Utilization of Solar Trackers to Increase Solar Panel Output Efficiency

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ABSTRACT: *This study aims to create a solar tracker tool to increase the power efficiency of solar panels. The solar tracker tool in this study uses an LDR sensor as a light tracker, Arduino nano as a signal regulator and L298N motor driver as a controller for 2 DC motors. This study uses PSIM software as a comparison of solar panels with real-world experiments. This study uses 2 solar panels that will be compared with one of the solar panels using a solar tracker and the other is static or not moving. The results of this study show that solar panels using a single-axis solar tracker produce energy of 128.7Wh, 21.2Wh higher than static solar panels and show an increase in power efficiency of 1.41%. While solar panels using a dual-axis solar tracker produce energy of 151.9Wh, 36Wh higher than static solar panels and show an increase in power efficiency of 2.28%.*

KEYWORDS: *Dual Axis Solar Tracker, Single Axis Solar Tracker, Solar Panel, Solar Power Meter..*

I. INTRODUCTION

Global energy demand continues to increase, contributing to the rise in global temperatures. This condition is primarily driven by the extensive use of conventional energy sources such as coal and petroleum, which significantly contribute to the increase in the Earth's surface temperature. Alternative energy sources offer a potential solution to mitigate global warming, whereas the use of fossil fuels has been widely identified as a major driver of global climate change [1]. The increase in CO_2 concentration and other greenhouse gases is attributed to various anthropogenic activities, but is primarily driven by the combustion of fossil fuels in energy production [2] As global surface temperatures continue to rise, the efficiency of fossil fuel–based power generation tends to decline. Therefore, power generation systems based on renewable energy sources present a viable solution to mitigate the increase in global temperatures, commonly associated with the greenhouse effect. One such renewable energy technology is solar power generation, known as Solar Power Plants (Photovoltaic Systems).

A Solar Power Plant is a system designed to generate electrical energy. It operates by converting solar radiation into electrical energy through the photovoltaic effect [3]. One of the key components of a Solar Power Plant is the solar panel. The solar panel serves as the primary component of the system, where solar energy is converted into direct current (DC) electrical energy.

A solar tracker operates by utilizing a Light Dependent Resistor (LDR) as a sensor to detect the direction of incoming solar radiation, enabling the photovoltaic panel to continuously align perpendicular to the sun's rays. By employing a solar tracking system, solar energy can be converted more efficiently compared to a fixed panel configuration, as the panel orientation dynamically follows the sun's trajectory [4].

Solar trackers can be classified into several types based on their axis of movement. Common examples include single-axis solar trackers, which operate along one of rotation, and dual-axis solar trackers, which operate along two axes, allowing for more precise alignment with the sun's position.

II. LITERATURE REVIEW

A. SOLAR POWER PLANTS

A Solar Power Plant is a power generation system that converts solar radiation into electrical energy using photovoltaic technology [5]. This type of power plant operates based on the principle of converting sunlight directly into electricity [6]. The system configuration employed in this study is illustrated in Figure 1 below:

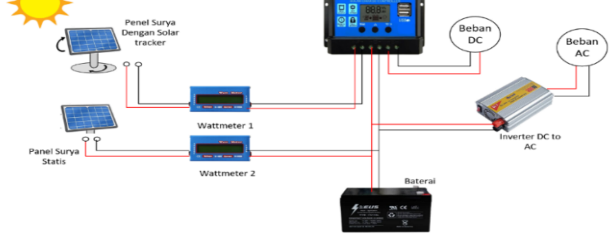

Fig 1. Implementation Series

The solar panel is the primary component of a Solar Power Plant (PLTS), functioning to convert solar energy into electrical energy. This conversion process is based on the photovoltaic effect. Photovoltaic technology enables the direct conversion of solar radiation into electricity. It operates by absorbing solar radiation with sufficiently short wavelengths and high energy, which excites electrons within the photovoltaic material, allowing them to escape from their atomic bonds.

B. PSIM

PSIM is a simulation software for electronic circuits that can be used to analyze circuit performance prior to practical implementation. The circuit configuration used in the PSIM simulation is presented in Figure 2 below:

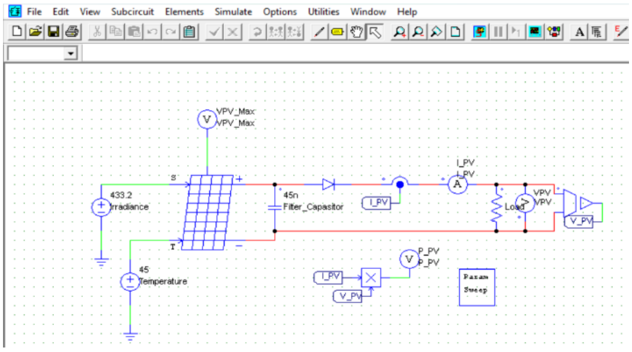

Fig 2. Solar Panel Simulation at PSIM

III. METHODOLOGY

A. TYPES OF RESEARCH

The research employed in this study is a quantitative approach with an experimental design. Quantitative research is defined as a systematic investigation of phenomena through the collection of measurable data, which are analyzed using statistical, mathematical, or computational techniques. It is predominantly conducted using statistical methods to obtain quantitative data from research studies[7]. Based on its nature, this study is categorized as experimental research. Experimental research aims to examine the effect of a specific treatment, considered as the independent variable, on the observed outcomes as the dependent variable. Specifically, this study seeks to determine the magnitude of power generated by a solar panel after the implementation of single-axis and dual-axis solar trackers.

B. DATA ANALYSIS TECHNIQUES

Power efficiency refers to the ability of a device or system to convert input energy into output energy with minimal losses. The output of a solar panel is the electrical power generated by converting solar energy into electricity. The equation used to determine the efficiency of the solar panel is presented as follows:

$$\eta = (FF \times V \times I)/Pin 100\% \quad (1)$$

Dimana:

η = Efficiency (%)

V = Solar panel voltage

I = Solar panel current

FF = Fill Factor (%)

$$Pin = (Irradiance \times Solar\ panel\ Area) \quad (2)$$

$$FF = (Vmp \times Imp)/(Isc \times Voc) \quad (3)$$

IV. RESULTS AND DISCUSSION

A. MEASUREMENT RESULTS

Based on the study conducted from September 16 to September 22, the researcher performed six sets of measurements. On September 16, 17, and 21, measurements were carried out to compare the power output of solar panels using a single-axis solar tracker with that of a fixed (static) solar panel. Subsequently, on September 18, 20, and 21, measurements were conducted on solar panels utilizing a dual-axis solar tracker and compared with static solar panels. Furthermore, the simulation results of the solar panel using PSIM software with the same irradiance data on September 16 are presented in Table 1 below.:

Tbl 1. Measurement Results of the Solar Panel and PSIM Simulation on September 16, 2025

No	Jam	Irradiance (W/m2)	Energi 1 (Wh)	Energi 2 (Wh)	Daya 1 (W)	Daya 2 (W)	Daya PSIM (W)
1	08:00-09:00	707.4	2.1	1.9	5.5	5.1	6.9
2	09:00-10:00	771.8	4.6	4.6	5.5	5.4	7.44
3	10:00-11:00	825.6	5.6	5.1	5.6	5.1	7.71
4	11:00-12:00	872.9	5.5	4.8	5.7	5.1	8.02
5	12:00-13:00	234.3	4.4	4.5	1.8	1.9	2.05
6	13:00-14:00	849.3	5.1	4.7	5.8	5.3	7.9
7	14:00-15:00	675.4	4.5	4.7	5.9	5.2	6.6
8	15:00-16:00	661.7	4	2.5	3.9	2.9	6.45
9	16:00-17:00	433.2	3.4	2	2.2	0	3.13

Based on Table 1, Energy 1 represents the energy generated by the solar panel using a single-axis solar tracker, while Energy 2 represents the energy generated by the static solar panel. Similarly, Power 1 refers to the power output of the solar panel with a single-axis solar tracker, whereas Power 2 corresponds to the power output of the static solar panel. Furthermore, the measurement results of the solar panels and the simulation results using PSIM software on September 21 are presented in Table 2 below:

Tbl 2. Measurement Results of the Dual-Axis Solar Tracker on September 21, 2025

No	Jam	Irradiance (W/m2)	Energi 1 (Wh)	Energi 2 (Wh)	Daya 1 (W)	Daya 2 (W)	Daya PSIM (W)
1	08:00-09:00	793.1	5.5	3.4	6.1	4.3	7.58
2	09:00-10:00	882.5	6.3	4.7	6.1	4.8	8.09
3	10:00-11:00	898.5	5.7	4.9	6.4	5.4	8.14
4	11:00-12:00	906	6.2	5.3	6.6	5.7	8.17
5	12:00-13:00	925.6	6.2	5.3	6.7	5.4	8.25
6	13:00-14:00	888	6.8	5.5	6.5	5.3	8.07
7	14:00-15:00	840.5	5.8	4.6	5.8	4.6	7.85
8	15:00-16:00	725.1	5.4	3.8	5.2	3.4	7.07
9	16:00-17:00	481	3.9	2	3	0	3.83

Based on Table 2, Energy 1 represents the energy generated by the solar panel using a single-axis solar tracker, while Energy 2 represents the energy generated by the static solar panel. Similarly, Power 1 refers to the power output of the solar panel with a single-axis solar tracker, whereas Power 2 corresponds to the power output of the static solar panel.

B. CALCULATION RESULT

Based on the measurement results above, data processing was carried out to determine the Fill Factor (FF) and input power *Pin* using Equations (1) and (3), in order to calculate the efficiency of the solar panel. The results of these calculations are presented as follows:

$FF = (Vpm \times Jpm)/(Voc \times Jsc)$

$FF = (17{,}4 \times 0{,}57)/(21{,}6 \times 0{,}63)$

$FF = 0{,}7288$

$Solar\ Panel\ Area = 19{,}5cm\ x\ 32{,}5cm$

$Solar\ Panel\ Area = 0{,}0633m2$

$Pin = Irradiance \times Solar\ Panel\ Area$

$Pin = 707.4 \times 0.0633$

$Pin = 44.78$

Tbl 3. Results of the Calculation of the Cross-Sectional Area and Fill Factor (FF)

No	Luas Panel Surya (m^2)	*FF*
1	0,0633	0,7288

Based on Table 3, the solar panel area is 0.0633 m^2, which is used to determine the input power *Pin*. In addition, the Fill Factor (FF) value is 0.7288, which is used in the calculation of solar panel efficiency. Furthermore, the results of the *Pin* and FF calculations for the solar panel with a single-axis solar tracker, the static solar panel, and the PSIM simulation on September 16 are presented in Table 4 below:

Tbl 4. Comparison of Input Power (Pin) and Fill Factor of the Solar Panel on September 16, 2025

No	Jam	Irradiance (W/m2)	Pin (W)	FF x P (1)	FF x P (2)	FF x P (3)
1	08:00-09:00	707.4	44.77	4.00	3.71	5.02
2	09:00-10:00	771.8	48.85	4.00	3.93	5.42
3	10:00-11:00	825.6	52.26	4.08	3.71	5.61
4	11:00-12:00	872.9	55.25	4.15	3.71	5.84
5	12:00-13:00	234.3	14.83	1.31	1.38	1.49
6	13:00-14:00	849.3	53.76	4.22	3.86	5.75
7	14:00-15:00	675.4	42.75	4.29	3.78	4.81
8	15:00-16:00	661.7	41.88	2.84	2.11	4.70
9	16:00-17:00	533.2	33.75	1.60	0	2.28

Based on Table 4, FF × P (1) represents the product of the fill factor and the power output of the solar panel with a single-axis solar tracker, while FF × P (2) represents the product of the fill factor and the power output of the static solar panel. Meanwhile, FF × P (3) represents the product of the fill factor and the simulated power output of the solar panel using PSIM software. Furthermore, the results of the *Pin* and FF calculations for the solar panel with a dual-axis solar tracker, the static solar panel, and the PSIM simulation on September 21 are presented in Table 5 below:

Tbl 5. Comparison of Input Power (Pin) and Fill Factor of the Solar Panel on September 21, 2025

No	Jam	Irradiance (W/m2)	Pin (W)	FF x P (1)	FF x P (2)	FF x P (3)
1	08:00-09:00	793.1	50.20	4.45	3.13	5.52
2	09:00-10:00	882.5	55.86	4.45	3.50	5.89
3	10:00-11:00	898.5	56.88	4.66	3.94	5.93
4	11:00-12:00	906	57.35	4.81	4.15	5.95
5	12:00-13:00	925.6	58.59	4.88	3.94	6.01
6	13:00-14:00	888	56.21	4.74	3.86	5.88
7	14:00-15:00	840.5	53.20	4.23	3.35	5.72
8	15:00-16:00	725.1	45.90	3.79	2.48	5.15
9	16:00-17:00	481	30.45	2.19	0.00	2.79

Based on Table 5, FF × P (1) represents the product of the fill factor and the power output of the solar panel with a dual-axis solar tracker. Meanwhile, FF × P (2) represents the product of the fill factor and the power output of the solar panel, and FF × P (3) represents the product of the fill factor and the simulated power output of the solar panel using PSIM software.

Furthermore, the calculation of the ideal solar panel power efficiency using Equation (4) is presented as follows:

$$\eta=(FF\times Voc\times Isc)/Pin\ 100\%$$

$$\eta= (0{,}7288\times 21.6\times 0{,}63)\ /\ (0.0633\times 1000)\ 100\%$$

$$\eta=15.67\%$$

Furthermore, the calculation of solar panel efficiency using Equation (1) is presented as follows:

$$\eta= (FF\times V\times I)/Pin\ 100\%$$

$$\eta= (0{,}7288\times 14.10\times 0{,}39)\ /\ (0.0633\times 1000)\ 100\%$$

$$\eta=8.95\%$$

The results of the comparison between the solar panel equipped with a solar tracker and the static solar panel are presented in the table below:

Tbl 6. Solar Panel Efficiency and Efficiency Difference on September 16, 2025

Panel Surya Dengan Solar Tracker Single Axis			
No	**Tanggal**	**Rata Rata Selisih Efisiensi**	**Efisiensi rata rata**
1	16-Sep	1.13%	7.87%
2	17-Sep	1.57%	7.66%
3	22-Sep	1.52%	7.29%
Rata-rata		**1.41%**	**7.60%**

Based on Table 6, Efficiency 1 represents the efficiency of the solar panel equipped with a single-axis solar tracker, Efficiency 2 represents the efficiency of the static solar panel, and Efficiency 3 represents the efficiency of the solar panel obtained from PSIM software simulation. Meanwhile, Efficiency Difference 1 refers to the difference between Efficiency 1 and Efficiency 2, whereas Efficiency Difference 2 refers to the difference between Efficiency 1 and Efficiency 3.

Tbl 7. Solar Panel Efficiency and Efficiency Difference on September 21, 2025

No	Efisiensi 1 (%)	Efisiensi 2 (%)	Selisih Efisiensi 1 (%)	Efisiensi 3 (%)	Selisih Efisiensi 2 (%)
1	9.39%	6.31%	3.08%	13.48%	4.09%
2	7.73%	6.26%	1.47%	11.80%	4.08%
3	8.22%	6.87%	1.35%	10.79%	2.57%
4	7.44%	6.43%	1.01%	10.65%	3.20%
5	7.36%	6.27%	1.09%	10.66%	3.30%
6	8.28%	7.34%	0.93%	10.47%	2.19%
7	7.94%	6.41%	1.53%	10.75%	2.81%
8	8.27%	5.25%	3.02%	11.61%	3.34%
9	6.56%	0.00%	6.56%	11.16%	4.61%
Nilai rata rata	**7.91%**	**5.68%**	**2.23%**	**11.26%**	**3.35%**

Based on Table 7, Efficiency 1 represents the efficiency of the solar panel equipped with a dual-axis solar tracker, Efficiency 2 represents the efficiency of the static solar panel, and Efficiency 3 represents the efficiency obtained from PSIM software simulation. Meanwhile, Efficiency Difference 1 refers to the difference between Efficiency 1 and Efficiency 2, whereas Efficiency Difference 2 refers to the difference between Efficiency 1 and Efficiency 3. Furthermore, the efficiency differences between the solar panel with a single-axis solar tracker and the static solar panel are presented in Table 8 below:

Tbl 8. Difference in Solar Panel Efficiency Between the Single-Axis Solar Tracker and the Static Solar Panel

No	Efisiensi 1 (%)	Efisiensi 2 (%)	Selisih Efisiensi 1 (%)	Efisiensi 3 (%)	Selisih Efisiensi 2 (%)
1	8.95%	8.30%	0.65%	11.23%	2.28%
2	8.20%	8.06%	0.15%	11.10%	2.89%
3	7.81%	7.11%	0.70%	10.75%	2.94%
4	7.52%	6.73%	0.79%	10.58%	3.06%
5	8.85%	9.34%	-0.49%	10.07%	1.23%
6	7.86%	7.18%	0.68%	10.71%	2.85%
7	10.06%	8.86%	1.19%	11.25%	1.19%
8	6.79%	5.05%	1.74%	11.22%	4.44%
9	4.75%	0.00%	4.75%	6.76%	2.01%
Nilai rata rata	**7.87%**	**6.74%**	**1.13%**	**10.41%**	**2.54%**

Based on Table 8, the average difference in the output efficiency of the solar panel equipped with a single-axis solar tracker shows an increase of 1.41%

compared to the static solar panel, while the average efficiency of the solar panel with a single-axis solar tracker is 7.60%. Furthermore, the efficiency difference between the dual-axis solar tracker system and the static solar panel is presented in the table below:

Tbl 9. Difference in Solar Panel Efficiency Between the Dual-Axis Solar Tracker and the Static Solar Panel

Panel Surya Dengan Solar Tracker Dual Axis			
No	**Tanggal**	**Rata Rata Selisih Efisiensi**	**Efisiensi rata rata**
1	18-Sep	2.23%	7.91%
2	20-Sep	2.22%	7.83%
3	21-Sep	2.40%	8.17%
Rata-rata		**2.28%**	**7.97%**

Based on Table 9, the average difference in the output efficiency of the solar panel equipped with a dual-axis solar tracker shows an increase of 2.28% compared to the static solar panel. Furthermore, the comparison of the energy generated by the solar panel with a single-axis solar tracker is presented in Table 10 below:

Tbl 10. Comparison of Energy Generated by the Solar Panel with a Single-Axis Solar Tracker and the Static Solar Panel

No	Tanggal	Total Energi (Wh) Panel Surya Solar Tracker Axis	Total Energi (Wh) Panel Surya Statis	Selisih Energi (Wh)
1	16-Sep	39,2	34,8	4,4
2	17-Sep	45,5	36,9	8,6
3	22-Sep	44	35,8	8,2
Total		**128,7**	**107,5**	**21,2**

The results of the study conducted on September 16, 17, and 22 from 08:00 to 17:00 show that the solar panel equipped with a single-axis solar tracker generated a total energy of 128.7 Wh, which is 21.2 Wh higher than the static solar panel, which only produced a total energy of 107.5 Wh. Furthermore, the comparison of the energy generated by the solar panel with a dual-axis solar tracker is presented in Table 11 below:

Tbl 11. Comparison of Energy Generated by the Solar Panel with a Dual-Axis Solar Tracker and the Static Solar Panel

No	Tanggal	Total Energi (Wh) Panel Surya Solar Tracker Dual Axis	Total Energi (Wh) Panel Surya Statis	Selisih Energi (Wh)
1	18-Sep	48,7	37	11,7
2	20-Sep	51,4	39,4	12
3	21-Sep	51,8	39,5	12,3
Total		**151,9**	**115,9**	**36**

Based on Table 11, over the three-day experimental period on September 18, 20, and 21 from 08:00 to 17:00, the solar panel equipped with a dual-axis solar tracker generated a total energy output of 151.9 Wh, which is 36 Wh higher than the static solar panel, which produced only 115.6 Wh.

V. CONCLUSION

Based on the calculated results, the Fill Factor (FF) value of the solar panel used in this study is 0.7288. The fill factor is a key parameter that links the electrical characteristics of the solar panel to its maximum power output. By knowing the fill factor value, the maximum achievable power can be determined, thereby enabling a more accurate calculation of solar panel efficiency..

Based on the experimental results, it can be concluded that the average power efficiency of the solar panel using a single-axis solar tracker increased by 1.41% and produced an energy output of 128.7 Wh, which is 21.2 Wh higher than the static solar panel that only generated 107.2 Wh. Furthermore, it can also be concluded that the average power efficiency of the solar panel using a dual-axis solar tracker increased by 2.28% and produced a total energy output of 151.9 Wh over three days, which is 36 Wh higher than the static solar panel that only generated 115.9 Wh. Based on the PSIM simulation results, the solar panel model in the simulation exhibits higher power and efficiency values compared to the experimental solar panel. It is expected that future researchers will be able to develop methods to further improve the power output and efficiency of solar panels so that they can better match the results obtained from PSIM simulations.

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