14th Annual International Conference on Industrial Engineering and Operations Management Dubai United Arab Emirates (UAE), February 12-14, 2024

Publisher: IEOM Society International, USA DOI: 10.46254/AN14.20240507
Published: February 12, 2024

Optimal Design of a Vortex Wind Turbine Using Taguchi Method

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Abstract

In the matter of clean energy, wind power is considered one of the most reliable and sustainable alternatives. Thanks to the progressed technology and diminishing expenses, its adoption has multiplied in the latest years. However, before the wind can become the most viable form of alternative energy, there are specific barriers we need to overcome. Conventional turbines have been known for their complex manufacture, expensive transportation, intermittence, and high maintenance cost. The vortex bladeless wind turbine (VBWT) is considered an advanced design that harvests energy from oscillation. This study focuses on optimizing VBWT design parameters using the Taguchi method to enhance electrical power production. Through meticulous analysis and mathematical modelling, we examine factors such as mast and rod lengths, diameters, and thicknesses. Numerical results show that the produced power of the 20 meters long turbine is around three times greater in comparison to the initial VBWT output. The increase rate is 176% at a wind speed of 7 m/s. The power produced by the optimal turbine reached 3.44 KW, while the production of the initial VBWT was only 1.25 KW. The output power can be further maximized at an optimum external load. In the future, this study will be continued to enhance the overall performance of the bladeless wind turbine through the integration of the offshore wind turbine with tidal power.

Keywords
Bladeless wind Turbine, Optimization, Taguchi method, Output Power

1. Introduction
Renewable energy is the future of the globe, it considerably reduces carbon dioxide emissions when compared to conventional energy resources. Producing renewable power involves harnessing nature's plentiful and vast elements to generate electricity. In line with the international Renewable electricity organization (IRENA), renewable energy can offer 90 percent of the world's energy by 2050 (A, 2020).Statistics show that renewable energy sources currently account for more than a third of the overall worldwide energy production (Ellabban et al., 2014).

In the realm of clean energy, wind power stands out as one of the most reliable and sustainable alternatives. Despite its promising potential, there are barriers that need to be addressed before wind energy can become the foremost viable alternative. Traditional wind turbines, while effective in generating electricity from wind, are burdened with several disadvantages. These include complex manufacturing processes, costly transportation, intermittent performance, and high maintenance requirements. As engineers, we have a responsibility to face these challenges and improve the options for the energy sector.

However, innovative solutions such as the vortex bladeless wind turbine (VBWT) are emerging to overcome these challenges. Developed by Vortex Spain, the VBWT represents a paradigm shift in wind turbine design, eliminating traditional rotor blades in favor of a more streamlined and efficient approach. VWTs boast a flexible cylindrical design capable of harnessing energy from moving air streams through vortex-induced vibration (VIV) methods. VBWT can

easily be deployed in urban areas and even integrated into the overall architecture of buildings (David & Villarreal, 2018).
Furthermore, with a steadfast commitment to clean energy and sustainability, the Kingdom of Saudi Arabia is at the forefront of addressing energy and climate challenges with innovative solutions. A push towards a more diverse energy mix, aiming for 50% renewable energy by 2030 and complete reliance on renewables, particularly in NEOM, underscores the strategic importance of exploring alternative energy technologies like VWTs (Vision 2030 Kingdom of Saudi Arabia, 2020).

The vortex bladeless wind turbine (VBWT) represents a unique type of unconventional wind turbine that capitalizes on vortex shedding phenomena. Unlike traditional wind turbines, vortex devices are characterized by their simplicity in design, facilitating easy manufacturing, installation, and operation. Comprising a fixed base and a cylindrical mast connected by a carbon rod, the bladeless wind turbine harnesses wind energy through the resonance frequency between the system and airflow, ultimately generating electricity via an alternator system. Experimental and analytical findings have demonstrated the VBWT's capability to generate electricity even at low wind speeds, as low as 3 m/s, a performance level often unattainable by conventional wind turbines. The mechanical components of the turbine work synergistically to convert wind energy into electrical power, with the cylindrical mast oscillating and leveraging the vortex shedding effect. Constructed primarily of fiberglass and carbon fiber materials, the VBWT's oscillatory motion within the alternator system efficiently generates electricity (Vortex, 2021).

Bladeless wind turbines offer innovative solutions for urban environments, particularly in areas with turbulent airflow and low wind speeds. These turbines excel in built-up areas like city centers, high-rise buildings, and urban infrastructure such as roads, railway tracks, and subway networks (Nguyen et al., 2022). Unlike traditional wind turbines, bladeless designs can effectively harness wind energy in urban settings, where conventional turbines may face limitations. Their unique characteristics make them suitable for deployment in urban landscapes, addressing gaps where traditional turbines may not be feasible or appropriate.

Bladeless wind turbines demonstrate efficiency, cost-effectiveness, and reliability in terms of manufacturability. Their simple design facilitates easy fabrication and assembly, with components like flat smooth discs replacing the complex geometries of curved blades. This simplicity lowers manufacturing costs and enhances quality control. Additionally, the design allows for easy adjustment and replacement of components, reducing maintenance costs and offering flexibility in turbine parameters (Zhao et al., 2019).

Bladeless wind turbines present significant cost savings compared to conventional turbines. With simplified manufacturing, transportation, construction, and assembly processes, they bypass the need for costly components like nacelles, support mechanisms, and blades. These manufacturing savings are estimated to be around 51% of the usual wind turbine production cost, making bladeless turbines an attractive option for the wind industry (Nguyen et al., 2022).

The adoption of bladeless wind turbines contributes to environmental sustainability by reducing carbon emissions and minimizing harm to wildlife. Compared to conventional turbines, bladeless designs reduce carbon emissions by 40% and pose no threat to birds due to the absence of blades.(Book, n.d.).

The aforementioned studies were many focused on analysing and optimizing the conventional wind turbines from both design and operational aspects. However, there are no studies that aim to optimize the design of vortex wind turbines. Since this is a new technology and hasn't been commercialized yet. Hence, this study aims to find the optimal design parameters of a vortex wind turbine using Taguchi method. Which is on of Design of Experiment (DOE) methods.

1. Methodology

1.1. Comparison of General Parameters Between Conventional Wind Turbine and Bladeless Turbine

Conventional wind turbines had shown a range of different prospects related to their design and operations, but we should recognize the other options for energy, especially for small scale. People must have enough references to avoid fossil fuels energy resources by replacing them with another eco-friendly, innovative, and a lower cost product. The use of traditional wind turbines is rarely useful on small scale, and there are many case studies indicating that the suitable wind speed for turbines is found at very few locations around the world. Therefore, unconventional turbines will facilitate the use of renewable energy even in our houses. In the following Table 1, we compared the variations between the mode of operation, mode of generation, structure, costs, and environmental impacts of the two different designs of wind turbines (Upadhyaya et al., 2020).

Table 1. Difference between the conventional wind turbine and bladeless turbine

SR.NO	Parameters	Conventional Wind turbine	Bladeless Turbine
1.	Mode of operation	Generates electrical power with blades.	Generates electrical power without blades.
2.	Mode of generation	Rotational motion of the blades.	Oscillating motion of turbine.
3.	Acoustics	Its operation produce noise above 20Hz.	doesn't produce noise (below 20Hz).
4.	Structure	The design is sturdy & there is high wear & tear.	The design is sturdy & there is minimal wear.
5.	Safety	It is not safe for birds	It is safe for birds.
6.	Maintenance	It is not feasible to maintain, as it has higher maintenance cost.	It is easy to maintain, 80% of maintenance cost is reduced.
7.	Construction	It requires many moving parts.	It requires less moving part & less material to produce same amount of electricity.
8.	Costs	The manufacturing cost is higher.	The manufacturing saving around 53% of usual production cost.
9.	Efficiency	It has higher efficiency (about 60%).	It has lower efficiency of energy conversion (about 30%).
10.	Space	The area required for installation is more.	There is possibility to put more vortex in the same area.

The primary objective of this study is to optimize VBWT design parameters using the Taguchi method to enhance power generation performance. Specifically, the study aims to:

i. Develop and validate a mathematical model of the VBWT, incorporating key design parameters such as mast and rod lengths, diameters, and thicknesses.
ii. Investigate the impact of varying design parameters on the oscillation ability and power output of the VBWT.
iii. Apply the Taguchi method to identify optimal levels of design parameters that minimize variation and maximize power generation efficiency.

The research methodology involves two main phases:

i. Analysis of VBWT Design Parameters: A dynamic model of the VBWT is developed using coupled nonlinear equations of motion. Design parameters such as mast and rod lengths, diameters, and thicknesses are varied to assess their impact on oscillation ability and power output.
ii. Optimization Using Taguchi Method: Taguchi orthogonal arrays are employed to design experiments and identify optimal levels of design parameters. The Taguchi approach minimizes variation and maximizes power generation efficiency by analysing the signal-to-noise ratio of output parameters.

While this study focuses on optimizing VBWT design parameters for enhanced power generation performance, certain limitations should be noted. The research does not include experimental validation or detailed simulation modelling using software such as SolidWorks.

The concept of VBWTs has been the subject of previous research, showcasing their potential as a bladeless alternative in wind energy generation. However, a notable gap exists in the literature regarding the comprehensive analysis of specific design parameters influencing VBWT performance. Recognizing this research gap, our study seeks to systematically investigate these design parameters to optimize energy output and address this critical knowledge deficiency in the field of wind energy generation. Utilizing the Taguchi design method, we aim to provide a structured approach to analysing and optimizing VBWT performance, contributing valuable insights to enhance the efficiency and effectiveness of this innovative technology.

1.2. Analysis of Vortex Bladeless Wind Turbine Design Parameters

Optimizing the vortex bladeless wind turbine (VBWT) design so that it enhances the output power performance, design parameters analysis is needed to study their effect on the oscillation ability. The turbine comprises three main components: a cantilever rod, a cylindrical mast body, and a harvesting unit (Chizfahm et al., 2018). The structure of the proposed VBWT that was designed by VORTEX Bladeless ® is presented in Figure 1.

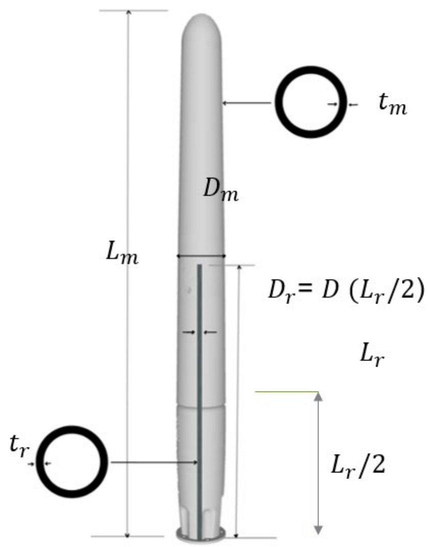

Figure 1. Proposed VBWT designed by VORTEX Bladeless ®.

The design parameters values that were used by VORTEX Bladeless ® are shown in Table 2. The values were measured through a 3D bladeless wind turbine model. This study found proportion formulas to present the lower and upper design parameters, see Table 3 using equations 1:4.

Table 2. Initial design parameters of VBWT

Variable	Description	Value	Unit
L_m	Mast length	12	m
L_r	Rod length	6	m
D_m	Mast diameter	1	m
D_r	Rod diameter	0.1	m
t_m	Mast thickness	0.25	m
t_r	Rod thickness	0.05	m

Table 3. Lower and upper bounds of VBWT design parameters

Design parameter	Lower bound	Nominal (Initial)	Upper bound	Unit
L_m	5	12	20	m
L_r	2.5	6	10	m
D_m	0.4	1	1.7	m
D_r	0.04	0.1	0.17	m
t_m	0.1	0.2	0.3	m
t_r	0.02	0.05	0.08	m

$$D_m = D_r \frac{v_\infty(y)}{v_\infty(L_r/2)} - aX(y) \quad (1)$$

Where $v_\infty(y)$ and $X(y)$ are the velocity of the fluid and the oscillation amplitude of the mast at each height y

$$\frac{L_m}{D_m} \leq 12 \qquad (2)$$

$$\frac{L_m}{L_r} \leq 2 \qquad (3)$$

$$\frac{L_r}{D_r} \leq 60 \qquad (4)$$

1.3. Bladeless Wind Turbine Mathematical Modelling

This section will express the bladeless wind turbine mathematical modeling, choosing the type of materials to use is required in this phase. A cylinder mast is made of glass carbon fiber polymer (GFRP), and a Flexible rod is made of reinforced carbon fiber polymer (CFRP). The lightweight mast connected to the rod's purpose is to harvest energy by converting mechanical energy to electrical energy. Therefore, this study used the design parameters as shown in Table 4.

Table 4. Characteristics of the materials used in the manufacture of the turbine.

E_m	Mast young’s modulus	72	GPa
E_r	Rod young’s modulus	180	GPa
ρ_m	Mast mass density (GFRP)	1.5	kg/m^3
ρ_r	Rod mass density (CFRP)	1750	kg/m^3
S_t	Strouhal number	0.21	dimensionless
C_d	Drag coefficient	1	dimensionless
ρ	Air density	1.225	kg/m^3
v	Air velocity	7	m/s

1.3.1. Resonance

When an oscillation is strengthened by a periodic movement, the phenomenon of resonance occurs. In aeroelasticity, the air can cause an oscillatory movement in a body if its natural resonance frequency and the wake frequency of vortex shedding are both identical. VIV phenomena are the vibrations created in a body by vortices. Vortex shedding occurs on a regular basis, with forces perpendicular to the incident wind flow direction. There is a proportionality constant S_t between the incident wind flow's average velocity$v$, the inverse of its characteristic length Φ, and the frequency of vortex shedding f_v (David & Villarreal, 2018).

$$f_v = \frac{S_t \cdot v}{\Phi}$$

1.3.2. Aerodynamic force model

F_t and F_m are respectively the lift force and moment exerted from the mast on the tip of the stand in Newton(N). defined by (Chizfahm et al., 2018) (Figure 2):

$$F_t = \int_{L_r}^{L_r+L_m} \frac{1}{2}\rho v^2 C_d\, D_m(x)dx - m_m\ \underline{\ddot{y}} \qquad (5)$$

$$F_m = \int_{L_r}^{L_r+L_m} \frac{1}{2}\rho v^2 C_d\, D_m(x)(x - L_r)dx - m_m\ \underline{L}_m\underline{\ddot{y}} - \underline{I}_m\ddot{\theta}_m \qquad (6)$$

where m_m for the center of mass of the mast , $\underline{L}_m$ is the distance to the tip of the stand, and $\underline{I}_m$, is the moment of inertia about z-axis.

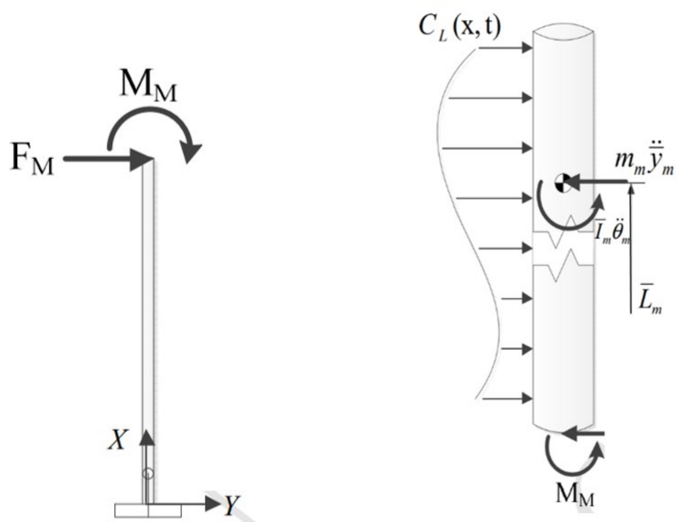

Figure 2. Free-body diagram of BWT designed by (Chizfahm et al., 2018)

1.3.3. Beam Deflection

To determine the maximum beam deflection of cantilever beam carrying uniform wind load (force). See equations 7-10.

$$\delta = \frac{F_w\, L^4}{8E_m\, I_m} \qquad (7)$$

$$F_w = A_s\, v^2 \rho \qquad (8)$$

$$I_m = \frac{\pi\left[\underline{D}m^4 - (\underline{D}_m - 2t_m)^4\right]}{32} \qquad (9)$$

$$A_s = 2\pi\, R_m L_m + 2\pi R_m^2 \qquad (10)$$

Where δ is the maximum beam deflection, F_w *is* Force of the wind on the projected area in N. I_m is the inertial moment of the mast in m^4. A_s is the Surface area of mast exposed to wind in m^2.

1.3.4. Output Power

$$P\ output\ power\ (joule) = f\ aerodynamic\ force * \delta\ (m)$$

$$f\ aerodynamic\ force = F_t + F_m$$

$$F_t + F_m = \int_{L_r}^{L_r+L_m} \rho v^2 C_d\, D_m(x)dx$$

$$Beam\ deflection\ \delta = \frac{F_w\ L^4}{8E_m\ I_m}$$

$$P\ output\ power\ (joule) = \int_{L_r}^{L_r+L_m} \rho v^2 C_d\, D_m(x)dx * \frac{F_w\ L^4}{8E_m\ I_m} \quad (11)$$

To convert the output power in watt the following formula can be used:

$$P\ in\ watt = \frac{P\ \ in\ joule}{t\ \ in\ second} \quad (12)$$

1.4. Optimization

In this research work, Taguchi orthogonal arrays were employed to obtain a design matrix by using Minitab software. The Taguchi design rules were applied to six factors and two levels that run 16 times $L_{16}2^6$. Table 5 shows an orthogonal array. It was constructed using data selected from the full-factorial mathematical modeling results. The Taguchi method optimizes design parameters to minimize variation before optimizing the design to hit mean target values for output parameters (Karazi et al., 2019).

The Taguchi approach defines the signal- to- noise (S/N) ratio to determine optimal levels of each parameter and analyze parameter variation. When the response is maximum, the "Larger is Better" state is considered, which can be calculated using Eq. (12), S/N ratio.

$$\frac{S}{N} ratio = (-10)\left(\frac{1}{x}\right) \sum_{i=1}^{x} \frac{1}{y_{ij}^2} \quad (13)$$

S/*N* = signal-to-noise ratio, where *x* = number of observations, y_{ij} = measured observation.

Table 5. Design of Experiments – Taguchi $L_{16}2^6$

Run	L_m	L_r	D_m	D_r	t_m	t_r	*Output power in KW*
1	5	2.5	0.4	0.04	0.1	0.02	0.00422208
2	5	2.5	0.4	0.17	0.1	0.08	0.00102270
3	5	2.5	1.7	0.04	0.3	0.02	0.00006162
4	5	2.5	1.7	0.17	0.3	0.08	0.00006163
5	5	10	0.4	0.04	0.3	0.08	0.00098944
6	5	10	0.4	0.17	0.3	0.02	0.00102270
7	5	10	1.7	0.04	0.1	0.08	0.00006162
8	5	10	1.7	0.17	0.1	0.02	0.00006163
9	20	2.5	0.4	0.04	0.3	0.08	3.93582508
10	20	2.5	0.4	0.17	0.3	0.02	4.06815669
11	20	2.5	1.7	0.04	0.1	0.08	0.22488957
12	20	2.5	1.7	0.17	0.1	0.02	0.22491200
13	20	10	0.4	0.04	0.1	0.02	3.93582508
14	20	10	0.4	0.17	0.1	0.08	4.06815669
15	20	10	1.7	0.04	0.3	0.02	0.22488957
16	20	10	1.7	0.17	0.3	0.08	0.22491200

Depending upon the objective of this study, the maximization of output power is of interest. Therefore, larger-the-better criterion is selected for these quality characteristics. See Figure 3

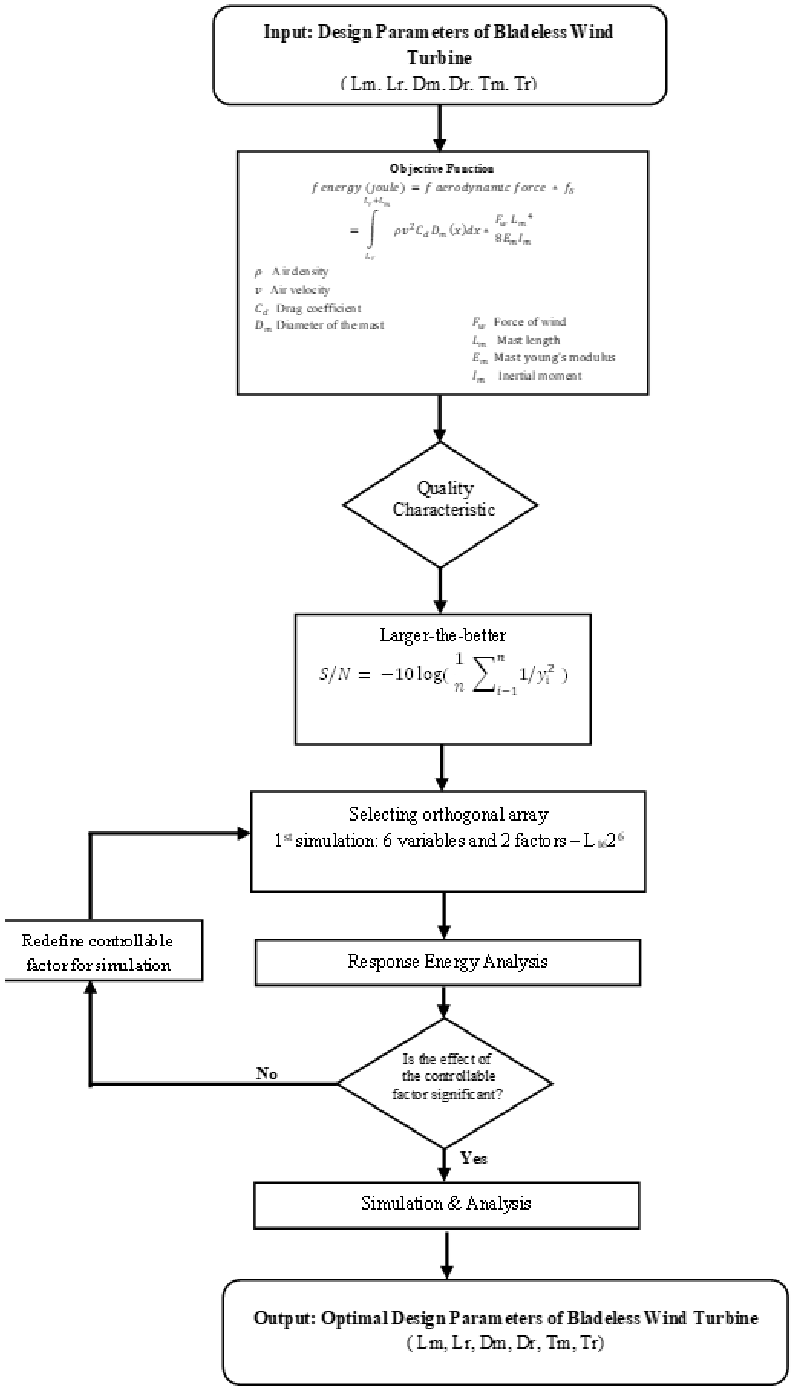

Figure 3. Optimization procedure in the Taguchi design

2. Results and Discussion

Minitab is a statistical software tool that helps in analysing data and improving processes. It is widely used by six sigma professionals, organizations, statisticians, manufacturers, and engineers to solve problems and improve quality. Minitab can perform a variety of statistical and graphical analyses such as Regression Analysis, Analysis of Variance

(ANOVA), Predictive Analytics, Time Series, Forecasting, Simulations, and Design of Experiments (DOE) including Taguchi Designs, which is the method used in this study.

Table 6. Response Table for Signal-to-Noise Ratios

Level	L_m	L_r	D_m	D_r	t_m	t_r
1	-70.5016	-34.6921	-22.3768	-34.7641	-34.6921	-34.6921
2	-0.4579	-36.2674	-48.5827	-36.1954	-36.2674	-36.2674
Delta	70.0436	1.5753	26.2056	1.4313	1.5753	1.5753
Rank	1	5	2	6	3.5	3.5

Response Table for Signal-to-Noise Ratios
Larger is better

The difference between the largest and smallest average of the response's values for each one of the design parameters is given as Delta. To indicate the relative effect of each parameter on the response, Minitab assigns rank scores to each parameter based on the value of Delta. The largest Delta value is assigned as Rank 1, the second highest as Rank 2, then the third highest as Rank 3, and so on. When there is a tie between the values as shown in column t_m and column t_r the average rank for both values is assigned.

The analysis shows that the mast length L_m where Delta equals to 70.0436 and is assigned as Rank 1 has the largest effect on the S/N ratio, indicating that an increase in the mast length will increase the energy production. The second largest effect is caused by the mast diameter D_m where Delta equals to 26.2056, followed by the mast thickness t_m and rod thickness t_r, then followed by rod length L_r, and finally, the smallest effect on the S/N ratio among all the design parameters is the effect of rod diameter D_r.

The optimal range of values that will lead to increased energy production is shown in Figure 4 down below. Since the larger value is better, the optimal value will be the upper limit:

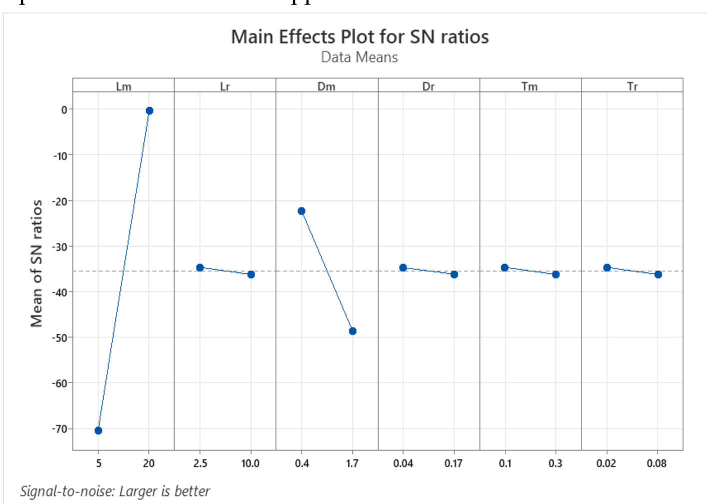

Figure 4. The Maximum Response of Design Factors

The upper limits for the design parameters ($L_m, L_r, D_m, D_r, t_m, t_r$) are clearly shown in Figure 5 which equals to 20, 2.5, 0.40, 0.04, 0.10, and 0.02 meter respectively as tabulated down below in Table 7.

Table 7. The Attained Optimal Values for design the parameters

L_m	L_r	D_m	D_r	t_m	t_r
20m	2.5m	0.40m	0.04m	0.10m	0.02m

A graphical comparison between the initial and optimal values for each design parameter is shown in Figure 5

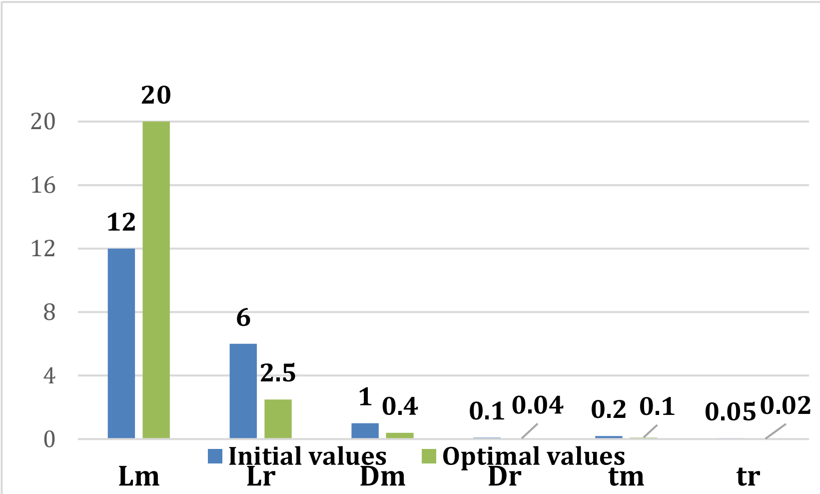

Figure 5. Initial VS Optimal Values

It is now apparent that the optimal mast length is significantly higher than the initial length, with 66.7% increase. Since it has been previously stated that the mast length has the largest effect on the S/N ratio, it is known for certain that whenever the mast length increases, the energy production increases as well.

Based on the new calculated values, the new energy production is expected to reach an approximation of 3.4438 kilowatts per day, equivalent to approximately 1000 kilowatts of energy produced per year assuming 90% efficiency. That is a marked increase by 175.504% in production compared to the initial energy production, which was only an approximation of 1.25 kilowatts per day and approximately 400 kilowatts of energy produced per year. The Taguchi method helped to increase the system's productivity by reducing potential variations through using the design of experiments. Figure 6 shows the comparison between the initial energy production before the optimization analysis, versus the maximized energy production after using the optimal values for the factors:

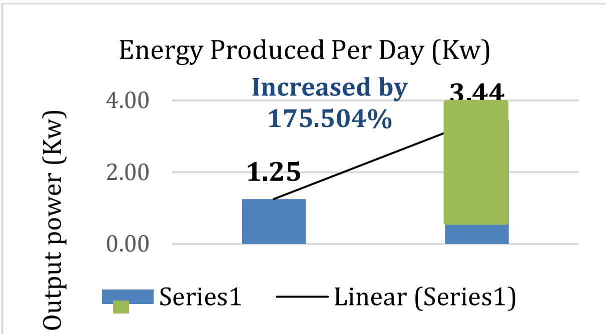

Figure 6. Initial Energy Production VS Optimal Energy Production

In addition, Minitab gives the Response Table for Data Means as tabulated in Table 8 as well as the Main Effects Plot for Means, shown in Figure 7.

Table 8. Response Table for Data Means

Level	L_m	L_r	D_m	D_r	t_m	t_r
1	0.00094	1.05739	2.00190	1.04085	1.05739	1.05739
2	2.11345	1.05699	0.11248	1.07354	1.05699	1.05699
Delta	2.11251	0.00040	1.88942	0.03269	0.00040	0.00040
Rank	1	4.5	2	3	4.5	6

The main effects plot shown in Figure 7 indicates that there is a main effect on the response and that different levels of factors will affect the response differently. The steeper the slope of the line, the greater the magnitude of the main effect.

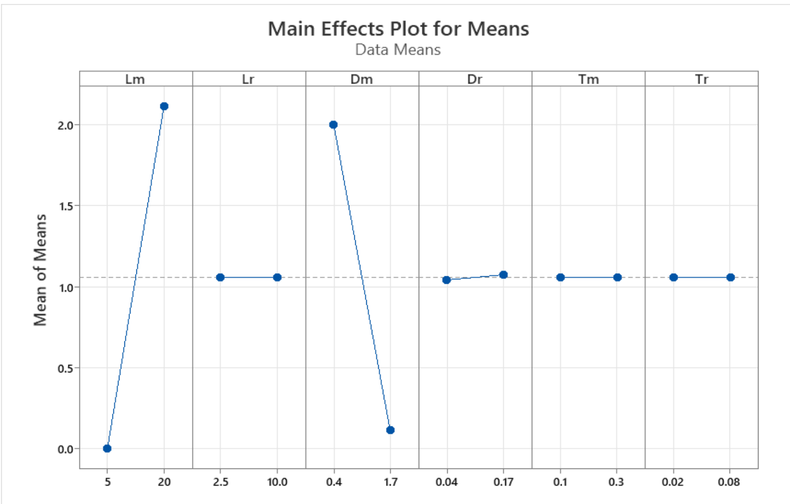

Figure 7. Main effects plot for means.

2.1. The Anderson Darling Test (ADT)

One of the most powerful statistical tools used to measure how well a set of data follows a particular distribution is the Anderson Darling Test (ADT). It is a general normality test employed to validate normality assumptions and detect all the departures from normality. Figure 8 shows a Probability Plot, which is a graphical technique that determines whether the set of experimental data follows a particular distribution or not, in addition to estimating percentiles, it also compares sample distributions. A probability plot displays each value versus the percentage of values in the sample that is less than or equal to it, along a fitted distribution line. The y-axis is transformed so that the fitted distribution forms a straight line. Figure 8 shows that the experimental data for all the responses fall near that fitted line. The Anderson-Darling Test is a hypothesis test. The null hypothesis H_0 is that the data follows a normal distribution, while the alternative hypothesis (Ha) is that the data does not follow a normal distribution.

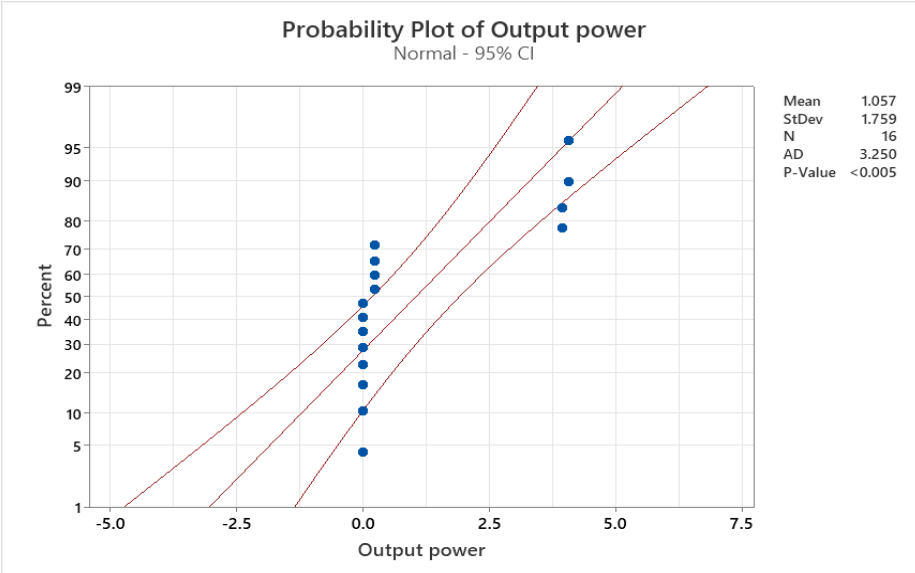

Figure 8. Probability plot of output power

The decision of whether to accept or reject the null hypothesis H_0 will be based on the P-Value, which is a probability that measures the evidence against the null hypothesis H_0 . In this study, alpha equals 0.05 and the obtained P-Value of the test is less than alpha, see Figure 8. Therefore, it is assumed that the experimental data does not follow a normal distribution.

3. Conclusion and Recommendation

Wind energy has become a main part of the global renewable energy sector, and the dependence on it is anticipated to increase in the foreseeable future. At present, traditional wind turbines are the most used machines to transform wind energy into electrical energy. The issues associated with traditional wind turbines include transportation problems, high maintenance costs, and harmful environmental impacts. These downsides lead to a consideration of the Vortex Bladeless Wind Turbine (VBWT), which focuses on less space requirement, less impact on wildlife, zero noise, as well as having fewer moving components, which means less wear and tear, and lower maintenance costs. The suitable size of this turbine also makes it simple to install in homes, schools, and any location.

The main objective of this study was to optimize the potential energy production of a vortex wind turbine using mathematical models. In the process of devising the tools to achieve that goal, the Taguchi method had to be created for VBWT design parameters. For the measurement of VBWT dimensions, the VORTEX Bladeless ® 3D model was used.

The main findings of this study can be summarized in the following points:

1. The optimal values of VBWT design parameters are:

   $$L_m = 20\ m\ , L_r = 2.5\ m\ , D_m = 0.4\ m\ ,\ D_r = 0.04\ m\ , t_m = 0.1\ , t_r = 0.02\ m$$

2. The output power of optimal VBWT is 3.44 KW. It increased from 1.25 KW for the initial design parameters to 3.44 KW.
3. The most significant design parameter is the length of the turbine, which takes the first rank in Taguchi design.

Future work concerns pursuing the following directions to improve the model:

1. In this study, a cylindrical shape of the mast was used to follow the VORTEX Bladeless® model, but designing a conical mast shape may achieve perfect synchronization of the vortex shedding all along the mast. Given that the wind velocity in the atmospheric boundary layer increases with height, the diameter of the oscillating structure should also increase with height to favour synchronization.

2. Although only uniform flows were tested in this study, it would be very effective to simulate the efficiency of VBWT under the dynamics of an atmospheric boundary layer. Furthermore, additional research would allow for determining the most efficient shape for the mast to optimize the synchronization of vortex shedding along the height of the mast that maximizes output power
3. The Integration of offshore wind with tidal energy can maximize the system's output.

Acknowledgement
The authors would like to express their gratitude to King Khalid University for its support throughout this study.

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Biographies

Dr. Mohammed M. Alqahtani is a Professor of Industrial Engineering at King Khalid University in Abha, Saudi Arabia. He obtained his undergraduate degree in Industrial Engineering (2010) from King Khalid University in Abha. And got his Ms degree in Industrial Engineering (2015) from The University of Arizona, Tucson, USA. Alqahtani received his Ph.D. in Industrial Engineering from the University of Illinois at Chicago (UIC) in 2021. After that, he was appointed to the Department of Industrial Engineering at King Khalid University in 2021 as an Assistant Professor. Alqahtani serves as a peer-reviewer for many scientific journals including: Applied Energy-Elsevier, Journal of Cleaner Production-Elsevier, Intelligent Transportation Systems-Wiley, Wireless Networks-Springer's, and Intelligent Transportation Transactions-IEEE.

Sarah Al Saeed is an Industrial Engineer, holding a bachelor's degree from King Khalid University. Certified by IBDL, she has been recognized for her academic excellence with an award. Her passion for research culminated in the publication of an article on utilizing UAVs for sustainability. Her training extends internationally, having undergone programs at the Technical University in Berlin (TU Berlin) and the Smart Methods Company, specializing in electronics and robotics. Notably, she pursued intensive courses in applied econometrics, public policy, data analysis, and leadership at the University of Chicago, Harris School of Public Policy.

Shahad Almasud is an Industrial Engineer who got a degree from King Khalid University, and she was selected among +55k students to get The Scientific Excellence Award depending on her scientific achievements. She is a Certified Industrial Engineer from IBDL, she got a nano degree in business and data analytics. Currently, she works as an engineer at The National Automotive Company CEER, a PIF joint venture. She had a blended traineeship program from SIDF and Fitch Learning. Her different interests are in data, business analysis, and product management. In addition, she participated in a variety of experiences in engineering, product management, and data analysis.

Involved in many activities and specific initiatives which developed her skills and gained various experiences in engineering. Like her participation in the OXAGON, Ai Artathon, and KAUST hackathons. Furthermore, Shahad founded different initiatives to empower Saudi youth in the paths of engineering and business.

Reham Alashwl has a Bachelor of Science in Industrial Engineering from King Khalid University with a first-class honour. During her academic years, she served as a Quality and Reporting Director for IEOM-KKU; writing semi-annual reports and managing three sub-teams. She received many awards for her academic excellence and extracurricular achievements, and in 2021 she was honoured by his excellency president of King Khalid University as a first-place winner in the Annual Award of Excellence (Student Chapter). Reham currently works as an assistant project analyst at the Saudi Industrial Development Fund and her career goals revolve around contributing to the industrial transformation in Saudi Arabia**.**

Fatimah Aljameel graduated with a bachelor degree in industrial engineering from King Khaled University. She got the opportunity to develop her skills and knowledge through the training in Technical Universe Berlin in green marketing and Java programming. Her core interests lays in project management and market research. Fatimah participated various competitions to apply her Industrial Engineering knowledge in projects such as Supply Chain Challenge "LogiThon" on the sidelines of the 5th,OXAGON Hackathon as market researcher , University Innovation Challenge .Fatimah joined AFHSR as volunteer in Supply Chain Management and Quality improvement department to expanding her knowledge and awareness, she has courses on International Introductory In Logistics and Transportation and Lean Six Sigma Yellow Belt and project management . Fatimah participated in Aseer Development Authority's international ideation workshop in London. She is passionate about raising engineering awareness within the community through her participation in volunteer initiatives such as Mohandas Podcast and IE HOME.

Sabah Alshahrani is an Industrial Engineer, holding a bachelor's degree from King Khalid University. Interested in environmental sustainability and occupational safety and health, She has OSHA 30-H General Industry by OSH Academy-USA. She worked as Director of Event Management Team of the Industrial Engineering and Operations Management Society IEOM-KKU and worked in the field of performance improvement at American Society of Mechanical Engineers ASME-KKU Student Branch. Sabah is currently works as an industrial engineer at Ingaz company and she is works as a volunteer in project management for a development project in Aseer region.