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GAUSSIAN APPROACH TO COMPARE CRYSTALLINE SOLAR PANEL PERFORMANCE

Eko Adhi Setiawan[1,2*], Kurniawan[2], Aiman Setiawan[1,2]

[1] *Tropical Renewable Energy Center (TREC), Faculty of Engineering, Universitas Indonesia, Kampus Baru UI Depok, Depok 16424, Indonesia*
[2] *Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Kampus Baru UI Depok, Depok 16424, Indonesia*

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ABSTRACT

The performance of solar panels is determined based on the Maximum Power Output and the Fill Factor (FF) under a Standard Test Condition (STC). STC is a standard test condition in which the solar panels ideally work. STC testing methods do not consider the factors that affect the performance of solar panels, such as solar radiation and temperature changes. This study discusses a method that is simple and easy to determine the performance of crystalline solar panels. This method is based on comparison of the normal cumulative probability distribution of the Fill Factor on radiation and temperature variations to STC conditions. The experiment shows that A-180 Photovoltaic (PV) has a better performance rating than B-180 PV with a probability ratio of 27.12% and 16.09, respectively. The Gaussian Method which is used also can be verified by maximum power measurement at radiation of 1000 W/m^2. Results show that A-180 PV has a better power ratio with 81.55%, which is higher than B-180 PV with 78.6%.

Keywords: Fill Factor; Gaussian approach; Photovoltaic; Solar characteristics analyzer; Solar panel performance; Solar radiation; Standard Test Condition; Temperature

1. INTRODUCTION

Solar energy utilization increases with increasing energy needs and rising oil prices. Solar energy is one renewable energy source that is not inexhaustible and is environmentally friendly. Solar panels work by converting solar radiation into electricity by a photovoltaic effect. Solar panels are continuously being developed following trends of higher efficiency and lower price. The efficiency of the general commercial product ranges between 13% and 17%, based on the consideration of increasing production costs. The materials of commercial solar cells can be cataloged into the following types: Single Crystal Silicon, Polycrystal Silicon, Amorphous Silicon, GaAs, InP, CdS, CdTe, CuInse, CuInGaSe and Dye-Sensitized Nanocrystalline Solar Cell, which are currently being researched. Solar panel performance is highly dependent on the availability of solar radiation. The larger the solar radiation received by the solar panel, the greater the electrical energy that can be generated. However, the increase in solar radiation will lead to an increase in the temperature of the solar panel, which results in a decrease in performance. The performance of a solar panel can be depicted in the parameters listed on the solar panel's name plate. These parameters are based on test results of solar panels under STC conditions. In conditions that are not standard, particularly in tropical regions, solar panels often operate with a lower performance standard that is not in line with conventional expectations.

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* Corresponding author's email: ekoas@ee.ui.ac.id, Tel. +62-21-7270078, Fax. +62-21-7270077
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Although the tropical regions receive stable sunshine at a high intensity level throughout the year, the great potential of solar energy is reduced because the selection of solar panels is not appropriate. As a result, the utilization of solar energy becomes minimal. Consequently, other methods are used to assess the performance of solar panels in all conditions. Raina et al. (2013) proposed a new method with a prototype for the real time monitoring capability of solar panels, by comparing the actual Fill Factor with optimal Fill Factor. The method aims to process the general equation of solar panels to obtain an optimum Fill Factor which aims to detect any errors or disruption of the solar panels, thus decreasing solar panel performance. On the other hand, this paper proposes a novel method to analyze the ability of solar panels with the cumulative distribution Fill Factor value method related to solar radiation and certain working temperatures of solar panels. This method is based on experimental data which is then compared with STC (Standard Test Condition). This study includes a sample test of 2 units of 180 Watt Peak (WP) crystalline solar panels from different manufacturers. Results of the research conducted are useful to analyze and determine better performance factors for solar panel products.

2. METHODOLOGY

2.1. Fill Factor of Solar Panels

This paper proposes a new method of determining the performance of solar panels using the cumulative distribution function for a normal distribution in relation to the Fill Factor of the two solar panels. Solar radiation factors cause variations in solar panel temperatures. To obtain the actual Fill Factor (FF) value of the solar panels, the measurement of solar panel characteristics is taken from the variation in the amount of solar radiation ranging from 200 to 900 W/m^2. The parameters measure the amount of solar radiation (G), panel temperature (T), Open Circuit Voltage (V_{OC}), Short Circuit Current (I_{SC}), Maximum Power Voltage (V_{MPP}), Maximum Power Current (I_{MPP}), and Maximum Power (P_{MPP}). The specifications of each solar panel can be seen in Table 1.

Table 1 Solar panel specification comparison

Variable	A-180 PV	B-180 PV
P_{MPP}	180 WP	180 WP
V_{OC}	44.6 V	44 V
I_{SC}	5.4 A	5.35 A
V_{MPP}	35.4 V	36 V
I_{MPP}	5.09 A	5 A
FF	0.74816	0.76466
Dimension	1580×808×50 mm	1580×808×45 mm

Data sampling of the Fill Factor is obtained by Equation 1, where the value of V_{OC}, I_{SC}, V_{MPP}, and I_{MP} sampled is located in the range from low to high variations.

$$FF=\frac{P_{MPP}}{V_{OC}\times I_{SC}}=\frac{V_{MPP}\times I_{MPP}}{V_{OC}\times I_{SC}} \quad (1)$$

where FF is the Fill Factor, V_{OC} is the Open Circuit Voltage, I_{SC} is the Short Circuit Current, V_{MPP} is the Maximum Power Voltage, I_{MPP} is the Maximum Power Current, and P_{MPP} is the Maximum Power.

The Fill Factor of the solar panels can be affected by temperature change because of the variation in solar panel characteristics, such as Maximum Power Voltage (V_{MPP}) and Maximum Power Current ($I_{MPP.}$) After the data are obtained using the solar characteristics analyzer, parameters are processed using a Gaussian approach.

2.2. Gaussian Method

A normal distribution (Gaussian) is a probability distribution that is often used in both theoretical and statistical applications. A random variable (X) is said to have a normal distribution within parameters μx and σx, where $-\infty<\mu x<\infty$ and $\sigma x>0$.

The Probability Density Function (PDF) of X is expressed as:

$$f_N(x;\mu_x;\sigma_x) = \frac{1}{\sigma_x\sqrt{2\pi}} e^{-\frac{(x-\mu_x)^2}{(2\sigma^2 x)}} \qquad -\infty < x < \infty \tag{2}$$

where σx is the deviation standard, and μx is the mean.

For every value of μx and σx, PDF is symmetrical to μx and the value of σx determines the expanse of the curve. The cumulative normal distribution is a normal random variable X with a probability value of less than or equal to a certain value of x. The cumulative distribution function of the normal distribution is expressed as:

$$F_N(x;\mu_{x;\sigma_x}) = P(X \le x) = \int_{-\infty}^{x} f_N(t;\mu_x;\sigma_x)dt = \int_{-\infty}^{x} \frac{1}{\sigma_x\sqrt{2\pi}} e^{\frac{(t-\mu_x)^2}{(2\sigma^2 x)}} dt \tag{3}$$

2.3. Fill Factor Analysis using a Gaussian Approach

After the Fill Factor of the solar panels has been obtained, the Fill Factor footage is processed using a Gaussian approach or a normal distribution to obtain the Fill Factor of the Gaussian curve. The next step is to find the area under the curve with the value z, which is the FF value under a STC condition. So, the Fill Factor cumulative probability distribution is related to the area of solar panels, while at the same time it can be obtained more or less within the STC. With these methods, solar panel performance can be compared. The greater the probability or the wide curve reading obtained indicates better solar panel performance. A flow diagram of the determination of the solar panel performance can be seen in Figure 1 below.

3. RESULTS AND DISCUSSION

The experimental results are used to determine the solar panel performance with a Gaussian approach to the Fill Factor (FF) distribution of the solar panels within a certain range of solar radiation and temperature measurements. These experiments compared the performance between the two monocrystalline 180_{WP} P_{MAX} solar panels from different manufacturers and analyzed the Fill Factor due to temperature and solar radiation shifts.

3.1. Solar Panel Characteristics Measurement

The output characteristics of solar panels were measured using a solar radiation analyzer at the same time in parallel with solar radiation variations to obtain the sampling results. The experimental configuration can be seen in Figure 2.

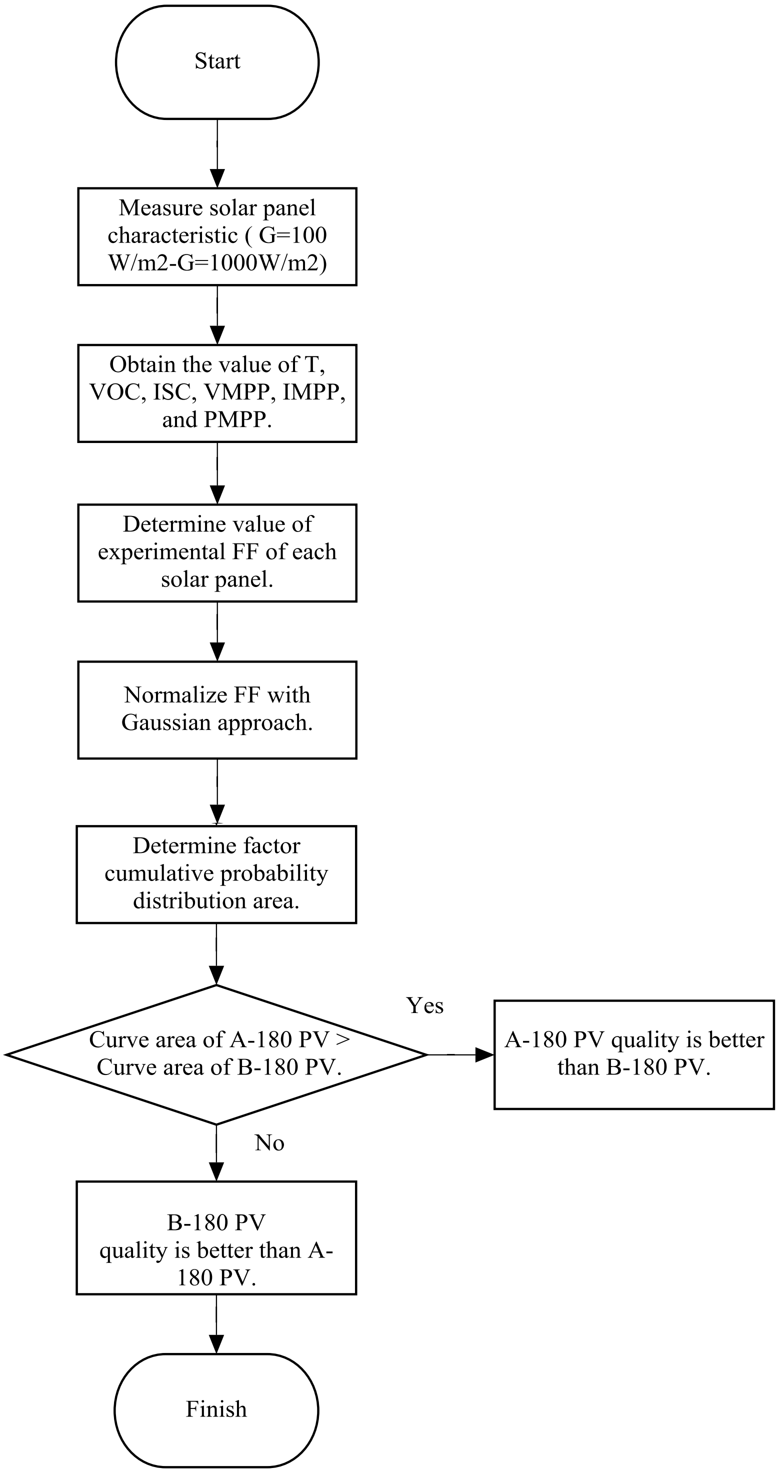

Figure 1 Flow diagram of the determination of the performance of solar panels

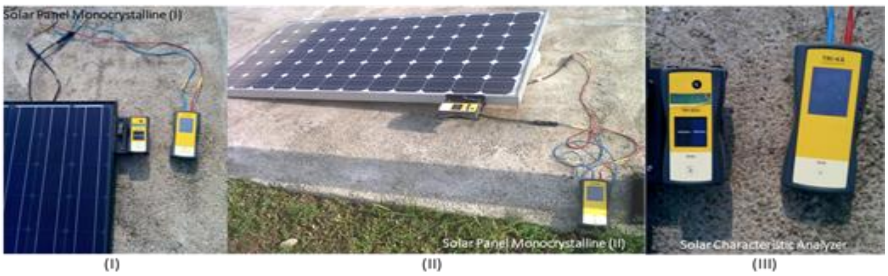

Figure 2 Measurement Setup

Sampling results obtained can be seen in Tables 2 and 3 for both solar panels.

Table 2 A-180 PV sampling result

G (W/m^2)	I_{SC} (A)	V_{OC} (V)	I_{MPP} (A)	V_{MPP}(V)	FF
293	1.780	40.05	1.676	32.83	0.771831
302	1.771	39.95	1.667	32.83	0.773519
369	2.189	39.66	1.987	31.97	0.731715
378	2.214	39.70	2.073	31.91	0.752589
511	2.857	39.78	2.702	31.78	0.755552
531	2.904	39.76	2.784	31.86	0.768196
542	3.009	39.80	2.821	31.86	0.750488
630	3.502	39.23	3.303	30.77	0.739778
649	3.586	39.21	3.344	30.96	0.736309
679	3.710	39.09	3.501	30.75	0.742331
709	4.003	38.71	3.700	30.33	0.724211
716	4.020	38.69	3.748	30.20	0.727749
722	4.054	38.69	3.758	30.18	0.723092
786	4.308	38.08	3.967	29.63	0.716508
804	4.422	38.16	4.069	29.53	0.712072
816	4.521	38.22	4.124	29.67	0.708127
866	4.789	37.74	4.416	28.88	0.705634
880	4.857	37.80	4.435	29.06	0.701987
882	4.913	37.82	4.503	28.71	0.695772

3.2. Result of a Gaussian Approach on the Solar Panel Fill Factor

The FF data of each solar panel are processed using a Gaussian approach (Equation 2) so that the normal distribution curve of the Fill Factor of each solar panel can be obtained (Figures 3 and 4). Figures 3 and 4 also show the Fill Factor cumulative probability distribution area of the solar panels after the data are processed using Equation 3. A summary of the experiment results is shown in Tables 4 and 5. It can be seen that A-180 PV has a greater probability than B-180 PV. The results indicate than A-180 PV has better performance than B-180 PV, even though under STC conditions B-180 PV has a larger FF value than A-180 PV.

Table 3 B-180 PV sampling result

G (W/m^2)	I_{SC} (A)	V_{OC} (V)	I_{MPP} (A)	V_{MPP}(V)	FF
260	1.499	40.20	1.389	33.17	0.764575
274	1.545	40.18	1.459	33.17	0.779583
332	1.867	39.87	1.700	32.37	0.739267
363	1.963	40.01	1.850	32.73	0.770955
371	1.978	39.95	1.8777	32.94	0.782721
427	2.303	40.14	2.158	32.85	0.766859
460	2.458	40.14	2.306	32.77	0.765908
461	2.499	40.25	2.299	32.81	0.749917
608	3.257	39.34	2.899	31.84	0.720392
633	3.491	39.49	3.135	31.00	0.704956
669	3.529	39.17	3.253	31.34	0.737527
675	3.578	39.25	3.320	30.92	0.730967
687	3.594	39.23	3.343	31.02	0.735498
791	4.086	38.67	3.806	30.03	0.723355
795	4.142	38.62	3.754	30.54	0.716706
801	4.185	38.67	3.879	29.84	0.715235
885	4.629	38.39	4.252	29.61	0.708478
900	4.720	38.29	4.293	29.51	0.700975
902	4.683	38.33	4.352	29.42	0.713294

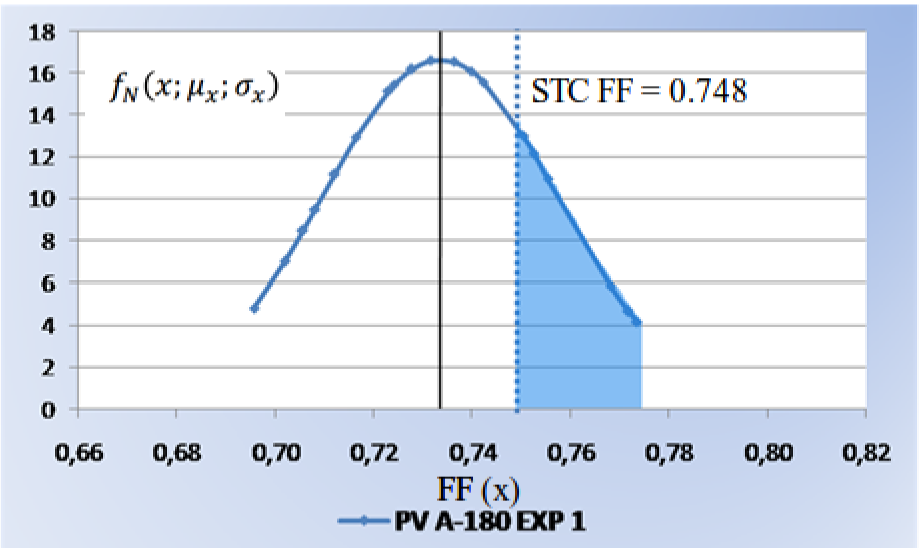

Figure 3 Fill Factor cumulative probability distribution curve of PV A-180

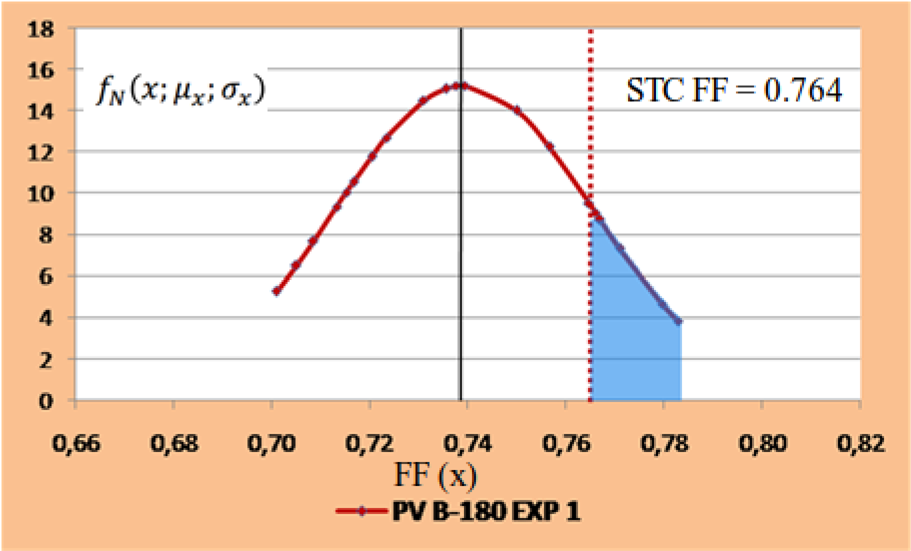

Figure 4 Fill Factor cumulative probability distribution curve of PV B-180

Table 4 Fill Factor Cumulative Probability Value A-180 PV

Fill Factor of PV-A			
Deviation Standard (σx)	Mean (µx)	FF STC (x)	Probability (%)
0.74816	0.73355	0.74816	27.12

Table 5 Fill Factor Cumulative Probability Value B-180 PV

Fill Factor of PV-B			
Deviation Standard (σx)	Mean (µx)	FF STC (x)	Probability (%)
0.76466	0.73827	0.76466	16.09

3.3. Evaluation of Maximum Output Solar Panels

Comparison of solar panel performance with a Gaussian approach can be verified by comparing the output of solar panels under a solar radiation value of 1000 W/m^2. But, in the experiments conducted, the solar radiation value obtained had not reached 1000 W/m^2, so it needed to be extrapolated. Experimental data were extrapolated with the help of the Microsoft Excel software to obtain maximum power output for a solar radiation value of 1000 W/m^2. Experiments, which were conducted on two types of solar panels, resulted in an experimental maximum power output, which was under the STC. The greater the radiation received, the greater was the difference in experimental power output under the STC. This is due to experiments carried out in less than ideal conditions, where temperatures were directly proportional to the amount of solar radiation. In conclusion, higher temperature readings taken at the solar panels will reduce the performance of solar panels.

Comparisons between the maximum power outputs of the solar panels under the STC can be seen in Table 6. It can be seen clearly that an increase in maximum output power of A-180 PV is more than B-180 PV, so in this experiment, the performance of A-180 PV can be said to be better than B-180 PV. This is proper and fits a Gaussian approach for the FF value of solar panels, which is described in the previous section. The power ratio of A-180 PV in the experiment has a higher value than B-180 PV, which indicates that the maximum power output generated by the A-180 PV is higher than B-180 PV, although under the STC B-180 PV has a higher FF value than A-180 PV.

Table 6 Maximum Power Output Ratio of solar panels which are tested

Photovoltaic	P_{MPP} STC (W)	P_{MPP} Experiment (W)	Power Ratio (%)
A-180	180	146.79	81.55
B-180	180	141.485	78.6

The difference in performance that occurs at A-180 PV and B-180 PV is influenced by several factors. One of the main factors is the solar panel fabrication process. In the fabrication process, differences in the fabrication techniques and materials used can occur, giving rise to differences in the characteristics of the solar panels. One of the differences in the fabrication of solar panels is the amount of impurities. This factor is given on both sides for the p-type and the n-type, which has the distinction that the values attributed to the characteristics of solar panels can be different. At the stage of solar cells assembly into solar panels, differences in resistance between connections of the solar cells can also occur. This will affect the characteristics of the solar panels, so that the output of solar panels will change.

4. CONCLUSION

This paper discusses a Gaussian approach that can be used to test the performance of 2 units of crystalline solar panels from different manufacturers. The performance of these two solar panel units can be compared by analyzing the Fill Factor value of each solar panel, which changes with the variation of solar radiation and temperature measurements by using a Gaussian approach. The experiment shows that A-180 PV has better performance rating than B-180 PV with a probability ratio of 27.12% and 16.09%, respectively. The Gaussian Method which is used can also be verified by the maximum power measurement at a solar radiation value of 1000 W/m^2. The results show that A-180 PV has a better power ratio of 81.55%, which is higher than B-180 PV with 78.6%, even though under the STC, B-180 PV has a higher FF value than A-180 PV.

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