Type of Contribution:

Editorial
Research Paper
Review Paper
Case Study

INTRO: JURNAL INFORMATIKA DAN TEKNIK ELEKTRO
DOI: 10.51747/intro.v5i1.p18-26
ISSN 3025-602X

This article contributes to:

SUSTAINABLE DEVELOPMENT GOALS
7 AFFORDABLE AND CLEAN ENERGY

Analysis of Photovoltaic Current Based on Tilt Angle Variation Using the ANOVA Method

Nanang Hermawan[1], Hartawan Abdillah[1*], Mas Ahmad Baihaqi[1], Moh. Zainul Falah[2]

[1] Faculty of Engineering and Informatic, Panca Marga University, 67271, **Indonesia**

[2] Department of Information and Communication Engineering, Chaoyang University of Technology, 413310, **Taiwan**

* hartawanabdillah@upm.ac.id

Abstract

Solar panels play a crucial role as the main component in a Solar Power Plant (PLTS), where solar energy is converted into electrical energy. The efficiency of power conversion in solar panels is influenced by various factors, including material type, tilt angle, and weather conditions. To optimize efficiency, proper adjustment of the panel's tilt angle is required to achieve maximum current output. The variation in tilt angles remains a challenge in obtaining high efficiency, necessitating a method to address this issue effectively. The use of ANOVA aims to analyze the effect of solar panel tilt angle variations on output current, providing a reference for PLTS installation. This study was conducted through experimental research on solar panels by applying various tilt angles to collect current distribution data. The data was then processed using sufficiency tests, normality tests, homogeneity tests, and ANOVA. The findings indicate that tilt angle variation significantly affects output current, as the ANOVA test result yielded a P-value of 0.0405, indicating statistical significance. Furthermore, the experiment identified an optimal tilt angle for maximizing current output, with a recommended angle of 20° facing eastward.

Keywords: Solar Power Plants (SPPs), Tilt Angle, ANOVA.

Article Info

Submitted: 2026-03-02
Revised: 2026-05-19
Accepted: 2026-05-25
Published: 2026-06-20

Publisher
Universitas Panca Marga

1. Introduction

The utilization of solar energy into electrical energy is achieved using the solar panel as the most important component in a Solar Power Plant (PLTS), because it is in this component that the process of converting solar energy into electrical energy occurs [1]. Solar panels convert solar energy into electrical energy through the photovoltaic process. In this process, the solar cells within the panels capture sunlight and change it into direct current (DC) electricity. With this technology, Solar Power Plants (SPPs) become an environmentally friendly solution that contributes to supporting the use of sustainable renewable energy, although in terms of efficiency, SPPs still require further development [2]-[5].

The power conversion efficiency of solar panels is influenced by the type of material used. Generally, the solar panels available on the market consist of two main types: monocrystalline and polycrystalline. In addition to the material type, the power efficiency of solar panels also depends on the duration of sun exposure and the angle of solar irradiation [6]-[8]. Setyawan & Agus (2022) in their research, proved that adjusting the solar panel angle according to specific times, combined with optimal weather conditions, can produce maximum output current.

Research conducted by Selian (2024), presented the results of their study, which employed the ANOVA method, demonstrating that this method can identify significant differences among data groups. Based on the analysis of the tilt angle, the highest output power occurred at a 30° angle with 76 watts, and the lowest output power occurred at a 60° angle with 36 watts. Another study also utilized ANOVA to analyze the effect of tilt variation on PV current, and the findings indicated that an 80° angle yielded the highest current.

The use of ANOVA in an experimental domain, such as with solar panels, requires a prerequisite test to ensure that the sample used is adequate. Previous studies that used ANOVA did not include prerequisite and post-hoc tests to confirm the significance among their variables. Therefore, this research will maximize the ANOVA method and ensure that the samples used meet the requirements. Consequently, the validity of the test results using ANOVA can be applied in setting the solar panel angle at the optimal degree to capture solar radiation for conversion into electrical energy.

2. Methods

This research was conducted in Plampang Village, Paiton District, Probolinggo Regency, with coordinates 7°44'07.9"S 113°30'16.0"E. The study employed an experimental method for data collection using a polycrystalline solar panel with a capacity of 10 Wp. The following outlines the experimental method for data collection:

1. Data collection was performed from 09:00 to 13:00 for 3 days, and the average calculation will be performed.
2. The solar panel will be set at angles (a) 0° to - 90° which is assumed to face East (Quadrant 2), and the solar panel will be set at angles (b) 0° to 90°, which is assumed to face West (Quadrant 1), as shown in **Figure 1**.

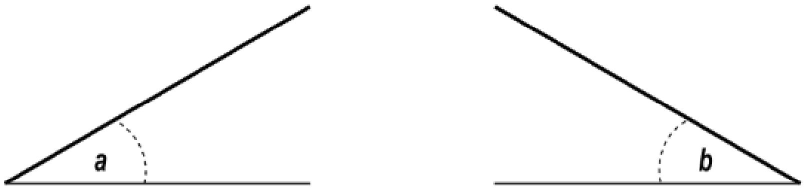

Figure 1. Tilt Angle Adjustment

To perform the prerequisite calculations before utilizing the ANOVA method, data testing and processing will be assisted by R Studio software. The following data processing techniques are used in this study:

1. Data Sufficiency Test is performed to verify that the collected data is sufficient to address the research problem.
2. Normality Test is conducted to determine the data distribution.
3. Homogeneity Test is performed to determine if the data meets this requirement, as this test is a prerequisite for performing ANOVA analysis.
4. ANOVA Analysis is performed to determine the significance of each variable.

3.Results and Discussion

3.1 Research Data

Table 1. Observational Data Results

Angle (°)	**Current (mA) Time -**				
	9	**10**	**11**	**12**	**13**
0	49,93	110,97	224,60	99,60	61,23
10	65,57	160,70	188,50	109,77	83,17
20	67,67	158,53	178,27	225,77	82,83
30	77,60	158,73	175,50	205,33	79,43
40	68,47	149,60	173,53	134,73	75,47
50	63,27	157,37	171,33	130,50	68,10
60	56,43	123,93	156,50	122,70	60,37
70	53,27	101,43	119,80	91,83	53,00
80	70,83	81,57	95,00	59,43	45,20
90	95,17	65,07	58,97	40,47	36,13
100	148,47	118,63	154,13	211,53	69,33
110	104,00	137,00	154,20	223,60	77,80
120	48,37	124,23	148,23	206,10	69,97
130	39,83	109,87	108,80	177,97	60,80
140	32,97	93,70	102,47	156,50	52,63
150	27,80	77,10	74,70	127,70	43,43
160	24,33	62,33	58,30	98,30	35,20
170	20,03	49,73	46,23	60,47	27,67
180	16,80	38,33	32,20	41,80	20,90

Table 1 presents the observed output current of the photovoltaic (PV) panel measured at different panel angles (0°–180°) and observation times (09:00–13:00). The current values were recorded at 10° angular intervals to investigate the influence of panel orientation and solar position on PV performance.

The results indicate that the output current varies significantly with both the panel angle and the measurement time. In general, the current increases from 09:00 and reaches its maximum between 11:00 and 12:00, corresponding to the period of highest solar irradiance. After midday, the current decreases as the solar elevation angle declines.

Regarding the panel orientation, higher current values are generally observed at angles between 20° and 40° during the morning period, while another increase appears at angles around 100°–120° at 12:00. This behavior suggests that the optimum panel orientation changes throughout the day following the apparent movement of the sun.

Conversely, the lowest current values are consistently recorded at extreme angles (160°–180°), where the incident solar radiation received by the PV surface is considerably reduced. Overall, the data demonstrate that both the panel angle and the time of observation substantially affect the output current of the photovoltaic system. Therefore, statistical analysis using a two-way Analysis of Variance (ANOVA) is appropriate to determine whether the effects of panel angle, observation time, and their interaction are statistically significant.

3.2 Sufficiency Test

Table 2. Sufficiency Test Result

KMO Test	
Time	**MSA**
9	0.74
10	0.78
11	0.83
12	0.64
13	0.73
Overall MSA	0.74
Barlett's Test	
Chi-Square (χ^2)	131.82
Degrees of Freedom (df)	15
p-value	9.35×10^{-21}

Table 2 presents the results of the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's Test of Sphericity to evaluate the adequacy of the dataset for statistical analysis. The KMO values range from 0.64 to 0.83, with an overall Measure of Sampling Adequacy (MSA) of 0.74. Since all MSA values exceed the recommended threshold of 0.50, the dataset demonstrates satisfactory sampling adequacy. In factor analysis, the correlation among variables is used to evaluate construct validity, where each variable should exhibit an MSA value greater than 0.50 to be considered acceptable [9], [10]. The results indicate that all observation periods satisfy this criterion, suggesting that each variable contributes adequately to the underlying factor structure.

Furthermore, Bartlett's Test of Sphericity yielded a chi-square value of 131.82 with 15 degrees of freedom and a p-value of 9.35×10^{-21} ($p < 0.001$). The null hypothesis that the correlation matrix is an identity matrix is therefore rejected, indicating that significant correlations exist among the observed variables. These findings confirm that the dataset possesses sufficient inter-variable correlation and is statistically suitable for subsequent multivariate analysis. Consequently, the KMO-MSA and Bartlett's test results demonstrate that the observational data satisfy the statistical requirements for further inferential analysis, including the evaluation of the effects of panel angle and observation time on the photovoltaic output current.

3.3 Normality Test

The Shapiro-Wilk normality test is used to evaluate whether the data in a small sample (≤ 50 samples) is normally distributed. According Agustin & Permatasari (2020) [7], the conclusion is drawn based on the probability value (Asymptotic Significance), with the following provisions:

1. If the probability is greater than 0.05, the data is considered normally distributed.
2. If the probability is less than 0.05, the data is not normally distributed.

Table 3. Sufficiency Test Result

Time	W	P-value
9	0.92321	0.1297
10	0.94071	0.2716
11	0.94811	0.3668
12	0.93303	0.1969
13	0.94592	0.336

Table 3 presents the results of the Shapiro–Wilk normality test for the photovoltaic output current at each observation time. The obtained W statistics range from 0.92321 to 0.94811, while the corresponding p-values vary between 0.1297 and 0.3668. Since all p-values are greater than the significance level of 0.05, the null hypothesis of the Shapiro–Wilk test cannot be rejected, indicating that the experimental data are normally distributed. Therefore, the normality assumption required for parametric statistical analysis is satisfied. With this prerequisite fulfilled, the dataset is appropriate for subsequent Analysis of Variance (ANOVA) to evaluate the effects of panel angle and observation time on the photovoltaic

output current. If the ANOVA results indicate statistically significant differences among the treatment groups ($p < 0.05$), a post hoc multiple comparison test is subsequently performed to identify the specific groups that differ significantly [11]-[15].

3.4 Homogeneity Test

Levene's Test is used to examine whether the variances of several populations are homogeneous or not. This test is an alternative to the Bartlett test. If the data has a normal or near-normal distribution, the Bartlett test is more recommended. Levene's Test is performed using one-way analysis of variance, where the data is processed by calculating the difference between each score and its group mean [8], [16]- [18]. The following are the test requirements:

1. If the significance value is less than 0.05, it means that the variation among the data groups is not equal.
2. If the significance value is greater than 0.05, it can be concluded that the variations among the data groups are similar.

Table 4. Homogeneity Test Result

Group	Df	F value	Pr(>F)
angle	18	0.9462	0.5282

Since the p-value is 0.05282, which is greater than 0.05, cannot reject the null hypothesis. This means there is no significant difference in variances between the groups in the tested data. The variances between groups are considered homogeneous or uniform.

3.5 ANOVA

The ANOVA test is used to determine whether the means of the four samples are equal or if there are significant differences among them. According to Dewi et al (2023), decision-making in the ANOVA test is based on the significance value as follows:

1. If the Sig < 0.05, there is no significant difference, so the means can be considered equal.
2. If the Sig < 0.05, there is a significant effect/difference among the sample means (Null Hypothesis H_0 is rejected).

Table 5. ANOVA Test

F-value	4.317
P-value	0.0405

Table 5 shows a p-value of 0.0405, meaning < 0.05. Based on the decision-making criteria, it can be concluded that in this research, the tilt angle of the solar

panel significantly affects the solar panel's output current. Further visualization for the ANOVA is presented in the following graph:

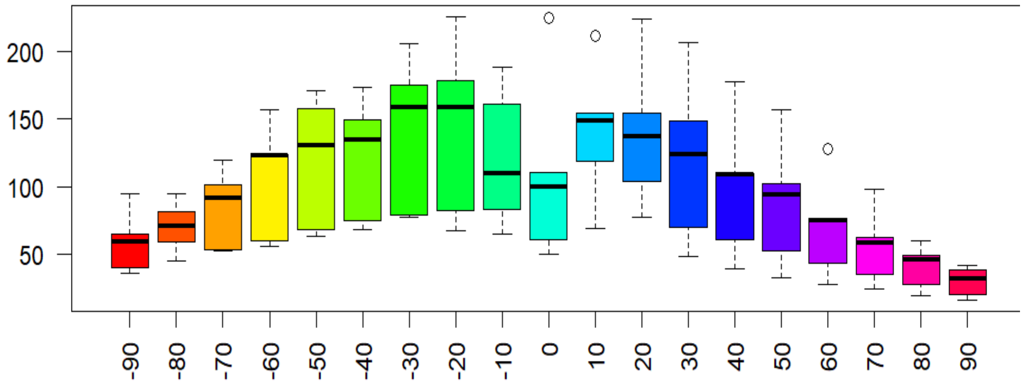

Figure 2. Results of the One-Way ANOVA Mapping

As seen in the **Figure 2**, the maximum solar panel output current is at a -20° angle, which then experiences a decrease when the angle moves towards -10° and the minimum value is at 0°.

4. Conclusion

The research results show that there is a significant effect between the variation of the solar panel tilt angle and the photovoltaic current. In the ANOVA test, the significance scale is 0.0405, or < 0.05, which confirms the effect between these variables. Other prerequisite tests for the ANOVA also showed fulfillment, such as the data adequacy test with an Overall MSA of 0.74, which meets the required qualification of > 0.5 to be considered sufficient data. Other tests, such as normality and homogeneity, also provide confidence to continue this ANOVA analysis because the probability value is > 0.05 and the significance value is > 0.05.

Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

Funding - No funding information from the authors.

Availability of data and materials - All data is available from the authors.

Competing interests - The authors declare no competing interest.

Additional information - No additional information from the authors.

References

[1] M. Müller, B. Wolpensinger, B. Min, G. Fischer, P. Palinginis, and D. H. Neuhaus, "Impact of Local Back-Surface-Field Thickness on Open-Circuit Voltage in PERC

Solar Cells: An Experimental Study Applying ANOVA to Determine Critical Sample Size Necessary to Differentiate Mean LBSF Values With Statistical Significance," IEEE Journal of Photovoltaics, vol. 10, no. 6, pp. 1702–1709, 2020, doi: 10.1109/JPHOTOV.2020.3026978.

[2] H. Abdillah, T. Asrori, M. A. Baihaqi, D. H. T. Prasetyo, and A. Muhammad, "Sistem Monitoring dan Manajemen Energi pada Pembangkit Hybrid PLTS, PLTB, dan PLN berbasis Internet of Things," JASIEK (Jurnal Apl. Sains, Informasi, Elektron. dan Komputer), vol. 5, no. 2, pp. 41–50, 2023, doi: 10.26905/jasiek.v5i2.10920.

[3] F. Pijoh, Brahmana Duta P. K, and Purba Parulian Lasman, "Pembangkit Listrik Tenaga Surya untuk Energi RamahLingkungan yang Berkelanjutan," Ind. Syst. Eng. Journals, vol. 2, no. 2, pp. 201–207, 2024.

[4] B. H. Hamadani and M. B. Campanelli, "Photovoltaic Characterization under Artificial Low Irradiance Conditions Using Reference Solar Cells," IEEE Journal of Photovoltaics, vol. 10, no. 4, pp. 1116–1122, Jul. 2020, doi: 10.1109/JPHOTOV.2020.2996241.

[5] M. Padmanaban, S. Chinnathambi, P. Parthasarathy, and N. Pachaivannan, "An e-ANOVA Tuned d-q Controller for Single Stage Grid Interface SPV System with Power Quality Improvement," International Journal of Renewable Energy Research, vol. 11, no. 4, pp. 1840–1850, 2021.

[6] D. D. Cahyono, S. I. Haryudo, and B. Suprianto, "Studi Literatur: Sistem Panel Surya Menggunakan Automatic Transfer Switch Dan Solar Tracking," J. Tek. Elektro, pp. 741–750, 2020, [Online]. Available: https://ejournal.unesa.ac.id/index.php/JTE/article/view/39161%0Ahttps://ejournal.unesa.ac.id/index.php/JTE/article/view/39161/34333

[7] A. Setyawan and U. Agus, "Pembangkit Listrik Tenaga Surya Off Grid Untuk Supply Charge Station," Transmisi, vol. 24, no. 1, pp. 23–28, 2022.

[8] M. D. Selian, "Analisa Temperatur Permukaan Panel Surya Terhadap Daya Keluaran Listrik Dengan Variasi Kemiringan," vol. 2, no. 2, pp. 144–154, 2024.

[9] J. S. Eviota and M. M. Liangco, "Jurnal Pendidikan MIPA," J. Pendidik., vol. 14, no. September, pp. 723–731, 2020.

[10] P. Agustin and R. I. Permatasari, "PENGARUH PENDIDIKAN DAN KOMPENSASI TERHADAP KINERJA DIVISI NEW PRODUCT DEVELOPMENT (NPD) PADA PT. MAYORA INDAH Tbk.," J. Ilm. M-Progress, vol. 10, no. 2, pp. 174–184, 2020, doi: 10.35968/m-pu.v10i2.442.

[11] R. Sianturi, "Uji homogenitas sebagai syarat pengujian analisis," J. Pendidikan, Sains Sos. dan Agama, vol. 8, no. 1, pp. 386–397, 2022, doi: 10.53565/pssa.v8i1.507.

[12] S. S. Dewi, R. Ermina, V. A. Kasih, F. Hefiana, A. Sunarmo, and R. Widianingsih, "Analisis Penerapan Metode One Way Menggunakan Alat Statistik SPSS. Sevita Sari Dewi, Rizka Ermina, Veila Anggoro Kasih, Fera Hefiana, Agus Sunarni, Rini Widianingsih. Fakultas Ekonomi dan Bisnis. Universitas Jendral Soedirman," vol. 2, no. 2, pp. 121–132, 2023.

[13] M. R. Braun, P. Walton, S. B. M. Beck, and W. London, "Illustrating the relationship between the coefficient of performance and the coefficient of system performance by means of an R404 supermarket refrigeration system," Int. J. Refrig., vol. 70, pp. 225–234, 2016, doi: 10.1016/j.ijrefrig.2015.10.020.

[14] Z. Ma, H. Bao, and A. P. Roskilly, "Thermodynamic modelling and parameter determination of ejector for ejection refrigeration systems," Int. J. Refrig., vol. 75, pp. 117–128, 2017, doi: 10.1016/j.ijrefrig.2016.12.005.

[15] M. Sarstedt and J. F. Hair, "Evaluating the Use of Exploratory Factor Analysis in Business Research," Journal of Business Research, vol. 146, pp. 1–12, 2022. doi:

10.1016/j.jbusres.2022.03.043.
[16] J. F. Hair, G. T. M. Hult, C. M. Ringle, and M. Sarstedt, A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM), 3rd ed. Thousand Oaks, CA, USA: Sage, 2022.
[17] A. Kamath, S. Poojari, and K. Varsha, "Assessing the Robustness of Normality Tests Under Varying Skewness and Kurtosis: A Practical Checklist for Public Health Researchers," BMC Medical Research Methodology, vol. 25, Art. no. 206, 2025, doi: 10.1186/s12874-025-02641-y.
[18] T. Uematsu, "Testing Normality for Quantitative Values Obtained From Repeated Dose Administration Toxicity Studies—Fraught With Challenges," Fundamental Toxicological Sciences, vol. 12, no. 2, pp. 49–55, 2025, doi: 10.2131/fts.12.49.