International Journal of Engineering and Innovative Research

http://dergipark.gov.tr/ijeir

INVESTIGATION OF PEAK POWER AND TECHNOLOGY OF PHOTOVOLTAIC IN ENERGY OUTPUT ACCORDING TO SYSTEM LOSS

Savaş Evran[1*], Ozan Deniz[2]

[1,2]Çanakkale Onsekiz Mart University, Faculty of Çanakkale Applied Sciences, Department of Energy Management, Çanakkale, Turkey.

[*]Corresponding Author: sevran@comu.edu.tr
(**Received:** 30.03.2020; **Revised**: 11.04.2020 **Accepted:** 13.04.2020)

ABSTRACT: The aim of this study is to evaluate the effects of peak power and technology of photovoltaic (PV) in energy output from fix-angle PV system according to system loss. The maximum efficiency tests were conducted using L8 orthogonal array with three control factors including two levels based on Taguchi method. Control factors consist of Peak PV power, PV technology, and system loss. In order to organize the optimum levels and effects of the control factors in the energy output, signal-to-noise (S/N) ratio analysis was implemented. The most effective control factors in the energy output were found by analysis of variance (ANOVA). According to results obtained, the most control factors in energy output were detected as peak PV power with 65.60 % contribution, PV technology with 19.37 % contribution, and system loss with 14.94 % contribution, respectively. The increase of levels of peak PV power and PV technology leads to the increase of energy output data while increase of level of system loss causes the decrease of energy output.

Keywords: Photovoltaic, PV power, PV module, Taguchi method.

1. INTRODUCTION

Many factors in the use of photovoltaic (PV) modules can play a significant impact on energy output. For example, peak PV power, PV technology, and PV system loss may be some of these factors. In addition, environmental factor such as temperature can has important effect in energy output of PV modules. A study [1] was mentioned that temperature of the photovoltaic modules occurs important effect on the energy harvest and energy conversion efficiency of solar cells. In open literature, there are many studies including PV modules. van Dyk et all. [2] presented a study about the planning of a low-cost current–voltage calculating system to display the current–voltage characteristics of different photovoltaic modules and they analyzed overall operational efficiencies between different years. Adinoyi and Said [3] analyzed the influence of dust on the performance of solar photovoltaic modules including various technologies and they also compared modules with each other for a tracker and fixed stand based on various times. Chang [4] analyzed electric energy obtained using photovoltaic module for various azimuths and tilt angles based on different months. Fanney et all. [5] presented a study including comparison of performance analyses of photovoltaic modules. Carr and Pryor [6] compared the performance of five various photovoltaic modules based on temperate climates. Xu et all. [1] investigated the effect of dust deposition on the temperature of soiling photovoltaic glass based on lighting and windy situations according to experimental analyses. Sarver et all. [7] presented an extensive review consisting of influence of dust on the use of solar energy. Muzathik [8] reported an new method for predicting the operating temperature of a photovoltaic module depending on a simple correlation. Schwingshackl et all. [9] analyzed wind influence on temperature of the photovoltaic modules. Jiang and Lu [10] evaluated the energy output ratio based on various surface temperatures of the photovoltaic modules and they used particle deposition densities in analyses. As can be seen from literature review mentioned, many studies based on PV modules have been published. In this study, the effects of peak power and technology of PV in energy output from fix-angle PV system were evaluated according to system loss. Numerical data were determined according to Taguchi L8 orthogonal array and optimal level of each control factor was found using S/N ratio analysis.

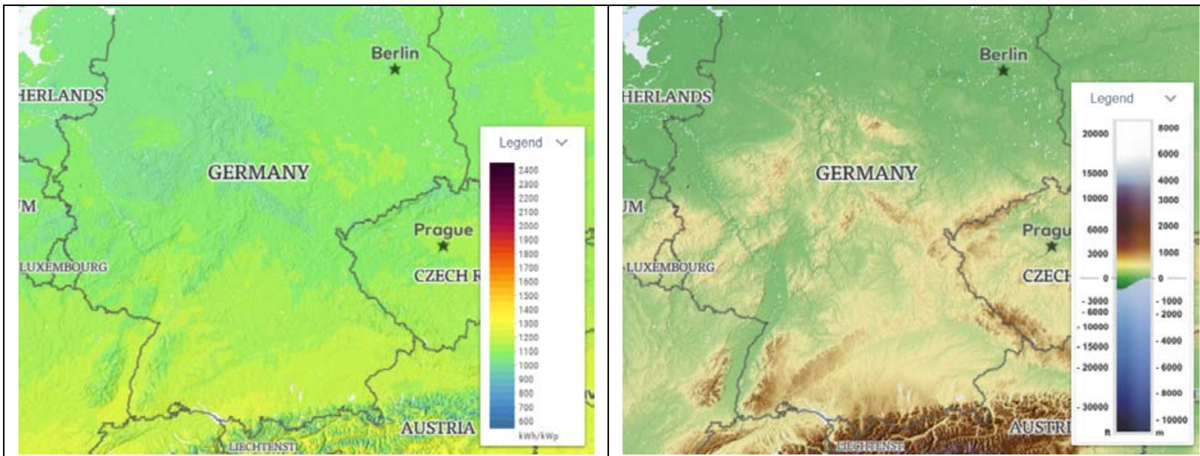
2. MATERIALS AND METHODS

In the tests, energy output from fix-angle PV system were used based on different factors and these data were taken from photovoltaic geographical information system (PVGIS) directly [11]. In this system, there are three different satellite-based databases. In analysis, energy output data used were taken from satellite-based databases called PVGIS-CMSAF and these data were presented in Table 1 [11].

Table 1. Energy output from fix-angle PV system

PV Technology	Peak PV Power (kWp)	System Loss (%)	Energy Output [11] (kWh)
CIS	1.0	10	128.66
CIS	1.0	14	122.94
CIS	1.1	10	141.52
CIS	1.1	14	135.23
CdTe	1.0	10	135.49
CdTe	1.0	14	129.47
CdTe	1.1	10	149.04
CdTe	1.1	14	142.42

Latitude and longitude were used to be 48.137 and 11.575 in degree. Map layers for specific photovoltaic power output and elevation of Germany were demonstrated in Figure 1 [13].



(a) (b)

Figure 1. Map layers (a) specific photovoltaic power output and (b) elevation [13]

The tests were organized using L8 orthogonal array based on Taguchi method. The orthogonal array has three control factors, which consist of two levels. As the first control factor, two different types of thin film modules were used. These are Copper Indium Selenide (CIS) and Cadmium Telluride (CdTe). The types of thin film modules were determined as levels of the first control factor. As the second control factor, peak PV power was utilized. This control factor is that the manufacturer reports that PV array may produce based on standard analysis, which is a stable 1000 W of solar irradiation per square meter in the plane of the array, for an array temperature of 25°C [11]. As the third control factor, system loss was used and it is related to loss, such as losses in cables, power inverters, dirt performed on the modules etc. [11]. The control factors and their levels were presented in Table 2.

Table 2. Control factors and levels

Control Factors	**Symbol**	**Levels**	
		Level 1	**Level 2**
PV Technology	A	CIS	CdTe
Peak PV Power	B	1.0	1.1
System Loss	C	10	14

In order to calculate the maximum energy output data, the signal-to-noise ratio analysis was conducted using “higher is better” quality characteristic and it was demonstrated in Equation 1 [12].

$$(S/N)_{HB} = -10.\log\left(n^{-1}\sum_{i=1}^{n}\left(y_i^2\right)^{-1}\right) \tag{1}$$

In Equation 1, n is organized to be the number of tests for energy output in a trial and yi demonstrates ith data determined. The S/N ratio analysis was implemented based on Minitab 15 statistical software. In addition, main effect plot for S/N ratio data of control factors was performed using statistical software Minitab 15.

3. RESULTS AND DISCUSSIONS

This study deals with evaluation the influences of peak power and technology of PV in energy output from fix-angle PV system according to system loss. Energy output data obtained using control factors were converted to S/N ratios using Minitab 15 statistical software and these results were listed in Table 3.

Table 3. Energy output data and their S/N ratios

Test	**Combination**	**Results**	
		Energy Output [11]	**S/N ratio**
1	$A_1B_1C_1$	128.66	42.1889
2	$A_1B_1C_3$	122.94	41.7939
3	$A_1B_2C_1$	141.52	43.0164
4	$A_1B_2C_3$	135.23	42.6215
5	$A_2B_1C_1$	135.49	42.6381
6	$A_2B_1C_3$	129.47	42.2434
7	$A_2B_2C_1$	149.04	43.4661
8	$A_2B_2C_3$	142.42	43.0714
Overall Mean ($\overline{T_{E_O}}$)		135.60	-

3.1. Analysis of Control Factors

In order to see the optimum levels and effects of control factors such as peak PV power, PV technology, and system loss in energy output from fix-angle PV system, S/N data of average means for each level of each control factor were calculated according to “larger is better” quality characteristic. Data obtained were given in Table 4.

Table 4. Response table for S/N ratios and means

Level	S/N ratio data in dB			Means in kWh		
	A	B	C	A	B	C
1	42.41	42.22	42.83	132.10	129.10	138.70
2	42.85	43.04	42.43	139.10	142.10	132.50
Delta	0.45	0.83	0.39	7.00	12.90	6.20
Rank	2.00	1.00	3.00	2.00	1.00	3.00

It can see from Table 4 that the optimum levels for peak PV power and PV technology were obtained using data at second level. However, the optimum level of system loss in energy output was found at the first level. In addition, as can be understood from Figure 2, the increase of levels of peak PV power and PV technology leads to the increase of energy output data while increase of level of system loss causes the decrease of energy output.

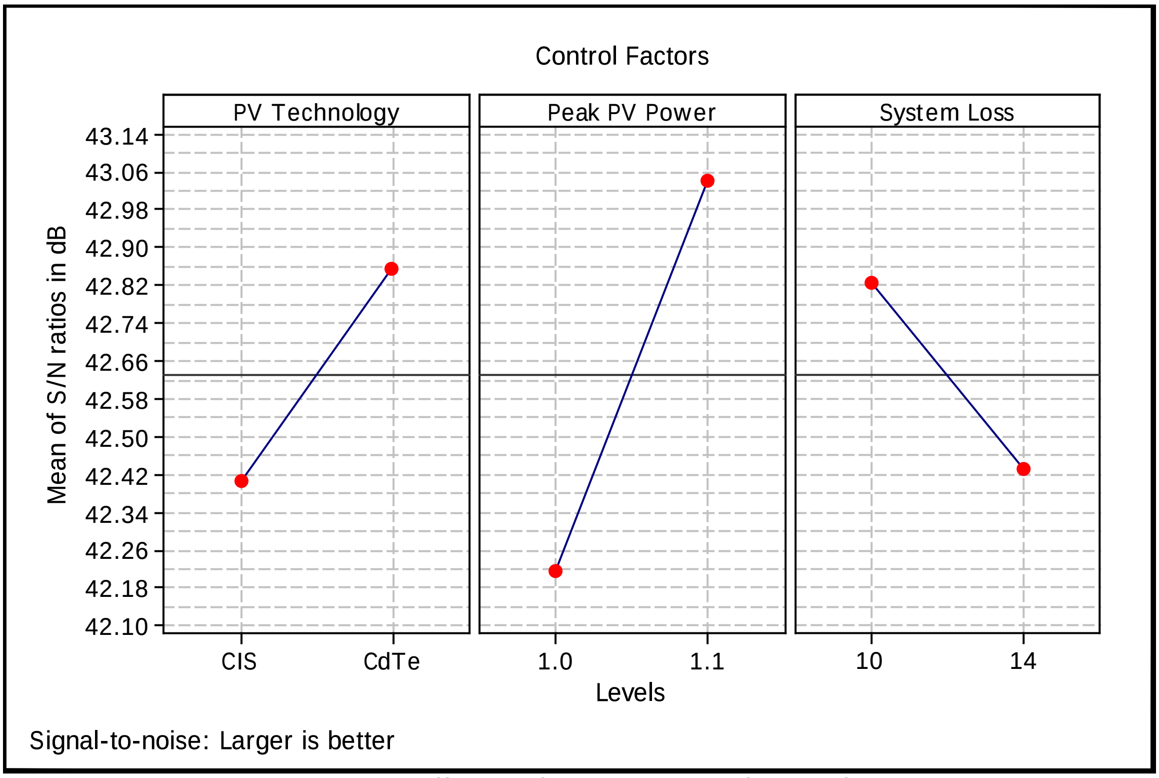


Figure 2. Main effect plot for S/N ratio data of control factors

3.2 Analysis of Variance

Each control factor has different contribution in energy output. In order to define the significant control factors and their percent contributions in energy output, analysis of variance (ANOVA) were implemented at 95 % confidence level. Results calculated for R-Sq = 99.91 % and R-Sq (adj) = 99.85 % were tabulated in Table 5.

Table 5. ANOVA results for energy output

Source	DF	Seq SS	Adj MS	F	P	% Contribution
A	1	98.49	98.49	878.11	0	19.37
B	1	333.47	333.47	2973.06	0	65.60
C	1	75.95	75.95	677.17	0	14.94
Error	4	0.45	0.11			0.09
Total	7	508.36				100.00

In order to determine significant control factors, P values were used. As can be seen from Table 5, PV technology, peak PV power, and system loss were found to be significant control factors since P = 0 is smaller than 0.05 data. In addition, the most control factors in energy output were detected as peak PV power with 65.60 % contribution, PV technology with 19.37 % contribution, and system loss with 14.94 % contribution, respectively. In analysis, error data was calculated to be 0.09 % contribution.

3.2 Estimation of Optimum Energy Output

In order to estimate the optimum energy output from fix-angle PV system for the maximum result, the significant control factors with optimum levels were used. The optimum result of energy output was carried out using A and B at the second level and C with the first level. The estimated mean of energy output can be solved using Equation 2 [12].

$$\mu_{\sigma_T} = \overline{A_2} + \overline{B_2} + \overline{C_1} - 2\overline{T_{E_O}} \tag{2}$$

In Equation 2, $\overline{A_2}$ = 139.1, $\overline{B_3}$ = 142.1, and $\overline{C_2}$ = 138.7 refer to average numerical values of A and B at the second level, and C with the first level respectively and these results were given in Table 4. Also, $\overline{T_{E_O}}$ = 135.6 shows the overall mean in accordance with Taguchi L8 orthogonal array in Table 3. Substituting data mentioned of various terms in Equation 2, μ_{E_O} is found to be 148.7 W. 95 % confidence intervals of confirmation test and population were solved according to Equation 3 and Equation 4 [12].

$$CI_{CT} = \left(F_{\alpha;1;n_2} V_{error}\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]\right)^{1/2} \tag{3}$$

$$CI_{POP} = \left(\frac{F_{\alpha;1;n_2} V_{error}}{n_{eff}}\right)^{1/2} \tag{4}$$

$$n_{eff} = \frac{N}{(1 + T_{DOF})} \tag{5}$$

where, $\alpha = 0.05$ presents the risk and $n_2 = 4$ is the error data regarding the degree of freedom in analysis of variance. $F_{0.05;1;4}$ is examined to be 7.71 [12] in accordance with F ratio table at 95 % confidence interval. T_{DOF} express the total number of degrees of freedom in accordance with the significant control factors and the value was organized to be 3. R refers to the sample size of confirmation tests of energy output and the data is utilized as 1. N denotes the total number of tests performed for energy output and it was solved to be 8 regarding Taguchi's L8 orthogonal array including 8 different combinations of control factors. V_{error} express the error value of variance in accordance with ANOVA data and this value is presented to be 0.11 in Table 5. n_{eff} was explained to be 2 value. As a result, CI_{CT} and CI_{POP} were analyzed as ± 1.13

and ± 0.65, respectively. The predicted confidence interval in accordance with confirmation tests for energy output [12] is:

$$\text{Mean } \mu_{E_O} - CI_{CT} < \mu_{E_O} < CI_{CT} + \text{Mean } \mu_{E_O}$$

The population related to the 95 % confidence interval [12] is:

$$\text{Mean } \mu_{E_O} - CI_{POP} < \mu_{E_O} < CI_{POP} + \text{Mean } \mu_{E_O}$$

The reference and predictive results for the optimal approach in accordance with predicted confidence intervals were tabled in Table 6.

Table 6. Optimal results for reference and predicted data

Combination	Reference [11]	Predictive Result	Estimated Confidence Intervals at 95% Confidence Level
$A_2B_2C_1$	149.04 W	148.70 W	$147.57 < \mu_{E_O} < 149.83$ for CI_{CT}
			$148.05 < \mu_{E_O} < 149.35$ for CI_{POP}

4. CONCLUSIONS

In the study, effects of PV module technology, peak PV power, and system loss in energy output from fix-angle PV system were analyzed using L18 orthogonal array, which have three control factors, based on Taguchi method. Numerical data were taken from photovoltaic geographical information system (PVGIS) directly. Optimum levels and significant levels of control factors were determined using S/N ratio and ANOVA analyses, respectively. Conclusions obtained from present study are as follows:

- Compared with thin film module made of CIS, the energy output obtained using thin film module made from CdTe is higher.
- The increase of peak PV power values causes the increase of the energy output whereas the decrease of system loss leads to the increase of the energy output.
- PV technology, peak PV power, and system loss were determined as the significant control factors since P value is smaller than 0.05 value according to ANOVA. In addition, the most control factors in energy output were identified as peak PV power with 65.60 % contribution, PV technology with 19.37 % contribution, and system loss with 14.94 % contribution, respectively.
- The optimum levels of control factors were found using thin film made of CdTe, peak PV power at the second level, and system loss at the first level.
- Estimated confidence intervals for 95% confidence level were found to be $147.57 < \mu_{E_O} < 149.83$ for CI_{CT} and $148.05 < \mu_{E_O} < 149.35$ for CI_{POP}.

REFERENCES

[1] Xu L, Li S, Jiang J, Liu T, Wu H, Wang J, et al. (2020). The influence of dust deposition on the temperature of soiling photovoltaic glass under lighting and windy conditions. Solar Energy, 199, 491-6.

[2] van Dyk EE, Gxasheka AR, Meyer EL, (2005). Monitoring current–voltage characteristics and energy output of silicon photovoltaic modules. Renewable Energy, 30, 399-411.

[3] Adinoyi MJ, Said SAM, (2013). Effect of dust accumulation on the power outputs of solar photovoltaic modules. Renewable Energy, 60, 633-6.

[4] Chang TP, (2009). Output energy of a photovoltaic module mounted on a single-axis tracking system. Applied Energy, 86, 2071-8.

[5] Fanney AH, Davis MW, Dougherty BP, King DL, Boyson WE, Kratochvil JA, (2006). Comparison of Photovoltaic Module Performance Measurements. Journal of Solar Energy Engineering, 128, 152-9.

[6] Carr AJ, Pryor TL, (2004). A comparison of the performance of different PV module types in temperate climates. Solar Energy, 76, 285-94.
[7] Sarver T, Al-Qaraghuli A, Kazmerski LL, (2013). A comprehensive review of the impact of dust on the use of solar energy: History, investigations, results, literature, and mitigation approaches. Renewable and Sustainable Energy Reviews, 22, 698-733.
[8] Muzathik A, (2014). Photovoltaic modules operating temperature estimation using a simple correlation. International Journal of Energy Engineering, 4, 151-8.
[9] Schwingshackl C, Petitta M, Wagner JE, Belluardo G, Moser D, Castelli M, et al, (2013). Wind Effect on PV Module Temperature: Analysis of Different Techniques for an Accurate Estimation. Energy Procedia, 40, 77-86.
[10] Jiang Y, Lu L (2015). A Study of Dust Accumulating Process on Solar Photovoltaic Modules with Different Surface Temperatures. Energy Procedia, 75, 337-42.
[11] https://eceuropaeu/jrc/en/pvgis.
[12] Ross PJ, (1996). Taguchi Techniques for Quality Engineering, McGraw-Hill International Editions, 2nd Edition, New York, USA.
[13] https://globalsolaratlas.info/map.