International Journal of Engineering and Innovative Research

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EVALUATION OF EFFECTS OF ORIENTATION ANGLE AND MOUNTING POSITION OF PV MODULES IN ENERGY OUTPUT FOR DIFFERENT LONGITUDES

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(**Received:** 05.04.2020; **Revised:** 10.04.2020 **Accepted:** 13.04.2020)

ABSTRACT: This study focuses on influences of orientation angle and mounting position of PV modules on energy output for different longitudes in August. Analyses were carried out using L8 orthogonal array, which has three control factors with two levels, according to Taguchi technique. Orientation angle and mounting position of PV modules and longitude were considered as control factors. Effects and the optimum levels of control factors in PV energy output were evaluated using analysis of Signal-to-Noise (S/N) ratio whereas importance and percentage contribution rates of control factors on PV energy output were determined using analysis of variance (ANOVA) at 95 % confidence level. According to results, the optimum energy output was obtained using the first levels of PV orientation angle, PV modules mounting position, and longitude. PV orientation angle, PV mounting position, and longitude are the significant control factors due to $P < 0.05$ value. Also, the most effective control factors are found to be PV mounting position which has 95.23 % contribution, longitude which has 2.98 % contribution, and PV orientation angle which has 1.67 % contribution, respectively.

Keywords: Orientation Angle, Mounting position, PV Module, Longitude.

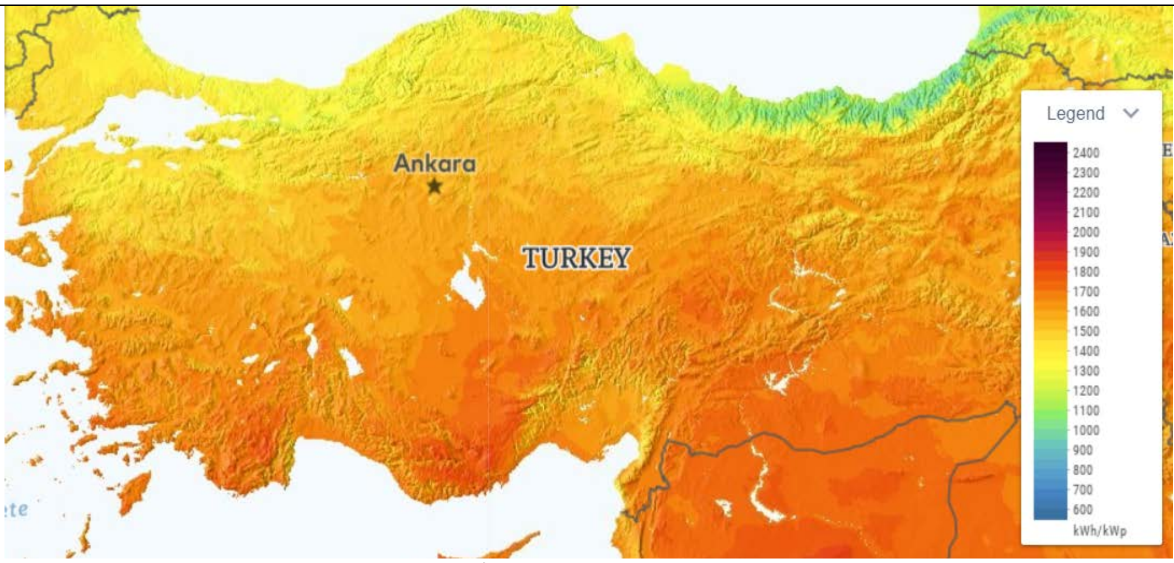
1. INTRODUCTION

The need for renewable energy has been increasing all over the world in recent years. Some of renewable energy resources are solar energy, wind energy, biomass energy, tidal power, geothermal energy [1]. Solar energy is known as one of the cleanest energy resources and it is generally referred to as “alternative energy” to sources including fossil fuel energy such as oil and coal [2]. A lot of studies have been presented due to the excessive use of solar energy. In literature, there are also many studies including PV modules. Sreenath et al. [3] investigated the formation of glare and its effect from the offered solar PV plant mounted in an airport. Shukla et al. [4] presented a study on building integrated photovoltaic applications for sustainable building based on South Asian countries. Hussein et al. [5] determined performance analyses of photovoltaic modules in accordance with various tilt angles and orientations. Kern and Harris [6] presented a study consisting of the optimal tilt of a solar collector. Xu et al. [7] investigated the optimal tilt angle of a photovoltaic panel soiled. Gunerhan and Hepbasli [8] examined the optimal tilt angle for solar collectors in accordance with building applications. Wilson and Paul [9] evaluated the influences on convection occurring using a photovoltaic panel based on a computational fluid dynamic model. Chang [10] analysed theorical electric energy output using photovoltaic modules in accordance with various tilt and azimuths angles in Taiwan. In literature, there are different studies with PV modules. In this study, effects of orientation angle and mounting position of PV modules on energy output for different longitudes in August using

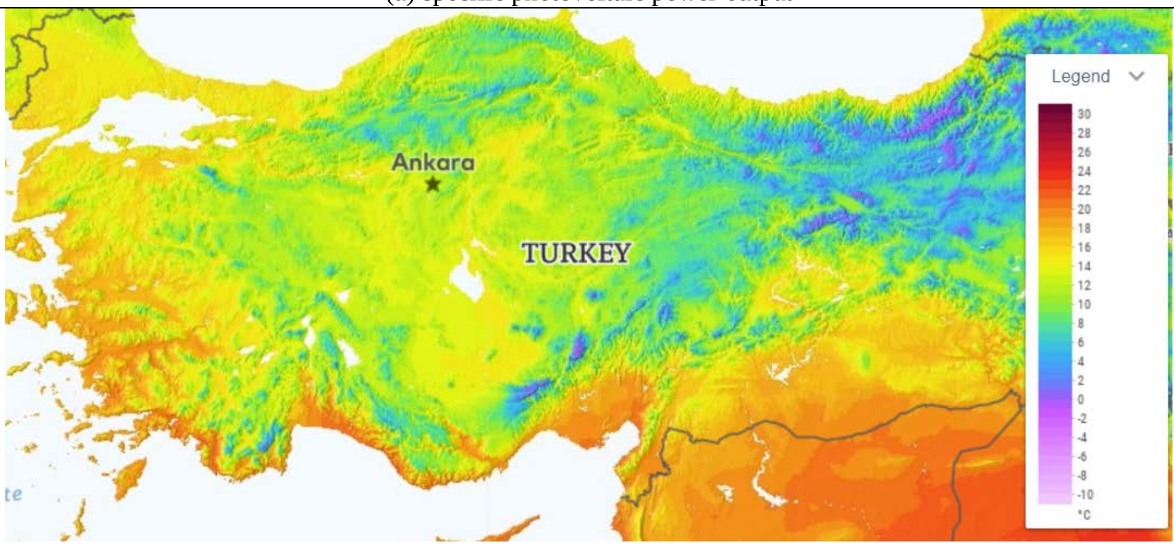
L8 orthogonal array, which have three control factors with two levels, according to Taguchi technique were evaluated.

2. MATERIALS AND METHODS

In analyses, the effect of mounting position of photovoltaic modules was evaluated in energy output. This factor is related to air temperature directly. The map layers regarding specific photovoltaic power output and the air temperature of areas for Turkey were presented in Figure 1 [11].



(a) specific photovoltaic power output



(b) air temperature

Figure 1. Map layers (a) specific photovoltaic power output and (b) air temperature [11].

Statistical analysis was conducted using Taguchi's L8 orthogonal array design and this array contains three control factors with two levels. Longitudes for areas in Turkey, mounting position of PV modules, and orientation angle of PV modules were accepted as control factor in determining energy output. Latitude value for every area was considered as 38.6 in degree while longitude values were used to be 27.5 and 41.5 in degree. For second control factor, mounting position of PV modules were assumed as free-standing and building-integrated systems. In free-standing system, the PV modules are fixed on a rack consisting of air flowing easily behind the modules [12]. In building-integrated system, PV modules are totally constructed into the structure of the wall or roof of a building and so air movement behind the modules was not occurred [12]. For third control factor, orientation angle of PV modules was considered as 0 and 5 in degree. In addition, this angle was generally used as azimuth and it is the angle of PV modules relative to South [12]. East, South, and West were determined as -90°, 0°, and 90° [12]. Control factors used and their levels in analyses were presented in Table 1.

Table 1. Control factors and levels

Control Factors	Symbol	Level 1	Level 2
Longitude	A	27.5	41.5
Mounting Position	B	free-standing	building-integrated
Orientation Angle	C	0	5

In analyses, data for PV energy outputs were obtained using control factors with different levels. These data were used from photovoltaic geographical information system (PVGIS) [12]. In system, there are many different solar radiation databases with hourly time resolution. However, in this study, analyses were performed using satellite-based database named as PVGIS-CMSAF, which is old default satellite-based database of PVGIS 4 for areas such as Europe, Africa and some areas of South America [12]. Energy output data obtained for different control factors including various levels were shown in Table 2 [12].

Table 2. PV energy output

Longitude (degree)	Mounting Position (-)	Orientation Angle (degree)	PV Energy Output [12] (kWh)
27.5	free-standing	0	168.63
27.5	free-standing	5	167.79
27.5	building-integrated	0	160.55
27.5	building-integrated	5	159.75
41.5	free-standing	0	167.32
41.5	free-standing	5	165.99
41.5	building-integrated	0	159.52
41.5	building-integrated	5	158.30

In order to obtain the highest energy output data, statistical analysis were carried out using "The higher is better" quality characteristic based on Taguchi Method and the approach was given in Equation 1 [13].

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

In here, n represents the number of analyses for energy output in a trial and yi shows ith data. In order to see effects of control factors in energy outputs, the S/N ratio analysis was employed using Minitab 15 statistical software [14].

3. RESULTS AND DISCUSSIONS

This study deals with influences of orientation angle and mounting position of PV modules on energy output for different longitudes in August based on L8 orthogonal array design with three control factors at two levels. PV energy outputs obtained from photovoltaic geographical information system and their S/N ratio data for "The higher is better" quality characteristic were tabulated in Table 3.

Table 3. Results and S/N ratio data

Test	Designation	Results	
		PV Energy Output [12] (kWh)	**S/N ratio η (dB)**
1	$A_1B_1C_1$	168.63	44.5387
2	$A_1B_1C_2$	167.79	44.4953
3	$A_1B_2C_1$	160.55	44.1122
4	$A_1B_2C_2$	159.75	44.0688
5	$A_2B_1C_1$	167.32	44.4710
6	$A_2B_1C_2$	165.99	44.4016
7	$A_2B_2C_1$	159.52	44.0563
8	$A_2\ B_2C_2$	158.30	43.9896
Overall Means ($\overline{E_s}$)		163.48	-

3.1. Examination of control factors

In order to find the optimal levels of PV orientation angle, PV mounting position, and longitudes in energy output, average means and their S/N ratio data in accordance with each control factor at two levels for energy output data were calculated by Minitab R15 statistical software. The results were shown in Table 4.

Table 4. Response table for S/N ratio and mean

Level	S/N ratio in dB			Mean (kWh)		
	A	**B**	**C**	**A**	**B**	**C**
1	44.30	44.48	44.29	164.20	167.40	164.00
2	44.23	44.06	44.24	162.80	159.50	163.00
Delta	0.07	0.42	0.06	1.40	7.90	1.00
Rank	2	1	3	2	1	3

Table 4 shows that the optimal control factors were obtained for the first levels. In order to see effects of PV orientation angle, PV mounting position, and longitudes, average S/N ratio data for control factors at two levels based on energy output data were plotted in Figure 2. According to Figure 2, the increase of levels of PV orientation angle, PV mounting position, and longitudes causes the decrease of energy output in system.

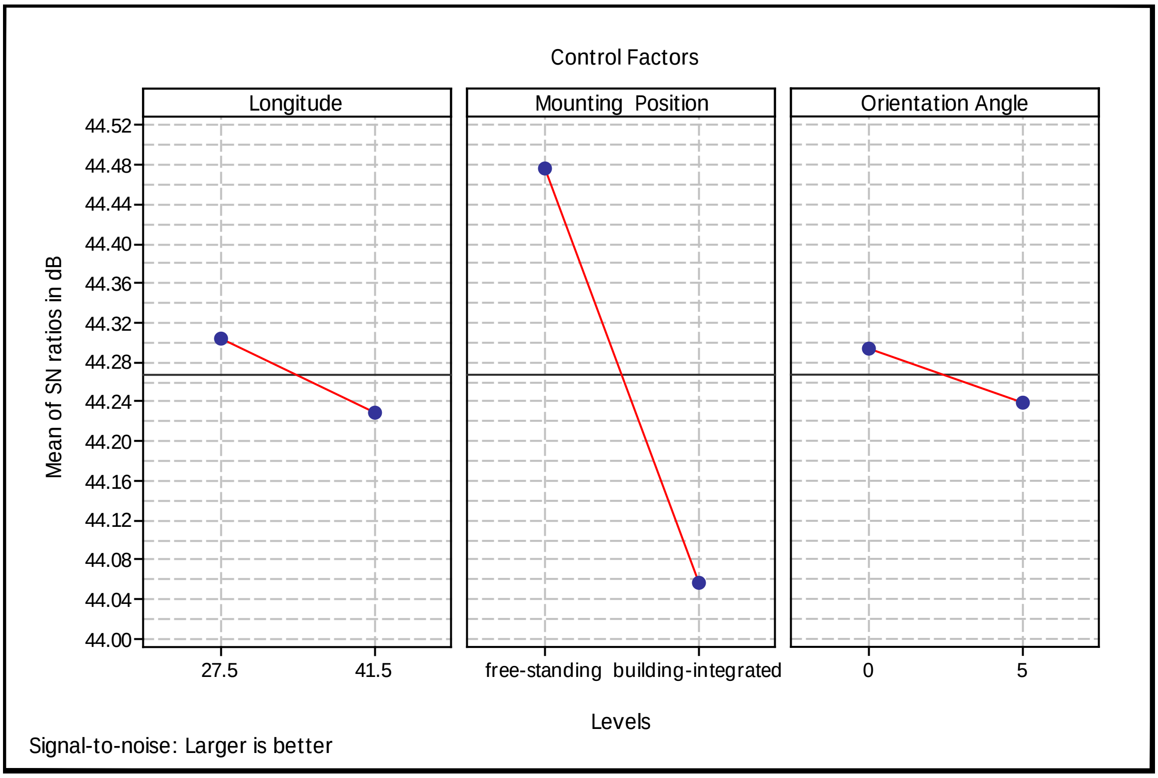


Figure 2. Effects of control factors in energy output

3.2. Analysis of Variance for energy output

In this study, three different control factors which have two levels were used and each control factor has various % effects in energy outputs. In order to calculate the % influences and the significant levels of PV orientation angle, PV mounting position, and longitude, variance analysis (ANOVA) was employed at 95 % confidence level. ANOVA results for R-Sq = 99.88 % and R-Sq (adj) = 99.79 % was presented in Table 5.

Table 5. Analysis of Variance for energy output

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Effect
A	1	3.906	3.906	3.906	99.80	0.001	2.98
B	1	124.899	124.899	124.899	3191.29	0.000	95.23
C	1	2.195	2.195	2.195	56.07	0.002	1.67
Error	4	0.157	0.157	0.039			0.12
Total	7	131.156					100

As can be seen from Table 5, PV orientation angle, PV mounting position, and longitude are the significant control factors due to $P < 0.05$ value. Also, the most effective control factors are found to be PV mounting position which has 95.23 % influence, longitude which has 2.98 % influence, and PV orientation angle which has 1.67 % influence, respectively.

3.3. Prediction of optimal energy output

In order to predict the optimal energy output for the highest data, the significant levels among PV orientation angle, PV mounting position, and longitudes were selected. Therefore, energy output data based on the optimal levels of control factors (A, B, C) were determined. The optimal result of response was calculated using control factors at the first levels. The predicted mean of energy output may be calculated based on Equation 2 [13].

$$\mu_{E_s} = \overline{A_1} + \overline{B_1} + \overline{C_1} - 2\overline{T_{E_s}} \tag{2}$$

In here, $\overline{A_2}$ = 164.20, $\overline{B_2}$ = 167.40, and $\overline{C_2}$ = 164.00 express the average means of PV orientation angle, PV mounting position, and longitude at the first levels for energy outputs. These data were given in Table 4. $\overline{T_s}$ is calculated as 163.48 and it is the average mean based on Taguchi's L8 orthogonal array. This data was given in Table 3. Substituting data given of different terms in Equation 2, μ_{E_s} is calculated be 168.64 kWh. Confirmation analysis and population at 95 % confidence intervals were solved in accordance with Equation 3 and Equation 4 [13].

$$CI_{CA} = \left(F_{\alpha;1;n_2} V_{error}\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]\right)^{0.5} \tag{3}$$

$$CI_{POP} = \left(\frac{F_{\alpha;1;n_2} V_{error}}{n_{eff}}\right)^{0.5} \tag{4}$$

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

In here, $n_2 = 4$ is the error value for the degree of freedom in ANOVA and $\alpha = 0.05$ express the risk. $F_{0.05;1;4}$ is solved as 7.71 [13] based on data of F ratio table for 95 % confidence interval. R express the sample size of confirmation analysis of response and this value is determined to be 1. N demonstrates the sum of number of analysis carried out for response and numerical value of this term was taken as 8. T_{DOF} presents the sum of the number of degrees of freedom (DF) for the important control factors in analysis of variance and numerical value of this term was solved as 3. Therefore n_{eff} was calculated as 2. V_{error} illustrates the error value for Adj MS in analysis of variance and numerical value of this term is given as 0.039 in Table 5. Numerical data for CI_{CT} and CI_{POP} were calculated as ± 0.672 and ± 0.388, respectively. The estimated confidence interval for confirmation analyses [13] is:

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

The 95 % confidence interval of population [13] is:

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

The comparation of reference and predictive results for optimum result at estimated confidence intervals is presented in Table 6.

Table 6. Optimal results for reference and predicted data

Test	**Reference** [12]	**Predictive Result**	**Predicted Confidence Intervals for 95% Confidence Level**
$A_1B_1C_1$	168.63 kWh	168.64 kWh	167.968 < μ_{E_s} < 169.312 for CI_{CT}
			168.252 < μ_{E_s} < 169.028 for CI_{POP}

4. CONCLUSIONS

In this study, the effects of orientation angle and mounting position of PV modules on energy output for different longitudes in August were investigated. Analyses were performed using L8 orthogonal array, which has three control factors with two levels, according to Taguchi technique. Impacts and the optimal levels of control factors in PV energy output were determined using analysis of Signal-to-Noise (S/N) ratio whereas importance and percentage contribution rates of control factors on PV energy output were examined using analysis of variance (ANOVA) at 95 % confidence level. According to this study, the following conclusions can be summarized:

- The optimum energy output was obtained using the first levels of PV orientation angle, PV modules mounting position, and longitudes.
- The increase of PV orientation angle and longitudes leads to decrease of energy output.
- Compared with PV mounting position which has building-integrated system, energy output of PV mounting position with free-standing system is higher.
- PV orientation angle, longitudes, and PV mounting position are significant control factors due to $P < 0.05$ value. Also, the most effective control factors are found to be PV mounting position which has 95.23 % effect, longitude which has 2.98 % effect, and PV orientation angle which has 1.67 % effect, respectively.
- Predicted energy output data at 95 % confidence intervals of confirmation analyses were calculated as $167.968 < \mu_{E_s} < 169.312$ for CI_{CT} and $168.252 < \mu_{E_s} < 169.028$ for CI_{POP}.

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