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Research Article

Harnessing Wind Energy for Power Generation in the Niger Delta Region of Nigeria

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Abstract— Sustainable power generation in any economy is the powerhouse to foster developmental innovation, productivity and industrialization to a country. Hence, scouting for green and cleaner energy source is the concern for contemporary research. Therefore, it is essential to harness wind energy for power generation in the Niger Delta Region of Nigeria been surrounded with coastline where wind is naturally abundant. The research was carried out in the Niger Delta University, Wilberforce Island, Bayelsa State with full use of its Weather House facilities. Data analysis for six (6) years average wind velocity was obtained. The evaluated average wind velocity of 4.8m/s was used as the design-based specification for a modelled aerofoil blade. The process is followed by wind tunnel experimentation with the modelled aerofoil blade in other to determine its aerodynamic properties. Results obtained were lift and drag coefficients of 0.731 and 0.439, a glide ratio of 0.25 and an output power generation of 134.6W all at 15° angle of attack. A confirmed zero bending moment was obtained from the graphical analysis of bending moment against wind velocity. This affirms the symmetric nature of the aerofoil, balancing and stabilising it at its design point. All these concepts are in conformity with the reviewed literature.

Keywords— Aerofoil, Angle of Attack, Drag Coefficient, Lift Coefficient, Pitch Angle, Wind Energy, Wind Tunnel, Wind Velocity.

1. Introduction

A continuous supply of energy is a critical concern for any developing nation. It is vital for a country's economic development, prosperity, and elimination of poverty as well as for national security. Therefore, one of the most essential needs for the growth and progress of a country includes raising living standards and encouraging business initiatives with commercial enterprises. The energy industry is an essential sector for every nation's developmental reforms. These are the baselines for the essence of this research in developing countries, Nigeria.

However, the lack of energy has led to the demise of manufacturing, small and medium-sized enterprises, and an unstable and unbalanced national economy. Therefore, the only surefire way to stop this intolerable scenario is to look for energy, primarily from the renewable sources.

Due to growing environmental risks worldwide and severe concerns about greenhouse gases (GHGs) from traditional energy sources, this extreme worry has given rise to research opportunities into renewable energy supplies. Academic studies have demonstrated that a nation's capacity to grow economically in the future depends on its ability to obtain cheap, readily available, and environmentally sustainable energy sources over the long run [1].

Without doubt, energy has an impact on a variety of productive endeavors, such as mining, manufacturing, commerce, and agriculture. This influences how a nation's average citizenry's living standard is measured, which is done by dividing per capita energy consumption by per capita income [2]. Third-world nations like Nigeria must take advantage of this enthusiasm and jumpstart their economies by primarily utilizing wind energy, which is free of pollutants that harm the environment and could destroy the ozone layer.

2. THE STATE OF ENERGY GENERATION IN NIGERIA

Nigerian energy generation has historically been a mirage. The evidence, as reported in a review literature verified the installation of a 60KW energy producing set for power supply at the Lagos colony in 1886—exactly 15 years after electricity was first generated in England [3], [4]. This is a clear illustration that England was just 15-years ahead of Nigeria in energy and electricity generation but today the

difference is far apart. Over the time, the different energy producing and regulating sectors in Nigeria such as Public Works Department (PWD) , Nigeria Electricity Supply Company (NESCO), Electricity Corporation of Nigeria (ECN), Niger Dams Authority (NDA), National Electric Power Authority (NEPA) and Power holding Company of Nigeria (PHCN) which is currently saddled with the responsibility to generate (GENCOs), distribute (DISCOs) and transmit (TRANSCOs) are just a few of the entities in Nigeria that have failed the country's citizens over time [5], [6], [7], [8], [9]. As a result, there are ongoing power outages and low-quality power supplies. Nigeria is a developing nation with a population of over 150 million. Due to the country's diversification of economic activity and growing population, the demand for energy is rising, but the supply of electricity is essentially unchanged. The Nigerian population requires more than 40,000MW of electricity, yet only 2,900MW to 4,000MW of that is supplied to Nigerians in real time [10], [11]. It obvious that there is a clear surplus of demand over supply of electricity. The growing disparity between the supply and demand of power is primarily due to inefficient generation and poor transmission infrastructure.
Research indicates that a large Nigerian population lacks connection to the national power source. Those that do have access to the grid, however, experience irregular supply because of high power losses, damping oscillations, and system instability in the generation, transmission, and distribution phases [1]. According to a study, those who live in rural areas are more likely to experience unplanned power outages, unstable power supplies, and electricity deprivation [12].

Nigerians suffer from widespread energy deficiency due to energy deprivation. 72% of Nigerians are thought of using locally source of cooking such as charcoal and woods. Thus, to what the 2003 National Energy Policy anticipated, growing poverty has compelled a reversal in the shift toward more contemporary and well-organized energy sources. However, Nigerians are now descending the energy pyramid and using firewood as a cooking fuel instead of electricity, gas, or kerosene [13]. Hence, this study of harnessing wind energy for power generation in the Niger Delta Region of Nigeria is to elevate and increase energy sufficiency and sustainability.

3. RESEARCH METHODOLOGY

The primary objective of the study is to gather wind data from credible sources and examine its availability for potential power generation. Thus, the major method for this research lies on investigative study and information on average wind speed gathered from 2018 to 2023. This will be achieved from the weather house at Niger Delta University (NDU). Also, a design analysis of aerofoil blade model of wind turbine will be considered using AutoCad, whereas the modelling will be done in a Matlab programme. Another method will be on experimentation with wind tunnel where a designed aerofoil model will be analysed. It will be used for the evaluation of average wind speed generated during the study period as mentioned above. It will also be tested in a wind tunnel in order to determine the aerofoil drag and lift forces as well as other aerodynamic properties and potential power output. Finally, a comprehensive comparative analysis of results will be considered for discussion.

4. ESTIMATION OF AVERAGE WIND SPEED

The Niger Delta University (NDU) Weather House is capable of rendering meteorological services, hence average wind speed measurement data per month for six years were collected and presented in table 1 to enhance the study.

Table 1: Summary of Average Wind Between 2018 - 2023

Months	Yearly Average Wind Speed (m/s)						Average Wind Speed (m/s)
	2018	2019	2020	2021	2022	2023	2018 to 2023
January	5.05	5.34	3.52	4	4.11	5.46	4.58
February	5.88	5.13	3.91	3.73	4.78	6.16	4.93
March	5.72	5.68	4.78	4.56	4.24	4.43	4.9
April	8.35	5.82	5.44	4.83	4.15	5.37	5.66
May	5.36	4.34	3.32	3.09	4.43	4.99	4.26
June	3.85	4.59	5.83	3.69	5.22	4.41	4.59
July	4.39	4.69	5.44	6.22	4.99	5.79	5.25
August	6.17	3.36	5.42	4.42	5.21	3.95	4.76
September	6.14	5.71	3.85	4.45	5.8	4.76	5.12
October	5.61	4.35	3.77	5.39	3.2	5.03	4.56
November	3.34	4.31	3.21	3.53	4.76	5.46	4.1
December	3.77	4.26	4.73	5.44	5.03	6.32	4.93
					Average Wind Velocity		4.8

5. DESIGN ANALYSIS OF AEROFOIL WIND TURBINE BLADE MODEL

A thorough understanding of the aerodynamic operations such as drag and lift on the blades of wind turbine is necessary for the design study of the aerofoil wind turbine blade model. Research indicates that these aerodynamic forces provide a clear study of the pressure and friction brought on by air or wind passing across the surface of the aerofoil [14],[15]. Figure 1 illustrates the likelihood that this scenario will arise at a pass way with an angle variation against the wind path. As a result, an angle of attack ($\propto$) that depends on the blade velocity (U) at a certain radius is caused by the relative velocities of the air streams passing across the blade (W) [14],[16]. This produces a pitch angle (β) from the air flow at varying velocities enclosed in a velocity triangle of the aerofoil profile [16]. The aerofoil blade model is designed in an AutoCad interface as shown in figures 2 and 3 respectively. The modelling was carried out on a Matlab tool with the provided aerodynamic properties and coordinates as shown in table 2 and the final model presented in figure 4.

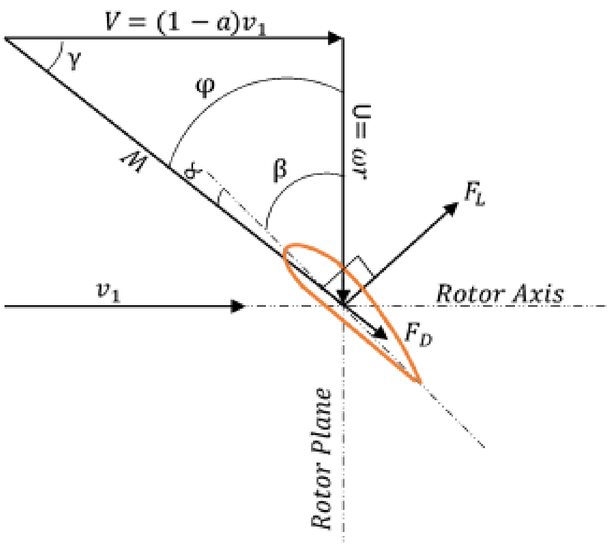

Figure1: Representation of Velocities, Angles and Forces of an Aerofoil Blade Section

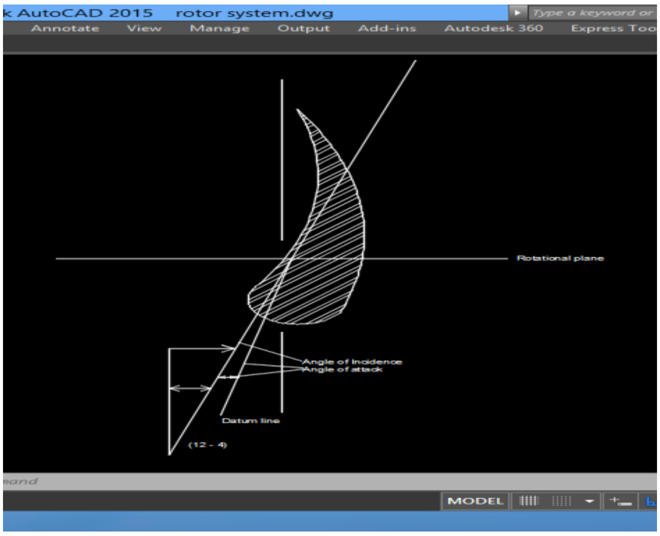

Figure 2: Design of Aerofoil Blade

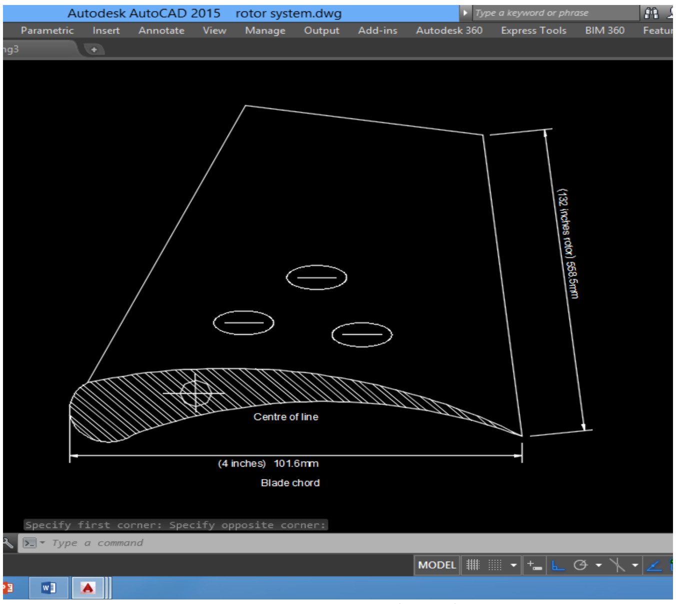

Figure 3: Sectional View of Aerofoil Blade

Table 1

UPPER SURFACE		LOWER SURFACE	
X/C	Y/C	X/C	Y/C
1	0	0	0.00075
0.99893	0.00039	0.00107	-0.00566
0.99572	0.00156	0.00428	-0.01102
0.99039	0.00349	0.00961	-0.0159
0.98296	0.0061	0.01704	-0.02061
0.97347	0.00932	0.02653	-0.02502
0.96194	0.01303	0.03806	-0.02915
0.94844	0.01716	0.05156	-0.03281
0.93301	0.02166	0.06699	-0.03582
0.91573	0.02652	0.08427	-0.03817
0.89668	0.03171	0.10332	-0.03991
0.87592	0.03717	0.12408	-0.04106
0.85355	0.04283	0.14645	-0.04166
0.82967	0.04863	0.17033	-0.04177
0.80438	0.05453	0.19562	-0.04147
0.77779	0.06048	0.22221	-0.04078
0.75	0.06642	0.25	-0.03974
0.72114	0.07227	0.27886	-0.03845
0.69134	0.07795	0.30866	-0.037
0.66072	0.08341	0.33928	-0.03547
0.62941	0.08858	0.37059	-0.0339
0.59755	0.09341	0.40245	-0.03229
0.56526	0.09785	0.43474	-0.03063
0.5327	0.10185	0.4673	-0.02891
0.5	0.10538	0.5	-0.02713
0.4673	0.10837	0.5327	-0.02529
0.43474	0.11076	0.56526	-0.0234
0.40245	0.11248	0.59755	-0.02149
0.37059	0.11345	0.62941	-0.01958
0.33928	0.11361	0.66072	-0.01772
0.30866	0.11294	0.69134	-0.01596
0.27886	0.11141	0.72114	-0.0143
0.25	0.10903	0.75	-0.01277
0.22221	0.10584	0.77779	-0.01136
0.19562	0.1019	0.80438	-0.01006
0.17033	0.09726	0.82967	-0.00886
0.14645	0.09195	0.85355	-0.00775
0.12408	0.08607	0.87592	-0.00674
0.10332	0.0797	0.89668	-0.00583
0.08427	0.07283	0.91573	-0.00502
0.06699	0.06541	0.93301	-0.00431
0.05156	0.05753	0.94844	-0.00364
0.03806	0.04937	0.96194	-0.00297

0.02653	0.04118	0.97347	-0.00227
0.01704	0.03303	0.98296	-0.00156
0.00961	0.02489	0.99039	-0.00092
0.00428	0.01654	0.99572	-0.00042
0.00107	0.00825	0.99893	-0.00011
0	0.00075	1	0


Figure 4: Aerofoil Blade Model

6. EXPERIMENTATION AND PERFORMANCE EVALUATION

HM170 wind tunnel test bed as presented in figure 5 with cross section showing the portion at which the aerofoil blade model aerodynamics characteristics is determined in figure 6, is designed and manufactured by GUNT Hamburg. This is a NDU based laboratory equipment for evaluating the performance of aerodynamics experimentations. It is a subsonic open wind tunnel having a square measurement section allows the measurement of different sample fittings for fluid mechanics and aerodynamics applications.


Figure 5: Cross Section of Wind Tunnel


Figure 6: Aerofoil in Wind Tunnel Measurement Section

The experiment of the aero profile is digitally controlled by a measurement amplifier having display screen to test for all aerodynamic characteristics of the wind turbine as the wind passes through the sample specimen. As observed the tunnel generates the following aero – parametric characteristics such as: drag and lift forces, wind velocities, pressures, etc as the tunnel fan is adjusted to the corresponding average wind speed as analysed in table 1. This also supports in determining the required energy generation.

A computer system is aided by the needed computerised facilities to process all necessary information for evaluation. It is an enhanced process to achieve and accomplish the practical/theory-based learning system. The software is developed with information about lift and drag forces, distribution of pressure curves, wind speeds and other vital parameters in a preferred interface. In the measurement portion, the testing sample is held in a force transducer having double electronic components. This is fixed on a circular measurement plate which has the capability of adjusting the attack angle. A very important feature in the tunnel is an inclined tube manometer. This measures the wind velocity with an adjustable fan control speed of 0 – 10m/s.

7. RESULTS PRESENTATION AND DISCUSSION

The following results as obtained from the wind tunnel test bed are presented below.

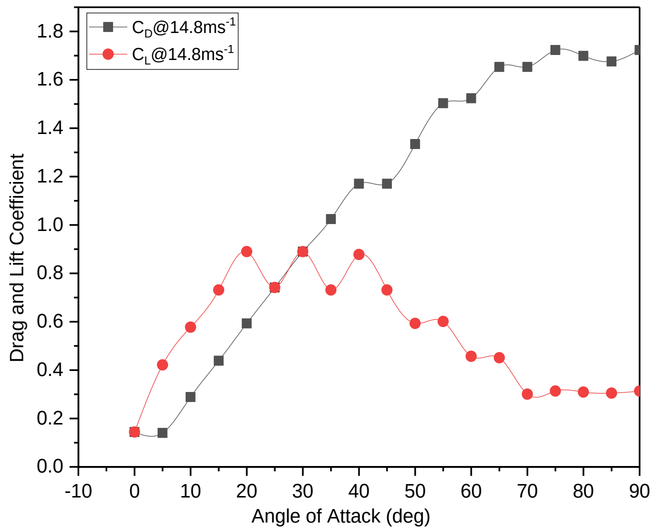

Figure 7: Drag and Lift Coefficients of the Aerofoil Model

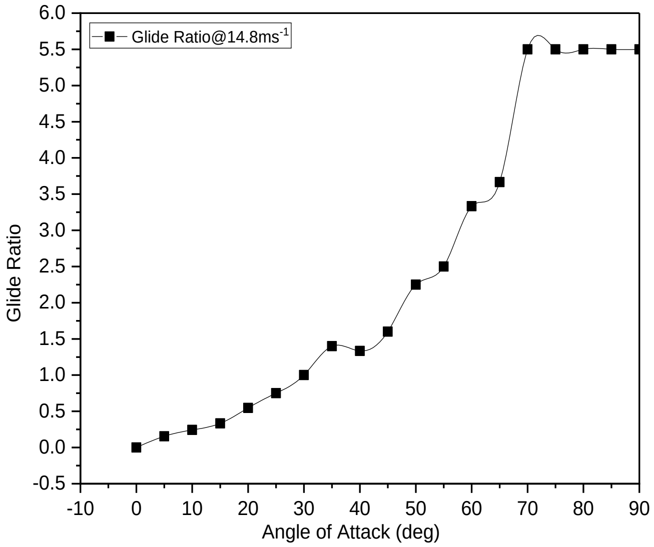

Figure 8: Glide Ratio for the Aerofoil Model

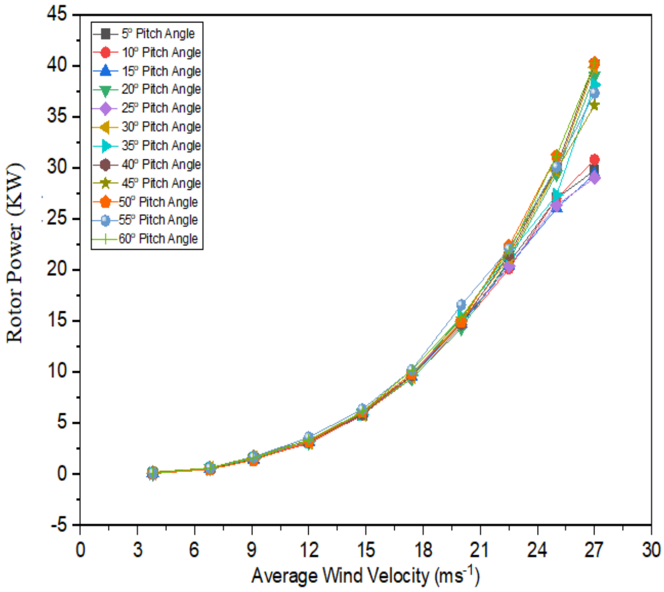

Figure 9 Power against Wind Velocity for Aerofoil Model

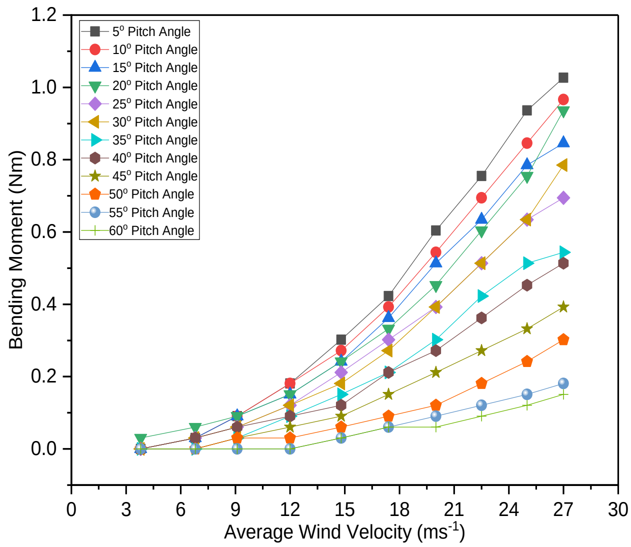

Figure 10: Bending Moment against Wind Velocity for Aerofoil Model

The determination of the peak performance of a wind turbine blade is to evaluate the generation of power. This is achieved most often by the means of wind tunnel like the sampled case for this study. Conversely, the conducted aerofoil blade analysis is discussed comprehensively. Results for lift and drag coefficients are obtained as 0.731 and 0.439 respectively at 15° attack angle of the model at predefined and evaluated average wind velocity of 4.8ms^{-1} is shown in the presented result at fig 6 and in table 1 respectively. According to unveiled research studies [17],[18],[19]; explains that the Horizontal Axial Wind Turbine (HAWT) is termed and referred as a lift force-based system. Hence, its lift coefficient should be slightly bigger than the drag. The obtained results are in conformity to the reviewed literature.

Similarly, fig.7; shows a graph plot of ratio of lift and drag coefficients simply known as glide ratio against angle of attack. It attests for aerodynamic efficiency of a wind turbine. Scholarly studies affirm that the high margin in the glide ratio is responsible for better performance of the system. However, it should be less than the drag coefficient [16],[20],[21]. Hence, in the analysis, a glide ratio of 0.25 is achieved with a drag coefficient of 0.439 all at reference attack angle of 15°. This validates the above concept. The graphical evaluation of rotor power and wind velocity is a function of the overall generation of energy. Thus, in the plot; at an average 4.8ms^{-1} wind speed at its reference point and bench mark, the rotor power increases in wattage up to 134.6W starting from the least pitch angle of 5° also considered as design pitch angle of the blade. It is been established that the increase in wind velocity gradually increases the produced energy in the wind turbine.

Meanwhile, the obtained bending moment is zero (0) from the plot of bending moment against wind velocity as shown in fig. 9. The aerodynamic moment about the aerodynamic center is zero for all angles of attack, indicating that the aerofoil is symmetrical. This confirms that the aerofoil is balanced and stable at the 5° pitch angle design point. Upon careful examination, it appears that the HAWT blade's bending moment across the design wind speed at various pitch angles is consistent. An applied aerodynamic force at a place one-quarter chord backward from the leading edge on the majority of low-speed aerofoils has the tendency to have a constant aerodynamic moment, which has been proved empirically and theoretically in a scholarly study [22]. However, as the figures show, the rotor power and bending moment appear to climb when the wind velocity rises with an increase in pitch angle. The findings verify that pitching happens following the attainment of the intended rotor power. This aids in regulating the turbine's speed and guards against damage from excessive speed. This is one of the key performance indicators used to assess the HAWT's efficacy.

8. CONCLUSION

Obviously, harnessing wind energy for power generation is a substantial fact undisputable. The study is a sample test that coastal region has relative effects from coastal storms though sometimes dangerous to the environment but useful for the harvesting wind energy. Over the considered study sample of six (6) years (ie, 2018 – 2023), the average wind velocity has been evaluated as 4.8m/s in the considered area of study from a reputable data source mostly on stormy hours in the days.

Therefore, the following conclusions with respect to this research are reached.

- Analysis validates study that the lift and drag coefficients are in confirmative order.
- High value of glide ratio for wind turbine study blade model is achieved and it gives quality performance to the wind turbine.
- A zero bending moment is achieved in the of plot bending moment against wind velocity. This confirms the symmetric nature of the aerofoil and validates the stability and balanced nature of the aerofoil at its design point.
- It is recorded that the average wind velocity of 4.8m/s is capable of generating 134.6W of power. This attests that the power generated in the wind turbine depends on the interaction between the rotor and the wind speed, however, the blade tilt angle to capture the stream line of the wind fluid is paramount.
- Therefore, study is recommended for future research mostly on coastal lines along the coastal rivers of the Niger Dela Region to ascertain the level and range of achievable wind energy.
- Also, research funding organization in the country and the globe in general should collaborate with renewable energy researchers for lasting solutions to the use fossil fuel.

Consequently, the contribution to knowledge is to bridge the elliptic energy supply to coastal and rural area by the harnessing of wind energy. This will elevate power generation in the Niger Delta Region and beyond to support productivity in small and medium enterprises, foster industrialization, and improve socio-economic activities.

Data Availability

The research data of this study were obtained from the weather house at Niger Delta University which were all analysed using the same University Thermo-fluid laboratory in the department of Mechanical Engineering. However, the survey literatures were obtained from relevant reputable journal publications as cited and referenced as shown in the reference list provided.

Conflict of Interest

There is no conflict of interest in the publication of this research work.

Funding source

The authors are the financers of this research work. We tasked ourselves for making sure all needed facilities are put together for the completion of the study. Hence, there is no external source of funds as regarding to this work.

Author's contribution

The spirit of team work was exhibited in this study though different tasks was shared amongst authors. The tasks being shared are as follows relevant literature review, data collection, materials and methods to be used, model design, etc. Meanwhile, conducting of experimentation was done and supervised by all authors. Developed results were analyzed separately as shared amongst authors. Finally, compilation and submission of manuscript were handled by the corresponding author.

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Orumgbe Chukwuekum obtained his first degree in 2006 from the Enugu State University of Science and Technology, Nigeria in Mechanical Engineering (Production Option). He MSc degree was obtained from Sheffield Hallam University, Sheffield, United Kingdom (UK) in 2015. Engr. Orumgbe is an academic staff of the Mechanical Engineering Department, Nigeria Maritime University, Okerenkoko, Delta State, Nigeria. He has numerous Conference/Journal papers publication to his credit. He is a registered member of many professional bodies in Nigeria and diaspora.

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