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Wave Energy Potential in Bonny Island Coastal Area of Nigeria Using Lẽvy Index and MATLAB

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Abstract

Power generation from fossil fuels has serious impact on the environment and climate change, steering the implementation of renewable energies. To reduce greenhouse gas emissions, the use of renewable wave energy requires prioritization for sustainable energy generation. This study presents an assessment of the impact of wave energy penetration on existing grid network performance of Bonny Island Rivers State, Nigeria to determine the suitability of siting wave farms power generation for energy sustainability. In this study, 39-years (1984 – 2023) data of nearshore and offshore wave regimes of Bonny Island at 13 m and 133 m water depth respectively was collected and used to predict the dynamic behavior of wave energy in the area using Lẽvy Index model and validated by MATLAB/Simulink. The results from the assessment showed the installation of a hybrid wave power plant (combining the existing generator, Battery energy storage and wave energy converter system) at Bonny Island can generate total annual electricity of 18,003 MWh at an energy cost of \$0.23/ kWh and 21.6 tons of CO2 on greenhouse gas reduction. These indices indicate that the 30 MW power plant in Bonny Island is a profitable investment portfolio. Therefore, Bonny Island has high potential to generate electricity from its wave energy resource. The results from load flow assessment showed the steady state condition of the existing Bonny Island network have some parts of the network are experiencing power loss and voltage dip more than acceptable limit of ±5 % set by National Grid Code. Finally, a wave energy converter (Alstom Kaplan wave converter) with battery energy storage system was introduced on the network for better optimization. The results showed the wave energy conversion system was able to improve the Bonny Island network power loss and voltage dip to acceptable limit of less than ±2 % while the battery provided the backup power to cater for periods where wave energy is low.

Keywords: MATLAB, GHG emission, Energy, Management.

I. INTRODUCTION

The capacity of a country to meet the energy needs of its citizens by effectively accessing, harnessing, and distributing affordable energy has always been crucial to the determination of its future success. This has been true since the industrial revolution and has continued up till date (Ozohu-Suleiman, 2021). Over the last 40-years the power generation system is from hydro-electric, oil, gas power plants with little effort towards renewable in recent past. While the power demand for the country has increased exponentially, the epileptic power supply continues to dwindle both in supply and reliability. This has posed significant effect on the resident's socio-economic lives (Athe *et al*., 2020). The power sector is battled with inherent structural issues across the supply chain. These include insufficient electricity generation, low operational capacity, transmission line capacity limit, perpetual vandalism, electricity theft, poor government energy policies among others. The need for energy to support population growth, development, and infrastructure is a problem for most developing economies especially Nigeria. This requires efficient use of the available energy generated. In the past, the Nigerian government has taken a few steps to address these challenges. Some of the step include introduction of Nigerian Electricity Regulatory Commission (NERC) in 2005 to regulate and control power generation and distribution, implementation of National Integrated Power Project (NIPP) in 2018 to enhance power generation. Despite these initiatives, there is no noticeable improvement in electricity supply to the populace (PWC, 2018).

According to Asiegbu (2021), an estimated 29,000 MW of electricity will be needed in

Nigeria by 2025. The current power generation capacity will not meet this near future need. The Nigeria entity has vast untapped renewable energies (covering wind, solar, biomass, geothermal among others) that can contribute to her energy generation and compensate for this energy deficiency (Okedu *et al*, 2024). In general, the sea holds vast number of renewable energies with emphasis on wave, tidal and ocean current; and harnessing them can boost a country blue economy (ANRC, 2021). The good news is the Nigeria coastal regions like Bonny Island, have wave energy from the ocean readily accessible to these coastal communities for about 853 km along the coastline facing the Atlantic Ocean.

On the other hand, the power supply to Bonny Island comes from a combined gas and diesel fueled 20 MW captive power generation connected to an isolated local microgrid. The power demand from the grid has exceeded its capacity limit of 20 MW leading to a load shedding regime being applied on the network by the operating company – Bonny Utility Company (BUC). In addition, some portion of the grid has been experiencing voltage deep and power loss which requires improvement.

Objectives

The specific objectives are to:

i. Gather wave data specific to Bonny Island.
ii. Develop fundamental governing wave energy equations for wave energy output.
iii. Utilize the Lévy Index method to model wave height variations and energy density distribution.
iv. Perform power flow analysis on the existing Bonny Island grid both before and after integrating wave energy to identify potential grid challenges.
v. Evaluate the technical and economic viability of a wave energy system in the Bonny Island coastal area, assessing its effects on power generation capacity and greenhouse gas (GHG) emission reduction.

II. LITERATURE REVIEW

The negative effect of hydrocarbon based fueled power generation on climate and environment has led to continuous concern over its use to satisfy human energy need in mordent times and to look for alternatives (Satymov *et al*, 2024). With the rising demand to protect the environment and control climate change, government, agencies around the world have turned to renewable energies to provide cleaner energy for human energy needs. And this is not stopping if we intent to secure our future and that of our children. The ocean inherently provides vast potential energy sources to meet the cleaner energy need of the planet. The global oceans contain the capacity of 93,100 TWh of power per year. Ocean energy in a general sense, refers to any energy derived from the sea kinetic, potential, thermal or chemical energy forms (Elizundia, 2022). Wave energy harnesses the power of ocean waves to generate electricity, presenting an opportunity to diversify Nigeria's energy portfolio and reduce reliance on fossil fuels.

The power conditioning may involve suitable control strategy and energy storage systems. (Said & Ringwood, 2021; Vujkov *et al* 2024). Energy storage systems have become alternatives to network reinforcement. One of such is the battery energy storage system which has gained popularity through considerable research in academia. They have been used to buffer short term power swing arising from WEC integration to the grid (Stecca *et al*. 2020; Pelosi *et al*. 2024). Among the battery types being used, the Lithium-ion have been prominent.

In general, renewable energy integration to power grid has some drawbacks associated with manageability and variability which can impact the grid stability. To manage these. the grid code specifies the parameters and operating envelopes to enable seamless integration. It specifies voltage and frequency variations to be within +/- 5%, and +/- 2% respectively, while the fault ride through capability that ensure the WEC remain connected to the grid under fault condition (Said & Ringwood, 2021).

Saim *et al.* (2020), conducted a review of UK wave energy status, potential, challenges, and prognostics. It concluded that the available wave energy resource in the UK is about 120 GW and harnessing this will help UK achieve her net zero energy target by 2050. It further concluded that wave energy system can pose environmental concerns related to alteration of the water ecosystem, limits dredging and contributes to noise and vibrations. The paper identified the commercial deployment of wave energy system is still being debated in the UK due to high cost of standalone wave energy conversion system, technical performance, and reliability of the wave energy devices. The paper recommended further research work is needed to improve these parameters in near future.

Omar *et al*. (2016), in one of their studies, designed and analyzed the performance of permanent magnet linear generator (PMSG) suitable for point absorber type wave energy device for the conversion of ocean wave energy into electricity using ANSYS/ANSOFT software. The simulation results showed the PMSG has excellent features of voltage output for constant and stable speeds related to wave conditions. These features can help designers select optimum PMSG that can generate the maximum power extraction from the sea wave energy.

Romero *et al*. (2020), studied the mechanical design of a wave power generation which transforms the heaving movement of a buoy into a rotation movement of the arm that house a linear generator in the Colombian Pacific Ocean using Ansys Aqwa numerical software under different swelling conditions. The amount of electric power generated was simulated using MATLAB calculus routine. The simulation results indicated under regular and irregular swell conditions, the electric power generated was 1.17 and 0.5kW respectively. The paper concluded that the proposed devices is suitable for rural coastlines that are far from the existing grid network.

Vivekraj (2021) research paper focussed on developing a prototype wave energy converter that eliminates the current limitations of wave energy converters. The prototype float system has direct contact with the ocean wave. As the wave transverses, the float captures the wave energy and transmit the energy to a gear system in a rotational motion. The gear is coupled to a generator which rotates in turn to produce the required electricity. In analysing the system performance, it was observed the prototype only generate power during upward movement of the float. The paper concluded both the upward and downward motion of the float can be harnessed by designing the gear box to generate power with single generator or by placing two generators which can convert both the upward and downward motion of the float into a common grid.

Ulugbek and Martin (2017) conducted feasibility study as a proof of concept for the design of wave power station integrated into abandoned offshore oil platforms in the UK for the purpose of generating electricity from ocean wave energy. A cost benefit of this approach is to save the cost of decommissioning the offshore platform. In the concept, ten-point absorber devices were fixed on each leg of the Murchison oil platform and four oscillating water columns under the platform. The study calculated a total power generation capacity of 66 MW with an efficiency of 45%. The study proved wave energy converter integration with offshore platforms can solve renewable energy high CAPEX implementation cost. The paper identified future work on this proof of concept to include structural integrity assessment of the platform members to withstand extreme wave conditions and legal issues associated with the conversion of the existing platform into wave power station as well as environmental impacts.

Arshit *et al.* (2016) studied the generation of electricity from wave power using a combination of offshore buoyant moored device and an overtopping system was investigated. The wave motion from the moored device and overtopping is coupled to a turbine which drives the generator to produce electricity. The generator used was a permanent magnet synchronous brushed machine. The output of the generator is connected to a battery storage system for energy storage.

Setiyawan *et al.* (2020), researched the potential of electricity generation from wave power conversion in Lindau water, Indonesia, using Oscillating Water Column System (OWC) based on Wilson method. The result of the study presented the Lindau water wave energy can produce electricity of about 21 kW which meets the power demand of the local community. The paper therefore recommended the use of wave energy conversion system to meet the power demand of Alindau village.

Ciorta and Rusu (2018) presented an ANN prediction method using wind speed retrieved from Gloria drilling unit between 1999 - 20007, to estimate the significant wave height and wave energy resource for Romanian nearshore part of the black sea at a depth of about 500 meters. The paper concluded that the ANN model can successfully predict the wave height of a sea wave based on the wind speed regime. The prediction is influenced by factors used for the ANN training such as volume of datasets, time step.

Osinowo *et al.* (2018) studied a 37-years (1980 – 2016) wave hindcast of extreme significant wave heights in the Gulf of Guinea area of Africa using the WAVWWATCH 3.14 software to simulate the Atlantic Ocean wave parameters. The spectra analysis indicated less than 0.3m per decade in almost all areas of the Gulf of Guinea. However, it was observed there is an increasing positive value towards the western part of the Gulf of Guinea, which suggested an increasing level of storminess and extreme wave height toward the western Atlantic Ocean of the area under study.

Vannucchi and Cappietti (2016) carried out the numerical modelling of offshore wave on four Italian coastal areas Tuscany, Liguria, Sardinia, and Sicily was presented on this paper. The seasonal water depths variability and wave power was analyzed. The result indicated Siciliy and Sardina showed a higher values of wave energy potential of 11.4 kW/m and 9.1 kW/m, respectively, while Tuscany and the Liguria regions are Characterized by 4.7 kW/m and 2.0 kW/m respectively. In addition, the performance on suitable WEC for the Italian sites was conducted. The assessment indicated that in terms of capacity factor at a water depth of 50 m is the wave dragon for the Tuscany and Liguria; and the Pelamis for Sardinia and Sicily. However, the maximum mean power output is always guaranteed by the Wave Dragon.

In a study by Lisboa *et al.* (2017) seasonal variability of the wave energy potential in a 10-year (1997 – 2006) wave hindcast were analyzed at 80m depth offshore and 14m depth nearshore south of Brazil, using Numerical simulations carried out by the Mike 21 SW spectral model. Detailed analyses were done for deep water (at 80 m depth) and three regions nearshore (at 14 m depth), namely Querencia (QUE), Cassino (CAS) and Sao Jose do Norte (SJN). Annual mean fluxes in the nearshore locations were similar with SJN highest value as 6.7 kW/m, while the wave energy flux. offshore was 22.3 kW/m with a significant wave height and energy period range of 1.1 – 2.1m and 5 -10s respectively.

Suherman *et al.* (2022) presented the findings from wave energy assessment of Mentawai Sea, by comparing the numerical computation against measured wave heights and periods for a 10-years. The bathymetric data were obtained from Global Bathymetric Chart of Oceans while wave data was obtained from AVISO satellite data from 2008 to 2018. The result obtained showed an annual significant wave height range of 1.5 – 2.5 meters and mean wave power potency of 6–20 kW/m considering monthly and seasonal variability.

Padrón *et al.* (2022) assessed El Hierro coastal area wave energy potential with the result indicating the best Llanos Blancos coast as best location to install WEC with an estimated annual energy generation of about 265.40 MWh/m, and the yearly average power was about 30.3 kW/m making the town suitable for small scale WEC system.

Dièye *et al*. (2023) assessed West Africa coast distribution of sea level with respect to climate variability modes. The study revealed the distribution of sea level rise in the West African region is heterogeneous with higher values near the coast of West Africa and near the equator. The paper suggested analysis to be carried on the influence of other environmental factors such as wind, precipitation, and atmospheric pressure on sea level variability, which could address the lack of in situ.

III. MATERIALS AND METHOD

Materials

The materials used in carrying out this research work include MATLAB and Excel.

Bonny Island is an industrial town in Niger Delta region of Nigeria and situated about 40 km south-east of Port Harcourt in Rivers State, Nigeria (Akintoye *et al.* 2016). Geographically, it is located roughly 4^0 24’ North, 7^0 11’ East and South of the inter-tropical convergence zone (ITCZ). It is surrounded by the Atlantic Ocean on the southern part, Bodo on the North, Yellow Island on the West and Opobo on the East. Bonny Island is a Town and a Local Government Area in Rivers State, of southern Nigeria.

Table 1: Bonny Island offshore wave heights and associated periods due to sea condition 1984-2023 (Source: Train 7 metocean modelling report, 2023)

Return period (years)	**Direction (SSE) 168.75° till 91.25°**		**Direction (SSW) 191.25° till 213.75°**		**Direction (SW) 213.75° till 236.25°**	
	H_S (m)	TP, (sec)	H_S (m)	TP, (sec)	H_S (m)	TP, (sec)
1	2.01	6.1	2.43	6.1	2.11	7.18
5	2.39	6.7	2.70	6.7	2.57	8.54
10	2.53	6.9	2.79	6.9	2.74	9.04
50	2.82	7.3	2.99	7.3	3.08	10.08
100	2.93	7.4	3.06	7.4	3.2	10.47

Table 2: Bonny Island nearshore wave heights and associated periods due to sea condition 1984-2023 (Source: Train 7 metocean modelling report, 2023)

Return period (years)	**Direction (SSE) 168.75° till 91.25°**		**Direction (SSW) 191.25° till 213.75°**		**Direction (SW) 213.75° till 236.25°**	
	H_S (m)	TP, (sec)	H_S (m)	TP, (sec)	H_S (m)	TP, (sec)
1	0.31	3.2	0.58	3.8	0.65	3.9
5	0.39	3.4	0.65	3.9	0.81	4.1
10	0.42	3.4	0.68	4.0	0.86	4.2
50	0.48	3.5	0.73	4.0	0.95	4.3
100	0.50	3.5	0.75	4.0	0.99	4.3

Method

The method used in this study is Lĕvy index method for a rigorous assessment of wave characteristics and energy generation capacity and validated using MATLAB/ Simulink.

In assessing wave power resource, a key factor giving indication of promising potential is the wave energy density. According to Houngue *et al.* (2018), wave power can be obtained using equation 1 in shallow waters.

$$P_{wave} = \frac{1}{T}\int_0^T \int_{-H}^0 (P + \rho g z)u\delta t \delta Z \quad (1)$$

where: t: Time (s); T: Wave period (s) and Z: Water depth (m), u: wave velocity (m/s); h : water depth, ρ is seawater density, and P is pressure (Pa).

Integrating equation 3.28 over the wave period and water dept yields equation 2

$$P_{wave} = \tilde{E}C_g \quad (2)$$

where: Cg denotes wave group velocity and E the wave energy density.

Ẽ (J/m^2) can be expressed by equation 3

$$\tilde{E} = \frac{1}{16}\rho g H_s^2 \quad (3)$$

Wave energy converters (WEC) is the mechanical component that converts mechanical energy of the wave into electrical energy (Jahangir *et al*, 2023). The maximum theoretical wave power extractable from the ocean wave regime if given in equation 4

$$P_{WEC} = \frac{1}{64\pi}\rho g^2 H_s^2 T_e L_{max} \quad (4)$$

Substituting equation 3 into 4

$$P_{WEC} = \frac{1}{512\pi}\tilde{E} g T_e L_{max} \quad (5)$$

where: P_{WEC} is the maximum power that can be extracted, **ρ** is the Water density, g (m/s^2) is the gravitational acceleration, Te is the Wave period, Hs (m) is the significant wave height and Lmax (m) is the Absorption width at maximum power.

BESS Integration with Wave Energy for Bonny Island using MATLAB

MATLAB/Simulink Model was used to assess and evaluate the technical performance of the hybrid wave energy and existing gas power generation for Bonny Island. Figures 1 to 3 shows the Simulink models

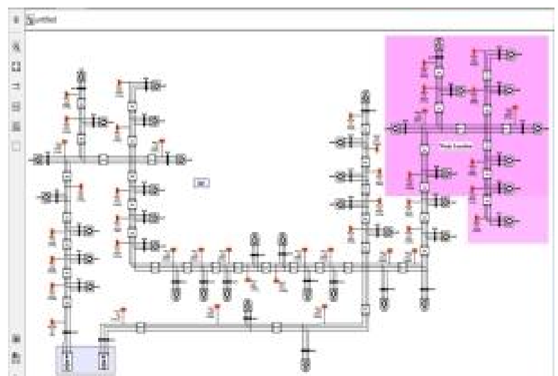

Figure 1. Simulink Model of Existing Bonny Island Distribution Network

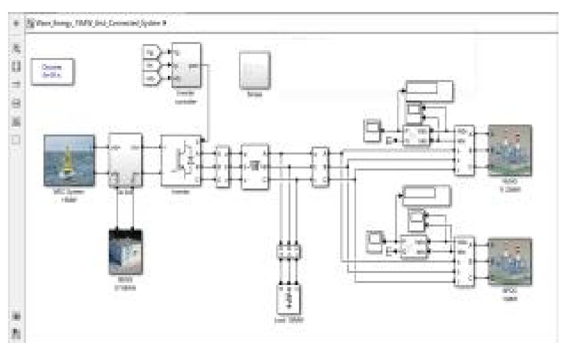

Figure 2. Wave Energy Converter System Design for Integration into the Existing Bonny Island Distribution Network

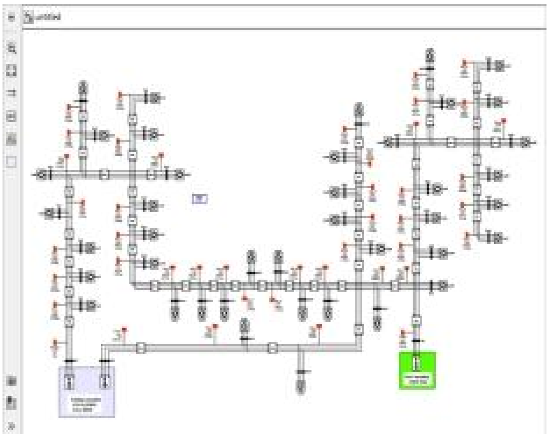

Figure 3. Simulink Model of Improved Bonny Island Distribution Network

Power Flow Study for Bonny Island

To conduct the power flow study using Gauss-Seidel method, the existing Bonny Island grid network was modelled using MATLAB in line with equations 6 to 11 using figures 1 to 3.

The power generated from the power sources are injected into the grid before and after the WECS integrations and used to assess the active and reactive load flow and voltage fluctuations at various buses on the network. Buses with voltage deviations above ± 5% of the nominal voltage are considered weak busses and problem areas on the grid network.

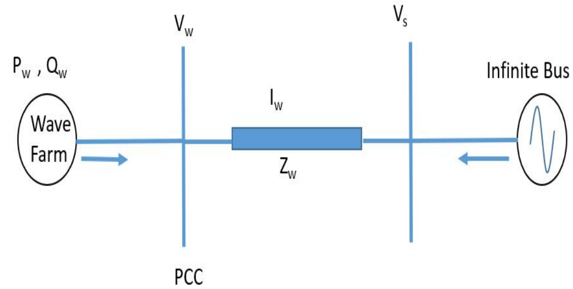

Figure 4: One Line diagram of wave farm connected to grid

For the wave farm, Z_w represent the short circuit impedance. The network voltage of the infinite or grid bus and that of the wave farm at point of common coupling (PCC) are represented by V_s and V_w. The active and reactive power of the wave turbine system to be denoted as P_w and Q_w respectively, with a corresponding current (I_w).

Applying basic electrical laws

$$I_w = \frac{V_w - V_s}{Z_W} = \frac{P_w - jQ_w}{V_w} \qquad (6)$$

$$V_w - V_s = \Delta V = Z_w I_w \qquad (7)$$

Where ΔV is the voltage difference between the infinite busbar and PCC.

Representing the parameters in complex form,

$$Z_w = R_w + jX_w \qquad (8)$$

$$\Delta V = (R_w + jX_w)\, I_w \qquad (9)$$

$$\Delta V = (R_w + jX_w)\left(\frac{P_w - jQ_w}{V_w}\right) \qquad (10)$$

$$\Delta V = \Delta V_P + \Delta V_Q \tag{11}$$

Where, ΔV_P is the active component of the line voltage drop and ΔV_Q is the reactive component of the line voltage drop.

IV. RESULTS AND DISCUSSION

Result of Wave Energy Power for Bonny Island.

The theoretical extracted power from the wave regime, for offshore location is (8 – 35 MW) while the nearshore areas was (0.25 – 0.6 MW). This showed offshore wave data have more promising power output than the nearshore regime as shown in figures 5 and 6.

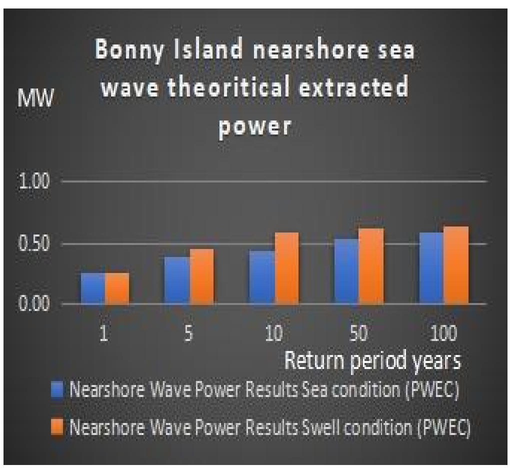

Figure 5. Bonny Island nearshore sea wave theoretical extracted power

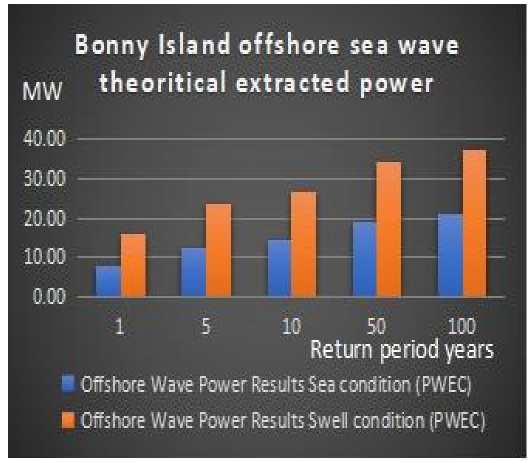

Figure 6. Bonny Island offshore sea wave theoretical extracted power

Result of Existing Network Condition before Integration of Wave Energy Converter

Figure 7 shows the operating voltage profile of the existing Bonny Island distribution network obtained from load flow simulation using MATLAB 2024a.

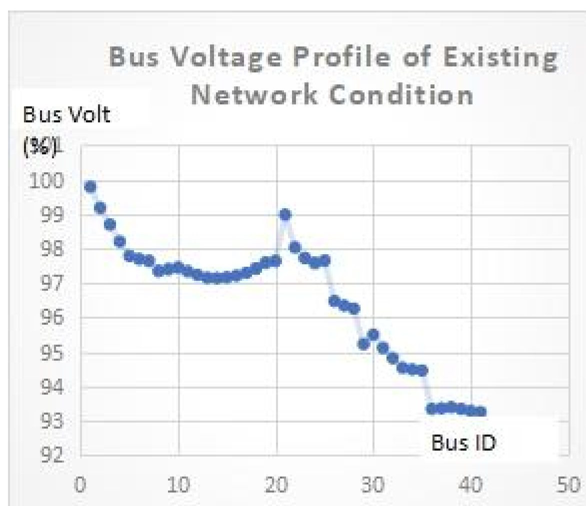

Figure 7. Bus Voltage Profile of Existing Bonny Island Network

A quick look at figure 7 shows that BUS_32, BUS_33, BUS_34, BUS_35, BUS_36, BUS_37, BUS_38, BUS_39, BUS_40, BUS_41 violate the statutory limit condition of 0.95-1.05pu for bus voltage and is considered weak according to national grid code (NCC) requirements for distribution system. The low voltage profile experienced in the buses is as a result of excessive load demand beyond the capacity of the distribution network. As we all know Bonny Island plays host to many multi-national companies and with the ongoing Train-7 construction by NLNG and the constructing of Bonny-Bodo link road to Port Harcourt, consequently there is anticipated rise in power demand and more pressure on the existing infrastructure due to the influx of people, workers, businesses, and commercials activities within Bonny Island environs.

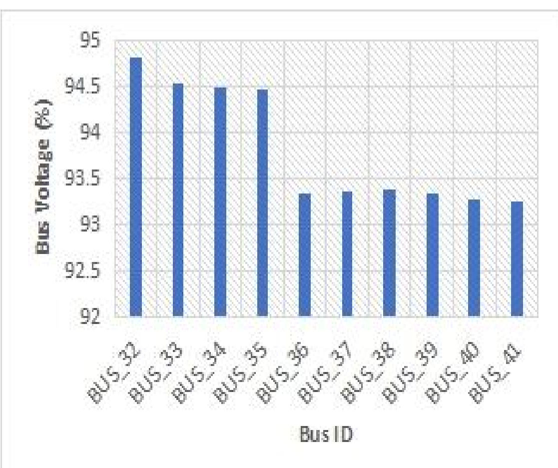

Figure 8. Voltage Profile Plot of Weak Buses in Bonny Distribution Network

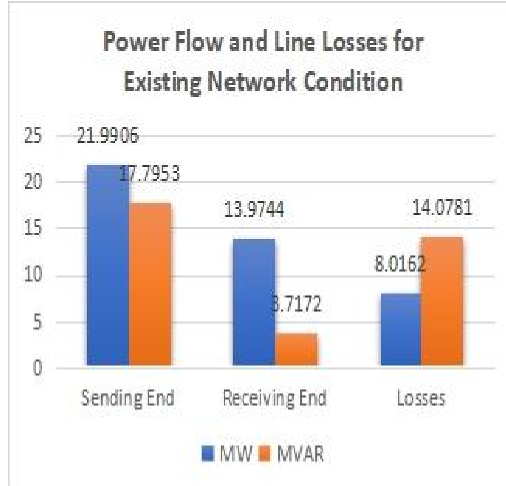

Figure 9. Power Flow and Line Losses on Existing Bonny Distribution Network

Figure 9 shows the result of power flow and power losses determination obtained from load flow simulation. From the base case system consisting of gas turbine generator, the total power generated from the source is 21.9906 MW + j17.7953Mvar, the total power flow to the receiving end is 13.9744 MW + j3.7172Mvar. Consequently, the total power loss from the sending end to the receiving end is 8.0162 MW + j14.0781 Mvar. The high-power losses is responsible for the low voltage profile experienced in some location due to excessive load demand beyond the capacity of the distribution network occasioned by the influx of workers, businesses, and commercials activities into Bonny Island community.

Result of Forecasted Electricity Demand

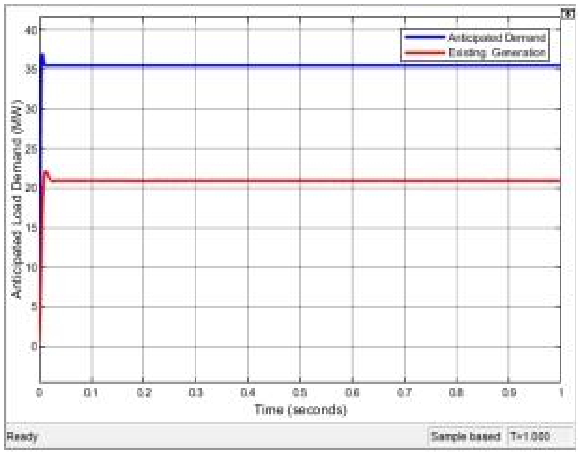

Figure 10. Plot of Anticipated Load Increase

Figure 10 shows the plot of the anticipated load increase from 20MW to 35MW on the Bonny distribution network occasioned by the influx workers, businesses, and commercials activities within Bonny Island and its environs due to the ongoing Train-7 project by NLNG and the constructing the Bonny-Bodo link road to Port Harcourt. The anticipated rise in power demand can strain the existing generation resources which already operating close to the limit capacity of 20MW as shown in red in Figure 10. If no action is taken can lead to overloading and other power quality issues which could potentially affect the network causing nuisance trips.

Generated Power from Wave Energy Conversion System

To address power shortage challenges in Bonny Island, a new generation resources using wave energy conversion (WEC) system was proposed to meet the increased demand.

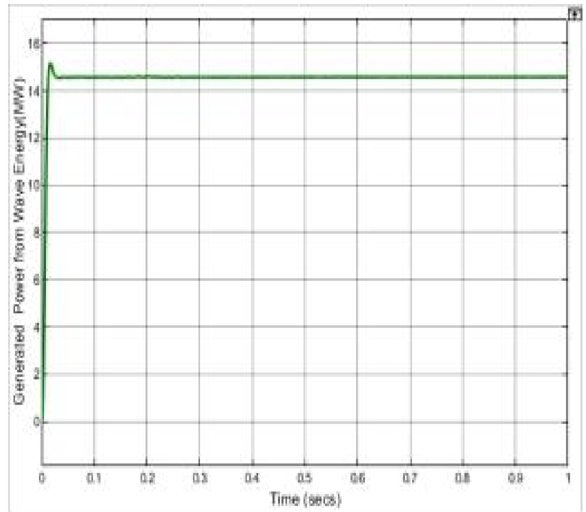

Figure 11. Generated Power from Wave Energy Conversion System

Figure 11 shows the plot of 15 MW power generated from the proposed wave energy converter system to address the challenge of existing generation deficit. The wave energy converter harnesses the kinetic energy from the ocean wave using buoys oscillating column to convert relative oscillating water motion occasioned by ocean wave in Bonny Island to mechanical energy which drive the turbine connected to a dc generator.

Result of Improved Network Condition after Integration of Wave Energy Converter

The figure 12 below shows the operating voltage profile of the improved Bonny Island distribution network obtained from load flow simulation after integration of WEC renewable energy resource of 15MW to provide reactive power support to stabilize and increase voltage level at weak buses.

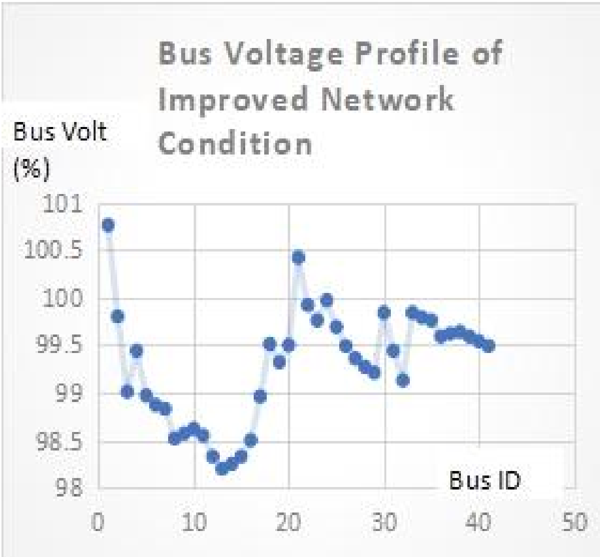

Figure 12. Bus Voltage Profile of Improved Bonny Island Network.

A quick look at figure 11 shows that BUS_32: 99.13%, BUS_33: 99.84%, BUS_34: 99.79%, BUS_35: 99.76%, BUS_36: 99.59%, BUS_37: 99.62%, BUS_38: 99.64%, BUS_39: 99.59%, BUS_40: 99.54%, BUS_41: 99.41% are now within the acceptable statutory limit of 0.95p.u-1.05 with no bus voltage violation.

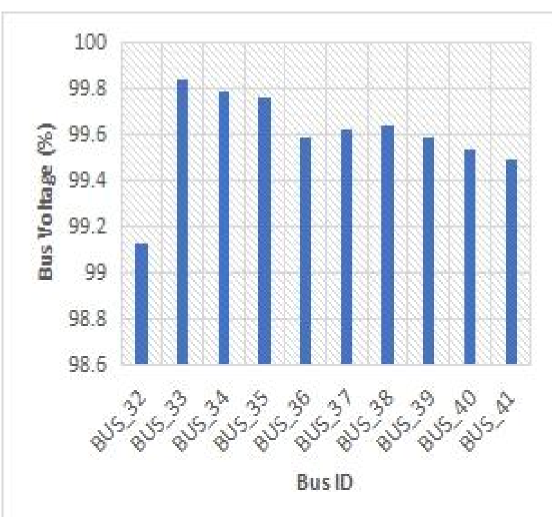

Figure 12. Voltage Profile Plot of Improved Weak Buses in Bonny Distribution Network

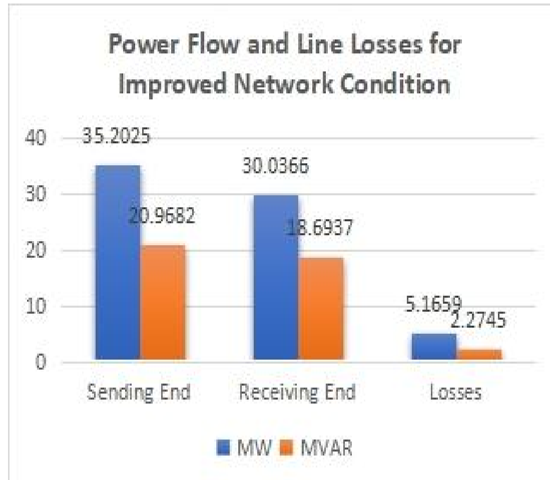

Figure 13. Power Flow and Line Losses on Improved Bonny Distribution Network

The figure 13, shows the result of power flow and power losses determination obtained from load flow simulation after integration of wave energy converter system of 15MW with the existing 20MW combined capacity from gas turbine generator to meet the anticipated load of 35MW. The total power generated from the source is 35.2025 MW + j20.9682 Mvar. The total power flow to the receiving end is 30.0366 MW+ j18.6937 Mvar and the total power loss from the sending end to the receiving end is 5.1659 MW + j2.2740 Mvar.

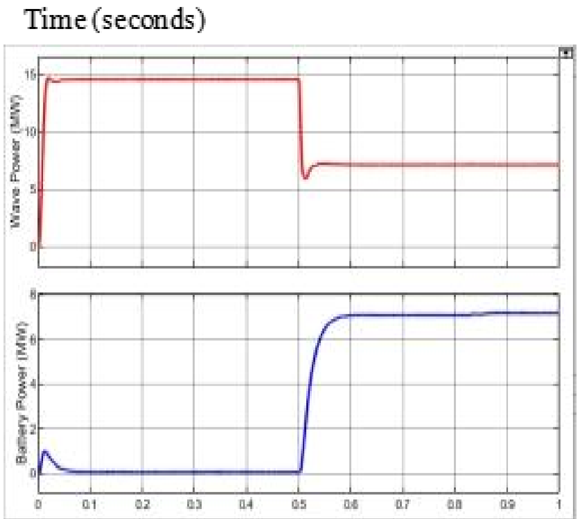

Figure 14. Plot of Battery Storage Performance in Wave Energy Converter System

Figure 14 shows the impact of battery energy storage integration on the wave energy converter system. The simulation scenarios are aimed to observe the dynamic behavior of the battery storage system integrated with the wave power plant to address peak shaving and load balancing condition occasioned by inherent variability and intermittency of wave energy. A quick look at Figure 14, the simulation time from 0 to 0.5s shows period of high wave energy output. The power generated by the wave converter suddenly increases to 14.5MW.

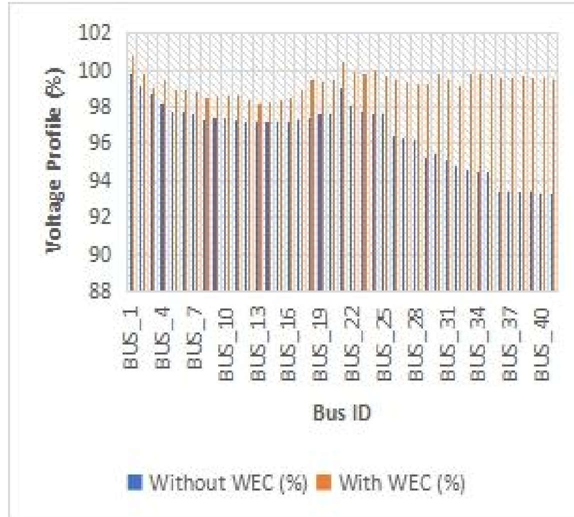

Figure 15. Comparison Plot of Bus Voltage Profile

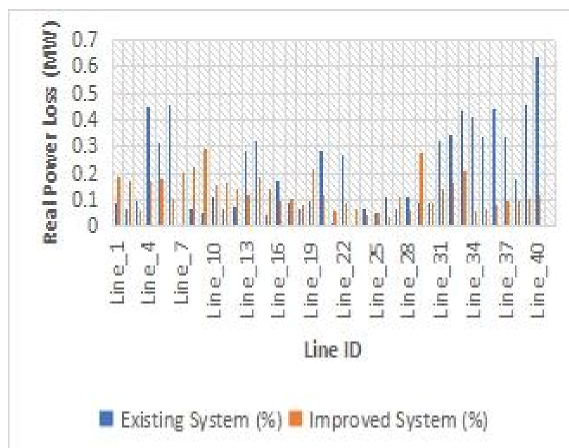

Figure 16. Comparison Plot of Real Power Loss

Techno--Economic Evaluation of Wave Energy for Bonny Island.

Table 3 shows the compared techno-economic result analysis performed using MATLAB software. The analysis ensures optimal system configuration in term of the economics and focused on minimization of net present cost (NPC), which is the difference between the present value of all costs incurred such as logistic, civil constructions, required license, administration and government approvals, labour wages, miscellaneous costs, and the present value of all the lifetime revenue earned.

Table 3 Compared Techno--Economic Analysis

S/N	System Type	Existing (USD)	Improved (US
1	Capital Cost	900,000,000.00	990,251,352.1
2	Replacement Cost	5,876,283,746.16	414,669,375.1
3	Net present cost (NPC)	79,924,110,000.00	10,813,540,00
4	Operating Cost	6,112,861,000.00	759,874,
5	Cost of Electricity (COE)	1.64	0.23
6	O&M Cost	73,043,054,001.27	9,371,226,274
7	Fuel Cost	182,387,653.97	74,910,821.59
8	Salvage	-77,616,743.43	-37,522,385.4

A quick look at Table 3 shows that for the base case system consisting of only gas turbine, initial cost is $900,000,000.00, replacement cost is $5,876,283,746.16, net present cost (NPC) is $79,924,110,000.00, operating cost is 6,112,861,000.00, levelized cost of electricity (COE) is $176.64, O&M cost is $73,043,054,001.27 and fuel cost is $182,387,653.97, salvage -$77,616,743.43. Similarly for the hybrid system consisting of gas turbine generator and wave energy converter system, the initial cost is $990,251,352.19, replacement cost is $414,669,375.12, net present cost (NPC) is $10,813,540,000.00, operating cost is $759,874, levelized cost of electricity (COE) is $23.90, O&M cost is $9,371,226,274.97, fuel cost is $74,910,821.59, salvage -$37,522,385.49.

Wave Energy Generation Impact on GHG Emission in Bonny Island.

Table 4 shows the compared greenhouse emission result performed using HOMER software based on net GHG constituent gases reduction method (kg of GHG pollutant gases/yr compared to base case of hydrocarbon gas fuel).

System Type	Existing (kg/yr)	Improved (kg/yr)
Carbon Dioxide	36,995,625	15,194,957
Carbon Monoxide	191,396	78,611
Unburned Hydrocarbons	10,158	4,172
Particulate Matter	1,637	672
Sulfur Dioxide	90,434	37,143
Nitrogen Oxides	36,682	15,066

For the base case system consisting of only gas turbine for 24hrs/day for a year the total fuel consumed is 14,108,484L/yr at an average of 38,658 L/day and 1,611L/hr. The 100 % emission per year comprises of 36,995,625kg/yr of carbon dioxide, 191,396kg/yr carbon monoxide, 10,158kg/yr unburnt hydrocarbons, 1,637kg/yr particulate matter, 90,434kg/yr sulfur dioxide and 36,682kg/yr Nitrogen oxide marking a total pollutant of 37,325,932kg/yr. Similarly for the hybrid system consisting of gas turbine generator and wave energy converter system, the gas turbine generator consumed a total of 5,794,680 L/yr at an average of 15,878L/day and 662L/hr which indicated that 41.1% of energy generated per year was solely from wave energy converter system thus saving an enormous amount harmful emission to air. The 58.9% emission per year comprises of 15,194,957kg/yr of carbon dioxide, 78,611kg/yr carbon monoxide, 4,172kg/yr unburnt hydrocarbons, 672kg/yr particulate matter, 37,143kg/yr sulfur dioxide and 15,066kg/yr Nitrogen oxide, making a total of 15,330,621kg/yr pollutants. Therefore, the total harmful emission saved using wave energy converter is 21,616 kg/yr.

Discussion on Impact of BESS on Wave Power Output Quality for Bonny Island

A plot of Bonny Island wave pattern is shown in figure 17 below.

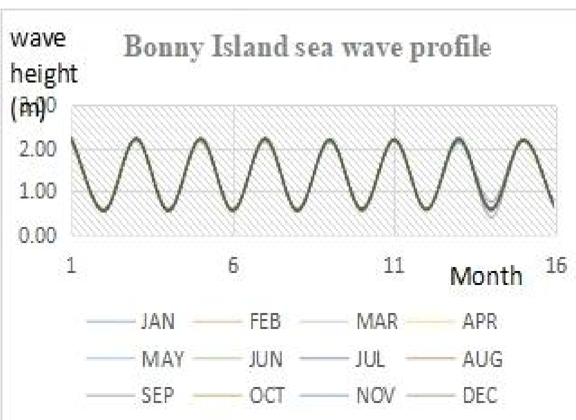

Figure 17. Profile of Bonny Island Sea wave.

From figure 17, the wave pattern is sinusoidal fluctuating between 0.5m at low or sea wave periods up to 2.3m at peak or swell period. Relating this wave profile to wave energy power generated from figure 5; the extracted power from the offshore wave regime is in the range 8 – 35MW. This shows that during normal sea wave periods, the power generated (about 8 MW) is inadequate to power the community load demand of 30 MW. Battery energy storage system would be needed during low wave periods.

V. CONCLUSIONS

In this research, the viability of wave energy in Bonny Island was investigated for power generation and sustainable development. In this work, 39-years wave data (1984-2023) for nearshore and offshore wave regimes of Bonny Island at 13 m and 133 m water depth respectively was analyzed and used to predict the dynamic behaviour of wave energy in the area. MATLAB was used to assess the techno-economic viability of the wave regime of Bonny Island for a 30 MW wave farm.

Based on the wave regime data of Bonny Island, the results from the assessment showed the installation of a hybrid wave power plant (combining the existing generator, Battery energy storage and wave energy converter system) at Bonny Island can generate total annual electricity of 18,003 MWh at an energy cost of \$0.23/ kWh and 21.6 tons of CO_2 on greenhouse gas reduction. These indices indicate that the 30 MW power plant in Bonny Island is a profitable investment portfolio. Therefore, Bonny Island has high potential to generate electricity from its wave energy resource.

The power flow study on existing Bonny Island distribution network showed some part of the network has power loss and volt drop above acceptable limits of +/- 5% specified by national grid code. The integration of a wave energy conversion and battery storage system improved the power and voltages losses observed on existing Bonny Island grid network to +/- 2%.

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