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Design Analysis and Modelling Of an Offshore Wind Turbine for Renewable Power Generation

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ABSTRACT: This research presents the current status of a simplified horizontal axis wind turbine model used for power generation and supply analysis. Offshore wind turbines are relatively complex, structural and mechanical systems located in highly demanding environment, andIn this research, the fundamental aspects and major issues related to the design of such structures to meet the power requirements of FSO PREM PRACHI in EBOK field at 1440kw were inquired. The system approach is proposed to carry out the design of the structural parts; Blade design,and structural performance, in order to organize the qualitative and quantitative assessment at various wind speeds. These can be faced by sub-models of different complexities both for the power output and for the load models. Analytical models were developed to assess the safety performance under aerodynamic and mechanical actions. In the structural and design analysis, the structures such as the blades and stator body design of a three blade horizontal axes turbine over a range of different wind speeds at OML 67, 4° 06’ 04. 184" N, 008° 10’ 29.016" E, 50KM offshore, in EKET, Akwa-Ibom State, Nigeria at a depth of 135feet. The design parameters were considered and compared using ANSYS, and MATLAB code to estimate and predict the required power using the estimated blade Design at different wind velocity’s obtained from **Nigeria Meteorological Agency (NIMET)** which gave a more satisfactory result of 1500kw.

KEYWORDS: Energy production, Offshore, Betz optimization equation, wind power potential, wind speed.

I. INTRODUCTION

Overdependence on fossil fuel generation is still prevalent in underdeveloped countries and the need for renewable energy has been increasingly justified in recent years as international powers turn to clean, green energy. Furthermore, research indicates that solar and wind energy is most likely to deliver economically accessible alternative energy sources in the near future, since other renewable energy sources such as tidal and biomass remains expensive. Wind and solar energy research will undoubtedly be at the forefront of future green engineering initiatives as continuous use of fossil fuels for power generation is highly expensive and unsafe for both humans and the ecosystem. In Africa, the devastating effects of these fuels on climate change, environmental safety, human health, ecological diversities, and the economies of many nations are enormous. According to **Alrikabi (2014**), with about 8 million metric tons of CO2 is emitted as a result of the use of fossil fuels consistently and around ₦126-billion (which is approximately US$ 984.38 million) deficit in revenue is caused by power failure annually as reported by **The Council for Renewable Energy of Nigeria**. Apart from the huge revenue deficit, (which could have been avoided by using an alternative source of energy) in addition, constant exposure to CO2 emitted as a result of ‘terrace generator’ brings about environmental and health hazards to offshore personnel’s and facilities **(Oyedepo, 2012).** In view of these, several countries have been coerced to sponsor research in environmentally friendly, renewable energy technology. However, when it comes to wind energy, the way to go is to construct offshore wind turbines capable of dealing with the far higher wind speeds available offshore while avoiding horizon and noise pollution issues. The average wind speed in the Eket community of southern Nigeria is excellent enough for a horizontal axis wind turbine using a Squirrel Cage

Induction Generator, according to this research, because of its factors as mentioned in the subsequent sections.

PROBLEM STATEMENT: Again, the over dependence on fossil-fuel power generator sets on offshore facilities for marine operations and cargo handling results in massive air/noise pollution. The running and maintenance costs of these generators are usually very large. Therefore, the outcome of this research, if considered, will improve energy efficiency; eliminate the release of greenhouse gases and annihilate the deafening generator-noise.

AIM: This research is aimed at designing a wind energy turbine with capacity sufficient to power FSO PREM PRACHI, with a power requirement of 1440kw, under varying operating conditions, using ANSYS modeller and analytical models

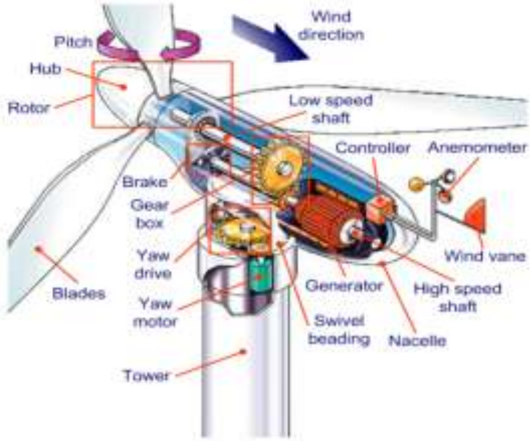
OBJECTIVES OF THE STUDY: The objective of this study is to:

i. Model a wind energy conversion system and develop a comprehensive simulation tool that can couple dynamic response of the variable speed wind turbines using ANSYS.
ii. Test the effects of varying wind speeds on the performance of the turbine
iii. Match the simulated wind turbine capacity against the actual power need of FSO PREM PRACHI.
iv. Simulate the aerodynamicdesign and operational behaviour of wind turbine under design conditions.

SCOPE OF THE STUDY: Wind turbines come in two sorts of axis (vertical and horizontal) and a wide range of sizes. Only the horizontal wind turbine is included in this study. It analyses and simulates the performance of a three-bladed wind turbine for offshore power generation. The static structureand power generated are considered. The effects of wind speed variation on performance are considered.However, detailed structural analysis and integrity assessment of stanchion and foundation are not included.

SIGNIFICANCE OF THE STUDY: Wind is a natural source of energy; and one of the largest on the planet which also has little to no pollution impact hence the fuel required for wind turbines are free and available on a daily basis. Different countries using fossil fuels, especially in Africa, are facing severe climate change, environmental pollutions, and ecological damage, leading to immense economic losses, health crisis, and loss of biodiversity. A good wind turbine design capable of harnessing clean and renewable energy is a panacea to the aforementioned. Also, the research will address the challenges of fluctuating wind speed on power supply reliability. The encumbrances of sustaining environmentally friendly power in FSO will be handled

II. OVERVIEW OF A HORIZONTAL AXIS WIND TURBINE



COMPONENTS OF A H0RIZONTAL AXIS WIND TURBINE

A wind turbine is an energy conversion device that converts the kinetic energy of the wind into electrical energy.
$$E = \frac{1}{2}\ x\ m\ x\ v^2$$

Wind turbines are powered by the wind, which turns two or three propeller-like blades around a rotor. The rotor is connected to the main shaft, which generates power by turning a generator. The wind power density (WPD) is a quantitative measurement of available wind energy at any given location **(Kunduru, et al., 2015**). It's computed as available mean power per square metre of area swept by a turbine in SI units of watts per square metre

Nonetheless, renewable energy sources are likely to play a larger part in energy over the next two decades, with wind energy contributing 1.1 trillion kilowatt-hours (kWh) of a total of close to 4 trillion kWh of renewable energy expected to be created by 2030 **(Ackermann &Soder,2000).**

Wind energy is divided into two categories:

i. Utility scale wind systems are wind turbines that generate more than 100 kilowatts (KW) of electricity to feed into the grid.

ii. Distributed or tiny wind systems use wind turbines with a power output of 100 kW or less to power a home, farm, or other structure directly.

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WIND ENERGYIN NIGERIA: Wind energy is, of course, one of the most cost-effective renewable energy sources per unit of energy produced, and its technology is one of the fastest-growing in the energy generation business worldwide, but not so much in Nigeria and Sub-Saharan Africa. A network of 2.5 MW land-based wind turbines could generate more than 40 times the world's current electricity consumption, according to some estimates (**Kunduru, et al., 2015**). Because wind energy is NOT considered viable due to low wind speeds in most parts of the country, renewable energy options in Nigeria have been limited to solar energy. With the EXCEPTION of coastal and offshore areas, wind speeds in the south are generally considered moderate. According to the survey, Nigerian coastline areas from Lagos to Ondo, Delta, Rivers, Bayelsa, and Akwa-Ibom showed promising potential for harvesting moderate wind energy throughout the year. The majority of oil and gas activities in the country take place along the coast, creating environmental deterioration and isolating some of these areas from the electricity grid, prompting a search for alternative energy sources (**Dafrose & Bayero, 2011**).

MAP OF NIGERIA SHOWING GOEGRAPHICAL LOCATIONS (WWW.THEODORA.COM/MAPS)

EFFICIENCY OF A WIND TURBINE:

The Efficiency of a Wind Turbine System and conservation of mass requires that the volume of air entering and exiting a turbine be equal. As a result, Betz's Law states that a wind turbine's maximum possible wind power is equal to 16/27 (59.3%) of the total kinetic energy of the air entering the turbine (**Okedu, et al., 2015**). A hypothetical power yield's best kinetic energy of the air entering the turbine effective area is thus 16/27 times the kinetic energy of the air entering the turbine effective area,

Were,

ρ = Density of air
A = Effective area of disk
V = Wind velocity
P = Power of wind turbine

Structural and environmental decomposition of the system: As previously said, the decomposition of the structural system is a critical tool for the design of complex structural systems, and it must be done in tandem with the decomposition of the structure's performance requirements. The breakdown is carried out by concentrating attention on various levels of detail, beginning with a macro-level vision and progressing to micro-level features (**Kuik & Bontempiet, 2014**). The environment is the initial phase in the structural system decomposition. This is because, under a global approach, the structure is viewed as a genuine physical entity situated in an environment in which a number of factors, all of which are tightly related to the acting loads, must be considered.

Energy producedby wind turbines: A wind turbine's power curve shows how much electricity the turbine produces across its entire working range. Wind turbines have a cut-in wind speed of about 3.0 to 7.5 m/s at which they begin to generate a tiny quantity of power. There isn't enough energy in the wind to generate electricity below the cut-in wind speed. Wind turbines also feature a cut-out wind speed (very high wind speed) at whichthey will shut down to prevent damage to the turbine. Keep in mind that the rated power of the wind turbine is a property of the wind turbine, while the capacity factor is a property of the wind turbine's location (a measure of the available wind energy at this location). Betz rule is used to calculate the annual energy production of a wind turbine with a rated capacity of 1500 kW on a given site.

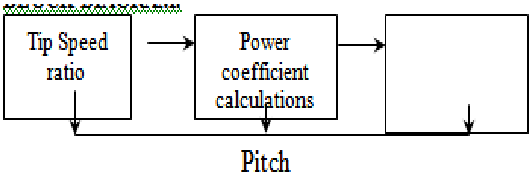
III. MATERIALS AND METHODS

The fundamental aspects linked to the design of wind turbine blade structures are investigated in this work. Sub-models of varying complexity can be used to deal with these issues, both for structural behaviour and load models. To analyse the safety performance under aerodynamic and mechanical activities, numerical models are designed. ANSYS was used to study and compare the turbine structure; blades and stator body design, and MATLAB code was used to estimate and anticipate the required power using expected blade velocity's using ANSYS model analysis. The modelling of a wind energy conversion system may be divided into three subsystems: aerodynamics, mechanical, and electrical. The aerodynamics block is a simple block diagram that demonstrates how wind energy is taken in the form of kinetic energy, which is used to accelerate the blades, and then turned into mechanical energy, which is used to drive the generator, which is then modified into electric power.

Theoretical and analytical approaches for blade design and analysis: This analytical study of the wind turbine structure, blade design, and performance evaluation can be done using the mathematical formulation below, which takes into account the Betz law. Wind turbine blades, on the other hand, can be built and assessed using a range of techniques, including experimental and numerical theory. Because of its numerical robustness and quick processing technique, this technology, as claimed, could be applied with reasonable precision. The purpose of the research was to develop blades that were specifically designed for the use of a common blade currently in use in the field.

The blades for their inboard and outboard designs were designed using the inverse design technique. According to his research, wind turbines require section designs that are significantly different from the standard general shape of a wind turbine blade. The method is noteworthy in that it does not require any empirical input other than the geometry of the blade under consideration and the angle of attack. Given the shape of the blade and the angle of attack, it might predict the flow over a specific design. The process also employs iterations, which have been proven to produce satisfactory outcomes through experimental measurements.

AERODYNAMIC SUBSYSTEMMODELLING BLOCK DIAGRAM.



The tip speed ratio is used to define the relationship between blade angular speed and air velocity; the tip speed ratio is defined by the equation

$$\lambda = \frac{w_m x R}{v}$$

Where:
R = blade radius
W_m= angular velocity of the rotor, and
"w_m*R" is the blade tip speed.

P_{BLADE}=

$$C\rho(\lambda,\beta)\ x\ P_w = C\rho(\lambda,\beta) x \frac{1}{2} x v^3\ x A x \rho$$

Cp= 0.593 (Beta law).
Note that the coefficient of rotor power is dependent on both the tip speed ration "λ" and the blade pitch angle "β" (in degrees). The angle between the blade cross-area and the plane of rotation is known as the blade pitch angle. It refers to modifying the attack angle to the best possible angles in order to adjust the blades' rotation speed and, as a result, the generated power. The calculation below can be used to calculate the tip speed ratio.
Therefore the rotor tongue could be expressed:

$$T_w = \frac{\rho_{BLADE}}{w_m} = \frac{C\rho(\lambda,\beta) x \frac{1}{2} x v^3\ x A x \rho}{w_m}$$

Finally, A represents the area the blade covers
A = $\pi\ x\ R^2$

$$T_w = \frac{\rho_{BLADE}}{w_m} = \frac{C\rho(\lambda,\beta)\ x \frac{1}{2}\ x\ v^3\ x \pi\ x\ R^2\ x \rho}{w_m}$$

The power coefficient is expressed in equation and Cp is its symbol

$$Cp(\lambda,\beta) = c_1\ x\ (c_2\ x \frac{1}{y} - c_3\ x \beta - c_4\ x \beta^{\alpha}\ - c_5)\ x\ e \frac{-c_6}{\rho}$$

gamma "y" can be expressed mathematically in equation

$$\frac{1}{y} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{1+\beta^3}$$

The power extracted from wind is defined below:

$$\mathbf{P} = \frac{8}{27}\ x\ \rho\ x\ V^3\ x\ A$$

REYNOLD NUMBER EVALUATIONS: The Reynold number is a critical quantity for determining the operating state of a wind turbine and the wind's aerodynamic behaviour. The Reynold number can be computed using the formula (3.13) below:
$Vrel$ = relative wind speed (m/s),

c = chord length (m),
v = kinematic viscosity of air

$$(v=1.511x10^{-5})(\frac{m^2}{s})\ at\ 20^0 C.$$

$$Re = \frac{V_{rel}\, C}{v}$$

Three-Blade design parameters

Number of blades	Radius of blade	Tip speed ratio	Coefficient of lift	Blade pitch	Density of air	Area of blade
3	41.m	6.5	0.88	30 deg.	1.225kg/m3	5289m2

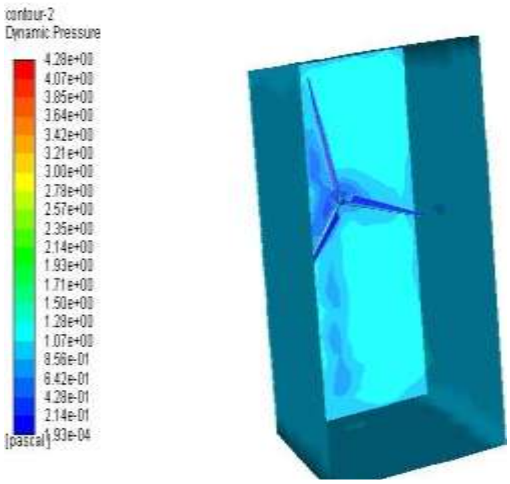
IV. RESULTS AND DISCUSSION

The entire study was conducted with a three-bladed wind turbine as the input flow direction, which was modelled in an assumed air flow boundary called the wall, as well as its inlet and outlet flow directions, and various analyses were conducted and discussed separately in order to best select the best suited for an offshore operation. First and foremost, Solid works software was used to create the model. The model was then exported to ANSYS, which was used to create the boundary layer for the air region.

Secondly, MATLAB was used to determine the various corresponding powers, using the wind velocities obtained from the NIMET. The variation of wind speed and pressure on the turbine analysis is shown. To provide accurate performance analysis results, tip loss correction, root loss correction, 3D correction, and Reynold Drag Correction are also used.

Obviously, the maximum performance from the three blade wind turbine is attained at the design Tip Speed Ratio, hence tip speed ratio is a function of wind velocity; it can be claimed that the power is a function of wind velocity.

ANSYS DYNAMIC WIND PRESSURE ON THE THREE-BLADE DESIGN



The figure above displays the dynamic pressure behaviour of the greater blade thrust. As the blade rotates higher, however, the pressure rapidly increases evenly. It's worth noting that the actual maximum pressure obtained from the three-blade design wind turbine was higher than what was projected. The power, on the other hand, rises in direct proportion to the wind speed.

ANSYS STATIC WIND PRESSUREON THE THREE-BLADE DESIGN.

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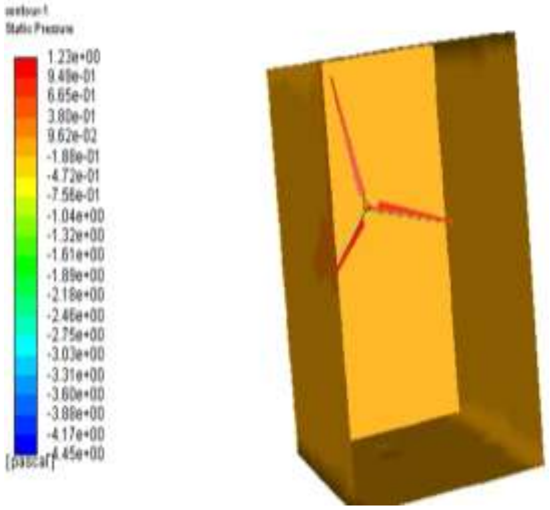
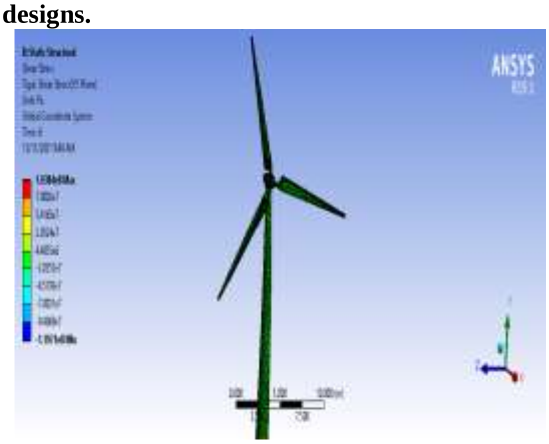


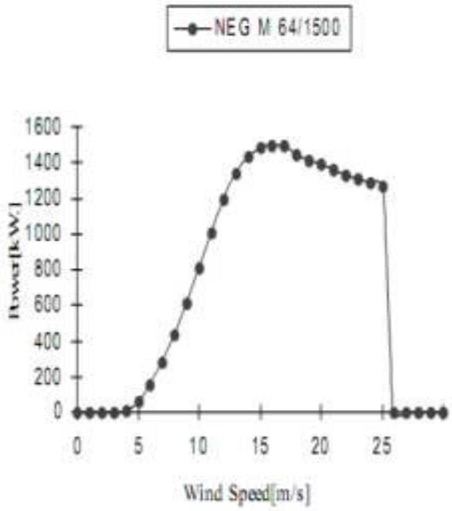
The turbulence model used to analyse the air interaction was employed in a CFD analysis to investigate the performance of the design wind turbine blade. CFD post, on the otherhand, is used to observe the simulation's outcome.

Ansys static shear stress for three- blade designs.



The amount of shear stress that will generate this deformation is shown. When the blade is vertically upward, the shear force is at its greatest. When the blade is oriented downward, the static structural shear stress is quite low. The blade's natural position is downward, where both static deformation and stress values are minimal as compared to the blade's upward position.

Mechanical power generated at various wind speeds.



The output power graph for various wind speeds as shown above was generated by simulating the intended model with various wind speeds. It can be seen that the turbine's output power curve increases as the wind speed increases, indicating that the power output is mostly dependent on the wind speed and a sudden drop at the cut-out speed of 25m/s. However, as a result of varying wind speeds in a real situation other than ideal, if a power storage device is connected, we can maintain a constant power output. The maximum power produced increases as the rotational speed increases, as seen and the tip speed ratio increases. However, 1500KW is the greatest that can be achieved.

V. CONCLUSION AND RECOMMENDATIONS

The research on a three-bladed wind turbine in the energy sector, which is one of the promising renewable energy sources, is presented in this dissertation. The study on turbines is being performed with the goal of developing a viable solution for a power supply for an FSO, PREM PRACHI with a power requirement ranging from 800KW to 1440KW. The research, on the other hand, is focused on the design, analysis, and modification of horizontal axis wind turbine blades. After that, two of the most dependable methods, ANSYS and MATLAB, are used to analyse the performance of the designed blades.

The wind turbine rotors showed good performance in terms of the rotor power and rotor power coefficients, whereas, the rotor power ranged from 200kw to 1500kw and the static structural properties were also shown. The rotor designed with a design angle of attack of 60°, which is the optimum angle of attack, had the best performance. The improved wind turbine rotor instils positive motivations for offshore renewable energy electrification. The small wind turbine design will be cheaper due to improved performance, and hence socio-economic development may also pick up.

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