



## PERFORMANCE ANALYSIS OF CRYSTALLINE (POLY-SI) AND THIN FILM (A-SI/ $\mu$ C-SI) PHOTOVOLTAIC SYSTEMS

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### ABSTRACT

Output performance of crystalline (poly-Si) and thin film (a-Si/ $\mu$ c-Si) photovoltaic (PV) array has been evaluated in the area of PUSPIPTEK-Serpong for a period of seven months. The output power of both types of PV array at STC conditions is 1.0 kWp and 0.88 kWp, respectively. Each type of PV array is equipped with 2,5 kW grid-type inverter. The aim of this research is to determine the amount of energy produced by both types of solar cells at outdoor conditions. The performance ratio ( $P_R$ ) and the module yield ( $Y_m$ ) have been used to examine the performances of both PV modules. The electrical outputs of the PV array such as, current, voltage, maximum power, and the environmental parameters such as light intensity, PV cell's temperature, ambient temperature, and wind speed were measured automatically by a data logger for every 5 minutes. For the data calculations, the output power of both PV array were normalized to their output power at the standard test conditions (STC). The electrical parameters output (I-V curve) of both PV modules measured by the Sun Simulator were used as based for the data calculation. Results from the analysis of seven months data accumulated at outdoor conditions shown that the performance ratio ( $P_R$ ) for a-Si/ $\mu$ c-Si PV module was about 10% greater than the Poly-Si module. The average value of module yield  $Y_m$  for Poly-Si was about 32% for Poly-Si, and 36% for a-Si/ $\mu$ c-Si, respectively. The difference of  $Y_m$  of both PV modules was approximately 3.1% for a-Si/ $\mu$ c-Si. This result indicated that the PV array of a-Si/ $\mu$ c-Si produced energy of about 3.1% greater than poly-Si on the conditions in Serpong.

**Keywords:** photovoltaic, performance ratio, energy yield, poly-Si, a-Si/ $\mu$ c-Si, STC.

### 1. INTRODUCTION

The application of PV systems in Indonesia, especially in rural areas is increased rapidly. In general, the implementation of PV systems in remote areas is a centralized type or namely off-grid system, and only a small portion of which is on-grid system. The aim of off-grid PV system application is to meet the needs of electrical energy in remote areas that cannot be reached by the state electricity. The application of on-grid system is to increase the power capacity of the local area due to the rising electricity needs of society. In the future, the role of renewable energy, especially PV cells, is very important due to the government policy which does not allow for the procurement of new diesel to meet the shortage of electricity in the state electricity. Up to now, the total capacity of PV systems installed in Indonesia is still relatively small at around 40 MWp [1].

The application of PV systems in Indonesia have not gained significant support from the private sector. Almost all of the installed PV systems were built from government funding. On the other hand, solar cell industry in Indonesia is not growing; only the industrial assembly of PV modules which PV cells used is imported. At present, there are eight manufacturers of PV modules in Indonesia with maximum production capacity of about 150 MWp/ year. They are joined in association of solar modules manufacturers of Indonesia (APAMSI).

Actually, the feasibility study of national PV cell industry in Indonesia has been compiled by the Agency for the Assessment and Application of Technology (BPPT) in 2011. At the same time, the results of the feasibility study has been disseminated to the relevant government

institutions and the private sector. The government through the ministry of state-owned enterprises responded quickly to the results of the feasibility study by forming a consortium with members PT. LEN industry and Pertamina to follow up. The consortium immediately conducted an international bidding to build the silicon crystalline photovoltaic cell industry with a production capacity of 60 MWp/year. Nevertheless, the government cannot provide assurance that the results of the PV cell production to be used by the related companies in the country, then the consortium finally resigned to cancel build the industry. Eventually, up to now there is no PV cell industry in Indonesia, although the chances of the application of PV cells in the future are quite large, especially for on-grid systems.

Other issues related to the solar cell industry is a type of PV cells to be built, crystalline or thin film. The results of the feasibility study stated that the first option is a type of crystalline PV cells, while the thin film as a second choice. However, there are other institutions hope that the type of thin film PV cells are preferred. Results of the analysis will not mean that the solar cell of thin film type becomes the priority to be built in Indonesia, but there are many other parameters that need to be analyzed, such as the efficiency of PV cell, PV cells' life time, the weight of PV module, the price/Wp, and the type of application.

In order to provide input to parties concerned, regarding the performance of both type of PV cells, the results of the performance analysis of silicon crystalline (poly-Si) and thin film (a-Si/ $\mu$ c-Si) PV modules that were conducted at outdoor conditions was reported.



Two parameters that were used to describe the performance of both types of PV cell were the performance ratio (PR) and the energy yield (Ym) based on the 7 months' measurement results. By calculating the amount of energy produced by both types of PV cell at specified intervals, it was also obtained information on how large the real output energy resulted from both PV cells compared to energy generated at their standard test conditions (STC). The performance evaluation of both types of PV cell were based on the measurement results of the electrical output characteristics using a sun simulator. This was caused the electrical parameters shown on the nameplate attached at the rear of both PV modules did not show the actual values, as were shown in the following measurement results.

## 2. EXPERIMENTAL PROCEDURE

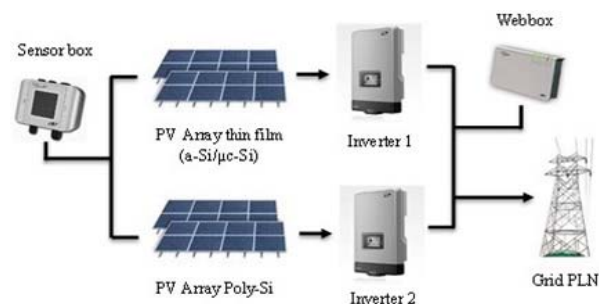
Measurement of the performance of both types of PV cell was carried out on the roof of the building Center of Energy Conversion and Conservation Technology, Agency for the Assessment and Application of Technology (BPPT), PUSPIPTEK, Serpong, for 7 months (starting from February to August 2015). Two types of PV modules used in this study were silicon crystalline (poly-Si) and thin film (a-Si/ $\mu$ c-Si). The technical specifications of both PV modules based on their name plate are shown in Table 1. The total unit of poly-Si modules were 20 units, with power output of each module was 50 Wp. While for the a-Si/ $\mu$ c-Si module was 8 units, with power output of each module was 110 Wp. The 20 units of poly-Si modules were connected in series to get 1 unit PV array with total power output of 1000 Wp, the electric current of 3.35 ampere, and output voltage of 250 volt. For a-Si/ $\mu$ c-Si, every 4 unit modules were connected in series to get 1 unit PV array, than for 8 units of PV module generated 2 units PV array with total power output of 880 Wp, electric current of 2.9 A and voltage of 506 V.

**Table 1.** Specification of Poly-Si and a-Si/ $\mu$ c-Si module at the STC (25 °C, 1.0 kW/m<sup>2</sup>, AM1.5) based on nameplate attached at the rear of their PV module.

	Module Pmp (W)	Voc (V)	Isc (A)	Vmp (V)	Imp (A)	Area (m <sup>2</sup> )
Poly-Si	50 ± 3%	21.50	3.35	17.50	3.05	0.44
a-Si/ $\mu$ c-Si	110	126.5	1.45	93.6	1.17	1.43

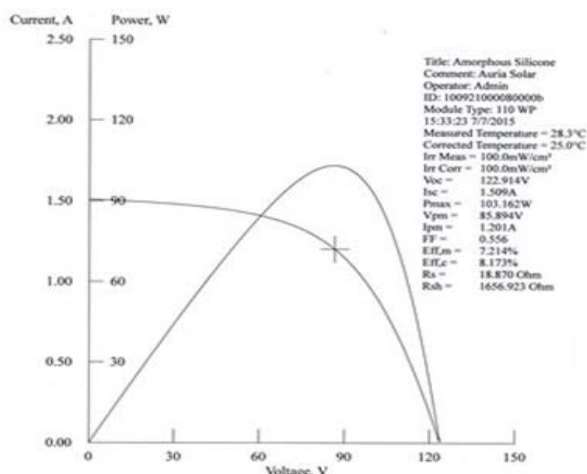
Each PV array was connected to a 2.5 kW PV-grid type inverter. Both inverters were specifically used for crystalline and thin film PV modules. All the electrical energy generated by both PV arrays was connected directly into the grid by inverter. The inverter also equipped with a data logger which could store data of the PV array output parameters, such as dc and ac of both of current and voltage, output power, frequency, etc. PV system was also equipped with piranometer to measure the intensity of incident light on the surface of PV modules, and sensors to measure the back surface of PV cell

temperature, ambient temperature, and wind speed. Additionally, the PV system also equipped with webbox data device that enabled monitoring the data over the internet in real time. All output parameters of PV system were measured every 5 minutes. PV system configuration described above, was shown in Figure-1. PV arrays are cleaned every two weeks to prevent contamination of the PV module surface from dust.



**Figure-1.** Configuration of PV system at the Center of energy conversion and conservation technology, BPPT, Serpong.

To obtain more accurate evaluation results, the characteristic of current and voltage (I-V curve) of both PV modules were measured in indoor using Sun-Simulator at the standard test conditions (STC). The measurement results were shown in Figure-2 and Figure-3. It was clear from both figures that the I-V curve of a-Si/ $\mu$ c-Si module more ramps compared to Poly-Si module that characterized by a fill factor 0.55 and 0.78, respectively. Smaller fill factor values demonstrated that the conversion efficiency ( $\eta$ ) of PV module were relatively lower as indicated by a-Si/ $\mu$ c-Si module with value of  $\eta = 7.2\%$ , while  $\eta = 14.5\%$  for poly-Si module. Furthermore, the other output parameters in Figure-2 and Figure-3 were summarized in Table-2.



**Figure-2.** I-V and P-V curve of a-Si/ $\mu$ c-Si PV module.



From Table-2, it can be clearly observed the difference in measurement results when compared to the data in Table-1, especially in the output power of both PV modules. Decrease in output power of a-Si/ $\mu$ c-Si module from 110 Wp (based on name plate) to 103 Wp was most likely caused by aging as the PV module was stored about 2 years in storehouse before used. These PV modules were products of the Auria Company from Taiwan. Meanwhile Poly-Si modules were new products from the PT. LEN Industry, Bandung. A considerable difference in the value of output power as written on the name plate (50 Wp) with the measurement results using the sun-simulator (61 Wp) is only shown the strategy of doing business.

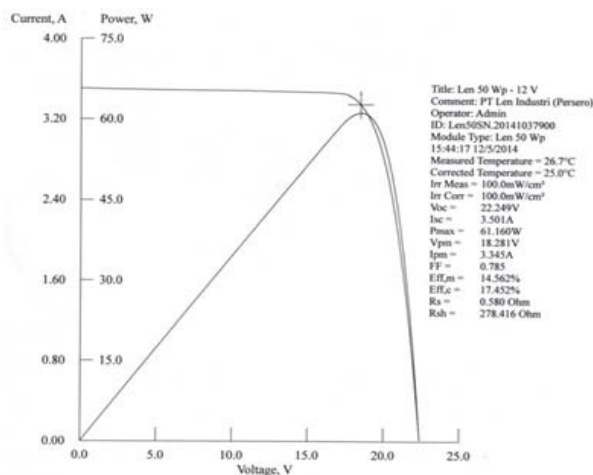


Figure-3. I-V and P-V curve of Poly-Si PV module.

Table 2. The summarized output parameters of Poly-Si and a-Si/ $\mu$ c-Si module from Figure-1 and Figure-2.

	Module Pmp (W)	V <sub>oc</sub> (V)	I <sub>sc</sub> (A)	V <sub>mp</sub> (V)	I <sub>mp</sub> (A)	Eff (%)	Area (m²)
Poly-Si	61.16	22.25	3.5	18.28	3.34	14.5	0.44
a-Si/ $\mu$ c-Si	103.16	122.9	1.51	85.89	1.2	7.2	1.43

The parameters used to analyze the performance of both PV arrays were the performance ratio ( $P_R$ ) and energy yield ( $Y_m$ ) which were defined as:

$$P_R = \frac{Y_m}{Y_r}$$

$$\text{with } Y_m = \frac{E}{P_{STC}} \text{ and } Y_r = \frac{H}{G}$$

where  $Y_m$  is the energy yield, and  $Y_r$  is the reference yield, with  $E$  is output energy of PV modules,  $P_{STC}$  is the nominal maximum power of PV modules,  $H$  is the incident radiation on the plane of PV module,  $G$  is the reference irradiation (1 kW/m²).

The performance ratio (PR) was a measure of the quality of a PV plant that was independent of location and it therefore often described as a quality factor. The

performance ratio gave information about how energy efficient and reliable PV plant which was stated as percent and described the relationship between the actual and theoretical energy outputs of the PV plant.

From the measurement data, it could be calculated the percentage of the real energy produced by both of PV modules to their value at the standard conditions. From the results of these calculations, it could also be calculated how much the real electrical energy was generated per-watt peak at outdoor conditions of each PV cell type.

## RESULTS AND DISCUSSIONS

### a) Performance ratio (PR)

Figure-4 and Figure-5 show the characteristic of PR of both poly-Si and a-Si/ $\mu$ c-Si module to the time (in month) on April 2015 at outdoor conditions based on the calculation result using the data attached on their PV module's name plate and from the measurement result using sun-simulator at STC, respectively.

From Figure-4, it can be clearly observed that the value of PR of the Poly-Si module is average above 1. This result was not possible because the maximum value of PR for crystalline silicone cell was 1 when incident radiation was 1 kW/m² and PV cell temperature was 25°C at outdoor conditions. In fact of the measurement results was never happened that the incident radiation was more than 1 kW/m² and the cell temperature was always greater than 25°C. The value of PR could be less than 1, depended on the condition of the radiation intensity in outdoor and the PV cell temperature that exactly higher than the standard conditions (25°C). The output power of this poly-Si cells decreased by increasing cell temperature [1]. Meanwhile, for the thin film PV cell of a-Si/ $\mu$ c-Si had a PR value above 1 for a certain time period. These results had strengthened previous research [2,3] which shown a material improvement of the physical characteristics for the amorphous silicon type solar cell because of the heating factor in the long term interval (annealing process), thus it produced electrical energy better than the previous condition.

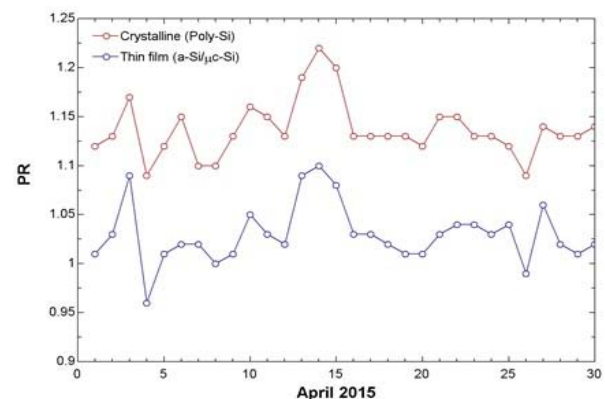
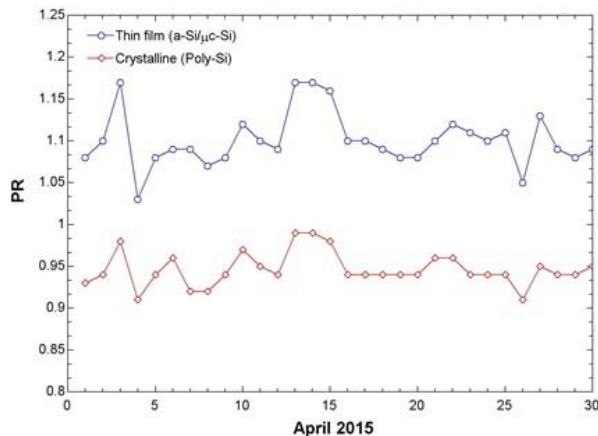


Figure-4. Values of PR for both PV modules on April based on the calculation result using electrical characteristics noted on their PV module's name plate.



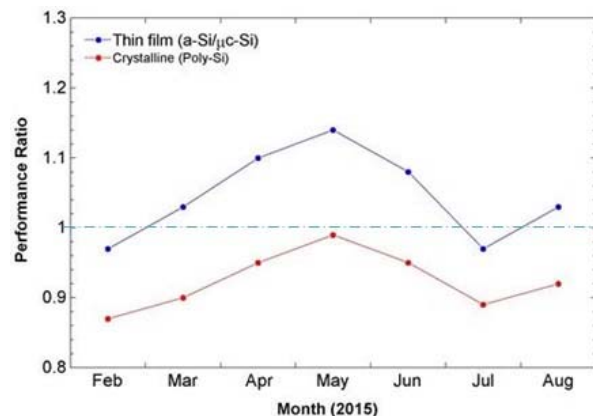
Figure-5 shows the results of the PR value from calculations based on the data using sun-simulator. It was clearly shown that the value of PR for Poly-Si cell varied below 1, otherwise the value of PR for a-Si/ $\mu$ c-Si cell varied above 1.



**Figure-5.** Values of PR for both PV modules on April based on the calculation result using the data from sun-simulator measurement.

These results were plausible since they were based on real data measurement with the sun -simulator. The PR value varied following the insolation that changed every day.

Figure-6 shows the result of monthly calculation obtained from the sum of the average daily value of both types of PV modules from February to August. Monthly value of PR changed according to the average insolation in month period measurement. From the calculation, the average value of PR for a-Si/ $\mu$ c-Si PV modules was greater 10% than the Poly-Si modules.

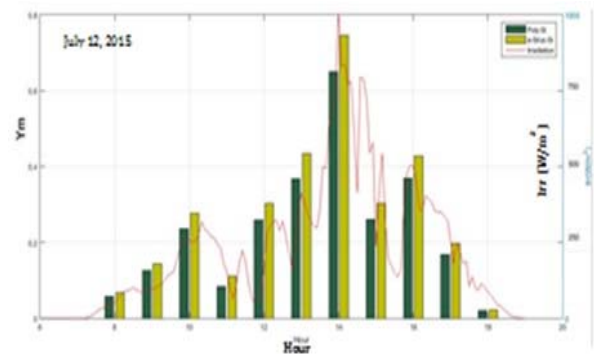


**Figure-6.** Values of PR for both PV modules based on the calculation result from the data using Sun Simulator.

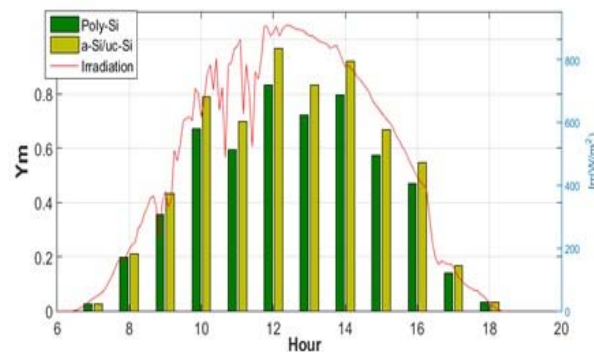
#### b) Energy yield (Ym)

Energy yield was the percentage of real electrical energy generated by the solar cells in outdoor compared to energy production at the standard conditions in indoor.

Figure-7 and 8 show Ym value for both types of PV modules in cloudy and sunny weather conditions. Figure-7 shows daily Ym value in cloudy weather conditions with insolation 2.96 kWh/m<sup>2</sup>/day. Insolation was the amount of sunlight energy that came to the surface of PV modules per unit area per day. The graph shows that Ym value for a-Si/ $\mu$ c-Si PV cell is always higher than poly-Si PV cell. The average Ym value on a cloudy day of the poly-Si PV cell is 21.6%, while for the a-Si/ $\mu$ c-Si is 25.2%. Thus, the difference Ym value is about 3.2 % better for a-Si/ $\mu$ c-Si PV cell than Poly-Si PV cell.



**Figure-7.** PV module yield (Ym) of both Poly-Si and a-Si module at cloudy.



**Figure-8.** PV module yield (Ym) of both Poly-Si and a-Si module at sunny weather.

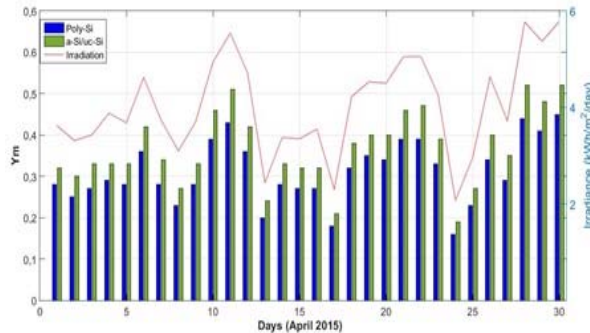
Figure-8 shows the Ym value for both types of PV modules in sunny conditions with insolation value of 5.78 kWh/m<sup>2</sup>/day. In this sunny weather, the value of Ym for Poly-Si PV cell was 45.0%, while for the a-Si/ $\mu$ c-Si PV cell amounted to 52.4%. The value of Ym for both PV modules was higher in sunny weather or high insolation values. This result also increased the difference of Ym value between the both PV modules, which was about 7.4%. The value of Ym depended heavily on the value of light intensity which was used as initial reference.

In this study, the incident intensity ranging from the minimum value was recorded in pyranometer in the morning and evening up to a maximum value during the day. For example, if the intensity of the incident light was restricted from the values > 0.1 kW/m<sup>2</sup>, then the value of



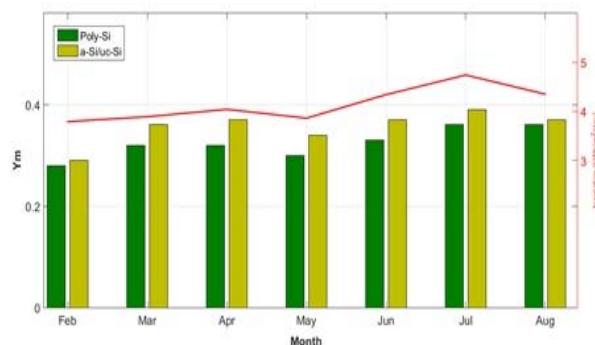


Ym of Poly-Si PV module was 51.8%, while for the a-Si/ $\mu$ -Si PV module amounted to 60.5%. Differences of the value of Ym between both types of PV modules were 8.7%. This value was higher than that described above.



**Figure-9.** Daily PV module yield (Ym) of both PV module and insolation on April 2015.

Figure-9 describes that the fluctuating value of Ym strongly depends on the value of insolation on the day. The difference in values of Ym between both types of PV modules were also evident that were greater on a sunny day with higher insolation values. Figure-9 also shows that the energy produced was only about 19% to 45% for the Poly-Si PV modules, while for a-Si/ $\mu$ -Si module was approximately 21% to 52%, compared to the energy produced in optimal conditions (STC). The average value of Ym in April for Poly-Si PV module was 32%, while for the a-Si/ $\mu$ -Si was 37%. Hence, the difference in the average value of Ym was about 5%. This information was important to understand by any PV system users that felt harmed by the electric energy which was generated by the installed PV system, since the energy output of PV systems was very dependent on the intensity of sunlight that came to the surface of the PV module.



**Figure-10.** Energy yield (Ym) of both Poly-Si and a-Si/ $\mu$ -Si module on the period from February to August.

Figure-10 shows the variation of the monthly value of Ym of both types of PV modules. The average value of Ym for seven months of the measurement was 32% for Poly-Si modules, and 36% for a-Si/ $\mu$ -Si modules. Thus, there was difference in value of Ym

between both types of PV module, which was approximately 3.1%. This maximum difference in value of Ym occurred on April and minimum value on February which were corresponded to the insolation conditions.

## CONCLUSIONS

The results of research carried out during the period of February to August 2015 shown that the values of PR and Ym of thin film (a-Si/ $\mu$ -Si) PV cell were better than crystalline (Poly-Si) based on the I-V curve measurement using sun-simulator. The value of Ym for the type of thin film module was greater 3.1% than the poly-Si module. This result did not mean that automatically thin film PV cell types to be the first option to developed in Indonesia. There were many parameters that required to be considered, such as the cell conversion efficiency, the weight of the module, the availability of raw materials in Indonesia, PV module life time, etc. In the future, it is expected to have more in-depth studies on these parameters before determining PV cell type as the first priority to be developed in Indonesia.

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