000 W/m², 25°C), each kWh/m² of incident irradiation will generate 1 kWh of electricity. Therefore for a network-connected system and concerning the Normalized Production index, the performance ratio can be defined as follows:

PR= E_Grid/ (GlobInc* PnomPV) (3)

With
GlobInc= Incident Global Irradiation in collector plan
PnomPV = PnomPV is the installed power of STC, which is the equivalent explained by the fact that at STC (1000 W/m², 25°C), each kWh/m² of incident irradiation will generate 1 kWh of electricity.

The data analysis method in this paper is a comparative data analysis method; in this study, the critical test carried out was correlation analysis. Comparative data analysis was used because, in this study, several scenarios were carried out with different variables, such as the PV angle to the window, to determine which scenario and variable produces the best-case scenario. Correlation analysis was conducted to determine whether a correlation between variables would produce different results. In this scenario, the correlation that needs to be analyzed is the angle for the PV.

III. RESULTS AND DISCUSSION

Reducing the cell thickness can reduce the absorption and thus reduce the photocurrent. The photocurrent increases with increasing film thickness up to 700 µm but decreases again at 800 µm thickness as resistance decreases and absorption increases. The energy dispersion for each thickness difference is not much different so we can ignore it [23]. In addition, thickness is input for manufacturers, and they must know what suitable thickness looks like. So the user can't change the thickness anymore. Therefore, this study investigated the effect of the installation angle of the smart window panel only.

In early research, simulations were carried out with 5 angle variations, 0°, 30°, 45°, 60°, and 90° to determine shading, energy production every month, performance ratio, and efficiency. The shading parameters of each of these variables can be seen in Figure 2.

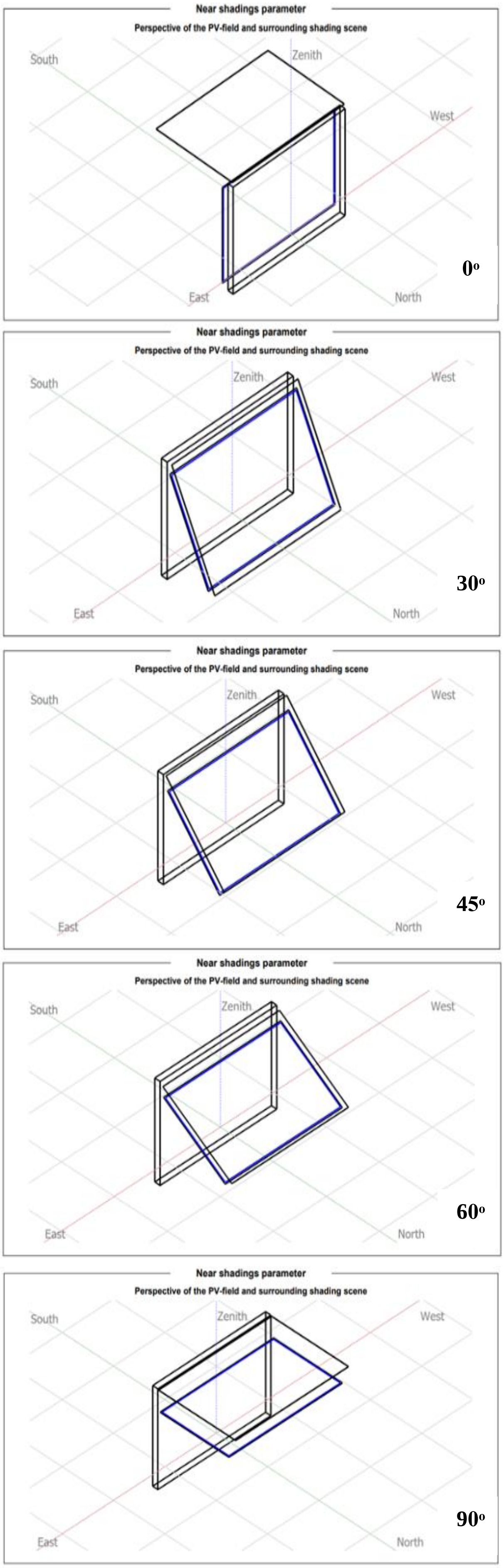

Figure 2. Parameter Shading 0°, 30°, 45°, 60°, and 90°

Then, the energy yield that can be produced every month and the performance ratio of the smart window panel installed with angles of 0°, 30°, 45°, 60°, and 90° are shown in Figure 3.

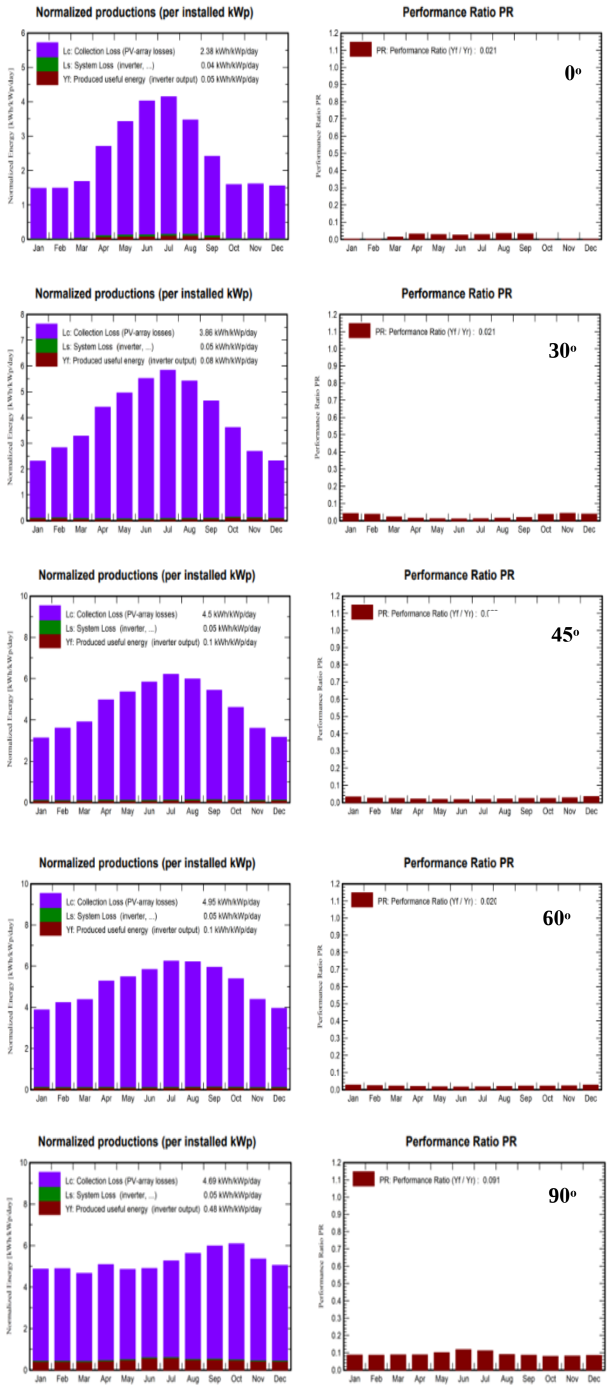

Figure 3. Production each month and performance ratio smart window panel installed in angles 0°,30°,45°,60°, and 90°

In this study, a simulation was carried out with five variables in the form of module placement degrees. The simulation is carried out using one module. Figure 2 shows how the smart window panel system functions if the solar illumination angle is at 0°, 30°, 45°, 60°, and 90°. Then, in Figure 3, there is a picture containing two graphs. The first graph shows the expected production results of the module over one year. Meanwhile, the second graph in the image explains the performance ratio of one module. Then, the critical parameter is E_Solar which is the total energy produced from the module each day according to the month. It can be seen that E_Solar is highest in the middle of the year, which coincides with summer. The next parameter is the E_Grid which describes how much energy the product can add to the grid. Then, EfrGrid is a parameter that shows how much energy will be drawn from other energy sources to meet daily power consumption.

The simulation results show a difference between the production yield and performance ratio on each smart window panel installed at different angles. In Figure 3, the result with the best production in a period is at an angle of 90° because the production will change over time and a year. The production of such modules is influenced by the angle used to manufacture the circuit. Installation at an angle of 90° makes all modules receive a relatively equal amount of sunlight resulting in a stable normalization of energy production of 4.89 Kw/day with usable energy of 0.49 Kwh/day. Smartwindow panels installed with other angles where the production results are unstable.

As for the performance ratio of one module, the performance ratio results are not highbecause the formation of the module is blocked by glass. Transparent materials can be used to increase the performance ratio [15]. Although the overall simulation results are relatively low, at an angle of 90° it produces the best performance ratio of 0.091. Furthermore, for in-depth module production results, the best results are on modules with an installation angle of 90° because the EfrGrid value is 19168Kw/year and the E_Solar is 104.28 kW/year.

Thus, a mounting angle of 90° will produce the best E_Solar and EfrGrid. However, the parameter E_Grid shows that the five simulation results cannot produce enough energy to be included in the grid if only one module is used. Therefore, increasing the number of modules used can be done using an adequate inverter. That way, optimizing the use of smart window panels on a household scale can be done to reduce carbon emissions and realize energy security in Indonesia.

IV. Conclusion

Based on a comparative simulation of a PV module carried out with five types of variables in the form of the degree of placement of PV modules at 0°, 30°, 45°, 60°, and 90°, energy production results and performance ratios are obtained. Based on the simulation results of 5 types of variables, it can be seen the difference in energy production results and performance ratio with the most optimal energy production results over a year located at an angle of 90°. Using an angle of 90 ° degrees, all parts of the module will receive a relatively even amount of sunlight. The module can produce stable energy of 4.89 Kw/day with usable energy of 0.49 Kwh/day.

The simulation results of all variables on one PV module look relatively low, but at an angle of 90° shows the best performance ratio with a simulation result of 0.091. The simulation results show that the 90° angle variable has an EfrGrid of 19.168 Kw/Year and an E_Solar of 104.28 Kw/Year. These results are better when compared to other variables. However, the E_Grid results of all variables do not have optimal results to produce enough electrical energy for the grid. An alternative solution to this problem can be to increase the number of modules used. With an adequate inverter, the number of modules can be increased without reducing the efficiency of the modules.

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