Improving the Performance of Anti-Reflection Spray Coated Solar Photo-Voltaic Panels Using Optimization Technique

KIRTHIKA R[1*], CHANDRASEKAR M[2], SENTHILKUMAR T[3]

[1]Research Scholar, Department of Mechanical Engineering, University College of Engineeirng, BIT Campus, Anna University Tiruchirappalli – 620024*
[2]Assistant Professor, Department of Mechanical Engineering, University College of Engineeirng, BIT Campus, Anna University Tiruchirappalli – 620024
[3]Dean & Professor, Department of Mechanical Engineering, University College of Engineeirng, BIT Campus, Anna University Tiruchirappalli – 620024
Corresponding author- KIRTHIKA R

Abstract

In this investigation, an attempt was made for improvement of the efficiency of the solar photovoltaic panel, by optimizing the important coating process parameters. Anti reflection coating was sprayed on the surface of the photo voltaic by using cold spraying technique. The important cold spraying process parameters were identified and they were subjected to feasibility studies. Using a central composite design model, twenty different combinations of cold spray process parameters were identified. Accordingly, the panels were coated and the output of the solar panel was recorded in Watts per hour. Empirical relationships were developed between the cold spray coating process parameters and the solar output panel was established. Using Analysis of Variance, the significance of the developed model was ascertained. The important coating process parameters were optimized by using response surface methodology, to predict maximum output, which was validated (less than 5% error). Interactions and perturbation plots indicated that the output was more sensitive to coating thickness than other coating process parameters.

Keywords: *solar panel, performance, optimization, cold spray coating, analysis of variance.*

Introduction

In recent times, a lot of importance is being given to identify alternative sources of energy [1]. Investigations in harnessing solar energy have gathered attention as it is available in abundance [2]. Photovoltaic solar panels are being manufactured and used extensively for producing solar power [3]. The efficiency of photo voltaic panels depends upon different environmental conditions. As the solar panels are installed in the atmosphere, away from shade and in direct contact with sunlight, the surface gets soiled due to dust, rain, smoke etc [4]. Anti reflective coatings are being used in many applications to reduce the scatter of light [5]. A slight reduction in the scattering light causes a considerable improvement in the overall efficiency of the solar panel [6]. Anti reflective coats helps in improving the efficiency and prevents water clogging to the surface of the solar panel. Solar panel efficiency improvement is required as practical efficiency of solar panels is nearly 11-13% [7]. Coating materials have better spectral stability

 https://doi.org/10.37896/pd91.3/91335

and higher band gap [8]. Hence, they help in reducing reflection. Hence, in this investigation, an attempt was made for improving solar panel efficiency by using boron nitride based anti reflective coating.

Materials and Methods

For this investigation, an indigenously developed solar panel test kit was used (365 watt capacity panel). For coating boron nitride based coating powder (Hexagonal boron nitride material) was used. The solar panel test kit was fixed with standard measurement equipments or measurement of the solar irradiance, the wind speed, wind direction, precipitation/ rainfall and temperature at the surface. The testing was done in the roof top of Department of Mechanical Engineering, University College of Engineering, Bharathidasan Institute of Technology, BIT Campus, Anna University Tiruchirappalli, Tamil Nadu, India. For coating, cold spray coating technique was used to deposit a film of boron nitride mixed silica sol over the glass cover of the solar photo voltaic panel Nitrogen was used as the carrier gas to deposit silica sol mixed boron nitride over the glass surface. The pressure of the gas was maintained at 2.1 MPa. Temperature of the carrier gas was maintained at 25°C. Coating powder feed rate was fixed at 2.5 g/min. The three important coating process parameters used in this experiment was coating thickness (nanometer), distance of spraying (mm) and spraying velocity (m/s). Using previous literatures and trial studies, the coating thickness was varied from 200 to 600 nm. The distance of spraying was varied from 15 to 25 mm and the spray velocity was varies from 500 m/s to 900 m/s. For identification of the feasibility of the coating process parameters the following observations were made in the trial experiments. Using nano coat meter, the variations in the coating thickness was calculated.

i. When the thickness of coating was lesser than 200 nm, the coating did not cause any significant improvement in the performance of the solar panel.

ii. When the thickness of the coating was lesser than 600 nm, excessive thickness caused reduction in travel of sunlight through the coating and it caused a reduction in solar panel performance.

iii. When the distance of spraying was fixed lesser than 15 mm, the agglomeration of the sprayed particles were excessive causing reduction in transparency.

iv. When the distance of spraying was fixed greater than 25 mm, improper patches were observed and certain areas in the glass substrate were not coated properly.

v. When the cold spraying velocity was lesser than 500 m/s, the coating density was improper and resulted in lower efficiency of the solar panel.

vi. When the cold spraying velocity was greater than 900 m/s, excessive opaque patches were found in the sprayed glass, resulting in low performance of the solar panel.

ISSN: 0369-8963

With these observations, the feasible limits of the cold spraying process parameters have been tabulated and are shown in Table 1.

Table 1. Feasible limits of process parameters

S No	Process Parameters	Levels				
		-1.68	-1	0	+1	+1.68
1	Coating thickness (nm) (CT)	200	280	400	520	600
2	Distance of Spraying (mm) (DoS)	15	17	20	23	25
3	Cold spraying velocity (m/s) (CSV)	500	580	700	820	900

In Table 1, the lower and upper limit of the process parameters were coded as -1.68 and +1.68. As the number of input variables (Coating thickness, distance of spraying, cold spraying velocity), a central composite design model was chosen with 6 star and 6 central points. The central composite design model for cold sray coating was prepared with twenty conditions. As per the methodology indicated by Montgomery D C, the matrix was prepared [9]. +1.682 was termed as the upper most value and -1.682 was termed as the lower most value. The in-between values were developed according to the equation indicated below

$Yi = 1.682\ [2Y – (Y_{max} + Y_{min})]/(Y_{max} + Y_{min})$ --- Eq. 1

In the above equation, the value of the variable Y in coded form is Y_i. Y assumes any value from Y_{min} to Y_{max}. The least value is designated as Y_{min} and the maximum value is designated as Y_{max}. The solar panel glass surface was coated with the cold spray coating parameters indicated in Table 2. According to the cold spraying process parameters indicated in the central composite design model, twenty coatings were done. Out of the twenty combinations six were repetitive. This was to reduce the error which occurs during the experimental procedure. After coating the glass over the solar panel with anti reflective coating, it was placed in sunlight and its output was recorded. The output values are shown in Table 2.

Table 2 – Central composite model for cold spray coating

No	Coating thickness		Distance of Spraying		Cold spraying velocity		Output
	CT-(nm)		DoS - (mm)		CSV - (m/s)		Watts/hr
Run	Coded	Actual	Coded	Actual	Coded	Actual	
1	0	400	0	20	0	700	82.6306
2	-1	280	+1	23	+1	820	140.177
3	0	400	0	20	0	700	187.394
4	+1	520	-1	17	-1	580	153.162
5	+1	520	+1	23	-1	580	151.981
6	0	400	+1.68	25	0	700	228.71
7	0	400	0	20	-1.68	500	178.541
8	+1.68	600	0	20	-1	700	168.212

https://doi.org/10.37896/pd91.3/91335

9	+1	520	+1	23	+1	820	153.162
10	0	400	0	20	0	700	188.575
11	-1	280	-1	17	-1	580	146.079
12	0	400	0	20	0	700	178.541
13	-1.68	200	0	20	0	700	125.421
14	0	400	0	20	+1.68	900	191.526
15	-1	280	+1	23	-1	581	200.379
16	0	400	0	20	0	700	197.428
17	0	400	-1.68	15	0	700	196.248
18	0	400	0	20	0	700	199.199
19	-1	280	-1	17	+1	818	193.297
20	+1	520	-1	17	+1	818	197.428

Results & Discussion

3.1 Developing Empirical Relationship between coating process variables and the coated panel responses.

The responses recorded while conducting the experiments using coated solar panel was the output power in Watts/hr. According to the relationship developed by Paventhan et al., [10] the relationship between the three important input variables such as coating thickness, distance of spraying and coating velocity with the output variable has been expressed as follows

Output Power = f {CT, DoS, CSV} --- Eq.2

The response surface H of output power of the coated solar panel is shown as second order polynomial regression equation

$H = g_0 + \Sigma\, g_i\, x_i + \Sigma\, g_{ii}\, x_{i2} + \Sigma\, g_{ij}\, x_i x_j$ ---- Eq. 3

For the three important input variables such as coating thickness, distance of spraying and coating spray velocity the expression the second order equation is indicated as follows

Output Power = { $g_0 + g_1\,CT + g_2\,DoS + a_3\,CSV + a_{12}\,CT \times DoS + g_{13}\,DoS \times CSV + g_{23}\,CT \times CSV + g_{11}\,CT^2 + g_{22}\,DoS^2 + g_{33}\,CSV^2$ } --- Eq. 4

g_o is indicated as the average of all the responses. g_1, g_2, g_3,…,g_{nn} are the regression coefficients of the second order polynomial regression equation. For evaluating the coefficients

 https://doi.org/10.37896/pd91.3/91335

ISSN: 0369-8963

of the regression equation, Design Expert software was used. The significance of the developed model was identified by using student t test and p values. Analysis of variance (ANOVA) was used for identification of the significance of the developed model. The objective was to improve the efficiency of the coated solar panel to the maximum possible extent. ANOVA test results of the output enhancement model are shown in Table 3.

Table 3- ANOVA results

Source	Sum of squares (SS)	Degree of freedom (df)	Mean square (MS)	F - ratio	p-value Prob>F	Note
Model	2119.41	9	233.41	128.31	<0.0001	Significant
CT	23.46	1	23.46	12.42	0.0056	
DoS	154.21	1	154.21	84.21	<0.0001	
CSV	227.32	1	227.32	124.56	<0.0001	
CT x DoS	17.48	1	17.48	9.49	0.0017	
CT x CSV	1.3.64	1	1.3.64	57.32	<0.0001	
DoS x CSV	77.41	1	77.41	41.41	<0.0001	
CT^2	896.32	1	896.32	496.54	<0.0001	
DoS^2	441.21	1	441.21	243.21	<0.0001	
CSV^2	457.32	1	457.32	254.12	<0.0001	
Residual	18.91	10	1.84			
Lack of fit	8.21	5		0.86	0.5984	Not significant
Std. Dev		1.36		R^2	0.9912	
Mean		258.32		Adj	0.9835	
C.V. %		0.51		Pred	0.9465	
PRESS		77.32		Adeq precision	31.21	

In ANOVA analysis the value of "Prob>F" is used for identification of the terms which are significant. When the value is greater than 0.0500, it indicates that the values are not significant. As most of the terms are <0.0001, it indicates that the developed model was significant to 95% confidence level. Lack of fit with 0.5984) was not significant, the standard deviation was 1.36, R^2 value was 0.9912, Adj R^2 was 0.9835 and Predicted R^2 was 0.9465 indicating that the model was developed with very high significance level. For development of empirical relationships between the coating input process parameters and output, the coefficients were used. The empirical equation is indicated below

 https://doi.org/10.37896/pd91.3/91335

Output power = 245.95 + 1.32 CT – 3.32 DoS + 4.03 x CSV + 1.46 x CT x DoS + 3.35 x CT x CSV + 3.07 x DoS x CSV + 7.87 x CT^2 + 5.53 x DoS^2 + 5.71 x CSV^2 ---- Eq. 5

The correlation between the actual and the predicted output has been shown in Figure 1.

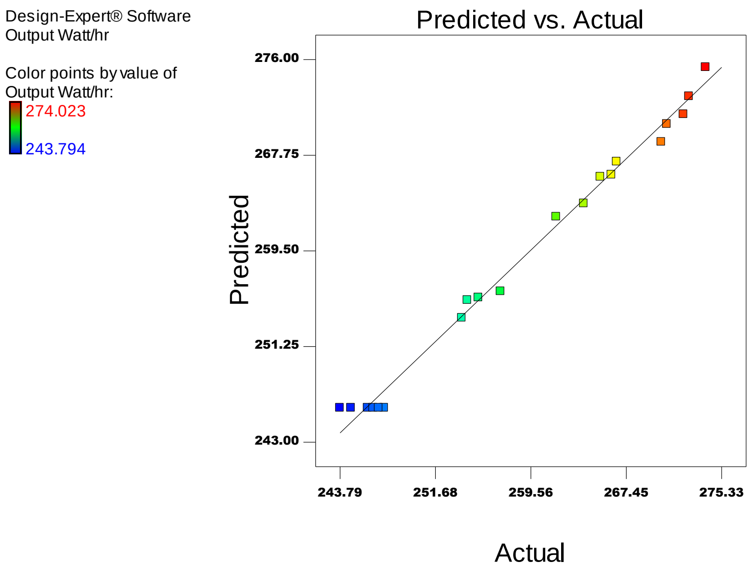


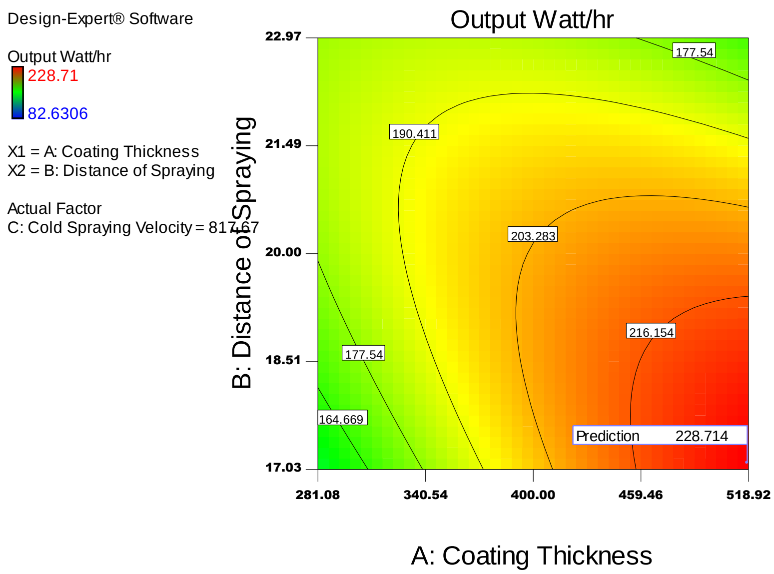
Figure 1. Correlation between the predicted and actual values of output power

From Figure 1, a high level of correlation between the predicted and actual values of output power was observed.

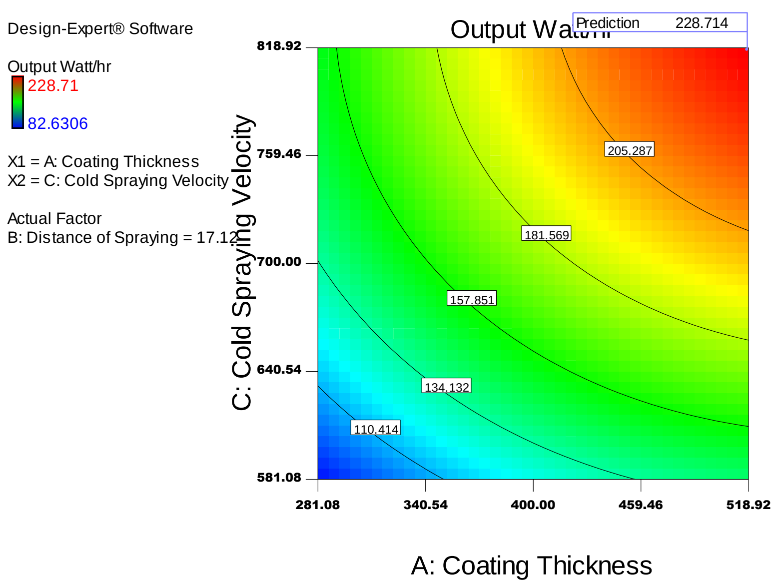
3.2 Optimizing important cold spray coating process parameters by using response surface methodology

Response surface methodology is a statistical and mathematical modeling tool which is being successfully used in different domains for obtaining predictable outputs with minimal number of inputs. In this investigation, response surface methodology was used for improving the output power of the coated solar panel. For this, contours and surface plots were developed. Contours are 2 dimensional plots used to identify the optimum combination of parameters for maximized output. 3-D surface plots enable identification of maximum, minimum or saddle point. The contour plots of the developed cold spray coating model is shown in Figure 2.

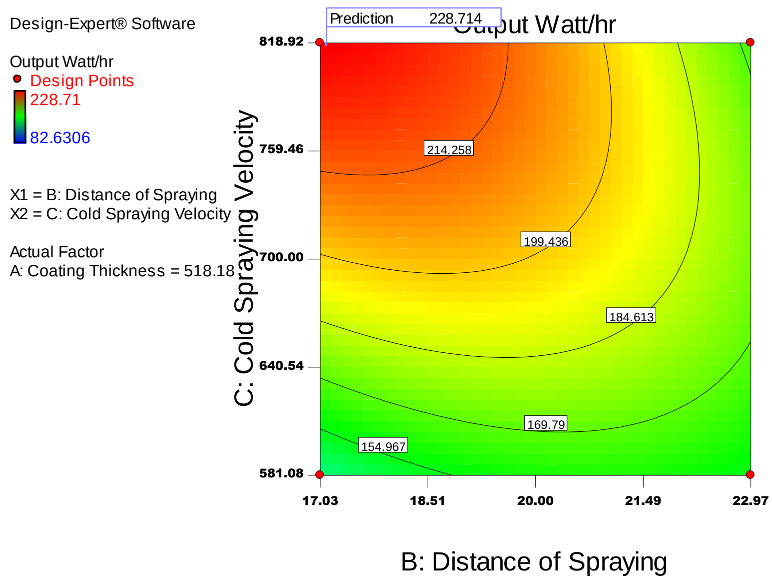
 https://doi.org/10.37896/pd91.3/91335


Design-Expert® Software
Output Watt/hr
228.71
82.6306
X1 = A: Coating Thickness
X2 = B: Distance of Spraying
Actual Factor
C: Cold Spraying Velocity = 817.67
Output Watt/hr
B: Distance of Spraying
A: Coating Thickness
Prediction 228.714

(a)


Design-Expert® Software
Output Watt/hr
228.71
82.6306
X1 = A: Coating Thickness
X2 = C: Cold Spraying Velocity
Actual Factor
B: Distance of Spraying = 17.12
Output Watt/hr
C: Cold Spraying Velocity
A: Coating Thickness
Prediction 228.714

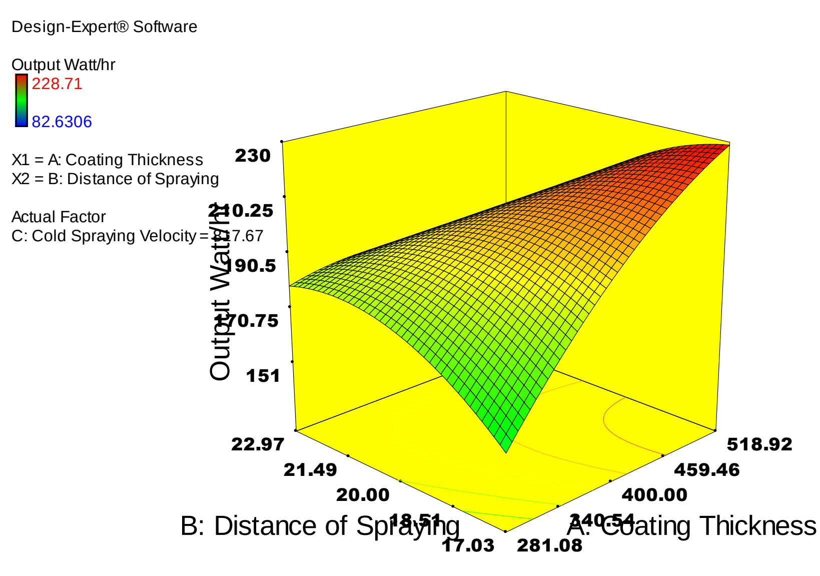
(b)



(c)

Figure 2 Contour plots for cold spray coating solar panel model

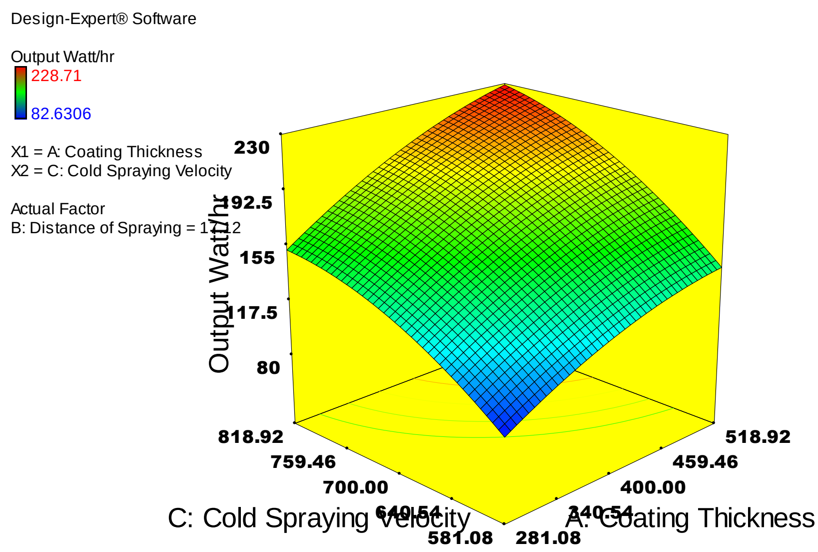
Figure 2 (a) shows the contour plots between distance of spraying and coating thickness. Figure 2 (b) shows the contour plots between cold spraying velocity and coating thickness. Figure 2 (c) shows the contour plots between cold spraying velocity and distance of spraying.



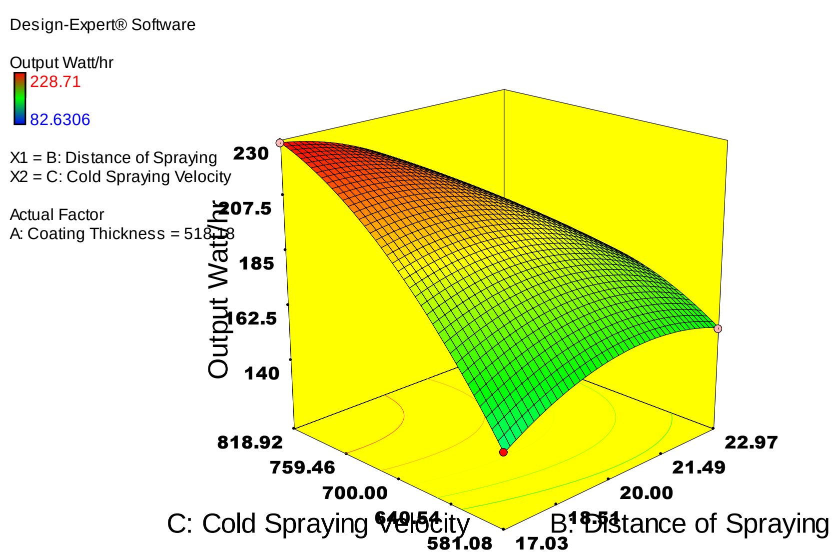
(a)

 https://doi.org/10.37896/pd91.3/91335

Volume 91, No. 3, 2022



(b)



(c)

Figure 3. Surface plots for cold spray coating solar panel model

The 3-D surface plots for cold spray coating solar panel model is shown in Figure 3.

Figure 3 (a) shows the surface plots between distance of spraying and coating thickness. Figure 3 (b) shows the surface plots between cold spraying velocity and coating thickness. Figure 3 (c) shows the surface plots between cold spraying velocity and distance of spraying. On evaluating the contour and surface plots the optimized values of process parameters were identified as 518

https://doi.org/10.37896/pd91.3/91335

nm thickness of coating, 17.1 mm distance for spraying and 817 m/s speed of cold spraying velocity. The predicted output power was 228.7 W/hr. For validation, three experiments were conducted using the optimized cold spray coating process parameters. The output was measured and the error between the predicted and actual values of output power is shown in Table 4. As the error between the predicted and actual output solar power was less than five percentage, it was observed that the optimization model was developed with very high predictability.

Table 4 - Validation results

Exp No	Coated Solar panel output power		Error %
	Predicted	Experimental	
1	228.7	219.6	-2.6
2		222.4	-2.4
3		220.6	-2.3

Conclusions

Hence, in this investigation an attempt was successfully made to improve the performance of photo voltaic solar panel using boron nitride coating on the surface of photo voltaic solar panel. Using a central composite design model, twenty experiments were conducted to identify the output power. Empirical relationships were developed between the important cold spray coating process parameters such as coating thickness, distance of spraying and spraying velocity. Using analysis of variance, the significance of the developed model was identified to more than 95% confidence level. Using response surface methodology, the process parameters were optimized. For the optimized values of 518 nm thickness of coating, 17.1 mm distance for spraying and 817 m/s speed of cold spraying velocity, the predicted output power was 228.7 W/hr. It was validated and as the error percentage was lesser 4 %, the model was found to be developed with high predictability.

ISSN: 0369-8963

REFERENCES

[1]. Farret, F. A., & Simões, M. G. (2006). Integration of alternative sources of energy (Vol. 504). Piscataway, NJ, USA: IEEE press.

[2]. Sukhatme, S. P., & Nayak, J. K. (2017). Solar energy. McGraw-Hill Education.

[3]. Dias, P. R., Benevit, M. G., & Veit, H. M. (2016). Photovoltaic solar panels of crystalline silicon: Characterization and separation. Waste Management & Research, 34(3), 235-245.

[4]. Maghami, M. R., Hizam, H., Gomes, C., Radzi, M. A., Rezadad, M. I., & Hajighorbani, S. (2016). Power loss due to soiling on solar panel: A review. Renewable and Sustainable Energy Reviews, 59, 1307-1316.

[5]. Krauter, S. (2004). Increased electrical yield via water flow over the front of photovoltaic panels. Solar energy materials and solar cells, 82(1-2), 131-137.

[6]. Rajvikram, M., & Leoponraj, S. (2018). A method to attain power optimality and efficiency in solar panel. Beni-Suef University journal of basic and applied sciences, 7(4), 705-708.

[7]. Shah, D. K., KC, D., Akhtar, M. S., Kim, C. Y., & Yang, O. B. (2020). Vertically arranged zinc oxide nanorods as antireflection layer for crystalline silicon solar cell: a simulation study of photovoltaic properties. Applied Sciences, 10(17), 6062.

[8]. Alemu, A., Freundlich, A., Badi, N., Boney, C., & Bensaoula, A. (2010). Low temperature deposited boron nitride thin films for a robust anti-reflection coating of solar cells. Solar energy materials and solar cells, 94(5), 921-923.

[9]. Montgomery, D. C. (2017). Design and analysis of experiments. John wiley & sons.

[10]. Paventhan, R., Lakshminarayanan, P. R., & Balasubramanian, V. (2011). Prediction and optimization of friction welding parameters for joining aluminium alloy and stainless steel. Transactions of Nonferrous Metals Society of China, 21(7), 1480-1485.

https://doi.org/10.37896/pd91.3/91335