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Optimizing Oar-Based Water Turbine Harvester using Response Surface Methodology for Improving its Hydrokinetic Efficiency

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Abstract:- In this manuscript, an attempt has been made to evaluate the performance of an indigenously developed oar-based water turbine harvester (OBWTH), with an objective to improve its power coefficient (CP) to the maximum possible extent. In this study, three important design parameters such as which included the ratio between blade length and blade width (bl/bw), the axle length (L), and the blade inclination angle (θ) were optimized. For optimizing, an advance methodology such as response surface methodology was used. For obtaining it, a Central Composite Design (CCD) model was employed and attempts were made to establish empirical relationships between the important three input design parameters with the output efficiency. The significance of the developed empirical relationships was identified with analysis of variance. Using contours and 3-D surface plots, the optimized process conditions for operating the oar-based water turbine harvester were identified, so as to achieve highest possible value of C_p. On conducting validation studies, the results were promising as the actual efficiency was very close with the predicted efficiency. OBWTH performance was the highest, with bl/bw, L, and θ values at 1.8, 185 mm, and 71.7°, respectively. On operating OBWTH under these conditions, highest C_p value of 0.591 was obtained, which was validated to an error percentage lesser than 2%. Interactions were identified and perturbation plots indicated that the performance of OBWTH was more dependent on blade inclination, than the other parameters.

Keywords*: ore based water turbine, design, analysis of variance, optimization, and response surface methodology.*

1. Introduction

In the present scenario, hydropower has gained a lot of attention as it is more reliability and versatile, compared to other energy generation methods [1]. Nevertheless, conventional methods used for harnessing hydropower have a lot of issues. It causes extensive damage to wildlife aquatic systems due to extensive installations, modification of habitat, chopping off fishes and marine lives. When the natural flow of water is changed, it induces certain disturbances in fish migration, sediment deposition and environmental damage [2]. On installing conventional large scale wind energy conversion systems, geopolitical conflicts originate due to modifications in downstream water stream pattern [3]. In developed countries, more or less all the water bodies have been utilized for generation of hydropower by constructing dams [4]. Hence, identification of newer and better hydrokinetic installations is difficult. These issues need to be addressed for reducing the environmental damages. Instead of relying on the gravitational potential energy of the water which flow from higher altitude, interest in identifying alternative approaches for harnessing the kinetic force of horizontal flowing water bodies have drastically increased [5]. Utilization of hydrokinetic energy helps in reducing ecological damages and helps in sustainable environment management [6].

Simple oar-based water turbine harvesters (OBWTH) have been used in small water flow systems for utilizing the kinetic aspects of the flow of water [7]. OBWTH can be effectively used for using sources with low head potential and for generating hydrokinetic power in small scale. Such small OBWTH are suitable for regions where water flow is in abundance, but possessing low hydraulic potential. For extracting water from ships and for small scale irrigation, OBWTH have been used. In recent times, OBWTH has found better applications such as helping in migration of marine fishes, removal of material from ground, as injectors for preparing plastic molds and replacing ventricles in the heart for ensuring proper blood flow in human beings. When OBWTH are used as turbines, they are effective when installed in inclined positions so that the flow rates are better. Even in places where there is zero head [8], OBWTH can be used for conversion of the hydrokinetic energy into useful electric power. The position of the turbines can be aligned with the flow of water. Depending on the geographical constraints, OBWTH can be used either in partially submerged manner or it can be used in fully submerged condition, in water current [9]. On comparing the partially submerged turbine harvesters with fully submerged turbine harvesters, partially submerged harvesters were found to be better, as they can be easily maintained and accessed [10]. OBWTH method was found to be feasible as it involved lesser costs, simple in design and does not damage the environment [11]. Due to its advantages research is being conducted for increasing its efficiency so that it can be used as a better small scale energy converter.

Zhu et al. (2021) investigated the effect of helical shaped triangular blades on the working efficiency of marine turbines under vertical axis rotation [12]. Utama et al. (2020) investigated the performance of tidal current turbines by conducting numerical simulations [13]. Satrio et al. (2022) conducted in-situ experiments of Cross-Flow type Savonius turbine by using a hydrokinetic deflector [14]. Metoyer et al (2021) prepared software models for conducting simulation studies on dual-rotor ocean current turbines. Equilibrium analysis of the modeled turbines was evaluated by using equilibrium analysis [15]. On investigating simple hydrokinetic turbines in aligned configurations, researchers found that the efficiency of C_p varied from 0.238 to 0.264 [16-18]. Even then, there is scope for conducting research in dimensional aspects such as blade length, blade width, length of axle, inclination of blade, and improve its performance.

While designing such turbines it is important to identify the significance of its geometry and dimensions. It is important to understand how the different response variables interact with each other determining the optimal size, shape and design of the turbine assembly. For maximizing the efficiency to the maximum possible level, determining the optimal structure and shape of the turbine assembly is very important. In this investigation turbine efficiency has been measured in C_p.

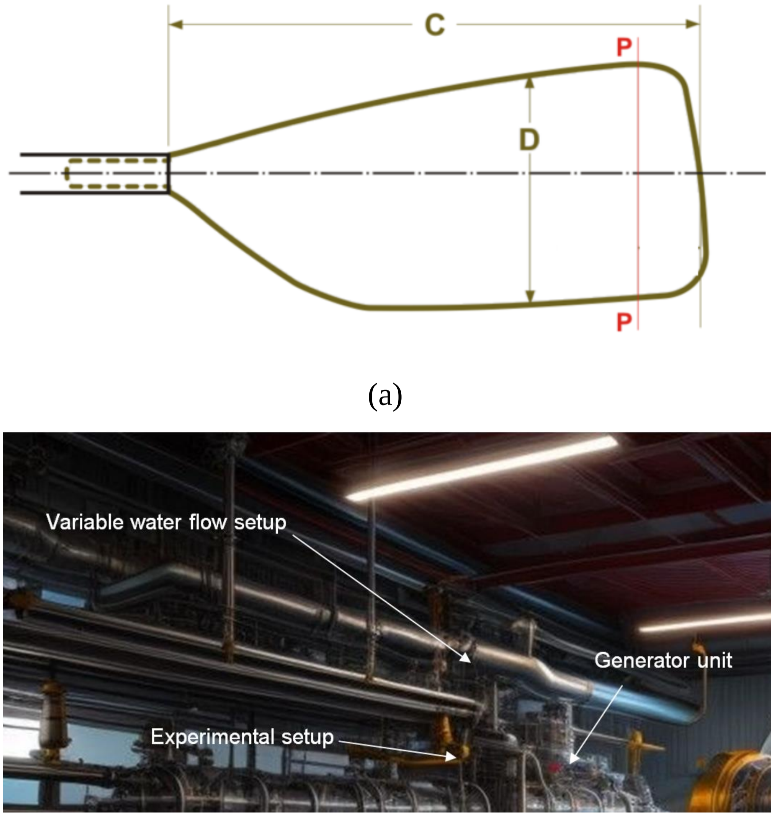
In literatures, a lot of optimization techniques have been reported. Out of them, Response Surface Methodology (RSM) has been preferred by many investigators for performing optimization studies [19]. RSM identifies the relationship between different independent factors, evaluates the effect of input variables on the output and simultaneously performs mathematical and logical operations to optimize the technological parameters. RSM helps in identifying interactions within the independent input variables [20]. It was found to be better than one-factor analysis as impact of all the different inputs can be analyzed in the same time.

In this study, the primary objective was to optimize the technological parameters involved in OBWTH working in hydrokinetic environment. For this purpose, RS has been used and crucial process parameters such as blade ratio “bl/bw," axle length "L," and blade inclination angle "θ" have been optimized. Then, the effect of these individual technological parameters on the target efficiency has been studies, for improving the performance of OBWTH.

2. Materials & Methods

2.1 Oar based water turbine harvester

In this investigation, an indigenously developed oar-based hybrid turbine array energy harvester (OBWTH) was used. This equipment consists of multiple turbine attachments connected to a common shaft. An array of turbines was used. Every single turbine setup consisted of arms which could be automatically adjusted, rotor hub, and automatically variable oar based arm in the periphery. The middle rotor comprises of gear attached generator, ultrasonic transducer, control unit, gyroscopic material, piezomaterial and anemometer. OBWTH converts the converts the kinetic energy of the flowing water into electricity with the piezomaterial, attached to the rotor hub. OBWTH consists of a rotatable arm with oar shaped heads whose axle length can be adjusted. These oar shaped turbine blades come in contact with water and helps in rotation of the turbine shaft. The oar blades are partially immersed in running water. The blades are connected to the central shaft which in turn is connected to the central hub. On either side of the water stream, the turbines are linked from one pole to another. During working, they rotate as a single unit for power generation. Blades of the turbines are fixed 45° to each other in the central shaft, thereby increasing the power generated from the flow of water. Depending on the level of the water in the region, the length of the axle from the central hub is adjusted. The arm height is detected with the help of ultrasonic transducers so as to ensure proper output even during fluctuations in water level. During movement of the turbine blades, electric current is generated from piezomaterial material and stores it in generator. The duration of immersion of the blades in water is identified by measuring the water flow. When water becomes stagnant, the blades are withdrawn from water. A process control unit is used to identify the direction of flow of water, force, pressure and positioning of the head. Direction of the wind is observed by the anemometer fixed in the shaft, which is present above the water level.



(a)

(b)

Figure 1. (a) Schematic representation of oar type turbine blade, (b) OBWHT unit testing setup

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It helps in improving the output of the OBWTH. Schematic representation of the oar type blade is shown in Figure 1 (a) and the test setup of the indigenously developed OBWTH is shown in Figure 1 (b).

2.2 Improving performance of OBHWT using response surface methodology

RSM is conducted to obtain the desired response under optimal conditions within an experimental domain by using the lowest number of experiments. This method allows modeling and analyzing problems in which several factors (independent variables) influence one or more variables of interest (i.e., the so-called responses) simultaneously. In the current case, it is desired to design the OBWTH in an optimal. For this, identification of the factors or parameters involved in its design that significantly affect the efficiency of the system is a must. There are several designs of experiments (DOE) that enable to discern the effect of several factors on the response variable simultaneously; among them, the central composite design of experiments (CCD) is commonly used for optimization purposes. In this work, a face-centered CCD was selected for determining the efficiency of an OBWTH in terms of CP.

In this investigation, Response Surface Methodology was used for achieving the desired output response under optimal conditions. RSM helps to reduce the number of experimental investigations and predicts the responses to a very high level of accuracy. This tool can effectively model complex problems which comprises of a lot of factors relating to a particular response. It can be used for identification of the optimize solution with a predicted set input process variables, with which the experiment has to be performed. The goal of this experiment is to improve the efficiency of OBWTH to the maximum possible extent. For achieving optimality, identification of crucial technological parameters relating to OBWTH working is important. Identification helps in improving the efficiency of OBWTH. For simultaneous investigation in multi criteria decision making, Design of Experiments (DOE) are used. DOE can quickly evaluate the effect of the various input factors on the output responses. In optimization problems, Central Composite Design model is preferred as they help in establishing relationship between the input and output parameters with high accuracy. In this study, using face centered CCD model, attempts were made to improve the coefficient of performance (Cp) [21] of OBWTH, to the maximum possible level.

For calculating Cp, the following formula was used

$$C_p = \frac{P}{0.5\rho A V^3} \quad \text{------- Eq. 1}$$

In the above equation, P indicates the generated power of the turbine, ρ indicates the water density of that system, A indicates the blade surface area and V indicates the velocity of the water system.

2.2.1 Developing feasible limits

The feasible limits of the three important turbine design parameters such as the ratio between blade length (bl) and blade width (bw), i.e., “bl/bw” the axle length (L) and the blade inclination angle (a) were identified. Other design parameters such as pitch, curvature and pitch to outer end were maintained as a constant. The pitch was fixed at 2.1°, curvature was 176° and pitch to outer end distance was at 40 mm. Along the water flow, the turbines were dipped into 50% of the flowing water by extending the arm of the turbine at 225 mm from the axis. The angle of contact of the turbine blade with the direction of water flow was at 71°. The speed of water flow was maintained at 12 km/hr for all experiments.

Trial and error experiments were conducted on OBWTH and the following observations were recorded.

(i). On conducting flow experiments on OBWTH with ratio of blade length to blade width (bl/bw) lesser than 1, the power coefficient was found to be very low (0.12)

(ii) On conducting flow experiments on OBWTH with ratio of blade length to blade width (bl/bw) greater than 2, higher drag caused a considerable reduction in the efficiency of the equipment.

(iii). On conducting flow experiments on OBWTH with axle length lesser than 175 mm, turbulence was greater, resulting in reduced output.

(iv). On conducting flow experiments on OBWTH with axle length greater than 225 mm, excessive splashing reduced the rotation of the turbine blades resulting in reduced output.

(v). On conducting flow experiments on OBWTH with blade inclination angle lesser than 40°, the movement was found to decrease drastically.

(vi). On conducting flow experiments on OBWTH with blade inclination angle lesser than 80°, excessive splash of water and water ploughing caused a considerable reduction in overall efficiency.

Hence, it was identified that on conducting flow experiments on OBWTH with different input process variables it was observed that bl/bw between 1 to 2, axle length between 175 mm to 225 mm and blade inclination angle between 40° to 80°, the output efficiency was found to be better. Table 1 indicates the feasible range of the technological parameters involved in the performance enhancement of OBWTH.

Table 1 Feasible limits of technological process parameters involved in evaluating the output power coefficient of OBWTH

No	**Testing Parameters**	**Coded Values**				
		-1.682	**-1.0**	**0**	**+1.0**	**+1.682**
1	Ration between blade length to blade width bl/bw (R)	1	1.2	1.5	1.8	2
2	Axle length (L) in mm	175	185	200	215	225
3	Blade inclination angle (θ) in °	40	48	60	72	80

According to the relationship established by Montgomery et al. (1992), the coded values for the three technological parameters were identified as -1.68, -1, 0, +1, and +1.68 [22]. The least value was coded as -1.68 and the maximum value was coded as +1.68 respectively. These values are presented in Table 1.

2.2.2 Central Composite Design Model

Table 2 shows the central composite design (CCD) model developed for improving the efficiency of OBWTH, with 6 star points and 6 centre points. For the CCD model for optimizing the OBWTH design process parameters, the response in the form of power coefficient (Cp) was used.

A total of twenty experiments were carried out, with 14 of them were unique, and 6 were repetitive experiments for minimization of the errors which could have occurred during experimentation. Experiments were performed according to the process parameters values shown in Table 2. While performing the experiments, values of Cp were calculated and shown in Table 2.

Table 2 Central composite design model for OBWTH efficiency improvement model

Run	R	L	θ	Cp
1	1.50	225.00	60.00	0.562069
2	2.00	200.00	60.00	0.567586
3	1.50	200.00	60.00	0.572414
4	1.00	200.00	60.00	0.546897
5	1.50	175.00	60.00	0.542759
6	1.80	214.87	71.89	0.555862
7	1.20	185.13	48.11	0.505517
8	1.50	200.00	80.00	0.569655
9	1.50	200.00	60.00	0.573793
10	1.20	214.87	48.11	0.566897
11	1.50	200.00	60.00	0.574483
12	1.20	214.87	71.89	0.562069
13	1.50	200.00	60.00	0.573103
14	1.80	185.13	48.11	0.53931
15	1.50	200.00	60.00	0.573103
16	1.80	214.87	48.11	0.546897
17	1.20	185.13	71.89	0.546207
18	1.50	200.00	60.00	0.570345
19	1.50	200.00	40.00	0.531034
20	1.80	185.13	71.89	0.591034

3 Results & Discussions

3.1 **Establishing Empirical Relationships**

Empirical correlations were developed among the input process variables such as - R, L, and θ - and the output response Cp. Relationships were developed with an aim to obtain highest possible Cp. The empirical correlations between the input variables and output Cp of OBWTH efficiency model has been developed according to the following regression equation [23].

$C_p = g + g_1 R + g_2 L + g_3 \theta + g_4 R \times L + g_5 L \times \theta + g_6 R \times \theta + g_7 R^2 + g_8 LR^2 + g_9 \theta^2$ ----------------- Eq. (1)

The second order regression polynomial equation developed between the input variables and response for OBWTH design improvement model is shown as follows

$Cp = + 272.73 + 3.04 R + 2.86 L + 5.63 \theta - 6.24 R \times L + 1.48 L \times \theta - 5.25 R \times \theta - 2.67 R^2 - 3.49 LR^2 - 3.83 \theta^2$ ----------------- Eq. (2)

2.2.4 Adequacy Evaluation Using Analysis Of Variance

For assessment of the adequacy of the developed OBWTH efficiency development model, Analysis of Variance (ANOVA) was used. Using “student t test”, the significance of the developed model was ascertained. Using two-way ANOVA, the predictability of the empirical equations was ascertained to a confidence limit greater than 95%. ANOVA results of the OBWTH improvement model is shown in Table 3. R-squared has been observed between 0 and 1. This indicates the extent of correlation between the process variables. If $R^2 = 1$, it signifies a perfect correlation and if $R^2=0$, it indicates no correlation at all [24].

In ANOVA analysis, Adjusted R-squared and R-squared are important metrics for evaluating the performance of input variables. In research, these metric indicate how well, the concerned variable aligns itself with the output response

Adjusted R-squared value provides a more accurate evaluation considering the relationship between the variable factors with output. Addition of independent variables to a model helps in improving the reliability of the model.

From ANOVA analysis, the values for Predicted R-squared, R-squared and Adjusted R-squared were 0.9937, 0.9962, and 0.9983, respectively. If the value of the determination coefficient approaches 1, then the model was attributed to have a very high level of significance.

Table 3 ANOVA analysis of OBWTH design improvement model

Source	**Sum of squares (SS)**	**DOF**	**Mean square (MS)**	**F value**	**p-value Prob>F**	**Note**
Model	7.2 x 10-3	9	8 x 10-4	733.962	< 0.0001	Significant
R	5.5 x 10-4	1	5.5 x 10-4	510.7863	< 0.0001	
L	4.9 x 10-4	1	4.9 x 10-4	453.0307	< 0.0001	
Θ	1.9 x 10-3	1	1.9 x 10-3	1751.768	< 0.0001	
R x L	1.3 x 10-3	1	1.3 x 10-3	1259.863	< 0.0001	
R x θ	7.7 x 10-5	1	7.7 x 10-5	70.67101	< 0.0001	
L x c	9.7 x 10-4	1	9.7 x 10-4	893.4211	< 0.0001	
R^2	4.5 x 10-4	1	4.5 x 10-4	416.9267	< 0.0001	
L^2	7.7 x 10-4	1	7.7 x 10-4	708.8455	< 0.0001	
θ^2	9.3 x 10-4	1	9.3 x 10-4	857.529	< 0.0001	
Residual	1.4 x 10-5	10	1.4x10-6			
Lack of fit	3.9 x 10-6	5		0.498111	0.8639	Not significant
Std. Dev		1.18 x 10-3		R^2	0.9968	
Mean		0.56		Adj. R^2	0.9962	
C.V. %		0.21		Pred. R^2	0.9938	
PRESS		4.5 x 10-5		Adeq. Precision	100.288	

The Model F-value of 568.96 is a very clear indication that the model has been developed with high significance. There is a very low chance (only 0.01%) that such large "Model F-Value" could occur due to randomness. When the "Prob > F" values are lower than 0.0500, it is a clear indication of very high significance of the model terms. From ANOVA analysis, A, B, C, AB, AC, BC, A^2, B^2, and C^2 were found to of high significance. The model terms indicate insignificance when the values are greater than 0.1. In some situations, when the number of insignificant terms is more, reduction of the model would help in improving the prediction accuracy of the model. "Lack of Fit F-value" of 0.39, indicates that Lack of fit is not significant compared to absolute error. Due to randomness, the chance of "Lack of Fit F-value" of this magnitude could occur was found to 84.02%. It is highly favorable to have this non-significance as it improves the fit of model. Figure 2 indicates the scatter diagram depicting the correlation between the predicted and actual values of the power coefficient in OBWTH efficiency improvement model.

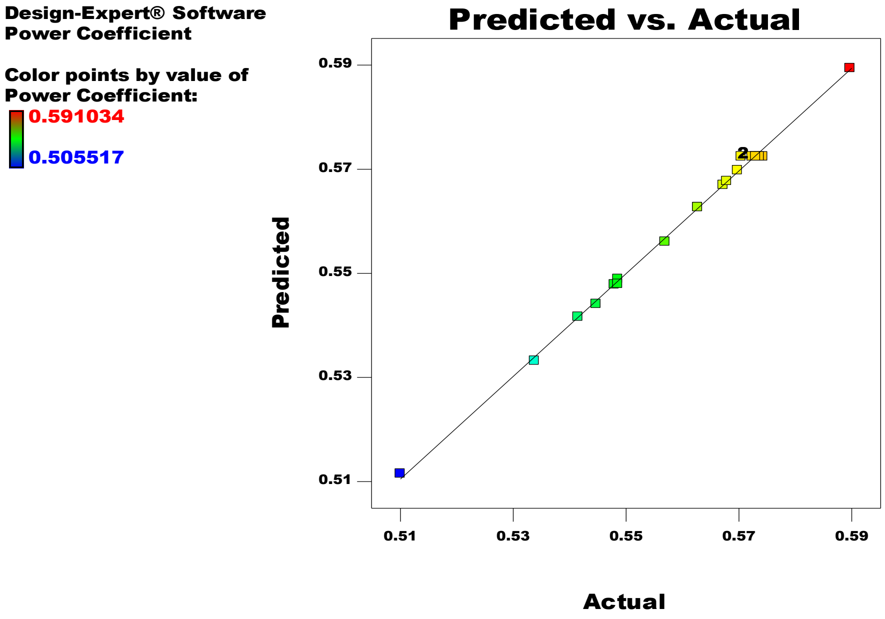

Figure 2. Scatter diagram between the predicted and actual values of power coefficient

On analyzing the scatter diagram between the actual and predicted power coefficient values, it was found that there was a very close relation between the two.

3.2 Developing Contours & Surface Plots

For optimizing the crucial technological parameters of the OBWTH design, contour plots and 3-D surface responses were formed. Contour plots are used for developing two-dimensional representations and the points with similar response values are connected by using contour lines. Surface plots are 3-dimensional representation of the contours. In these, the input variables are displayed in the x-axis and y-axis. The output response is shown as a smooth surface with gradient ascent or gradient descent.

The contour plots for power coefficient maximization model for OBWTH are shown in Figure 3. Contour plots indicating the variations in R vs L, at constant inclination of 71.75° are shown in Figure 3 (a). Contour plots indicating the variations in R vs θ, at constant L of 185 mm are shown in Figure 3 (b). Contour plots indicating the variations in L vs θ, at constant R of 1.8 mm are shown in Figure 3 (c). The 3-D surface plots for power coefficient maximization model for OBWTH are shown in Figure 4. The 3-D surface plots indicating the variations in R vs L, at constant inclination of 71.75° are shown in Figure 4 (a). The 3-D surface plots indicating the variations in R vs θ, at constant L of 185 mm are shown in Figure 4 (b). The 3-D surface plots indicating the variations in L vs θ, at constant R of 1.8 mm are shown in Figure 4 (c).

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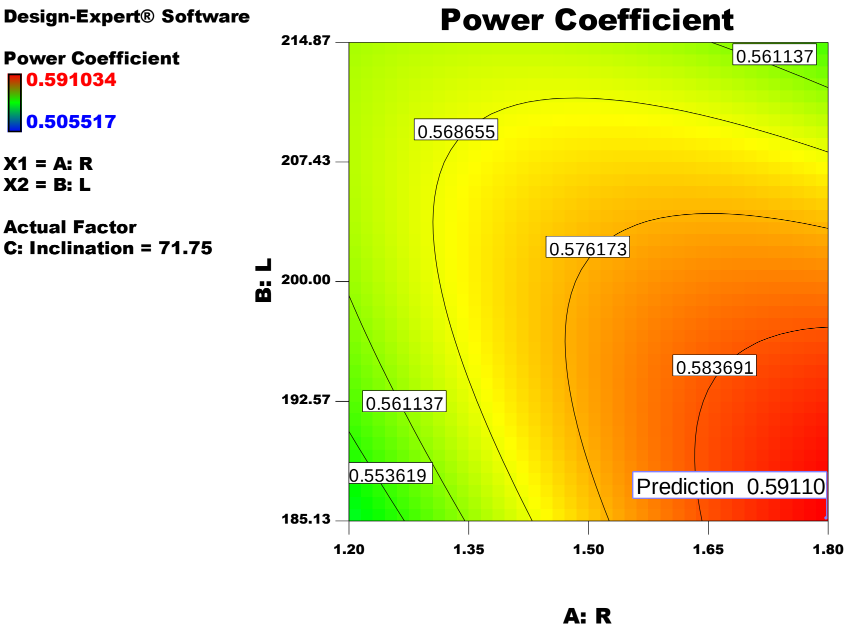

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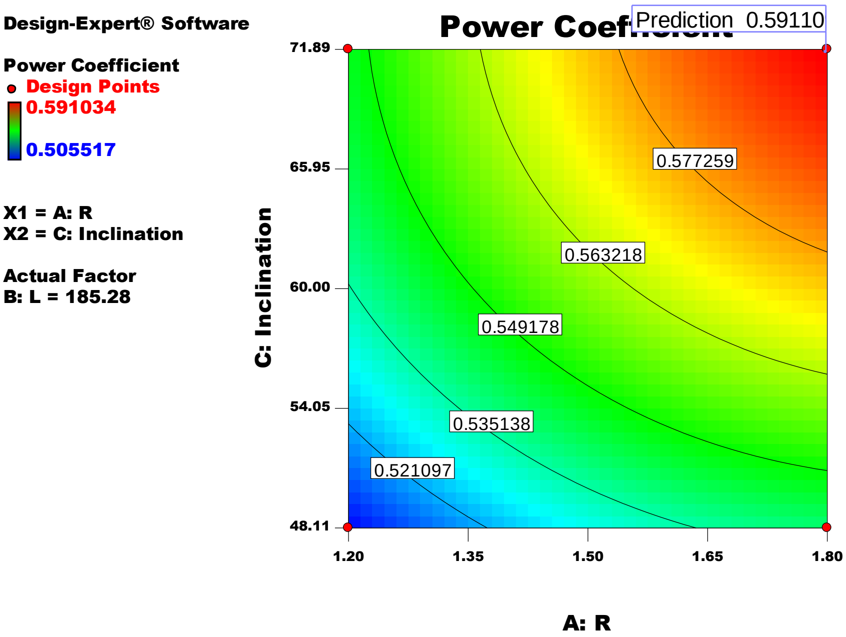

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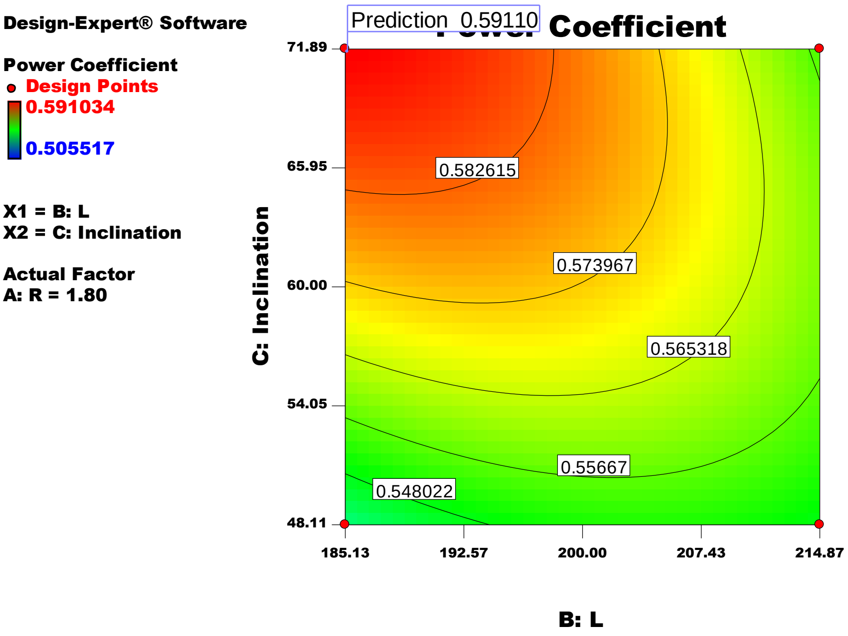

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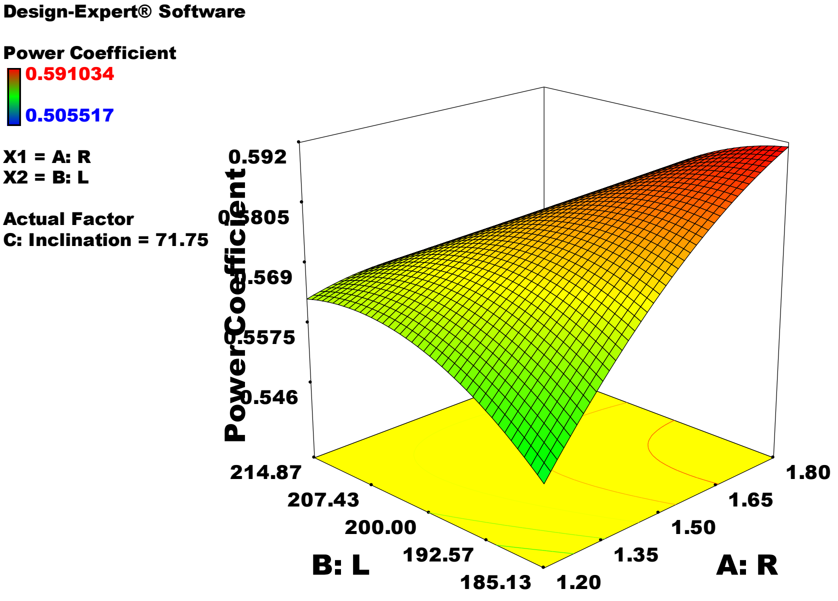
Figure 3 Contour plots of power coefficient maximization model for OBWTH



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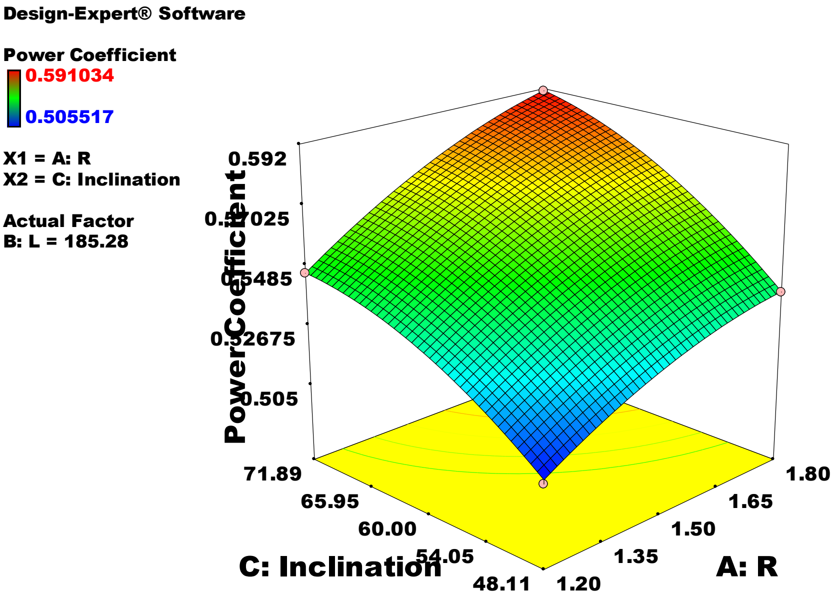

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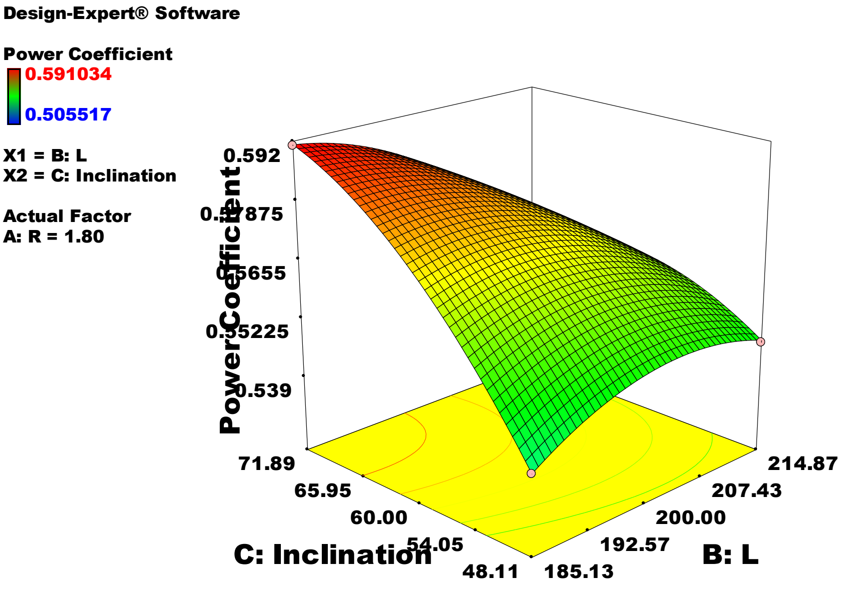


(c)

Figure 4 3-D surface plots of power coefficient maximization model for OBWTH

From the contours and surface plots, the optimized values of the OBWTH process parameters for power coefficient maximization and the corresponding value of maximum possible power coefficient were predicted and the values have been shown in Table 3.

Table 3. Predicted values of input variables and output C_p of the optimization model

Power coefficient maximization model for OBWTH		
	Optimized Process Parameters	Values
1	Ratio between bl/bw	1.8
2	Axle Length (mm)	185
3	Blade inclination angle (θ°)	71.7°
	Predicted Responses	Values
1	Power Coefficient	0.591

3.3 VALIDATION

After optimizing the process parameters, validation experiments were conducted for identifying the predictability of the optimization model. With the predicted optimized values of the input process parameters such as Ratio between bl/bw, Axle Length (mm) and Blade inclination angle (θ°), performance study experiments on OBWTH. After conducting performance study experiments the optimized values of the process parameters, the responses were calculated. The error between the predicted and the actual values were identified. The results of the validation experiments were recorded and are shown in Table 4.

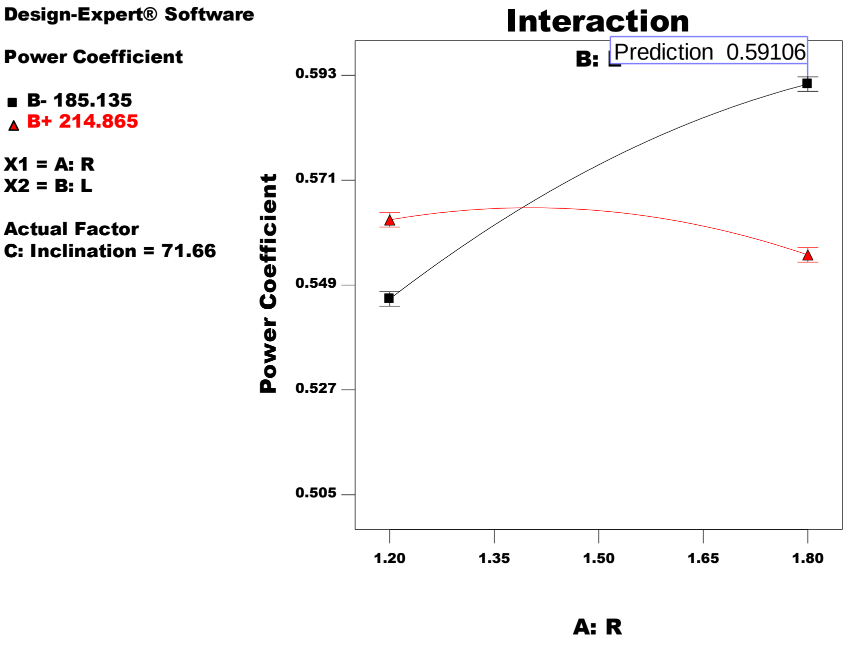
Table 4 Results of the validation experiments

Power coefficient maximization model for OBWTH				
	Power coefficient	Predicted	Actual	Error
1	Experiment 1	0.591	0.584	-2.36 %
2	Experiment 2	0.591	0.536	-3.69 %
3	Experiment 3	0.591	0.559	-2.86 %

From validation studies, it was found that the error between the predicted values and actual response values were lesser than 4%. Hence, the model was found to exhibit very high predictability.

3.4 Interaction & Perturbation Plots

Interaction plots are prepared for understanding how the different input variables relate with each other. Figure 5 indicates the interaction plots of the input variables which play a pivotal role in determining the output efficiency of OBWTH. The interaction plots indicating the variations in R vs L, at constant inclination of 71.72° are shown in Figure 5 (a). Interactions were identified near the mid region of the process parameter values. The interaction plots indicating the variations in R vs θ, at constant L of 211.65 mm are shown in Figure 5 (b). Interactions were identified in the lower end of the feasible process parameter limits. The interaction plots indicating the variations in L vs θ, at constant R of 1.8 are shown in Figure 5 (c). Interactions were identified in the lower end of the feasible process parameter limits.



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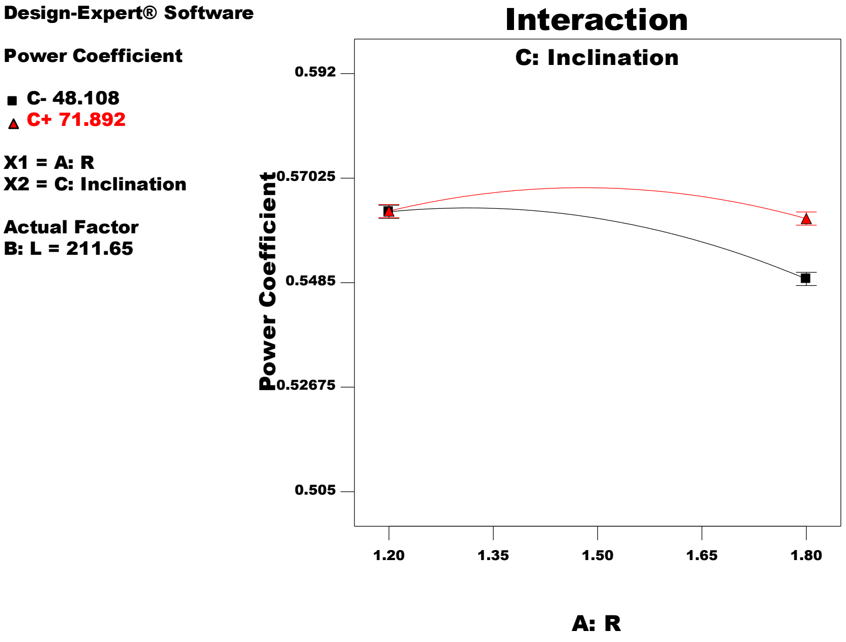

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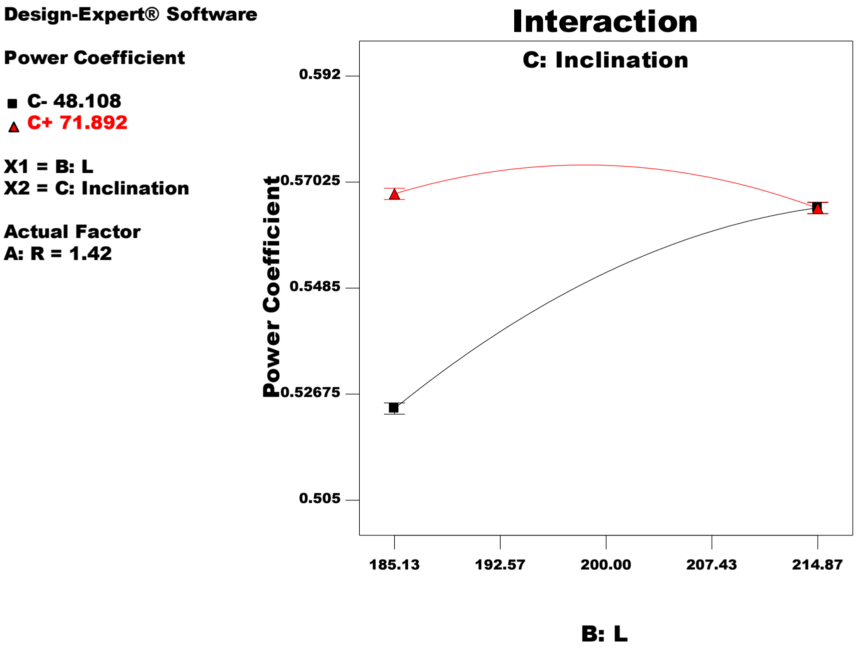

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Figure 5 Interaction plots of power coefficient maximization model for OBWTH

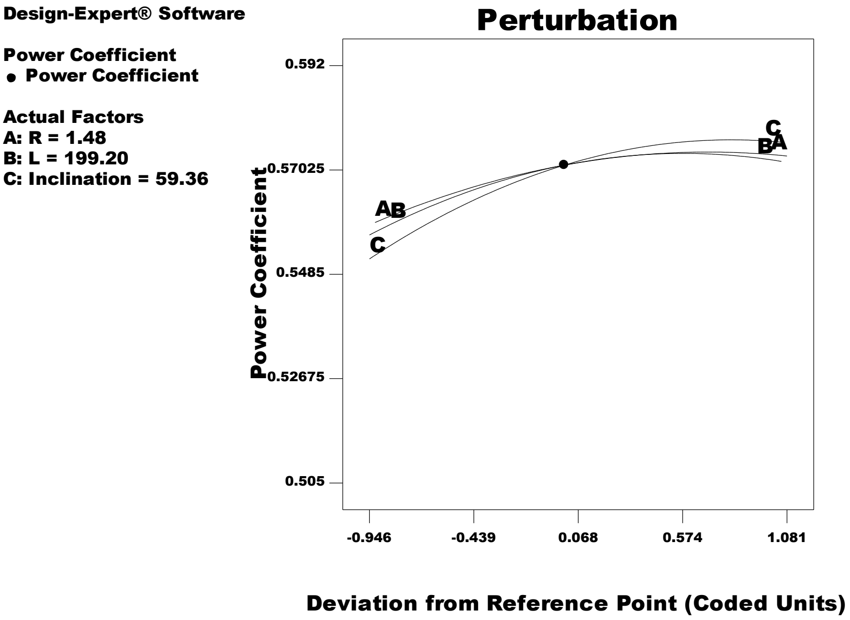

Figure 6 Perturbation plots of power coefficient maximization model for OBWTH

Perturbation plots help in identifying how the range of output response varies with each input. The control of each input process parameter on the output responses can be evaluated by using perturbation analysis. The impact of the input variables on the output can be determined. It can be used for ranking the input variables according to their influence on the output values. Perturbation plots for the important process parameters involved in OBWTH efficiency improvement model are shown in Figure 6, with R as 1.48, L = 199 mm and Inclination (θ) as 59.36. From Figure 6, it can be identified that inclination exhibited a better control over the variations in the output efficiency of OBWTH, than blade ratio and axle length.

4 Conclusions

In this investigation, optimization of the important process parameters affecting the output power coefficient of the oar-based water turbine harvester was successfully done. The feasible limits of the crucial technological parameters, such as the blade length to blade width ration, length of the axle and inclination of the blade were identified by conducting trial experiment experiments on the oar-based water turbine harvester. Twenty different combinations of experiments were created by developing central composite design model and experiments were conducted accordingly. The responses in the form of power coefficient were also recorded. Empirical relations were developed with the input process variables and the output response, using second-order polynomial equations. The significance of the developed model was ascertained with analysis of variance, with a confidence level greater than 95%. The closeness between the actual and predicted values was identified by developing scatter diagrams, which showed good agreement. The maximization model was subjected to optimization using response surface methodology. For finding the optimized input process variables and the maximum possible power coefficient, contour and surface plots were used. On validation, the prediction models indicated high predictability, as the difference between experimental values and predicted values was less than 4%. Interaction and perturbation plots were developed for the model, revealing that blade inclination played a more significant role in controlling the output response compared to blade ratio and axle length.

References

[1] Zisos, A., Sakki, G. K., & Efstratiadis, A. (2023). Mixing renewable energy with pumped hydropower storage: Design optimization under uncertainty and other challenges.

[2] Maheshwari, A., Sood, Y. R., & Jaiswal, S. (2023). A Comprehensive Review on Stochastic Optimal Power Flow Problems and Solution Methodologies. IETE Technical Review, 1-28.

[3] Cheikh, N. B., & Zaied, Y. B. (2023). Renewable energy deployment and geopolitical conflicts. Journal of Environmental Management, 344, 118561.

[4] Kamani, D., & Ardehali, M. M. (2023). Long-term forecast of electrical energy consumption with considerations for solar and wind energy sources. Energy, 268, 126617.

[5] Rotor, M. A. (2023). Multidisciplinary Design Optimization of Horizontal-Axis Tidal Turbine Blades for Tropical Site Conditions in a Shear-Flow Environment with Wave-Current Interaction (Doctoral dissertation, State University of New York at Stony Brook).

[6] Mat Yazik, M. H., Wei Shyang, C., Ishak, M. H. H., & Ismail, F. (2023). An overview of blade materials and technologies for hydrokinetic turbine application. International Journal of Green Energy, 1-24.

[7] Chaulagain, R. K., Poudel, L., & Maharjan, S. (2023). A review on non-conventional hydropower turbines and their selection for ultra-low-head applications. Heliyon.

[8] Chaulagain, R. K., Poudel, L., & Maharjan, S. (2023). A review on non-conventional hydropower turbines and their selection for ultra-low-head applications. Heliyon.

[9] Cacciali, L., Battisti, L., & Dell'Anna, S. (2023). Backwater assessment for the energy conversion through hydrokinetic turbines in subcritical prismatic canals. Ocean Engineering, 267, 113246.

[10] Rashid, H., Benbouzid, M., Titah-Benbouzid, H., Amirat, Y., & Mamoune, A. (2023). Tidal Stream Turbine Biofouling Detection and Estimation: A Review-Based Roadmap. Journal of Marine Science and Engineering, 11(5), 908.

[11] Mun, T. J., Moon, J. H., Park, J. W., Baughman, R. H., & Kim, S. J. (2023). Environment-Adaptable Rotational Energy Harvesters Based on Nylon-core Coiled Carbon Nanotube Yarns. Small Methods, 2300526.

[12] Zhu G, Feng J, Wang X, Jing X and Luo X 2021 Influence of helical triangle blade on the performance of vertical axis marine current turbine Ocean Eng. 241 110060

[13] Utama I K A P, Satrio D, Mukhtasor M, Atlar M, Shi W, Hantoro R and Thomas G 2020 Numerical simulation of foil with leading-edge tubercle for vertical-axis tidal-current turbine J. Mech. Eng. Sci. 14 6982–92

[14] Satrio D, Wiyanto A A and Mukhtasor M 2022 In-Situ Experiment of Cross-Flow Savonius Hydrokinetic Turbine With a Deflector J. Mar. Sci. Technol. 3 1–4

[15] Metoyer R, Chatterjee P, Elfering K, Bryant M, Granlund K and Mazzoleni A 2021 Modeling , simulation , and equilibrium analysis of tethered coaxial dual-rotor ocean current turbines Energy Convers. Manag. 243 113929

[16] Wu, K. T., Lo, K. H., Kao, R. C., & Hwang, S. J. (2023). Design and performance analysis of a passive rotatable deflector diversion tail for tidal current power generation hydrokinetic turbines. Energy, 128484.

[17] Al-Gburi, K. A. H., Alnaimi, F. B. I., Al-quraishi, B. A. J., Tan, E. S., & Kareem, A. K. (2023). Enhancing Savonius Vertical Axis Wind Turbine Performance: A Comprehensive Approach with Numerical Analysis and Experimental Investigations. Energies, 16(10), 4204.

[18] Patel, C., Rathod, V., & Patel, V. (2023). Experimental Investigations of Hydrokinetic Turbine Providing Fillet at the Leading Edge Corner of the Runner Blades. Journal of Applied Fluid Mechanics, 16(4), 865-876.

[19] Veza, I., Spraggon, M., Fattah, I. R., & Idris, M. (2023). Response surface methodology (RSM) for optimizing engine performance and emissions fueled with biofuel: Review of RSM for sustainability energy transition. Results in Engineering, 101213.

[20] . Shah, S. A. R., Kahla, N. B., Atig, M., Anwar, M. K., Azab, M., & Mahmood, A. (2023). Optimization of fresh and mechanical properties of sustainable concrete composite containing ARGF and fly ash: An application of response surface methodology. Construction and Building Materials, 362, 129722.

[21] Khani, M. S., Shahsavani, Y., Mehraein, M., & Kisi, O. (2023). Performance evaluation of the savonius hydrokinetic turbine using soft computing techniques. Renewable Energy, 118906.

[22] Montgomery, D. C. (1992). The use of statistical process control and design of experiments in product and process improvement. IIE transactions, 24(5), 4-17.

[23] Paventhan, R., Lakshminarayanan, P. R., & Balasubramanian, V. (2011). Fatigue behaviour of friction welded medium carbon steel and austenitic stainless steel dissimilar joints. Materials & Design, 32(4), 1888-1894.

[24] Reddy, S. A., Forsyth, C., Aruliah, A., Smith, A., Bortnik, J., Aa, E., ... & Lewis, G. (2023). Predicting swarm equatorial plasma bubbles via machine learning and Shapley values. Journal of Geophysical Research: Space Physics, e2022JA031183.