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Experimental study of slope angle and low E glazing effects on photovoltaic module

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Abstract. The intensity of solar radiation received by the PV Module can be maximized by installing a PV module with a slope angle. Besides, when the intensity of solar radiation increases, the surface temperature of PV also tends to increase, which decrease PV power output. Temperature Surface can also be reduced by the additional glazing with low emissivity. By knowing the appropriate angle of inclination and the glazing addition, it will able to maximize light energy (photon) and minimize heat energy received by PV surface. So the system can obtained maximum output power and minimum surface temperature. The heat transfer can be determined by analyzing the thermal resistance occurring from the sun down to the PV surface and from the PV surface to the surroundings. The test was performed using a commercial PV module with 180 Watt Peak power, where the test results were discussed and presented. The results shown that PV module facing North with slope angle 30^o has the highest output power. The heat release was large enough compared to the other slope angle variation. Besides, the addition of glazing system decreases the output power due to its medium transmittance about 70% and the temperature of PV module also decrease due to low emissivity about 0.26.

1. Introduction

Solar panel or photovoltaic module (PV) is the example of solar energy application. Photovoltaic has been widely used and developed as one of the power plant in many countries as a solution to suppress the use of fossil resources. But the output power of PV module is not constant, depend on the intensity of solar radiation. The intensity of solar radiation that reach the PV module is certainly not constant.

This is because of the pseudo motion of the sun (daily and monthly), and weather conditions (sunny, cloudy and rainy), as well as the geographic location of PV itself. So the positioning of the PV surface greatly affect the amount of radiation received by the solar cells. The intensity of solar radiation received on the PV Module can be maximized by installing a PV module with the correct slope angle (β) and azimuth angle (γ) [1].

Kandil [2] concluded that the increasing solar radiation received on PV modules, increases almost all parameters affecting the performance of module PV, particularly current, maximum power and module efficiency. So it is very important to conduct further research on PV module performance at different angle and orientation. Gopinathan [3] conducted research on several surface orientations with three inclinations for six different azimuth angles. The research found different angle and optimum orientation for summer, cold and yearly. Gunerhan [4] reported the optimal orientation for solar

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collectors in Izmir is south facing. To improve the efficiency of solar collectors, it was recommended, if possible, that solar collectors should be positioned at the average angle of inclination and the slope was adjusted once a month. Ekadewi [5] concluded that for the installation of solar collectors in Surabaya, the maximum inclination angle for March12th– September 30th was varied between the angle 0^{o} - 40^{o} (north facing) and for October1st – March 11th installed between 0^{o} - 30^{o} angles (south facing).

Wasted energy such as heat causes an increase in PV module temperature and there is a correlation between efficiency and temperature [6]. So it is necessary to reduce the PV module temperature. Tripanagnostopoulos [7] concluded that cooling PV modules can improve the electrical efficiency of PV modules. The addition of glass is to raise the thermal output, diffuse reflector can increase the electrical and thermal output. In solar cells there are also reflection losses that occurring above the cell surface which can be reduced by the addition of antireflective coating glass [8].

The solar radiation exposed to PV modules can increase the module temperature because the excess photon absorbed by the PV module is converted to heat. This phenomenon can reduce the performance of PV module. Many research analyzed heat transfer on PV/T module or solar collector. Thus, this experiment analyze the heat transfer happened between PV module and surrounding air, Beside knowing the performance of PV module with slope angle variation. Special glass with low emissivity added to the PV module, expecting that we can know its effect to the heat transfer and the performance. This experiment aims to determine the effect of slope angle and the addition of glass to heat transfer in PV module.

2. Experimental method

PV module used for this research was monocrystalline type with maximum power 180 Watt. This research was take place in Electronic Engineering Polytechnic Institute of Surabaya on July 3rd until July 5th 2017and July 21st2017 (test with glazing addition)from 09.00 to 15.00 WIB. The PV module was directed towards the north because the position of Surabaya is south of the equator line. Then the module was tilted according to the angle variation that is 0^{o}, 10^{o}, 20^{o}, 30^{o}, and 40^{o}. The test system is shown in figure 1.

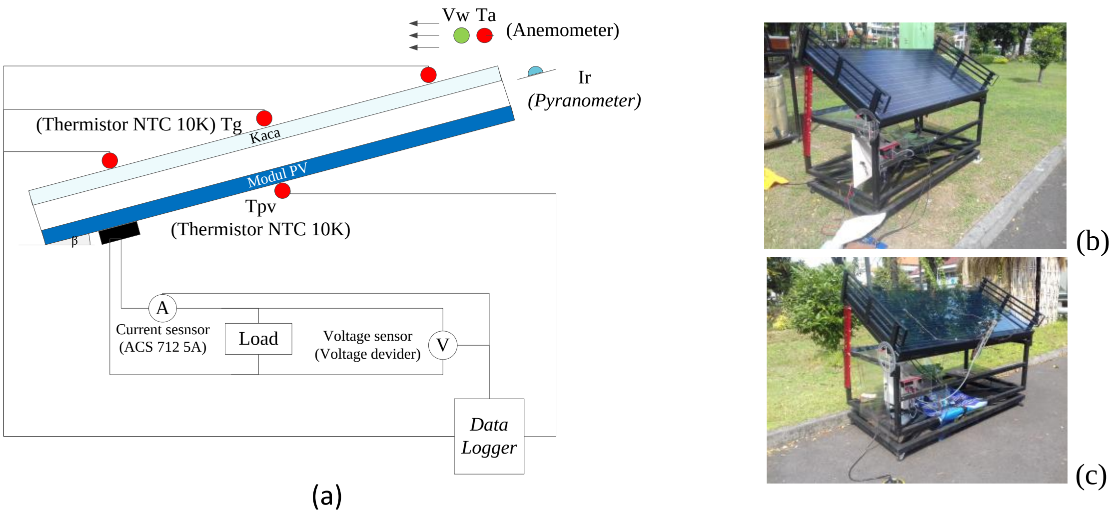

Figure 1.(a) Experimental models, PV system (b) without glass and (c) with glass.

Pyranometer was used to measure solar radiation received by the PV surface. The measurement of output current using ACS712 5A sensor and output voltage was measured by using an integrated voltage divider with data logger to record all data from the sensors.

To calculate the heat release, several parameters required, such as PV and glass temperature, wind velocity, and ambient temperature. The module temperature was measured using a thermistor NTC 10k mounted below the PV module that was also integrated with the data logger and it was recorded by data logger every three seconds. Wind velocity and ambient temperature were measured using an anemometer. The data was recorded by data logger every three seconds. The data from pyranometer, wind velocity and ambient temperature was written manually every one hour.

Calculation of heat release occurred in the PV module was done in steady state operation and analyzed in one dimension at y axis. There is a multistage heat transfer process on the cover glass, including natural convection heat transfer and radiation to the surrounding air. Due to perfect heat transfer conduction happened in the PV module and the glass cover, the conduction was not taken into account. This the following equations can be used to calculate the heat transfer that occurs in the PV module [8].

$$h_{c,pv-a} = h_{c,g-a} = h_w = 8.55 + 2.56V_w \tag{1}$$

$$h_{r,pv-a} = h_{r,g-a} = \varepsilon_{pv}\sigma\,(T_{pv} + T_a)({T_{pv}}^2 + {T_a}^2) \tag{2}$$

$$h_{r,pv-g} = \frac{\sigma\,(T_{p-pv}+T_g)({T_{p-pv}}^2+{T_g}^2)}{1/\varepsilon_{pv}+1/\varepsilon_g-1} \tag{3}$$

Where $h_{c,pv-a}$ [9]and $h_{r,pv-a}$ are convection and radiation heat transfer coefficients between PV module to environment, $h_{c,g-a}$ and $h_{r,g-a}$ are convection and radiation heat transfer coefficients between glass cover to environment, $h_{c,pv-g}$ and $h_{r,pv-g}$ are convection and radiation between PV module and glass cover. v is environmental wind velocity; T_{pv}, T_a, T_g are temperatures of PV module, ambient air, and glass cover; ε_{pv} and ε_g are the emissivity of PV module and glass cover;$\sigma$is the Stefan-boltzmann constant.

$$h_{c,pv-g} = \frac{Nu\ .\ k}{L} \tag{4}$$

In the enclosed air gap or parallel flat plates for natural convection at various slopes from 0^o to 75^o ,Nusselt number from duffie [8] can be applied :

$$Ra = \frac{g\,\beta'\Delta T\,L^3}{v\alpha} \tag{5}$$

Ra = *Rayleigh number*; g = gravitational constant (m/s^2); β'= volumetric expansion coefficient (for an ideal gas), $\beta' = 1/T$), (1/K); ΔT = temperature difference between plate (K); v = kinematic viscousity (m^2/s); α = thermal diffusivity (m^2/s)

$$Nu = 1 + 1.44\,1 - \left[\frac{1708(\sin 1.8\beta)^{1.6}}{Ra\cos\beta}\right]\left[1 - \frac{1708}{Ra\cos\beta}\right]^+ + \left[\left(\frac{Ra\cos\beta}{5830}\right)^{1/3} - 1\right]^+ \tag{6}$$

Then, the overall heat transfer coefficient of PV module with (U_{T0}) and without glass cover (U_{Tg}) can be expressed as :

$$U_{T0} = \left(\frac{1}{h_w+h_{r,pv-a}}\right)^{-1} + \left(\frac{1}{h_w+h_{r,pv-a}}\right)^{-1} \tag{7}$$

$$U_{Tg} = \left(\frac{1}{h_w+h_{r,g-a}} + \frac{1}{h_{c,pv-g}+h_{r,pv-g}}^{-1}\right) + \left(\frac{1}{h_w+h_{r,pv-a}}\right)^{-1} \tag{8}$$

So, the heat transfer (Q) in PV module :

$$Q = Ac\ U_T\left(T_{pv} - T_a\right) \tag{9}$$

3. Result and discussion

For the first experiment, PV module without glass at various slopes, the result is shown in figure 2 and figure 3. Figure 2 shows the poweroutput PV module at various slopes and figure 3 showsthe electrical efficiencyof PV module at various slope. The highest power output was achieved at 30^o slope angle with total power 700 W and the highest efficiency was 9.20 % at the same slope. The lowest power output was at 0^o slope angle with total power 628.5 W, but the efficiency of 0^o was not the lowest. The lowest efficiency was about 8.69% at 40^o slope. Both figure show that by increasing the slope angle facing to north, the power output and electrical efficiency increase just until 30^o slope. But then, if the slope angle is bigger than 30^o slope, the power ouput and the efficiency decreasing gradually. At slope angle 40^o, the power output decrease into 640.36 W. The decreasing caused by the position of the PV module that nearly vertical so the PV module could not get the maximal irradiance.

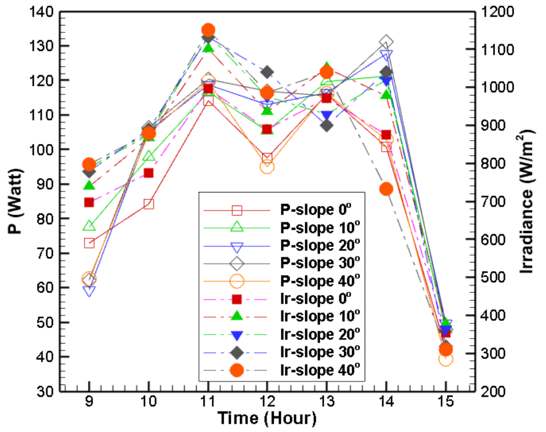

Figure 2. Power output at various slope angle.

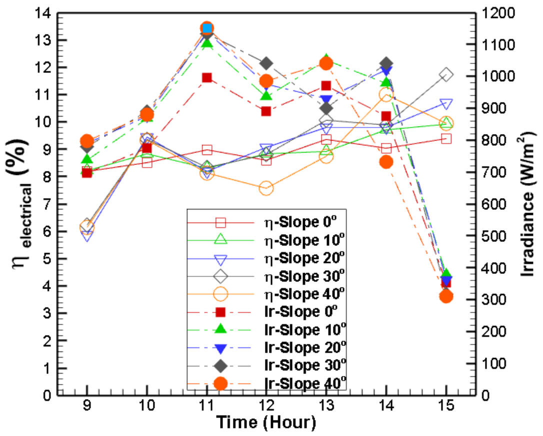

Figure 3. Electrical efficiency at various slope angle.

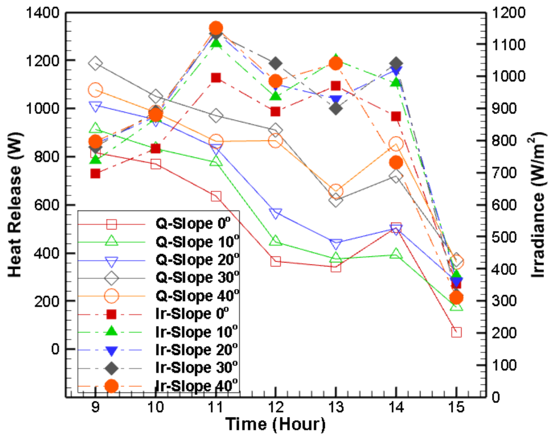

Figure 4. Heat release at various slope angle.

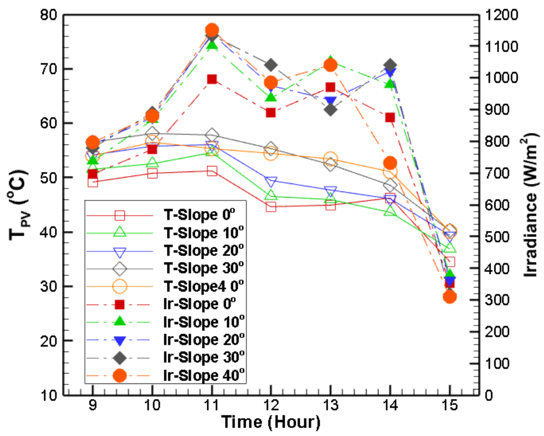

Figure 5. Temperature PV moduleat various slope angle.

In figure 4, The heat release also shows thatat slope angle 30° has the highest heat release value, about 832.91 W. An increase in irradiation that also carries heat energy leads to an increase in PV module temperature as shown in figure 5. Heat transfer is influenced by wind speed and ambient temperature. Higher PV module temperatures cause larger temperature differences with ambient temperatures. The temperature difference is proportional to the value of heat transfer, so the value of heat transfer is also greater. Increasing the temperature gives an impact by reducing the voltage, followed by a decrease in output power. In PV modules, temperature increases can lead to some failure and decrease in function, as temperature increases increase the pressure associated with thermal expansion and also increase the functional degradation value by a factor of about 2 for every 10°C temperature rise [10].

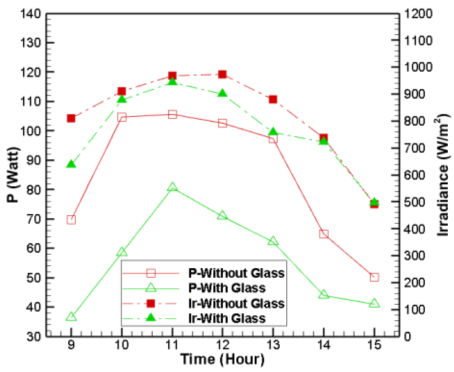

Figure 6. Output power on PV module with and without glass.

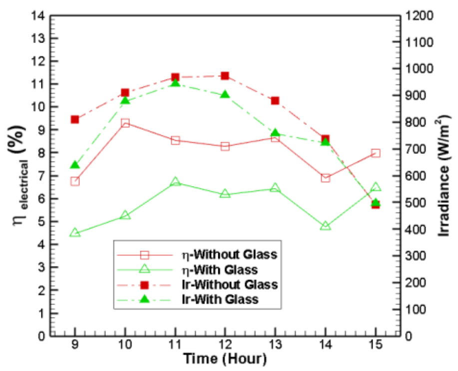

Figure 7. Electrical efficiency on PV module with and without glass.

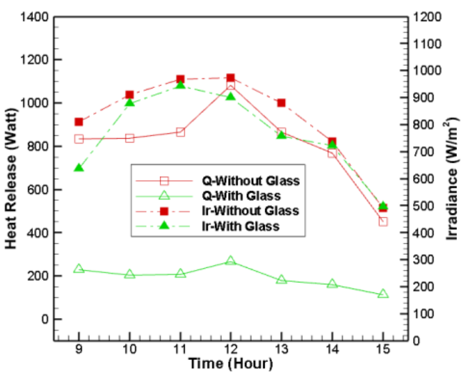

Figure 8. Heat Release on PV module with and without glass

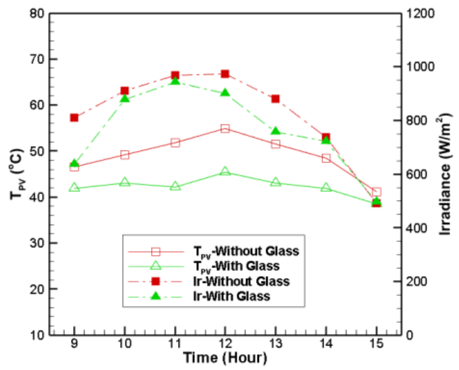

Figure 9. Module PV Temperature with and without glass.

To improve the performance of PV module, the experiment with glazing system with 5 mm gap performed on 30° slope angle which has the best performance. The result shown in figure 6 and figure 7. In figure 6 shows the glazing effect on power output and figure 7 shows the glazing effect on electrical efficiency. Both figure show that PV module with glazing decrease the power output and electrical efficiency. The power output was decreasing from 595 W to 393.4 W and the electrical efficiency from 8.1% to 5.74%.

Output Power decreasing that happened in the PV module with glazing system caused by the glass characteristic which has transmisivity about 70%. So the photon that reach PV surface could not be maximized. But, PV module needs higher light intensity to produce maximum output power, although temperature is also a significant factor in PV module performance.

But the different result on PV temperature. It can be seen in figure 9 that the PV module with glass cover decrease the module temperature up to 12°C. The average of Tpv are 49.1°C without glass cover and 42.27 °C with glass cover. This is caused by the radiation heat transfer that is affected by the emissivity value of an object. Characteristics of dark-colored PV modules that have a 0.8 emissivity cause the surface of the PV module to have a large heat-absorbing ability.

Reduced surface temperature of PV modules causes the heat transfer also to decrease. It can be seen in figure 8, The value of heat treatment without using glass is much higher than the PV module given the addition of glass. Without the addition of glass, the average heat release value is 595 W, whereas with the addition of glass the average value of heat release to 194 W. In glass PV module has a low heat release value due to the characteristics of glass that has a low emissivity of 0.26. So the ability of the glass to absorb heat is lower and make the temperature of the cover glass does not increase significantly. So the module heat transfer is also low and causes low PV module temperature.Although temperature also affects the performance of PV modules but still has to be considered the characteristics of glass that have high transmissivity and low emissivity. Because both light and temperature factors are important to improve the performance of PV modules.

Based on the above discussion can be seen that the addition of glass can reduce the temperature. So the heat transfer to the surrounding air is also lower. In addition, the addition of cover glass also lowers the output power and efficiency. This is in accordance with Wu's research [11] which states that the efficiency of PV-TE without glass cover is always greater than that using cover glass. However, the glass closure system can compete or be superior to that without glass if at the condition of a figure of merit Z, concentration ratio C and high glass transmissivity.

4. Conclusions

The results showed that in the PV module facing North with slope angle 30° has the highest output power and large heat release compared to the other slope angle. In addition, the addition of glazing decrease the output power due to medium transmittance 70% and the temperature of PV module decrease due to low emissivity 0.26

5. Acknowledgements

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6. References

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