Techno-Economic Viability Assessment of Offshore Wind Power Generation in the Bight of Benin - Nigeria Coast

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Abstract

The offshore wind energy data of the Bight of Benin, southwest Nigeria coast in the Gulf of Guinea Atlantic Ocean, were collected at 10m and 50m Above Sea Level (ASL) from various ground and high-resolution satellite recording stations for comparison, conformity, and confirmation of results for accurate analysis and modelling with various technical and economic feasibility measurement tools for offshore wind power generation based on Direct Drive Horizontal Axis Wind Turbine (HAWT) with Synchronous Permanent Magnet Generator (SPMG) configuration in Nigeria's Bight of Benin littoral zone.

The results were analysed to determine the technical and commercial viability of an offshore wind farm for sustainable power generation via interoperable mini-grids as well as in hybridization with other energy sources using proven techno-economic tools, which include: Techno-Economic Renewable Energy Viability Index (TEREVI), Techno-Economic Levelized Cost of Energy (TELCOE), conventional Levelized Cost of Electricity (LCOE), and HOMER software simulated Cost of Electricity.

Wind speeds were found to be significantly higher on average at altitudes of 10m and above on the offshore compared to onshore and the average windspeed in all the data gathering stations were found to meet or exceed the 3.5m/s minimum windspeed threshold required for power generation with values varying strongly with seasons resulting in very good above average commercial prospect yielding TEREVI of 0.7625, TELCOE of 0.0265, LCOE of 0. 0.0249, and a HOMER generated COE of 0.019.

Keywords: offshore wind power generation, Bight of Benin, TEREVI, TELCOE, LCOE, HOMER COE, windspeed, wind energy, wind power, southwest Nigeria

1.0. Introduction

Clean, affordable, and sustainable renewable energy resources are key to attaining the Social Development Goals (SDG) and are at the top of the agenda of the United Nations and global economies focused on development.

To this end, mini-grids powered by locally available renewable energy resources are key to mitigating the huge energy deficits resulting in inhuman Multi-Dimensional Poverty Indices (MDPI) in Sub-Saharan African nations which includes the southwest Nigerian region.

Nigeria has in the last 25years suffered massive de-industrialization due to high cost of production occasioned by inadequate and epileptic power supply coupled with ever heightening cost of gas and other petroleum products which makes the country to lose over $20billion annually which slows the growth of the economy and frustrated series of economic growth and development plans by successive governments(Nasir, 2020).

The lingering power problems has gulped over $16biilion in the last 20years with an estimate $100billion needed to be invested in the next 20years while the federal government is planning a $20billion short term investment to address electricity shortage through new power generation stations and transmission lines(ITA, 2023; Adelabu, 2023; Ugwuanyi and Ofikhenua, 2015).

The National Renewable Energy and Energy Efficiency Policy (NREEEP) as a part of the National Energy Masterplan (NEMP), National Energy Plan (NEP) and other national development strategies needs to take into consideration marine renewable energy resources irrespective of technological maturity in order to be at the forefront of growths and optimize naturally endowed resources no matter how small they are perceived to be(FMOP, 2015; Onu, 2022).

Some strategic but quite ignored locally probable renewable energy sources include marine renewable energy resources of which offshore wind power generation is the lowest hanging fruit and most precedential with over \$100billion worth of projects carried in the last 15years and over \$150billion more projected to be invested in the next 10years worldwide especially in Europe and North America which underscores the massive prospects it has given the high capacity factor of offshore wind turbines compared to onshore wind energy conversion systems(Buljan, 2021; Fernandez, 2022; Kuhn et al, 2022).

The Southwest of Nigeria is blessed with over 30% of Nigeria's 853Km coastline bounded and entirely within the Bight of Benin in the Gulf of Benin Southeast of the Atlantic Ocean characterized by moderate wave and tidal regimes which fairly reflect the intensity of the sea surface windspeed and associated ocean parameters.

Due to lack agelong lack of interest in ocean energy resources and blue economy generally in Nigeria until recent cosmetic efforts, there is practically no functional local comprehensive ocean data gathering facility in Nigeria as at the time of this research with only scanty information available from the handful of security and research agencies in existence thus driving the need for more effective data acquisition and larger number of stations which informs the reason why several stations were taken from several sources in the process of this study.

Given the tendency for high population concentration in coastal cities, strategically developing wind farms in the Southwest Nigerian coast will enhance electricity supply and efficiency due to proximity to market and less need for transmission lines thus saving the cost of power sector midstream and bypassing the highly inefficient national grid with line losses well over 30% compared to best modern grid systems with less than 5% loss aside the challenges of sabotage and vandalization(Okwori, 2011).

This study is inspired by the need to address perennial power problems suffered by both households and businesses in Nigeria by focusing on alternative solutions that are based on locally available renewable energy resources by which offshore wind energy provides a good prospect to explore and possibly exploit being a city built on water.

In addition, the recent establishment by the Federal Government of a ministry for blue economy is a strong impetus for researches to aide development of ocean – based economic and social opportunities for which sustainable energy solutions and power supply is need to be given the primacy for the expected results to be realized in the short, medium, and long – term.

1.2. Objectives

This study is aimed at investigating and evaluating the technical and economic feasibility of developing sustainable, commercially viable offshore wind energy mini-grid electric power generation for coastal communities along the South-West Nigerian coast based on the following objectives:

I. Determine the eastern sector of the Bight of Benin under observation for this study

II. Acquire the ocean wind energy data for the area under study

III. Evaluate the wind energy potential of the area under investigation

IV. Design a hypothetical 100 kW wind turbine mini-grid system for the study

V. Use results from energy models such as Techno-Economic Renewable Energy Viability Index (TEREVI), Techno-Economic Levelized Cost of Energy (TELCO), HOMER Simulation, and MATLAB Simulink on the hypothetical mini-grid to determine Techno-Economic Viability.

2.0. Literature Review

Due to lack of existing offshore wind power system in the South of the Atlantic Ocean, there is no practical precedence for proof of concept in the Bight of Benin of the Gulf of Guinea maritime sector. Aza-Gnandji et al (2021) investigated the bathymetry of Benin Republic's Exclusive Economic Zone on the Bight of Benin Coastline which showed that the average wind speed varies between Class 5 and 7 at 50mAMSL to 100m AMSL respectively

Onoruoiza et al (2021) carried out a 10-year assessment of the offshore wind energy potential of 3 key Nigerian coastal states, which reveals an annualized windspeed class of 6 to 7. This study was based on Weibull distribution and a number of stochastic modelling techniques.

Obasi et al (2025) carried out a techno-economic study on Niger Delta onshore and offshore wind energy potentials. The study showed significant variation of potentials from mild to very good. However, transmission cost and infrastructure deficits constituted the biggest drawback though the analysis showed a very good return on investment and modest recovery time

While these studies dived deep in assessing the energy potentials, the number of stations where far too low for a comprehensive assessment due to the highly localized and discretised nature of windspeed variations. Also, these studies also used single data sources which presents a critical data integrity risk in addition to lack of redundancy given that no single source or method of wind energy measurement gives all-round best information for every context and geographical peculiarities. Also, the economic analysis were very limited and based on single model in addition to lack of specificity on the wind energy turbine conversion technology.

3.0. Offshore Wind Power Principles and Methodology

Offshore wind power works based on the same technological principles and science as onshore wind farms, except for economic considerations that pertain to the challenges and opportunities offered by the marine environment.

While the limited ground wind data available shows marginal wind speeds in most coastal cities, Nigeria's coastal states of Lagos, Ondo, Delta, Rivers, Bayelsa, and Akwa Ibom have high offshore wind energy potentials (Adedipe et al, 2018).

Offshore wind turbines are simply wind turbines that are installed to operate on vast water surfaces such as on a lagoon, sea or ocean to take advantage of the high capacity factors (which could be well up to of up to 57.1%), high and consistent wind speeds, non – residential interference and location far away from human line of site and so on(Smith, 2014).

Offshore wind farms are usually built in large commercial scale and could be of either fixed platform design or floating platform designs called floating wind farm. A fixed offshore wind turbine is constructed on shallow waters, typically with water depths not exceeding 100m, which is constructed like a telecoms mast from the sea bird up to the sea level from which its hub height is measured.

Floating offshore wind turbines are installed on floating structures like flat barges anchored with chords to the sea bed in order to keep it operating while the barge freely moves around within its radius or operating envelop with respect to the 6 degree of freedom floating objects are subjected to at sea, thus more suitable for deep offshore and farther away from land or human sights from the beach.

So far, floating wind offshore farms have proven more efficient than fixed offshore farms which are in turn more efficient than onshore wind farms considering higher and more consistent uninterrupted wind because no fixed structures to break winds as well as availability of vast space unlike on land.

Considering that they operate in marine environment, offshore wind turbine components have to be designed and installed with the best rated material and quality available in order to minimize maintenance intervention as much as possible.

The high windspeed in offshore impacts heavily on the mechanical components and materials coupled with marine salinity thus resulting in high ware and teat which raises the cost of maintenance thus posing serious investment cost.

Also, the technical skills requirements, environmental process, regulatory hurdles, and cost of working in a marine environment are huge; offshore wind farms investment is not economically viable on a small scale, and the financing demand is way beyond the capacity of individuals, communities, or even state governments; thus, excluding local participation to a large extent if not completely. Note that waterways and oceans are in the Exclusive Legislative List according to Nigerian laws, and thus only the Federal Government has the constitutional right over the waters.

It is argued by some environmental scientists and activists that offshore wind farms could reduce light penetration to the subsea, which could negatively impact sea life; however, floating wind farm technology takes care of such issues. On the other hand believed that wind farms offshore act as a sanctuary for sea life, given that ship movements are restricted in such locations, as well as subsea activities.

The sight of wind turbines from the beach is a serious concern for most people and ethical investors who think such development mars the natural beauty, aesthetics, and innocence of the sea. This is again better taken care of by installing such turbines further into the sea beyond visibility, such as 50Km or even more, which means deeper waters, of which only floating wind farms can be used due to the challenges posed by metocean conditions at deep and ultra-deep waters, among other things.

The mean offshore windspeed data are presented based on 10m Above Sea Level in table 3.1 and 50m Above Sea Level in table 3.2 as obtained from high capture Earth Data(2022), NASA, and Langley satellite compiled through 2018, 2019, 2020, 2021, 2022, and 2023 in conservative comparison to ground station results obtained from some offshore oil and gas companies, research institutions, and private readings operating within the Gulf of Guinea to ensure conservativeness of values.

4.0. Methodology

4.1. Site Selection:

This study was conducted by first analyzing the geospatial area of Nigeria's Bight of Benin coastline from the western maritime boundary with the Benin Republic at Badagry shoreline to the eastern boundary at Akassa shoreline bordering the Bight of Bonny. The Bight of Benin is a bay on the Gulf of Guinea East of the Atlantic Ocean stretching about 640Km from the west at Cape of St. Paul in the Volta Delta to the East at Akassa on the Nun River outlet of Niger Delta and a breath up to 300Km offshore beyond the continental shelf. Nigeria's portion of the Bight of Benin stretches from Ibereko, Badagry in the west at 6.37, 2.72 to Akassa River estuary in the eastern coastline at 4.33, 6.08.

However, Southwest Nigeria's coastal stretch on the Bight of Benin extends about 267Km from the Ibereko coastal channel at Badagry, Lagos, to Omolomo at 5.86, 4.99 in Ondo State as shown in Figure 5.1. The South-West Nigerian sector is intentionally selected in order to assess the Nigerian maritime blue energy potential and to exclusively observe the Bight of Benin by limiting the eastern boundary to Omolomo in order to avoid metocean interference of the Bight of Benin at the Akassa threshold for clearly distinct assessment. Finally, 3 evenly spaced points were selected on the Bight of Benin within 200Km offshore between Omolomo and Ibereko.

4.2. Data Acquisition:

The Metocean information of the Bay of Benin area under observation was acquired, which includes the 21-year hourly wind energy data for the 3 points taken between 2000 and 2021, and thereafter averaged monthly. The data were obtained primarily from the National Aeronautics and Space Administration (NASA) Langley Research Center (LARC) satellite recording, using data from the National Renewable Energy Laboratory (NREL) record as a comparator. In addition, limited data obtained from the Nigerian Meteorological Agency (NIMET) and those from an International Oil Company concerning operations within and near the area were also scanty. Individual ground measurements were also obtained as other information for further proof of primary data veracity and integrity.

Due to the effect of altitude on windspeed measurement, the windspeed information on the Bight of Benin was obtained for both 10m hub height Above Mean sea level (AMSL) and 50m AMSL to provide a more comprehensive view of the wind energy potentials, given the need for greater above-water blade tip clearance. The mean 21-year wind energy data are given in Tables 5.2 and 5.3 for 10mAMSL and 50 m AMSL, respectively.

4.3. Wind Power Theory

To evaluate the wind power potential, the kinetic energy, G_K of the impinging wind on the turbine blade profile is evaluated based on the principle of conservation of momentum relations given A, V, $\boldsymbol{\rho}$, $\dot{m}$, as the blade swept area, wind speed, density of air, and air mass flow rate:

$$\dot{G}_K = \frac{1}{2}\dot{m}V^2 \quad \text{...........4.1}$$

$$\dot{m} = \rho AV \quad \text{...........4.2}$$

$$\dot{G}_K = \frac{1}{2}\rho AV^3 \quad \text{...........4.3}$$

The exergy of wind energy conversion is greatly limited by the blade profile design and configuration; hence, the coefficient of power (C_P) must be less than unity and relates to the Tip Speed Ratio (λ), blading (pitch) angle (**β**), thus the wind power is as follows :

$$\dot{G}_K = \frac{1}{2}\rho A V^3 C_P(\beta,\lambda)$$ ...……4.4

The C_P, β, and λ are related by the following equation by Heir (1998) for wind turbine modeling, simulation, and analysis as in the following functions:

$$C_P(\lambda,\beta) = C_1(\frac{C_2}{\lambda_i} - C_3\beta - C_4)e^{-\frac{C_5}{\lambda_i}} + C_6\lambda$$ ……4.5

$$\frac{1}{\lambda_i} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1}$$ ……..4.6

From finding Betz (1966), the theoretical exergy limit of a wind turbine is 0.593. Therefore:

$$C_{Pmax} = 0.59$$ …….4.7

By factorizing the turbine generator efficiency (η_G), the effective wind power output relations become :

$$\dot{G}_K = \frac{1}{2}\rho A V^3 \eta_G C_P(\beta,\lambda)$$ ………4.8

The Tip Speed Ratio is the ratio of the blade speed to the prevailing wind speed, which is given by the following equation, taking ω, the angular blade speed, and T, as turbine torque, with R as blade radius, thus:

$$\boldsymbol{\lambda} = \frac{\omega R}{V}$$ ………4.9

$$T = \frac{\dot{G}_K}{\omega}$$ ……..4.10

Taking velocity at proposed height, V, measured velocity, V_{im}, proposed height, h, measured height, h_m, and Hellman Exponent (Coefficient of Friction), **α**, the Power Law relations of wind speed variation with height above ground level, referencing Oyedepo **(**et al, 2012) and Egwaile (2020) are given by :

$$V = V_m(\frac{h}{h_m})^\alpha$$ ………4.11

The resultant speed $\vec{V}$ of imping wind is at maximum and minimum at blade orbital(azimuthal) angles of ψ = 0 and ψ = 180, respectively. If we take the blade radius as $\vec{R}$ and put the angular speed as $\vec{\omega}$ with prevailing wind speed given as $\vec{U}$, the vectoral velocity of wind becomes the sum of $\vec{U}$ and $-\vec{\omega}\ \vec{R}$ as follows:

$$\vec{V} = \vec{U} + (-\vec{\omega}\ \vec{R})$$ ………4.12

Referring to the blade wind flow diagram, the tangential speed of the wind turbine blade V_H and the angle of attack **α** (the angle between the wind and the blade chord) is given by the following equation:

$$V_T = UCos\psi + \omega R$$ ……..4.13

The velocity due to the wind impinging the blade perpendicularly is given by:

$$V_N = Usin\psi$$ ………4.14

Based on Islam et al (2008) the resultant wind speed is given by the following equation:

$$V = \sqrt{V_T^2 + V_N^2}$$ ……..4.15

Hence, from infusing the Tip Speed Ratio expression, we get

$$V = U\sqrt{1 + 2\lambda Cos\psi + \lambda^2}$$ ………4.16

$$\alpha = Tan^{-1}\left(\frac{V_N}{V_T}\right)$$ ………4.17

Further simplification by (El Kasmi et al, 2008) yields:

$$\alpha = Tan^{-1}\left(-\frac{Sin\psi}{Cos\psi + \lambda}\right)$$ ……….4.18

Taking the blade chord length as C, the kinematic viscosity as Ʊ, the mean Reynolds' number as expressed by Guilherme Silver is given by :

$R_e = \frac{VC\sqrt{\lambda^2+1}}{\upsilon}$ ……..4.19

Given the drag, D, the lift, L, the tangential force, G_T and the perpendicular component of the wind force on the blade to be G_N the coefficient of the Lift, Drag, Normal, and Tangential forces are given by the follow equations respectively:

$C_L = \frac{L}{0.5\rho AV^2}$ ………4.20

$C_D = \frac{D}{0.5\rho AV^2}$ ………..4.21

$C_N = \frac{G_N}{0.5\rho AU^2}$ ………4.22

$C_T = \frac{G_N}{0.5\rho AU^2}$ ……..4.23

4.4. Mini-Grid System Design

The mini-grid is designed as an off-grid autonomous power system, interoperable with the main grid, and can operate in a hybrid configuration with multiple energy sources or in a concatenated configuration with neighboring mini-grids. This is to optimize energy generation and utilization for more sustainable and cost-effective energy management. The wind turbine powertrain is shown in Figure 4.3, while the offshore wind turbine system integration and mini-grid schematic are shown in Figures 4.1 and 4.2, respectively.

Due to the relatively benign metocean conditions and consistent wind speed regimes in the West African coastline, the ≤100kW turbine units are preferred for pre-continental shelf littoral installation as shown in Figure 4.4. Wind farm in these in such positions not only optimize energy but also ensure more sustainable operations with minimal impact on socioeconomic life, flora, fauna, and the landscape as well as enabling cost-effective installation, maintenance, scaling, assessment, and decommissioning, among other things, in addition to the high siltation rates of the coastlines. From the field data obtained in the course of this research, the capacity factors for littoral ≤100kW wind turbines are in Nigerian coastlines are medium to high (Koné et al, 2022; Copernicus, 2025)

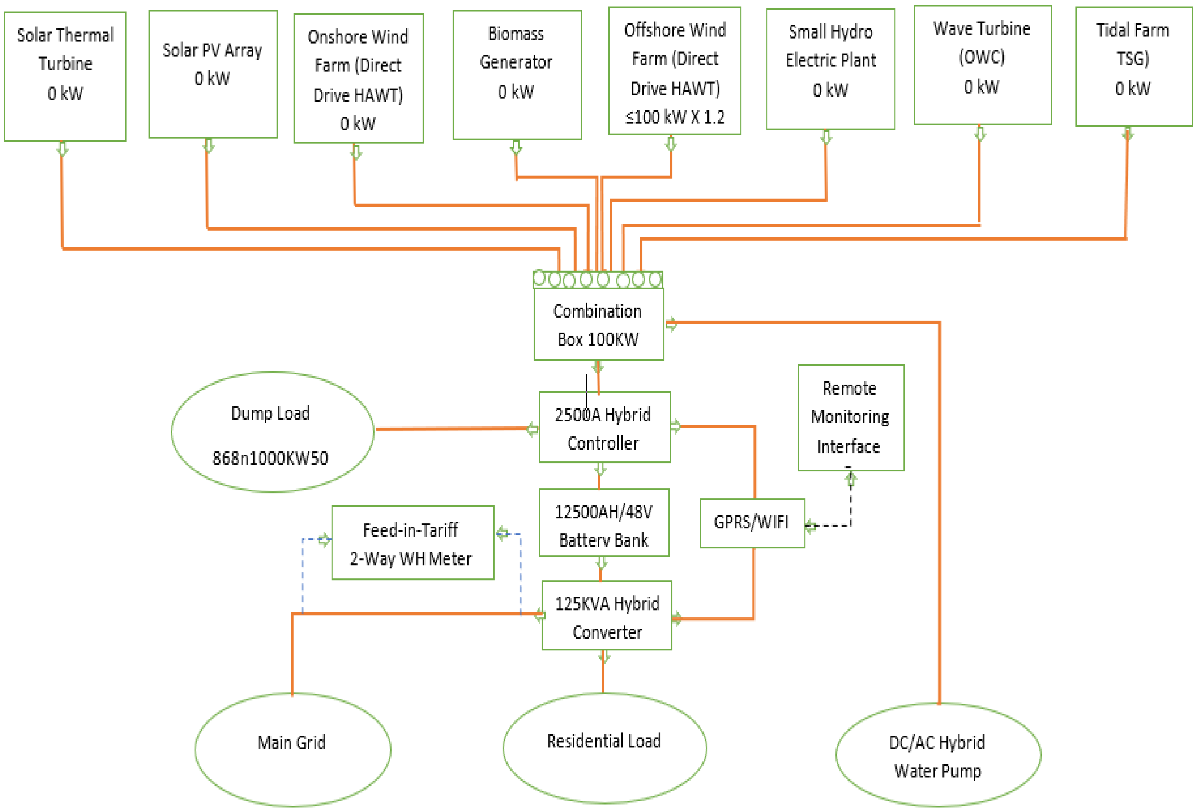

Figure 4.1: 100kW Offshore HAWT SPMG Wind Energy Integration in the Mini-Grid Littoral Power Configuration

Figure 4.2: Schematic of Offshore Windpower in Littoral Power Integration

4.5. System Design Configuration and Schematic

In order to save operational costs, increase reliability, ensure higher energy conversion efficiency, and ensure smoother output irrespective of wind speed fluctuation, aside from ease of maintenance and technical simplicity, a Direct Drive Synchronous Permanent Magnet Generator (DD SPMG HAWT) is selected with a total generator output of 100 kW. The Cut-in wind speed is 3.5m/s, and the cut-out wind speed is 25m/s.

The wind turbine is of 50mAMSL hub height, 40m to 50m blade radius, with concrete tower fixed onshore platform at water depth not exceeding 50m from the mudline, without prejudice for smaller units on floating configurations. The blade material is made of composite or superior materials in order to avoid corrosion owing to the saline marine environment.

The satellite bathymetric view of the Bight of Benin is shown in Figure 5.1 while the power train and installation configuration for the HAWT is shown in figure 4.3 and Figure 4.4. The choice of turbine, design, component, and materials are based on service requirement, lifecycle, maintenance, environmental challenges, local and global marine regulations, safety, and best return on investment given global learning rates and technical experience of the authors among sevrela considertions.

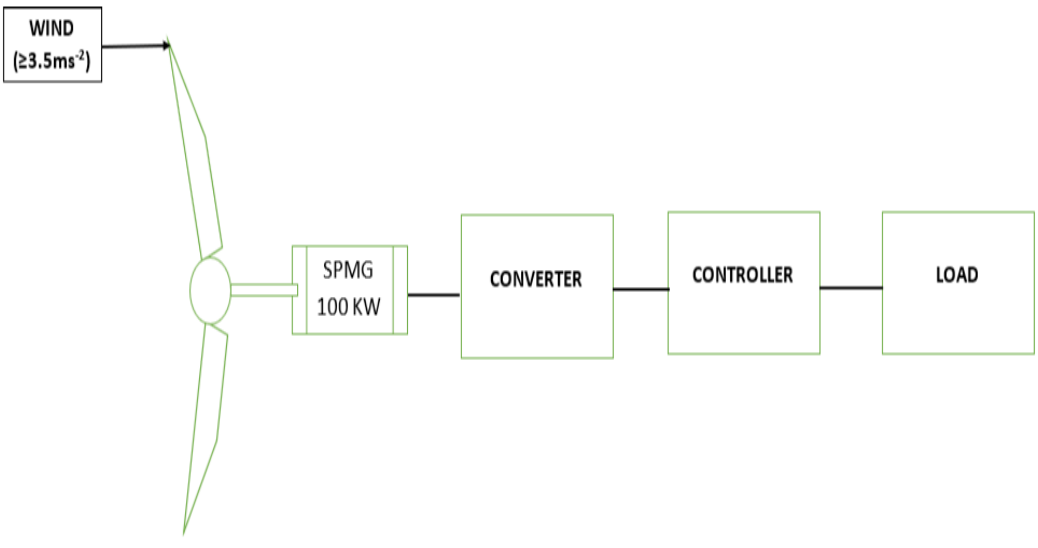

Figure 4.3: Offshore Dire ct Drive HAWT SPMG Power Train Configuration

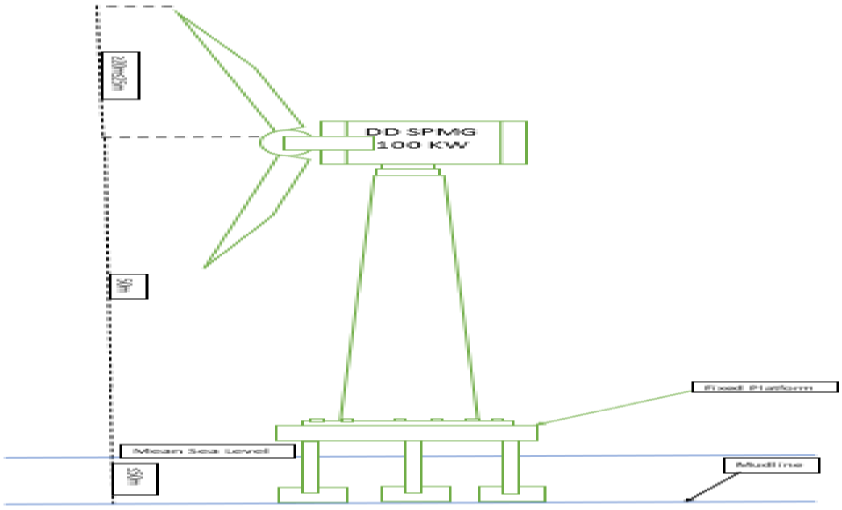

Figure 4.4: System Design of the Direct Drive SPMG HAWT in Littoral Installation Configuration

5.0. ffshore Wind Energy Data and Results

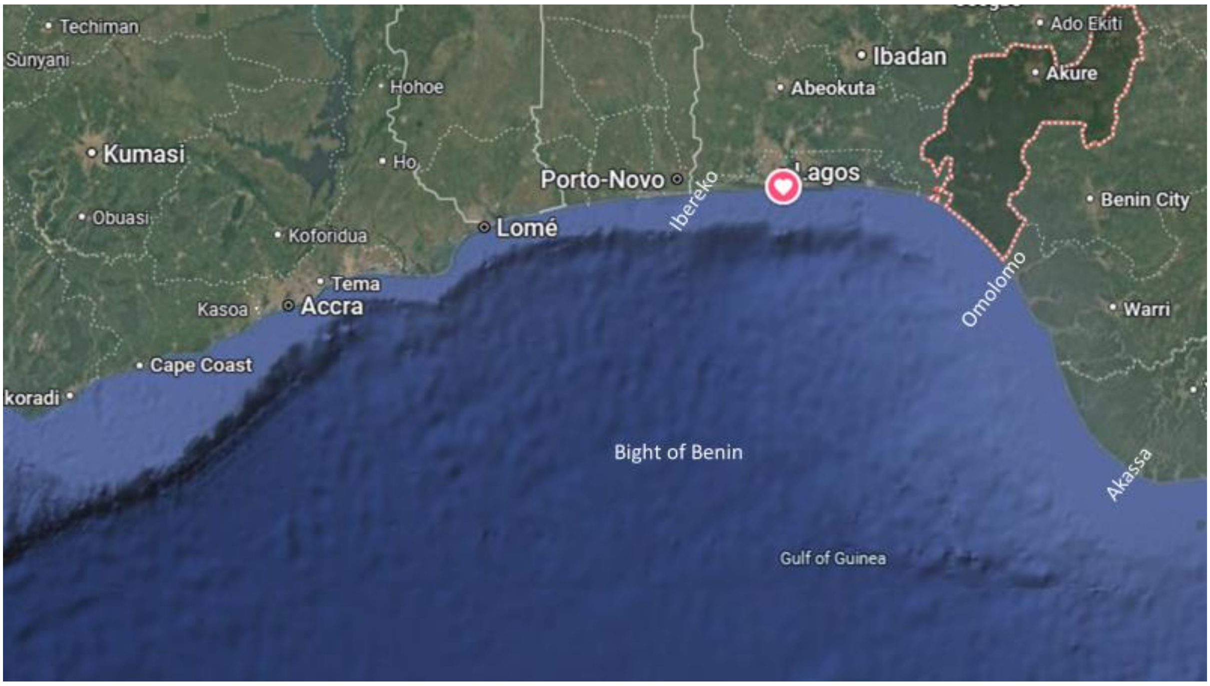

Figure 5,1: Aerial Bathymetry of the Bight of Benin and the Pre-Continental Shelve Line for Offshore Direct Drive HAWT SPMG Wind Turbine Installation

Offshore Windspeed Data at 10m ASL for Bight of Benin South – West Nigeria Coast 2000 - 2021													
TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2000	3.88	3.27	3.98	4.8	4.59	5.01	5.77	5.86	5.98	4.62	3.68	3.23	**4.56**
2001	2.66	3.26	4.87	4.76	4.51	5.43	6.15	5.9	5.84	4.62	4.05	3.24	**4.61**

2002	2.8	3.95	4.73	4.84	4.51	5.45	6.19	5.96	5.6	4.45	3.36	3.3	**4.60**
2003	3.55	4.47	4.03	4.7	4.71	5.34	5.59	6.4	5.3	4.57	3.78	2.86	**4.61**
2004	3.23	3.88	4.27	4.88	5.21	5.73	5.91	6.01	5.06	4.35	3.89	3.82	**4.69**
2005	3.39	4.56	4.59	4.88	4.78	6.19	6.12	6.01	5.63	4.38	3.64	3.62	**4.82**
2006	4.56	5.2	4.82	4.57	4.3	4.53	6.32	6.14	5.56	4.41	2.91	2.79	**4.68**
2007	3.27	4.21	4.59	4.95	4.12	6.02	6.16	6.13	5.14	4.44	3.91	3.2	**4.68**
2008	3.28	2.93	4.8	4.13	4.09	5.11	5.59	5.79	4.86	4.36	3.62	3.47	**4.34**
2009	3.82	4.53	4.48	4.4	4.05	4.78	6.09	5.88	5.45	4.94	3.27	3.06	**4.56**
2010	3.63	4.44	3.98	4.23	4.49	5.06	5.76	5.69	5.15	4.29	3.61	2.88	**4.43**
2011	3.23	4.72	4.79	4.38	4.13	5.26	5.95	5.99	5.09	3.97	3.55	2.64	**4.48**
2012	3.29	5.19	4.49	4.98	4.34	5.25	6.14	6.03	5.28	4.33	3.69	2.84	**4.65**
2013	3.53	4.42	4.96	4.02	4.02	5.52	5.96	5.64	5.62	4.44	4.06	4.12	**4.69**
2014	3.73	4.07	5.03	4.41	3.7	4.66	5.81	5.93	5.2	4.36	3.96	3.21	**4.51**
2015	3.88	5.16	4.72	4.34	4.37	5.95	5.63	5.77	5.57	4.48	3.6	2.87	**4.70**
2016	3.36	4.35	5.05	4.62	4.71	5.38	5.83	5.59	5.3	3.91	3.59	3.21	**4.58**
2017	3.87	3.83	4.88	4.34	3.78	4.45	5.73	5.77	4.97	4.16	3.66	3.46	**4.41**
2018	3.02	4.81	4.97	4.91	4.74	5.3	5.2	5.88	4.62	3.72	3.52	2.52	**4.43**
2019	3.87	4.18	4.54	4.56	4.09	5.12	5.58	5.7	4.86	4.1	3.22	2.49	**4.36**
2020	3.08	3.41	4.79	4.53	3.89	4.95	5.99	5.59	5.38	4.05	3.19	3.96	**4.40**
2021	3.8	3.88	4.73	4.45	4.33	3.99	5.63	5.49	4.48	4.27	4.03	3.23	**4.36**
MEAN	**3.488**	**4.215**	**4.664**	**4.576**	**4.339**	**5.204**	**5.868**	**5.87**	**5.27**	**4.3282**	**3.627**	**3.183**	4.55

Table 5.1: mean 2000 – 2021 windspeeds of the Bight of Benin at 10m ASL

Average Windspeed Data for Bight of Benin South – West Nigerian Coast at 50m ASL 2000 – 2021													
2000	4.11	3.45	4.23	5.19	4.9	5.38	6.3	6.47	6.59	4.97	3.86	3.41	**4.905**
2001	2.8	3.47	5.23	5.13	4.82	5.88	6.75	6.6	6.43	4.95	4.27	3.4	**4.9775**
2002	2.95	4.2	5.11	5.2	4.84	5.87	6.79	6.62	6.16	4.79	3.5	3.47	**4.9583**
2003	3.76	4.79	4.27	5.05	5.03	5.77	6.2	7.06	5.73	4.88	3.97	2.99	**4.9583**
2004	3.42	4.12	4.57	5.29	5.6	6.23	6.57	6.62	5.45	4.63	4.11	4.04	**5.0542**
2005	3.6	4.92	4.91	5.23	5.13	6.73	6.74	6.62	6.2	4.67	3.83	3.84	**5.2017**
2006	4.9	5.59	5.17	4.89	4.6	4.84	6.93	6.78	6.1	4.71	3.01	2.91	**5.0358**
2007	3.46	4.51	4.94	5.35	4.38	6.53	6.74	6.73	5.55	4.73	4.12	3.36	**5.0333**
2008	3.46	3.09	5.15	4.38	4.33	5.5	6.09	6.33	5.27	4.63	3.78	3.65	**4.6383**
2009	4.08	4.84	4.79	4.7	4.29	5.11	6.66	6.5	5.92	5.31	3.45	3.2	**4.9042**
2010	3.84	4.75	4.23	4.52	4.8	5.45	6.27	6.27	5.57	4.58	3.78	3.01	**4.7558**
2011	3.42	5.06	5.16	4.7	4.4	5.66	6.51	6.59	5.55	4.22	3.71	2.76	**4.8117**
2012	3.5	5.59	4.83	5.36	4.62	5.64	6.71	6.61	5.73	4.61	3.91	2.98	**5.0075**
2013	3.77	4.77	5.37	4.28	4.27	5.97	6.55	6.17	6.12	4.74	4.29	4.39	**5.0575**
2014	3.98	4.36	5.44	4.71	3.92	4.98	6.32	6.52	5.66	4.66	4.2	3.38	**4.8442**
2015	4.17	5.61	5.12	4.68	4.66	6.5	6.17	6.36	6.12	4.8	3.78	3.02	**5.0825**
2016	3.57	4.73	5.48	5	5.05	5.84	6.4	6.13	5.76	4.15	3.78	3.37	**4.9383**
2017	4.14	4.09	5.27	4.65	4.02	4.74	6.25	6.33	5.38	4.44	3.85	3.67	**4.7358**
2018	3.2	5.23	5.38	5.3	5.08	5.72	5.65	6.45	4.97	3.94	3.7	2.64	**4.7717**
2019	4.12	4.47	4.88	4.91	4.35	5.57	6.09	6.23	5.25	4.39	3.37	2.6	**4.6858**
2020	3.27	3.63	5.17	4.85	4.13	5.3	6.53	6.11	5.84	4.29	3.33	4.19	**4.72**
MEAN	**3.691**	**4.537**	**4.986**	**4.922**	**4.63**	**5.677**	**6.439**	**6.481**	**5.779**	**4.6233**	**3.79**	**3.347**	**4.9085**

Table 5.2: mean 2000 – 2020 windspeeds of the Bight of Benin at 50m ASL

For Onshore wind power, we are limiting the coastal environment for this study to the Bight of Benin of the Gulf of Guinea in the Atlantic Ocean for which the average windspeed stands at 4.91m/s mean representing a general wind class of 3 to 4 in the Beaufort Scale with higher values expected in the far ocean beyond the Bight of Benin within the Gulf of Guinea.

6.0. Discussion of Results

Tables 5.1 and 5.2 show the 21-year mean wind speed at 10mAMSL and 50mAMSL at various stations across Nigeria's coastal segment of the Bight of Benin. Figures 6.1 and 6.2 show that the wind energy and wind power potentials are well above the minimum threshold for commercial electricity.

The mean windspeed at 10m varies greatly across months of the year, between 3.1m/s and 5.9m/s, while averaging at 4.6m/s for 10m ASL and 3.7m/s to 6.5m/s, while averaging at 4.9m/s with July – August as peak.

The data corroborates the fact that windspeed generally increases with altitude, given that the mean value at 50m ASL is 7% greater than the mean value at 10m ASL. 92% of the wind speed average value is equal to, while 83% are greater than the 3.5m/s minimum windspeed practically required for a commercially viable wind energy conversion system for power generation.

In addition, some geolocations within the Bight of Benin are 100% much higher than the threshold wind power generation speed, coupled with the trend of surface wind speeds showing higher values as relative distance from the shoreline increases in congruence with wave heights, tidal range, and return periods.

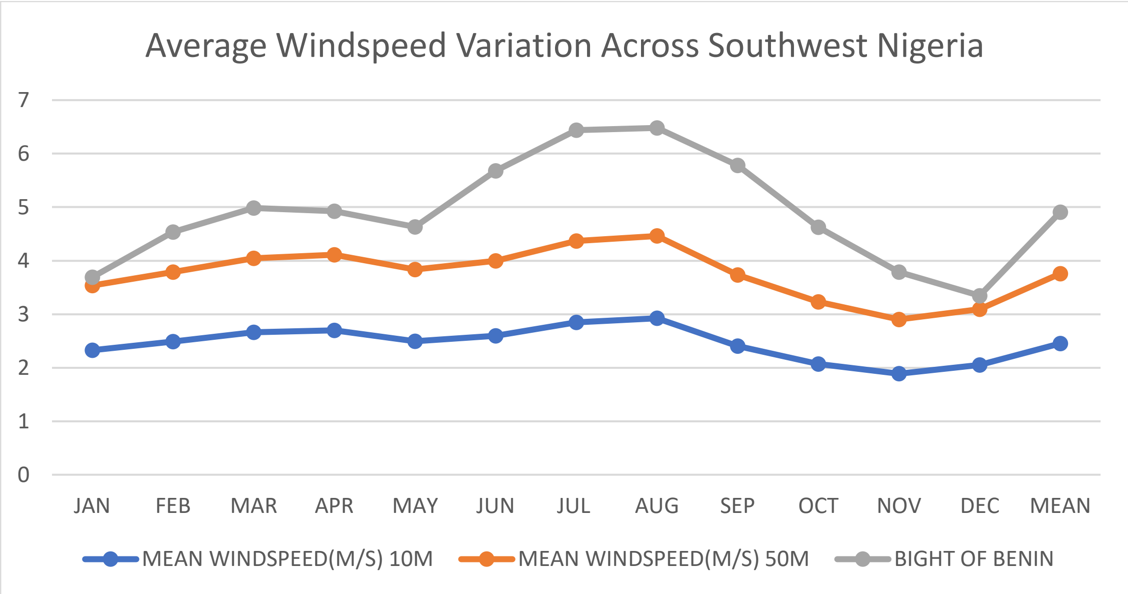

Figure 6.1

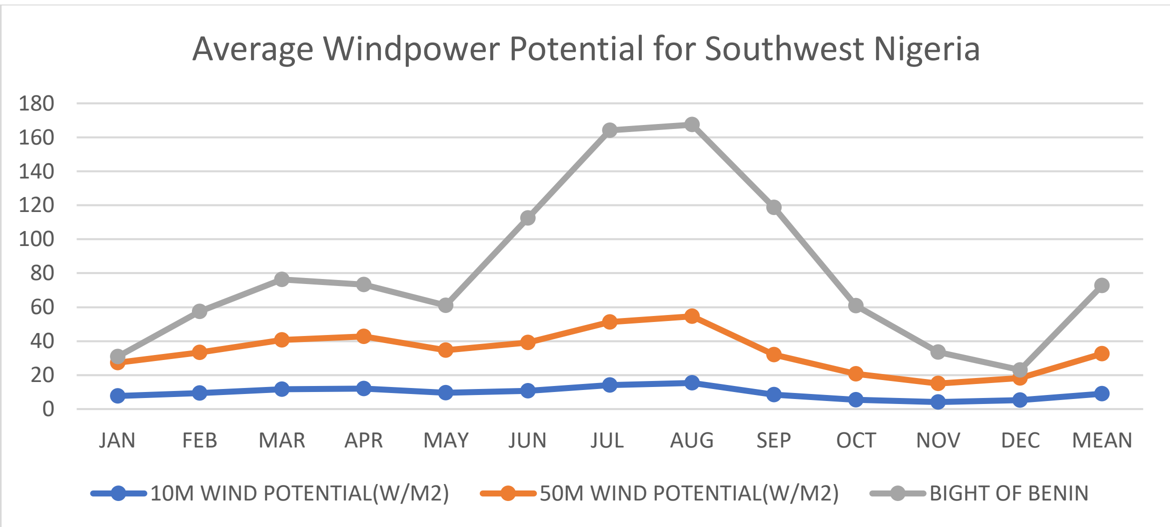

Figure 6.2

Generally, the wind energy map for the Bight of Benin Nigerian coast suggests higher windspeeds at the extreme east and west as well as deeper offshore with localized high pressure points betwixt that need to be zeroed in for the siting of fixed or floating offshore wind farms for ample electricity production to be transmitted onshore via subsea underground cables to the grids.

7.0. Conclusion and Recommendation

Offshore wind energy conversion system using commercial scale Horizontal Axis Wind Turbine(HAWT) units is a veritable electric power generation prospect for Nigeria with high capacity factor, dispatchability, module longevity, and ample windspeed especially at 50m ASL and higher altitudes aside from being integrable offshore petroleum platforms and hybridizable with other marine renewable energy resources like wave, tidal, and thermo – saline system among other possible applications.

Given that most of Nigeria's main lands are of low wind speeds, harnessing offshore wind energy for electricity generation is a strategic method of solving power problems, reducing or eliminating transmission costs, catalysing local blue economic revolution, and cutting carbon emissions among other direct and indirect benefits apart from the fact that lots of technical skillsets will be necessarily developed locally in the process.

It is an urgent imperative for the various governments at all tiers to prioritize ocean energy resources of which wind power generation is the lowest hanging fruit and a key should for sustainable power generation and Net Zero drive by funding the establishment and operation of satellites backed by ground data energy data stations in order to aid research and development effort on offshore wind power generation and ancillary resources and technologies towards addressing the current gross electricity supply shortage in the short, medium, and long term .

Statements and Conflict of Interest Declarations

a. Conlict of Interest

The author has no relevant social, political, competing, or compromising affiliation to declare

b. Funding Statement

This research is fully self–funded by the author and therefore has no external sponsorship to declare

c. Financial Interest

The author has no immediate, short, medium, or long-term financial interest to declare with respect to this research

d. Employment

The authors of this research have no present, past, or future employment interest to declare with respect to this research

e. Social/Political Interest

The author of this paper has no past, present, or future political interest to declare with respect to this research

f. Authorship

I hereby declare that I, Christian Onuminya Okwori, is the only author of this research

g. Publication

This paper has never been published by another journal nor under consideration for publication elsewhere

h. Data Availability

The author is open to making available all relevant data from this study upon reasonable request

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