Effects of Direct Window Film Installation on Photovoltaic Solar Panel

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Abstract. Indonesia is very suitable country to use solar energy because Indonesia has a tropical climate and produces daily average energy radiation per unit area and time equivalent to about 4.8 kilo watt/m\textsuperscript{2}, however there are several factors that influence the performance of solar energy, namely PV panel temperature and shadow. Both of these factors are parameters with big influences on PV system behavior due to it greatly affects the system efficiency and output energy. The main effect of increased cell temperature is that on open circuit voltage decreases linearly while cell temperature is increasing. Cell voltage decreases about 2.2 mV per 1°C increase in operating temperature and thus efficiency decreases by about 0.5% for crystalline PV cells. One of the solutions to reduce the effects of excessive heat which results in high temperature in solar PV panels is by installing window film with a distance of 2.5 cm which can produce solar panel output power product with the increase of 23.53% to 24.39% compared to output power product without coating. From the results above, researcher tried to install the window film directly onto the PV solar panel with observation and research methods as well as to analyze the results of the study. The outcome of the study was the temperature was stable at the same conditions while the energy produced was reduced due to direct installation of window film making it as a shadow for PV solar panel

1. Introduction
The development of modern technology nowadays, primary energy needs around the world are expected to increase around 1.5–3 times before 2050 due to increased energy demand in various regions of the world, such as for electricity use for household, social, government and business. It is estimated that the global population will continue to increase by more than one billion people and could reach up to 8.5 billion people in 2030, 9.7 billion in 2050 and around 11.2 billion people by 2100. The world population increases 1.18% each year or nearly 83 million additional people each year. The highest population growth rate is in Africa, with 2.55\%[1]. However, if it is not accompanied by the growth of electricity generator, these needs cannot be fulfilled, whereas if we only expect fossil raw materials to supply electricity with non-renewable energy, burning traditional fossil fuels can cause some environmental problems, such as climate changes, global warming, air pollution and acid rain [2]

National electricity consumption based on the Ministry of Energy and Mineral Resources data, Indonesia's electricity consumption in 2017 reached up to 1,012 Kilowatts per Hour (Kwh)/capita,
making its way to 5.9 percent from the previous year. For this year, the government is targeting public electricity consumption to increase reaching up to 1,129 kwh/capita [3].

The Ministry of Energy and Mineral Resources claims domestic oil reserves remain only until 2030 with the assumption of 800,000 barrels productions per day without any new reserve discovery and Indonesia continues to show a significant decline from year to year, even defeated by neighboring countries; Malaysia and Vietnam [4].

The future sustainability of energy supply depends on the paradigm of switching from non-renewable fossil fuels that produce pollution to renewable sources. Solar energy is an interesting choice and has attracted great attention since the last few decades, especially in recent years due to significant price reductions in photovoltaic (PV) cells. Non-concentrator PV technology has now been developed from the first generation for example monocrystalline silicon, polycrystalline silicon, and GaAs, the second such as amorphous silicon thin films, CIS / CIGS thin films, and CdTe thin films, and third generation for example organic and color sensitive substances [5].

Indonesia is located along the equator, making Indonesia owns solar energy sources very abundantly. Indonesia receives an average daily energy radiation per unit area and time approximately 4.8 kilo watts/m2 [6]. PLTS is an alternative renewable energy that is able to be one solution to be a substitute for fossil energy. In addition, PLTS is one of the clean energy sources that has minimal negative impacts to the environment and solar energy will be one of the energy that can accommodate human needs and is most widely used in many countries including Indonesia. PLTS is very suitable also for use in remote areas that have not been powered by the PT. PLN (Persero). However, there are a number of environmental impacts making PV performance not optimal caused by many factors, natural factors such as clouds, dust and temperature, or artificial factor such as pollution from different factories.

These effects can cause variations in PV electrical output because the spectrum, intensity, local shadowing or reflecting, and distribution of solar radiation variations falls over it [7], panel technology also only has efficiencies ranging from 11-25 percent depending on the constituent semiconductor materials. Single crystal silicon has 24 percent of efficiency, 18 percent of polycrystalline silicon, 11-12 percent of Amorphous Silicon, 25 percent of Gallium Arsenide, 17 percent of Cadmium Telluride, and 18 percent of Indium Diselenide [8].

Temperature and shadow (shading) factors are two of the factors we should be able to overcome. The temperature continues to rise in the solar panel resulting electrical energy produced will decrease [9]. The PV panel temperature is significantly influenced by solar radiation, wind speed, and ambient temperature [5], PV panel temperature and shadow are parameters that have a large influence on PV system behaviour, since it greatly affects the efficiency of the system and output energy. The main effect of an increase in cell temperature is on the voltage of the open circuit which decreases linearly with increasing cell temperature. Cell voltage decreases about 2.2 mV per 1°C increase in operating temperature and thus efficiency decreases by about 0.5% for crystalline PV cells [9], based on the research journal data, the influence of sunlight absorption by glass film on the output power of previous solar cell plates [8], with the installation of window film at 2.5 cm distance above solar panels and produce an increase in solar panel output power of 23.53% reaching up to 24.39% compared to the production of non-coating output power, the highest average output power is 24.39 Watt, that is when the panel is coated with glass film with a 60% darkness [8], however if there is a difference in the distance it does not rule out the possibility that it may cause production of dust between glass film and PV solar panels themselves, while dust is one of the environmental factors that must be considered in optimizing the efficiency of PV solar panels [10], on this basis the researchers installed window film directly into PV solar panels to find out the impact on the amount of voltage, energy and efficiency produced, whether the results will be the same as the previous journal can have an impact as a cooler that can reduce temperature, increase energy and efficiency or will have an impact on the contrary as a shadow that can reduce the amount of voltage, energy and efficiency.
This paper presented the effects of direct window film installation on PV solar panel to find the alternative solution of reducing the temperature on the surface and at the same time to catch most of the exposed irradiance.

2. Methodology and experimental setup

2.1. Methodology

2.1.1. Advantages and disadvantages renewable energy

Some of the advantages of new renewable energy are as follow:

1. Free primary energy (sun). You don't need to pay for solar energy, the quantity is very large in contributing to world electricity demand,
2. Make a large contribution on the technical side because it can stabilize the network and minimize technical losses
3. This renewable energy includes smart, simple and tested

Renewable energy has many advantages but there are also disadvantages including resources, limited potential and major resources. So it is not possible, just to switch from fossil to solar energy, this new renewable energy must be combined with other energy in order to get more optimal results [11]

2.1.2. Effect of temperature

Natural factors that affect the surface temperature of PV modules are exogenous climate parameters such as wind speed, ambient temperature, relative humidity, accumulation of dust and solar radiation, every 1 °C increase in surface temperature of the PV module causes a reduction in efficiency of 0.5% and the cell voltage decreases around 2.2 mV per 1 °C because of the increase in temperature, not all solar energy absorbed by photovoltaic cells is converted into electrical energy. To fulfill the law of conservation of energy, the remaining solar energy is converted to heat, the consequence of this wasted heat causes a reduction in overall conversion efficiency [12].

2.1.3. Shading

The power in the PV system output will be reduced due to partial shadows, soiling, non-uniform irradiation and cell damage. Partial shading is the most significant factor that causes nonconformity, partial shading is caused by snow, shadow of trees or bird droppings covering the surface of the PV module [13].

2.1.4. Solar panel efficiency

Ambient temperature, as well as the temperature of the module, affects a PV module efficiency and this is because the module voltage and current depend on temperature[14].

The formula for calculating efficiency ($\eta$) from the panel can be calculated by the following equation [15]:

$$\eta = \frac{P_{mp}}{(E \times A)}$$  \hspace{1cm} (1)

Where:
E is irradiance or light intensity (w/m2).
A is the surface area of photovoltaic solar panel (m2).
$P_{mp}$ is obtained from maximum voltage calculation ($V_{mp}$) with maximum current ($I_{mp}$) as the following equation:

$$P_{mp} = V_{mp} \times I_{mp}$$  \hspace{1cm} (2)

Fill factor of solar cells is one the parameters of solar cells ability to work. This value is not dimensional and is obtained from the ratio of solar panel ($V_{mp}$ and $I_{mp}$) maximum power in the open circuit divided by the closed circuit voltage and the short circuit current (Voc and Isc), and the result is the greater the value, the greater the quality of the solar panel, vice versa, the smaller the value, the worse the quality, shown in the following equation:
2.1.5. Window film

The raw material used in the manufacture of glass film consists of clear, colored or metal-coated polyester film, a liner coated with a silicon protective glue, and glue to attach the film to the glass surface [16].

The development of glass film has also been many, in accordance with the technology used:

1. 1st Generation, Dye Film
   - Is the earliest and conventional film generation where the manufacturing process uses the dyeing method. This type of glass film is very cheap, considering the manufacturing method is very simple. The basic material is polyester which uses dyes. Because of the low cost and easy manufacture, the glass film refuses heat and easily wears off.

2. 2nd Generation, Evaporation Film
   - Making this glass film is done by evaporation. This type of film has an aluminum base material, making this kind of material is the easily evaporated. This glass film includes metalized films because they contain metal materials. The evaporation method is less effective because the metal composition cannot be controlled so that the placement is not evenly distributed. This glass film also slightly rejects heat and fades easily.

3. 3rd Generation, Sputtering Film
   - Sputtering is a technical term where the manufacturing method is done by spraying shots of atoms made of metal, such as stainless steel, titanium, and bronze. The fired atoms are collected on the polyester surface so that an even metal layer is formed. This glass film can resist heat better than the previous generations. The metal composition is even and does not contain dyes.

4. 3B generation, Infra Red Dye Film
   - Commonly known as Hybrid Films. This glass film absorbs heat. If installed on a vehicle, glass film will not last long, let alone continuously exposed to sunlight.

5. 4th Generation, Multi Layer Sputtering Film
   - This glass film has many layers of selective waves in one layer of polyester. The manufacturing process is called a multi layered dielectric coating process with a sophisticated DC Magnetron machine. The multi-layer sputtering film has the selective power of the waves so that it can transmit visible light as much as possible and reject the heat waves coming from the sun.

   The window film used by researchers are the ones manufactured by Maxpro which is made using an advanced technology that is strong in all types of weather, not easily cracked and not easily bubbly. There are several percentages types of Maxpro window film, including 48/20 percent Maxpro hp, 28/40 percent Maxprohp, 18/60 percent Maxprohp and 5/80 percent Maxprohp, this 18/60 percent Maxprohp window film is able to hold Visible Light Transmission by 18 percent, glare reduction by 76 percent, rejected total solar energy by 46 percent, total reflected solar energy by 7 percent and UV rejection by 99 percent.

2.2. Experimental setup

This prototype design uses Polykristaline 100 wp solar panel, digital watt meter, Maxpro 60 percent window film and 40 watt of dc solder load. This research does not use an inverter in order to find out the pure energy produced by solar panels before and after installation of Maxpro 60 percent window film, as shown in Figure 1.
Figure 1. Prototype design

Table 1. Parameter of PV solar panel Sankelux model type: SPV.1610.

| Parameters                     | Variable | Value   |
|-------------------------------|----------|---------|
| Nominal Maximum Power         | P<sub>max</sub> | 100 W   |
| Optimum Operating Voltage     | V<sub>pm</sub> | 18.74 V |
| Optimum Operating Current     | I<sub>pm</sub> | 6.20 A  |
| Open Circuit Voltage          | V<sub>oc</sub> | 22.04 V |
| Short Circuit Current         | I<sub>sc</sub> | 6.57 V  |
| Maximum System Voltage        |          | 1000 V  |
| Maximum Series Fuse Rating    |          | 10.00 A |

The following work steps procedures must be carried out for research data collection:
1. Preparing and installing in advance the PLTS prototype of the 100 wp polykristaline type that will be examined.
2. Preparing the digital watt meter measuring instrument, infrared digital temperature measuring device, solar power meter and research data collection tables.
3. Preparing the necessary K3 tools.
4. Retrieval of research data before the installation of 60 percent maxpro window film in PV solar panel type polykristaline 100 wp as much as 4 days, starting from August 26, 2018 until August 29, 2018 at 08.00 hours until 14.00 wib, the data is open circuit voltage (V<sub>oc</sub>), open circuit current (I<sub>sc</sub>), load current (I<sub>load</sub>), load voltage (V<sub>load</sub>), maximum voltage (V<sub>m</sub>), energy (watts), temperature (°C) and Irradiance (w/m).
5. Retrieval of research data after installation of 60 percent maxpro window film in PV solar panel type polykristaline 100 wp as much as 4 days, starting from August 30, 2018 until September 2, 2018 at 08.00 WIB until 14.00 WIB, the data is open circuit voltage (V<sub>n</sub>), open circuit current (I<sub>n</sub>), load current (I<sub>load</sub>), load voltage (V<sub>load</sub>), maximum voltage (V<sub>m</sub>), energy (watts), temperature (°C) and Irradiance (w/m).
6 Recording research data results from the first day before the installation of window film until the last day of data collection.
7 Calculating the efficiency and fill factor based on the formula.
8 Conducting analysis and evaluation of the obtained research data results.

3. Results and Discussion
Installation of PV solar panel directions based on the compass angle of 118.0° E with Latitude -2.97° N and Longitude 104.79° E, determining the direction of this installation is only to facilitate or determine the position of the research before and after mounting the maxpro window film directly to the PV solar panel.

Based on data retrieval that has been done as many as 6 days and for 6 hours from 8:00 am to 14:00 pm because to get the ideal time of light intensity, before installing maxpro window film to PV solar panels directly carried out for 3 days and after installation of maxpro window film directly to PV solar panels also carried out 3 days.

The results obtained by researchers from measurements over the past 6 days, researchers evaluated the results of these measurements starting from comparing irradiance with temperature, energy with irradiance, fill factor and efficiency before with after installing maxpro window film directly into PV solar panels.

![Figure 2. Irradiance vs Temperature before installation window film.](image-url)
Based on the results of the comparison of measurements between irradiance and the temperature before and after the installation of window film directly to PV solar panels, can be seen in Figure 2. The highest measured temperature is on 27 August 2018 at 12:00 wib at 46.6 °C with irradiance of 944.9 w/m and the lowest on August 28, 2018 at 08.00 WIB at 31.2 °C with irradiance 80.3 w/m.

The measurement results between irradiance and temperature after installing maxpro window film directly into PV solar panels, we can see in figure 3. The highest temperature measured is located on August 31, 2018 at 11.00 wib at 48.4 °C with irradiance 991.5 w/m and most low on August 30, 2018 at 08.00 a.m. at 32.2 °C with irradiance 77.9 w/m, so the measured temperature before installation of the window film is ranging from 31.2 °C to 46.6 °C with irradiance ranging from 80.3 w/m to 944.9 w/m while after installation of window film the measured temperature ranges from 32.2 °C to 48.4 °C with irradiance ranging from 77.9 w/m to 991.5 w/m, meaning that before and after installation of window film directly to PV solar panels can not affect temperature changes in solar panels and the installation of the film glass also does not function as a cooler.

Figure 3. Irradiance vs Temperature after installation window film.

Figure 4. Power vs Irradiance before installation window film.
Researchers also compared the results of measurements between energy and irradiance before and after the installation of window film directly to PV solar panels, before the installation of window film can be seen in figure 4, the energy measured was highest on August 28, 2018 at 11:00 a.m. by 19.1 watts with irradiance 798.3 w/m and the lowest energy on 28 August 2018 at 14.00 wib at 11.2 watts with irradiance 130 w/m.

The measurement results after the installation of window film directly to PV solar panels can be seen in Figure 5, the energy measured is highest on August 29, 2018 at 08.00 wib at 18.2 watts with irradiance 197.8 w/m and the lowest energy on August 31, 2018 at 14.00 wib of 10.23 watts with irradiance 163.7 w/m.

Based on table 2 and table 3 below, the efficiency results before the highest installation of window film on August 27, 2018 at 14.00 wib amounted to 39.34 percent and the highest fill factor on August 27, 2018 at 08.00 wb was 0.95 while after installation of efficient window film highest on August 29, 2018 at 1:00 p.m. at 32.37 and the highest fill factor on August 30, 2018 at 8:00 p.m. at 0.78, from these results obtained a decrease in efficiency from 39.34 percent to 32.37 percent, there was a decrease of 6.97 percent and a decrease in fill factors from 0.95 to 0.78, there was a decrease of 0.17 or equal to 17.98 percent.

**Figure 5.** Power vs Irradiance after installation window film.

| Time (WIB) | Sunday, August 26, 2018 | Monday, August 27, 2018 | Tuesday, August 28, 2018 |
|------------|-------------------------|-------------------------|--------------------------|
|            | Efficiency (%) | Fill Factor | Efficiency (%) | Fill Factor | Efficiency (%) | Fill Factor |
| 08.00      | 28.46              | 0.72         | 33.53          | 0.57         | 31.43          | 0.95        |
| 09.00      | 24.18              | 0.56         | 37.92          | 0.46         | 25.46          | 0.60        |
| 10.00      | 17.83              | 0.16         | 26.06          | 0.49         | 19.84          | 0.15        |
| 11.00      | 25.95              | 0.58         | 25.42          | 0.72         | 17.32          | 0.16        |
After reviewing the results of the existing analysis, the researchers tried to install the 60 percent maxpro window film in 5 mm glass, comparing the results with those that were not installed on the window, it turned out the film made the irradiance less than the window film. we see in figure 6.

Therefore, installation of 60 percent maxpro window film does not directly affect the temperature drop which can increase the amount of voltage, energy and efficiency produced, but on the contrary makes the energy, voltage and efficiency magnitude less than before the installation of window film directly to PV solar panels, because the amount of irradiance that must be received by PV solar panels directly but is hampered by the installation of the glass film and makes the irradiance reduced can be seen from Figure 6, irradiance from 137.7 w/m to 63.1 w/m or reduced by 50 percent before installation of window film directly to PV solar panels, while irradiance itself is the basic source of PV solar energy.

The effect of installing window film directly makes it a shadow for photovoltaic solar panels so that the resulting voltage, energy and efficiency are not in accordance with the results of a previous journal about the effect of sunlight absorption by window film on the output power of solar cell plates that a distance of 2.5 cm from photovoltaic solar panels and generating energy up to 24.39 percent
before installing window film, perhaps the installation between window film and the spaced PV solar panel gets a cooling from the environmental air factor or the humidity factor that exists or passes through the distance space.

4. Conclusions

The results of the study before and after the installation of 60 percent projection window film directly on photovoltaic solar panels included no decrease in temperature, decreased energy and reduced efficiency resulting from direct installation of window film to PV solar panels making it decrease from before installation of glass the film, the temperature measured both before and after the installation of window film did not decrease, before the installation of window film 31.2°C up to 46.6°C while after the installation of window film 32.2°C up to 48.4°C, there was a decrease of 19.1 watts of energy before installation the installation is measured at 18.2 watts, there is a decrease after the installation of window film directly to PV solar panels of 0.9 watts or 4.71 percent and its efficiency also decreases from 39.34 percent to 32.37 percent, there is a decrease of 6.97 percent and a decrease in fill factor from 0.95 to 0.78, there is pe decrease by 0.17 or 17.98 percent. Irradiance is supposed to be the main source for generating energy from PV solar panels, because the greater the irradiance that goes into PV solar panels the greater the energy produced by the PV solar panels, but with the installation of window film directly to PV solar panels making the irradiance decreases by approximately 50 percent from before the installation of the film glass, this is a factor that makes the PV solar panel's performance is not optimal so that the reduction in the amount of voltage, energy and efficiency. Installation of 60 percent maxpro window film directly to the photovoltaic solar panel also does not function to cool the temperature on the surface of PV solar panels, mounting window film directly to PV solar panels only makes it a shadow and different from the previous journal installation of 2.5 cm film glass lower the temperature and increase the voltage and energy produced.

5. References

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