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# Integration of Wind and Tidal Energy for Generation of Electricity: A Case Study of Dawes Island

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***Abstract—The development of any Country is estimated from the amount of energy it produces and consumes in relation to its population. The present shortage of electricity supply in Nigeria is attributed to the too much reliance on depletable energy resources in addition to the Youths Militancy in these oil and gas-bearing communities. Nigeria coastline communities have for long suffered from the combined effect of total absence of electricity and environmental degradation. This study focuses on developing a sustainable hybrid power generation system that combines onshore wind and tidal current energy to provide a stable energy supply for Dawes Island. By addressing the challenges of intermittency and unpredictable nature of renewable energy sources, the study integrates wind and tidal energy with a battery energy storage system (BESS) to ensure reliability. Reducing the cost of electricity generation. The objective of this study is to design and evaluate an integrated wind-tidal renewable energy system that can generate electricity efficiently and reliably while reducing fossil-fuel consumption, greenhouse-gas emissions, and dependence on conventional power sources. A simulation of a hybrid wind an tidal energy system can be developed to model how wind and tidal resources are converted into electrical power and combined to supply a common load. The study employed the Hybrid Optimisation Model for Electric Renewable (HOMER) software to perform simulations to ascertain the hybrid systems' optimal design. Based on Dawes Island's geographical location, regional climate data, wind speed and tidal current runs obtained from NASA database and the internet were integrated into the model with geographic data from Google Maps. The hybrid system consists of one Atlantis AR 2000, 2 MW, 11KV output voltage tidal turbine with a WES 30 540 KW, 11KV output voltage, Wind Turbine to harvest the energy resources available at Dawes Island. With water runs of more than 10m/s at flood and ebb tides, in addition to a modest average wind speed of 3.1m/s, the result shows a reliable complementarity of the Power generators, for a stable provision of electricity for the community. The study underscores the need for sustainable energy solutions to balance environmental conservation and socio-economic growth of the numerous Island communities. Modelling and simulation using MATLAB-Simulink software are employed to evaluate the system's performance under variable weather condition. The simulation results demonstrate the system's reliability and ability to consistently deliver quality power output and meets the load demand. By leveraging the complementary characteristics of wind and tidal energy, the system mitigates the limitations of single-resource dependency, creating a more resilient and adaptable energy infrastructure. Tidal energy provides a stable and predictable base load, while the wind turbine can boost energy production when wind conditions are favourable. The integration of an onshore wind and tidal energy system would be the best option to meet the energy demand of these communities. In addition, it has the potential to ameliorate climate change and substantially reducing $CO_2$ emission. It is envisaged that the implementation of the suggested energy system for Dawes Island would no doubt support the Niger Delta communities whose livelihoods have been negatively affected by the combined effect of oil and gas exploration to attain their needed economic and environmental potentials which is driven by availability of electricity.***

***Keywords— Hybrid Renewable Energy Sources (HRES), HOMER Pro, Sustainable Energy, Reliability, Optimal System Sizing.***

## I. INTRODUCTION

A review of the performance and achievement of the electricity industry in Nigeria leaves a very pathetic history behind it. Since the installation of the first power station in 1895 in Lagos till date, the challenge of providing a stable and reliable power supply to the relatively few consumers of electricity in the country has been a puzzle yet to be resolved. The availability of electrical energy and its per capita consumption is regarded as an index of national development and standard of living in the present-day civilization.

### 1.1 History of Nigeria Electric Power Sector

With the present estimated population of about 170 million, Nigeria is the most populous country in Africa. It is located in West Africa and divided into 36 states and Federal Capital Territory. Electricity generation in the country dated back to 1895 when the first generator was commissioned in Lagos. Since then, the Nigeria electricity industry has undergone several transformations both in Physical structure and organization. The transformations started with the establishment of Electricity Cooperation of Nigeria (ECN) in 1951 and Niger Dam Authority (NDA) in 1962. The ECN and NDA were merged through Degree 24 of 1972 to form Nigerian Electric Power Authority (NEPA), later called Power Holding Company of Nigeria (PHCN).

PHCN was a vertically integrated utility with the sole custodian of generation, transmission, distribution and sales in the country before the opening up of electric power sector to competition through the Electricity Power Sector Reform Act (ESPRA) of 2005. As a result of the Act, PHCN was unbundled into 18 successor companies; including 11 Distribution Companies (DISCOS), 6 Generation Companies (GENCOS), many Independent Power Producers (IPPs), a Transmission Company of Nigeria (TCN) and Nigerian Electricity Bulk Trader (NEBT). The function of the NEBT is mainly to support the initial take off of the competitive electricity market during the transitional period. NEBT buys generation from the GENCOS and resell same to the DISCOS.

The much-anticipated better services, lower prices, reliable and efficient power supply expected from the deregulation of electricity market have not been felt by Nigerian. In fact, the opposite is the case, electricity demand is presently far more than the generation and the transmission wheeling capacity is not enough to evacuate the available generation to the electricity consumers. The distribution system is also confronted with its own multitude of problems.

Access to the grid presently stands at only 40% of the population. Even the available electricity capacity is insufficient to meet existing power needs of less than 40% who have access to the national grid. Consequently, the connected population faces power problems 60% of the time.

This makes large segment of Nigerians to rely on alternative sources of power using mostly fossil fuel to take care of their daily energy need. The reliance on Fossil fuel based generators (both centralized large-scale and small diesel generators) contribute significantly to carbon footprints compared to power generated form the freely available Renewable Energy (RE) sources such as solar, wind, hydro, biomass, geothermal, etc. Considering the abundant RE resources in the country. It is envisioned that electric power system in Nigeria will undergo tremendous changes in the near future in order to overcome the present electricity challenges in the country. The country needs to diversify her energy supply mix using RE to support socio-economic and technological development of the country with immediate impact on job creation, crime reduction, sustainable energy and clean environment for all. Diversification of energy supply mix requires a thorough knowledge of the existing power system. This past and the present refer respectively to the pre-handing and post-handing over of the generation and distribution segments to the private investors. The challenges facing the power sector were then investigated to bring to fort the future direction of the power system in the country.

International energy institutes comparative analysis of the per capita consumption of electricity worldwide places Nigeria at the bottom. This Comparative study shows the inadequacy of Nigeria in the power sector which gives a sad reflection of the economic down turn of the Nation inspite of its abundant potentials in the area of renewable energy resource.

A major challenge of the electricity sector since the establishment of the Nigeria Government Electricity Undertaking (NEGU) in 1946 to the present day has been how to generate enough power, and make it available to the over seventy percent of her population who duel in the rural areas. And Unfortunately, most of these rural communities especially those in the mangrove swamp lands of the salt water area are yet to be connected to the National grid. The likely hood that such communities would be linked to the National grid in the next thirty years is very remote. It should be noted that most of these communities are Islands separated by numerous rivers, creeks and in some cases big seas.

This study seeks to harness the potential energy in the tidal flow of the sea and sea wind in such environment to generate power for the residents. The integration of these abundant renewable energy resources for the generation of electricity will in no small measure ignite the flame of economic and social development in these almost forgotten parts of our country.

Historical Background of Integrated Renewable Resources

The integration of wind and tidal power plants has evolved from separate systems to combined energy generation leveraging the strengths of both renewable sources. This evolution involves advancements in

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technology, design, and integration strategies, aiming to optimize energy production and system reliability.

By bringing together two marine renewable technologies with considerable synergies, the combined harnessing of offshore energies creates excellent potential for development. This is corroborated by some recent European Union (EU) funded projects: MARINA, ORECCA, TROPOS, MERMAID, and H20CEAN MARINA classifies combined wave-wind systems according to the technology, water depth (shallow, transition, or deep water), or location relative to the shoreline (shoreline, near shore, offshore) (Perez et al, 2021). ORECCA analyzes the offshore renewable energies (ORE) combined resources in Europe. Looking particularly at Europe's combined wave-wind resource, this can be divided into three main sea basins: the Mediterranean Sea, the North and Baltic Seas, and the Atlantic Ocean. TROPOS is aimed at developing a floating multi-purpose platform system for deep water. (Christensen et al 2021) The MERMAID project which seeks to develop concepts for the next generation of offshore activities for multi-use ocean space. It proposes new design concepts for combining offshore activities, such as energy extraction, aquaculture, and platform-related transport at various ocean areas
H2OCEAN is developing a wind-wave power open-sea platform for hydrogen generation with support for multiple energy users (H2OCEAN 2021). The main projects installed in the previous decade (2010-2019) were the 2.3 MW Hywind in Norway in 2009, the 2 MW Principal Power in Portugal in 2011, and the Ministry of Environment (MOE) project in Japan with capacities of 100-kW half-scale model in 2012, and 2 MW full scale in 2013.

### 1.2 Review of the Integration of Wind with Tidal Energy

(Nichita et al 2020) present the "accelerated simulation time" method and its experimental validation. Wind or tidal turbine characteristics are obtained using the simulation approach developed at the GREAH lab and are validated with an actual, Ocean turbine installed in the Circulating Water Channel at Inha University Ocean Engineering Laboratory, South Korea.

(Phurailatpam et al 2020) present a DC microgrid for rural applications in economic analysis of microgrid deployment in different Swedish regions using PV/WT/DG, a battery bank, and an energy management system to identify the optimal system size and configuration.

(Thakur et al 2019) designed, constructed, and tested a new physical simulator under different operating conditions in a real microgrid environment. The simulator replicates the behavior of a designed wind turbine that can work in harmony with PV power modules and battery storage in response to weather and load variations in an island microgrid environment.

(Wang et al), analyzed the stability of a microgrid system containing an offshore wind farm (OWF), an offshore tidal farm (OTF), and a seashore wave farm (SWF) fed to an onshore power grid. (Adetunji et al, 2018). proposed an optimized grid-connected microgrid for South Africa using photovoltaic panels (PV) and a supporting lead-acid battery for downtime.

(Green & Vasilakos, 2021) observed that over the recent decades, offshore wind farms have attracted more investment. According to them, it is estimated that onshore and offshore wind power will generate more than a third of the total electricity needed in the medium term, becoming the primary generation by 2050 they concluded.
(Sierra & Santos 2021) The authors noted, compared with onshore wind energy resources, offshore wind fields have many advantages, such as persistent wind, faster-flowing speed, higher uniformity, and longer available time per year, flat sea surface, and low turbulence intensity, which promotes the vigorous development of the offshore wind power industry.

(Zhang et al 2020) According to them, installing wind turbines in the ocean can protect the environment and save land resources. The vast ocean area provides good conditions for developing large-scale wind farms and tidal turbines. The power generated by the identical turbines in the offshore area is 50-100% higher than in the onshore area. However, the main issue for investors is capital cost which results in increasing the electricity cost for customers. The most expensive component of an offshore wind and tidal turbine is the foundation, accounting for 19% of the capital cost. In addition, foundation installation with 6% of the capital cost is the highest cost compared with other parts.

(Nasah et al, 2020) The research focused on prosing and evaluating an optimized hybrid system of wind and tidal turbines for generating energy in New Zealand. The authors showed that using the capacities of wind and tidal energy in renewable technologies would be a suitable alternative for fossil fuels an would prevent their detrimental effects on the environment. Optimized system model was created using Simulink.
(Nasah et al, 2021) This paper evaluates the feasibility of using a hybrid system consisting of wind and tidal turbines connected to a micro grid for power supply to coastal communities that are isolated from a main supply grid. The case study is Steward Island. HOMER PRO was used to optimize the micro grid design and to analyze the cost of the components. They concluded that there was enough tide to generate electricity during 65% of the year at an offshore site close to Stewart Island. There was also enough wind to generate electricity during 90% of the year at Fourveaux site close to stewart island.

(kangaji et al, 2024) The study focused on developing a stable, renewable energy supply for off grid coastal communities. By addressing the challenges of intermittency and unpredictability in renewable energy sources. The proposed system integrates wind and tidal energy with energy storage and diesel back-up to ensure reliability while reducing greenhouse gas emission and minimizing environmental footprints. HOMER Pro Version 3.20 was used to optimize the system with a configuration of one wind turbine and five tidal turbines and a diesel generator was demonstrated to be the most effective combination. The result emphasized the environmental benefits of this combination offering a blue print for achieving energy security and sustainable development in coastal regions.

(Wande et al, 2023) The authors discussed power generation from tidal and wind energy. It proposes a hybrid offshore wind and tidal turbine (HOWTT) generation system that could harness both tidal and wind power. Simulation was created in MATLAB/Simulink to model the tidal turbine system to illustrate how tidal energy could be used for generation. The result validate that the proposed tidal turbine control system can provide primary power responses to the electrical grid. (Tousif et al, 2021) This article is about tidal power. It describes tidal power and the various methods of utilizing tidal power to generate electricity. The methods briefly discussed each method and provides details of calculating tidal power generation and energy most effectively. The study is also focused on the potential. This method of generating electricity has and why this could be a common way of producing electricity in the near future.

(Blanco, 2020) In his assessment, the cost of electricity using offshore wind is still high as another offshore energy source. Installing tidal turbines has attracted less investment because tidal turbines are exposed to harsh currents. Their lifetime is low, and foundation design is complex in most cases, where the water depth is more than 30 meters. However, tidal turbines can produce an enormous amount of electricity, more than four times per square meter of the rotor than wind turbines. Integration of both wind and tidal turbines with the separate foundation may be a way to reduce the cost of electricity and enable predictable power generation from two different energy sources.

Although considerable research has been conducted on individual wind and tidal energy technologies and on hybrid renewable energy systems, there remains limited research on the co-ordinated integration of onshore wind generation with tidal barrage generation for electricity supply under Nigeria coasted conditions. Existing studies have demonstrated the potential benefits of combining wind and tidal resources, but relatively little attention has been given to the development of a comprehensive model that simultaneously considers local wind and tidal resources characteristics, optimal capacity sizing, energy storage and techno-economic feasibility. This creates room for a location specific integrated wind- tidal energy model capacity of evaluating the complementary behaviour of the two resources and determining whether their combination can provide a more stable, reliable and economically viable electricity supply than either resource operating independently.

There is insufficient location – specific research on the integrated modelling, control, optimal sizing and grid integration of onshore wind and tidal barrage energy systems located at the same post for reliable electricity generation in coastal Nigeria.

## II. METHOD

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Optimization model of the hybrid system is illustrated in Figure 1. It is a general model for optimizing a hybrid generation system which integrates multiple energy sources such as wind and tidal. The research employed a methodical approach starting with a thorough and detailed in-depth review of relating existing literature. Subsequently, comprehensive data collection was conducted which makes the way for simulation and analysis.

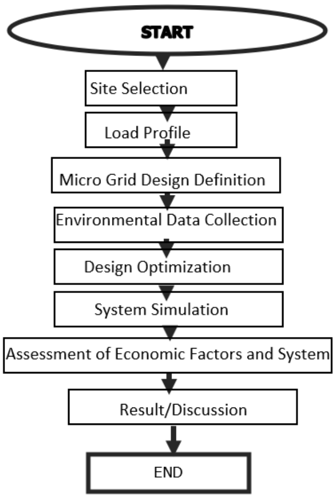


Figure 1 Hybrid Generation System Optimization General model

The HOMER Pro Software was utilized to ascertain the hybrid system optimal design, also environmental data on daily, monthly and yearly wind speed, tidal heights and tidal currents of the specific location is obtained from the internet and HOMER linked to NASA data base.

To find solution for the electricity demand for a remote, off-grid island community such as Dawes Island, the following steps were carried out

2.1 Site Selection

The selection of an appropriate potential sites should take into account the maximum available energy and an Environmental Impact Assessment (EIA) study. A thorough EIA study is required on the potential site, However, that is beyond the scope of this study, instead a pre-feasibility study was conducted for Dawes Island. Key geotechnical findings showed that the soil composition of Dawes Island is suitable for construction of a tidal barrage with bearing capacity ranging from 463.3 in the top soil to 995 $KN/m^2$ in the deeper layers.

Site selection for tidal power plant requires data on strong tidal currents of more than 3m/s, sufficient water depth for the installation of turbines with adequate clearance from seabed. The tidal range (vertical difference between high and low tides) must be significant, at least 2.5 meters and a good understanding of the tidal current distribution is crucial for optimizing energy extraction combined with the geotechnical conditions.

Tidal resources are considerable in coastal areas which are underutilized also largely unmapped in most Coastal areas. However, global records show that the technically harvestable part of these resources are around in area close to the coast with significant tidal ranges and strong tidal currents.

Dawes Island with Global Positioning System (GPS) (Latitude $4.067^0$ and Longitude 7.163°E) is less than one nautical mile off the Bonny Coast. The southern edge of the Island has a bay which is suitable to accommodate a barrage of approximately 38m length suitable for installation of tidal Plant. Measurements were taken using Google Maps.

The Island also benefits from a strong coastal wind moving towards the hinterland with an average monthly speed of 4m/s which is suitable for wind energy harvesting. It should be noted that the tidal patterns along the Gulf of Guinea is semidiurnal tidal cycle (figure 2.11), it experiences two high and two low tides of approximately equal size every lunar day, and with a height difference of about 3.5m, and a water depth of 20m, Dawes Island is suitable for the installation of a hybrid tidal and wind turbine.


Plate 1 Map of Nigeria showing Dawes Island

Plate-1: Location of Dawes (Google Map)

2.2 Load Profile

Load Profiles are extremely important and crucial when designing a power system to ensure that all loads are met and for determining the system's optimal size and selection of renewable energy sources. Sometimes data cannot be collected on expected load profile, in such a situation it has to be estimated. The number of electrical power sources in a hybrid renewable system is determined by the electrical load demand. Dawes Island, a predominantly fishing community lacks historical electrical load data because it is not being connected to the national grid, therefore we relied on assumptions to estimate its electrical load.

The Community has 110 houses with an average of nine persons per household with an estimated population of about one thousand persons. It is mainly residential with minimal commercial activities. It has no functional school system, with no basic Health Centre. The Community benefits from a Federal Government Nomadic Education Scheme for migrant fishermen to meet the academic demands of the people at the Basic School Level. It enjoys a seasonal visit of Health Workers from the Local Government Council. Table 1 Summarizes the needed power consumption of the community.

Table 1 Typical Household Electrical Appliances

| | USER INPUT | | | |
|---|---|---|---|---|
| Device | Power Rating (W) | Quantity | Total Power (Kw) | Estimated Kwh/Day |
| | | | Power * Quantity/1000 | Total Power |
| Desktop Computer | 100 | 1 | 0.1 | 0.8 |
| LED Light Bulbs | 10 | 10 | 0.1 | 0.5 |
| Phone chargers | 5 | 2 | 0.01 | 0.05 |
| (slow charging) | 30 | 1 | 0.03 | 0.15 |
| Television (22 inch) | 1000 | 1 | 1 | 3 |
| Air conditioner | 4000 | 1 | 4 | 12 |
| Water Heater | 500 | 1 | 0.5 | 0.5 |
| Clothes Washer | 3000 | 1 | 3 | 3 |
| Clothes Dryer | 2400 | 1 | 2.4 | 2.4 |
| Oven | 180 | 1 | 0.18 | 4.32 |
| Refrigerator | 1000 | 1 | 1 | 1 |
| Electric iron | | | | |
| | | | | 27.7 |

2.3 Selection of Components

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The turbines selected for evaluation are the WES 30 onshore wind turbine and the Atlantis AR 2000 tidal turbine below sea level.

Wind Turbine

Wind turbines are designed to operate within a specific range of wind speeds. The limits of the range are known as the cut-in speed and the cut-out speed. The cut-in speed is the point at which the wind turbine is able to generate power. The wind velocity at which the turbine automatically shuts down to prevent damage from high winds is known as the cut-out speed (typically 25m/s).

Between the cut-in speed and rated speed where maximum output is reached, the power output increases cubically with wind speed, that is if the speed doubles, the output power is increased 8 times. However, this cubic habit dependence does cut-out at rated speed, this leads to a relatively flat portion of the curve in a typical power curve of a wind turbine.
A suitable wind turbine in terms of low cut-in speed (3m/s), a generating capacity capable of meeting peak load, supplying substantial percentage of peak load, and low purchase, installation and maintenance cost is the WES 30 (540KW) wind turbine with a 20-year life span and a hub height of 48m is used in the simulation. The initial capital cost (installation, wiring and mounting) replacement and maintenance are $500,000, $400,000 and $40,000 respectively.

The WES 30 wind turbines were selected because of their capability to function optimally in Dawes Island's erratic wind patterns with 540 KW rated capacity, the WES 30 should be able to provide a sizeable power output to meet energy demands in the Island. Based on its selection, a good mix between initial investment and current operating savings would be provided.

Table 2 HOMER Pro, WES 30 Onshore Wind turbine

| Quantity | Value |
|---|---|
| Name | WES 30 (540KW) |
| Rated capacity | 540 KW |
| Capital cost | $500,000 |
| Replacement | $500,000 |
| O&M | $40,000/yr |
| Manufacturer | Wind Energy Solutions |
| Hub Height | 48m |
| Cut-in Speed | 2.5m/s |
| Cut-out Speed | 20m/s |
| Rotor Diameter | 24m |

Tidal Turbine

The Atlantis AR2000, 2 MW tidal turbine manufactured by SIMEC is selected. It is known for it's large single rotor design which is one of the most powerful single axis turbine. The design allows for easy deployment and maintenance suitable for the saline waters of Dawes Island. It has a low cut-in Speed (0.7m/s), a generating capacity capable of providing base load as well as meeting peak load demands, and it is bi-directional, generating power during flood (high) tide and ebb (low) tide.
The AR2000 has a 25-year design life with quarter life interventions for routine maintenance. HOMER software provides different types of tidal turbines that are available in Hydro Kinetic, a part of its library components.
Choosing one AR2000 tidal turbine, four cost parameters need to be fed to the software;

i. Capital (installation, mounting) cost
ii. The replacement cost
iii. Maintenance cost
iv. Life time of the tidal turbine

For the purpose of this study the following parameters were used: $3,000,000, $3,000,000 and $60,000/year and 20-years respectively. Details of the AR2000 tidal turbine is shown in table 2Table 3 AR2000 Tidal Turbine Parameters (HOMER Pro)

| Item | Value |
|---|---|
| Model | AR2000 tidal turbine 2MW |
| Rated Power(kw) | 2000 |
| Rotor diameter (m) | 20 |
| Height from the seabed (m) | 10 |
| Swept area of rotor ($m^2$) | 314 |
| Cut-in speed (m/s) | 0.7 |

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| | |
|---|---|
| Cut-out speed (m/s) | 3 |
| Weight (t) | 150 |

Battery (Energy Storage)

In an Hybrid Renewable Energy Sources (HRES) ; batteries are a necessary component that acts against the fluctuation of power generations to improve grid stability.

Plate 2 Battery Strings (Power/DC Storage Systems)

This is done by storing surplus energy during times of high energy production and supplying power at times of high demands or insufficient power generation from the renewable sources. Energy storage plays a critical role in Integrated systems that generate power from diverse renewable sources. When energy storage is included, HOMER requires specifying the storage type. To ensure dependable performance and cost-effective operation, a standard Trojan SAGM, 12V, 219 Ah deep cycle battery is selected for this study.

This battery has a string size of 35 (19 batteries/string) and a nominal voltage of 12 volts. It also has a capacity of 219Ah. It's initial State of charge is set at 100% anticipated to be fully charged at on set. A battery replacement will cost $500 with initial outlay for each battery set at $600. Knowing that batteries have limited operational life, their eventual replacement will cost a portion of the system operating budget. A battery string refers to a series-connected group of battery cells or modules designed to reach a specific voltage level required by the system it powers. In large battery systems such as those in electric vehicles (EVs) or battery energy storage systems (BESS), multiple cells or modules are connected in series to form a string, which is then often combined with other strings in parallel to meet both voltage and capacity requirements.

Purpose of Battery Strings:

i. Achieve desired system voltage levels
ii. Enable modular design for scalability
iii. Improve fault isolation and system redundancy
iv. Facilitate thermal and electrical balancing

With an exceptional resilience to temperature changes and a very low maintenance requirements, the Trojan SAGM 12V, 219Ah battery is a perfect choice for Dawes island's variable renewable energy system. It also provides excellent energy storage efficiency. It's extended service life and capacity to recover from deep discharges are guaranteed by it's deep cycle application design which increases the dependability of the system which relies on intermittent energy sources. This battery is a reasonable solution to meet Dawes island's energy requirements due to it's affordability and compatibility with renewable technologies. Details of Trojan SAGM 12V, 219Ah. Battery is shown in Table 4

Table 4 HOMER Pro Trojan SAGM 12 details.

| Quantity | Value |
|---|---|
| Name | Trojan SAGM 12 219 |
| Nominal Voltage | 12V |
| Nominal Capacity | 2.63 kWh |
| String Size | 35 |
| Voltage | 415V |
| Maximum Capacity | 219Ah |
| Capital Cost | $600 |
| Replacement Cost | $500 |
| O&M | $50/year |
| Initial state of charge | 100% |

Converter

A bi-directional converter, the Eaton 2000 model is used in the hybrid energy system design. The Output

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Power of the converter is 2000KW, 90% efficiency. It has a life span of 15 years.

All equipment specifications were sourced from HOMER's catalogue. The converter cost $6,000 to purchase, $4,000 to replace and about $100 to maintain each year. HOMER optimizes the converter's size, capital, replacement cost and maintenance cost.

Table 5 HOMER Pro Eaton

| Quantity | Value |
|---|---|
| Name | Eaton Power Xpert 2000kW |
| Capital Cost | $6,000 |
| Replacement cost | $4500 |
| Operation & Maintenance (O&M) | $100/year |
| Lifetime | 15 years |

Energy Mix (Controller)

An Energy Controller could be a software or hardware system that manages combination of different energy sources such as renewables to meet energy demand. Controllers aim to improve efficiency by balancing energy supply and demand in real-time.

A load following (LF) controller is selected for this study by ensuring the load demand is always met by producing only enough power. The capital, replacement, maintenance and life of the controller are taken as $200, $200, $50/year and 25 years respectively.

2.4 Environmental Data for Dawes Island

Dawes Island (Rivers State, Nigeria) is a typical coastline community which has the attributes of coastal communities in Nigeria. It has geographical coordinate of Latitude 4°.07 N and Longitude 7°.16 E. with an elevation of 452m above sea level (Google Map).

(i) Wind Energy Potential

The monthly average wind speed of Dawes Island is obtained from NASA surface meteorology data base as shown in figure 4. The wind speed presented in Table 6 (internet) are extrapolated at a 50m hub height as wind speeds at lesser heights are not feasible for electrical energy generation especially for the site considered which is 452m above sea level.

Table 6 Estimated Monthly Average Wind Speeds for Dawes Island/Bonny Island (Internet 2025)

| | | | |
|---|---|---|---|
| January | ~5.2 mph | ~2.3 m/s | Calmer dry season, harmattan influence |
| February | ~5.6 mph | ~2.5 m/s | Slight rise as dry season fades |
| March | ~6.0 mph | ~2.7 m/s | Transition to wetter, windier period |
| April | ~6.3 mph | ~2.8 m/s | Increased coastal breeze |
| May | ~6.8 mph | ~3.0 m/s | Start of windier monsoon months |
| June | ~7.2 mph | ~3.2 m/s | Stronger south-westerly winds |
| July | ~7.0 mph | ~3.1 m/s | Steady high winds, wettest period |
| August | ~7.5 mph | ~3.3 m/s | Windiest month |
| September | ~6.5 mph | ~2.9 m/s | Gradual decline begins |
| October | ~6.0 mph | ~2.7 m/s | Transition to calm |
| November | ~5.5 mph | ~2.5 m/s | Calm, dry period |
| December | ~5.0 mph | ~2.2 m/s | Calmest month, harmattan return |

Summary

Annual Mean Wind Speed: ≈ 6.1 mph (2.7 m/s)

Windiest Month: August (~7.5 mph / 3.3 m/s)

Calmest Month: December (~5.0 mph / 2.2 m/s)

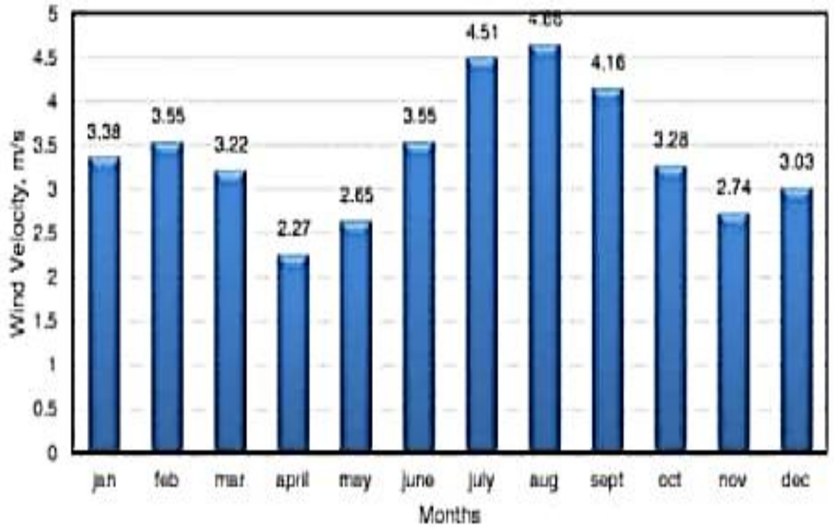


Figure 2 Monthly Average Wind Speed of Dawes Island

(ii) Tidal Energy Potential

Tidal Current runs (speed) data for Dawes Island is been source from the Hydrographic office of Nigerian Navy (HONN), Nigerian Hydrographic Agency (NHA) and the internet because Dawes Island is not a designated tidal station in Nigeria. Since Port Harcourt has almost the same geographic co-ordinates (Latitude. 4°.46N, Long 7°.00 E) with Dawes Island (Lat. 4°.07N, Long 7°.16E) the approximate mean velocity profile of tidal current of Port Harcourt was adopted for Dawes Island in this study. Plate 3 shows Designated Tidal Stations in Nigeria.


Plate 3 Designated Tidal Stations (Goole map)

Table 4 shows flood and ebb velocities of seven designated stations over a period of five years, Hydrographic Office of Nigerian Navy (HONN).

Table 4 Peak Flood and ebb velocities over 5 years period of 7 Designated Sites (ANOO, L.M 2021)

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| Year | Sambreiro River | | Tom Shot Point, Calabar River | | Warri Port | | Opobo River Entrance (Sandy Point) | | Port Harcourt /Dawes Island | | Calabar Port | | Brass River Entrance | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flood (m/s) | Ebb (m/s) | Flood (m/s) | Ebb (m/s) | Flood (m/s) | Ebb (m/s) | Flood (m/s) | Ebb (m/s) | Flood (m/s) | Ebb (m/s) | Flood (m/s) | Ebb (m/s) | Flood (m/s) | Ebb (m/s) |
| 2011 | 10 | 10 | 10 | 17 | 10 | 11 | 10 | 17 | 10 | 16 | 10 | 18 | 10 | 15 |
| 2012 | 10 | 10 | 10 | 17 | 10 | 11 | 10 | 17 | 10 | 16 | 10 | 18 | 10 | 15 |
| 2013 | 10 | 14 | 10 | 16 | 10 | 11 | 10 | 16 | 10 | 17 | 10 | 19 | 10 | 18 |
| 2014 | 10 | 10 | 10 | 16 | 10 | 11 | 10 | 17 | 10 | 16 | 10 | 19 | 10 | 15 |
| 2015 | 10 | 10 | 10 | 18 | 10 | 11 | 10 | 17 | 10 | 16 | 10 | 19 | 10 | 15 |

2.5 Systems Modelling

HOMER is an acronym for a Hybrid Optimization Model for Electric Renewables. An outstanding software for sizing a hybrid system with a variety of wind turbines and converters to make selection process easier is the HOMER Pro.

In this study, HOMER uses the load demand estimation data of Dawes Island (daily load profile) as given in table 1, the resources (the monthly average wind speed and tidal height and current speeds), as presented in tables 4 and 5 respectively, and the components details with cost as input to simulate various feasible configurations and ranked by the net present cost (NPC).

Wind Generation Model

Wind energy set up consists of three parts; air's Kinetic energy is converted into rotational energy during the aerodynamic stage. The energy is converted into mechanical energy transferred through gear systems to the generator where the energy of mechanical motion is converted to three phase

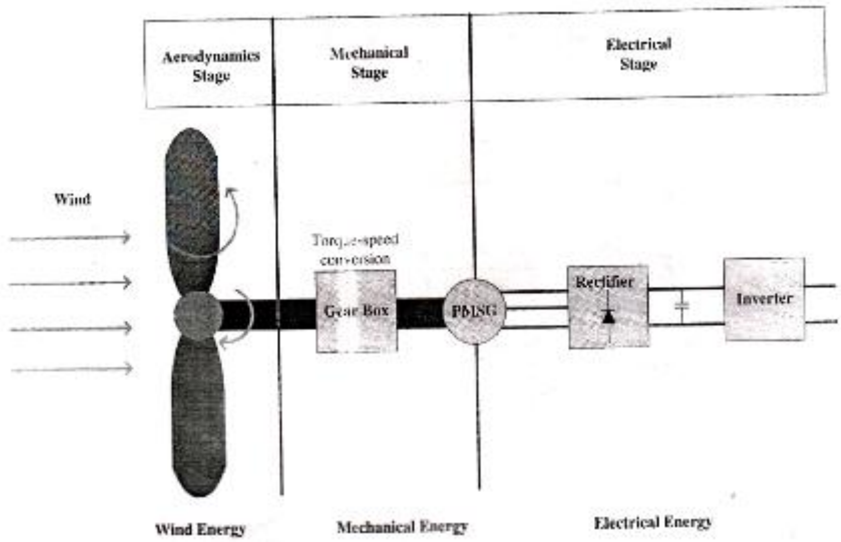


Figure 3 Stages of Wind Turbine

electrical energy. The third stage known as the Electrical, involves the control and transformation of electrical signals using inverters and converters to achieve various values of voltage. The wind turbine stages are illustrated in Figure 3

The Wind Velocity, $V_w$ can be written as;

$$V_w = V_{wB} + V_{WG} + V_{WR} \quad (1)$$

Where, $V_w$ is the total wind velocity, $V_{wB}$ is the base wind Velocity, $V_{WG}$ is the gust wind component and $V_{WR}$ is the ramp wind component. The Kinetic Energy of a wind turbines rotor with cross-sectional area (A) exposed to the air stream is expressed as;

$$E_w = \frac{1}{2} mv^2 \quad (2)$$

Where V is the air velocity, m is the parcel volume of air interacting with the rotor.

Power is the rate of change of the Kinetic Energy which gives,

$P = \frac{1}{2}\frac{dm}{dt}V^2$ (3)

Where $\frac{dm}{dt}$ is the mass flux given by

$\frac{dm}{dt} = \rho A V^2$ (4)

where $\rho$ is the density of air, therefore given V(t) which is the instantaneous velocity at time t, substitute equation 3.19 into 3.18 we have

$P = \frac{1}{2}\rho$ Av $V^2 = \frac{1}{2}\rho A V^3$ (5)

Thus, the power which is the Kinetic Energy Per unit time is expected as

$P_w = \frac{1}{2}\rho A V^3 C_p(\lambda\, \beta)$ (6)

Cp is the power co-efficient of the wind turbine, it is a function of both the Tip speed Ratio (TSR) and the blade pitch angle of the rotor (β).

The TSR changes when the rotor speed and wind speed change, resulting in a new operating position on the power curves at various speeds and pitch angles.

The turbine torque $T_m$ (Produced by the wind) accelerates the turbine inertia and is counter balanced by the shaft torque $T_{s1}$ (Produced by the torsional oscillation action of the low-speed shaft).

$T_m - T_{s1} = Jm\frac{d\omega_r}{dt}$ (7)

where $\omega_r$ is the angular velocity of the turbine, and $J_m$ is the moment of inertia of the turbine.

Similarly, the torque produced by the high-speed shaft ($T_{s2}$) accelerates the rotor and it is counter balanced by the electromagnetic torque ($T_e$) produced by the generator

$T_{s2} - T_e = J_m\frac{d\omega_r}{dt}$ (8)

where ωr = Angular velocity of the rotor, $J_m$ = Moment of inertia of the rotor.

Tidal Generator Model

As tidal currents are periodic horizontal flow of water accompany to the rise and fall of the tide, they can be modelled as a stream of harmonics.

$Vi(t) = \sum_0^n Vi\sin(\omega t + \phi i)$ (9)

Where $V_i$ is the amplitude, t is the period and $\phi_i$ is the phase for ith harmonic constituents, ω = 2πf the frequency component.

The power harnessed from a tidal turbine was calculated as;

$P_{av} = 0.\ 225\ AR^2$ (10)

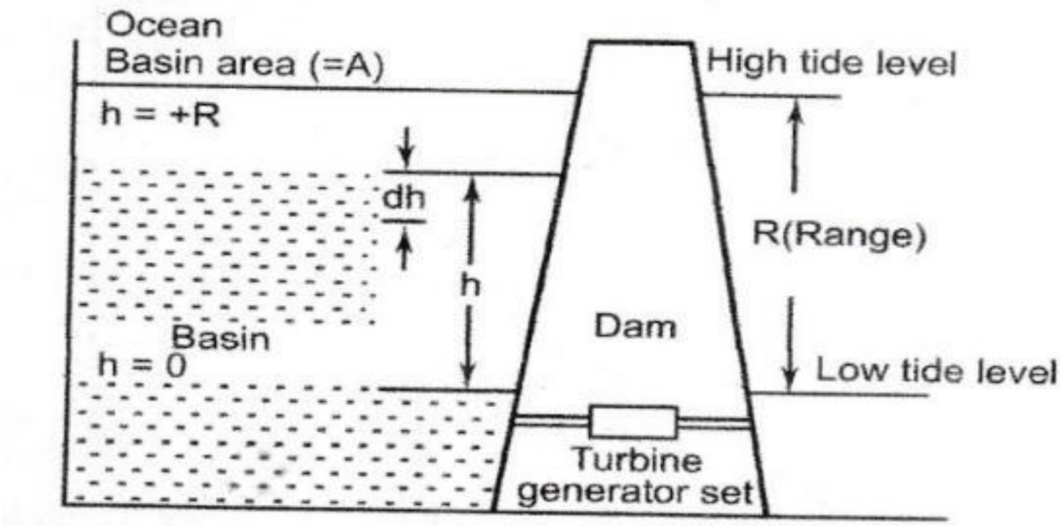


Figure 4 Model for a Single Basin, two-way Tidal Barrage Scheme (Tidal Energy (Hardouts.pdf)

- W = Work done by water flowing through turbine (J)
- For tidal range (amplitude) R. and certain head (h) at the given time during the flow from the ocean to basin, the differential work done (dw0 is equal to the change in potential energy.
- A = Area of basin, considered constant ($m^2$)
- $\rho$ = Density of water ($kg/m^2$)
- g = Gravitational constant
- m = Mass flowing through the turbine (kg)
- h = Head, (m)

Energy due to change in mass (dm) of water.

dw = dm . g . h (J) (11)

Where dm = - $\rho$.A dh

- Where negative sign indicates decrease in the mass of water during in emptying operation

dW = - p . A dh . g . h (J). (12)

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- The total work done (W) by water while emptying
  the basin is obtained by integrating dW from R to 0:
  $W_{empty} = \int_R^0 dW = \int_R^0 -\rho \cdot A \cdot dh \cdot g \cdot h$ (13)
  $W_{empty} = -\rho \cdot g \cdot A \int_R^0 h \; dh$
  $W_{empty} = -\rho \cdot g \cdot A \left[\frac{h^2}{2}\right]_R^0 = \frac{1}{2}\rho \cdot g \cdot A \cdot R^2$ (14)
- Where, $\rho =$ Sea density in kg/m$^3$ = 1025 kg/m$^3$ and
  g = 9.81 m/s$^2$
- Work is proportional at to square of the tidal range
- The Power is the rate of doing work.
- The power is generated during emptying (or filling) and no power is generated during rest of the time.
- The average power (theoretical) delivered = W/time
- The duration of time for single effect is 6h 12.5 min

which is equal to 22,350 seconds

- $P_{av} = \frac{W}{time\ (s)} = \frac{g\rho AR^2}{2x22350} = \frac{1}{44700}\ x\ 9.81\ x\ 1025\ x\ AR^2$
- $P_{av} = 0.225AR^2$ (15)
- $\frac{P_{av}}{A} = 0.225 \cdot R^2 \frac{MW}{km^2}$
- The average power generated is calculated based on average operating head of R/2 which is available only for limited period under a single-basin emptying operation
- There are friction losses, conversion efficiencies of the turbine and generator that reduce the power. Studies have shown that the optimal annual energy production is about 30 percent of the average theoretical power.

2.6 Steady – State Modelling of Double Fed Induction Generator (DFIG)

The doubly fed induction machine like other induction machine can be represented in a simple form of electrical transformer connected into balanced three phase source. Modelling of DFIG is built up on the following assumptions:

i. Only one phase of the stator and rotor is represented and the other two phase are modelled as essentially similar.
ii. The machine is symmetrical and balanced in structure
iii. Magnetization is linear
iv. The stator windings are supplied by three- phase voltages directly from the grid
v. The rotor windings are supplied by the three-phase voltage but independent of the stator voltages.

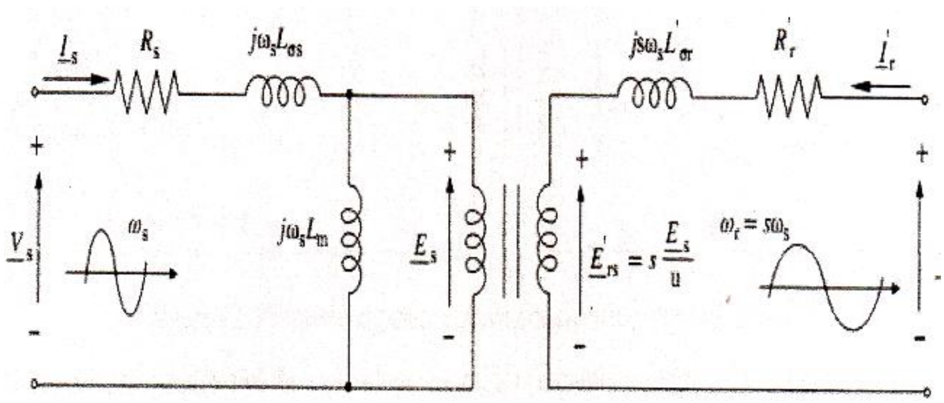

Figure 5 Single-phase steady-state equivalent electric circuit of the DEIG

Where;

- i. $\underline{V}_s, \underline{V}'r$: are supplied stator and rotor voltages respectively
- ii. $\underline{I}_s$ $\underline{I}'_r$ are stator and rotor currents
  iii. $\underline{E}_s$, $\underline{E}'rs$: are induced e.m.f in the stator and rotor respectively
  iv. Rs, R'$_r$ are stator and rotor resistances in (Ω)

v. Lm, L$\sigma$s, L$\sigma$r: mutual stator, and rotor leakage inductances respectively expressed in

vi. Ns, Nr: are number of turns of the stator and rotor windings per phase u, is the coefficient that relation between the stator and rotor turns per phase as follow:

$u = \frac{N_s}{N_r}$ (16)

Therefore, the induced e.m.f in the stator and rotor calculated by:

$E'_{rs} = \frac{E_s}{u} S$ (17)

Note; if the number of turns of rotor and stator and slip between them is equal then the induced emf of both rotor and stator are the same.

In order to facilitate the analysis, the stator windings are reduced to be equivalent to that of the rotor winding. this provides us with the equivalent phase circuit of figure 8.

- To simplify the analysis of the equivalent circuit, it is recommended to subject both the stator and rotor circuits to the same frequencies. thus, the rotor circuit is 'converted' to the stator frequency by doing:
- $V_r - SE_s = (R_r + j_s\ \omega_s L\sigma r)\ I_r \Rightarrow \frac{V_r}{s} - E_s = (\frac{R_r}{s} + j\omega L\sigma r)I_r$ (18)
- So, the final configuration of equivalent circuit will be as in figure 3.28.

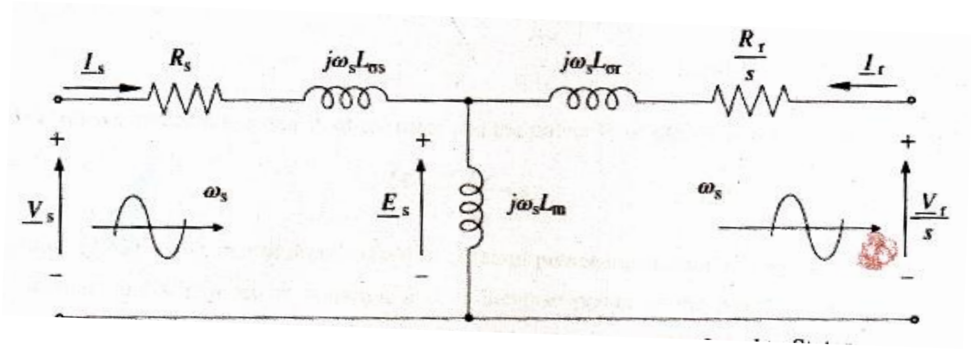


Figure 6 Steady-State Equivalent Circuit of the DEIG Referred to Stator

The final steady- state voltage and flux electric equations of the equivalent circuit of the DEIG are as follows:

Voltages:

$V_s = R_s I_s + j\omega_s L\sigma_s I_s + j\omega_s L_m (I_s + I_r)$ (19)

$\frac{Vs}{S} = \frac{R_r I_r}{S} + j\omega_r L\sigma_r I_r + j\omega_s L_m (I_s + I_r)$ (20)

Fluxes:

$\psi_s = L_m (I_s + I_r) + L\sigma_s I_s = L_s I_s + L_m + I_r$

$\psi_s = L_m (I_s + I_r) + L\sigma_r I_r = L_m I_r + L_r + I_r$

Where Ls= $L_m$ + Lȯs being the stator inductance and $L_r = L_m$+ Lȯs being the rotor inductance.

DC Link Model

It is the linkage between the grid side and rotor side converters. It is a capacitor used to minimize power fluctuation; its function is to maintain a constant voltage in the terminals of the grid side converter. figure 3.30 shows a simplified model of a DC link.

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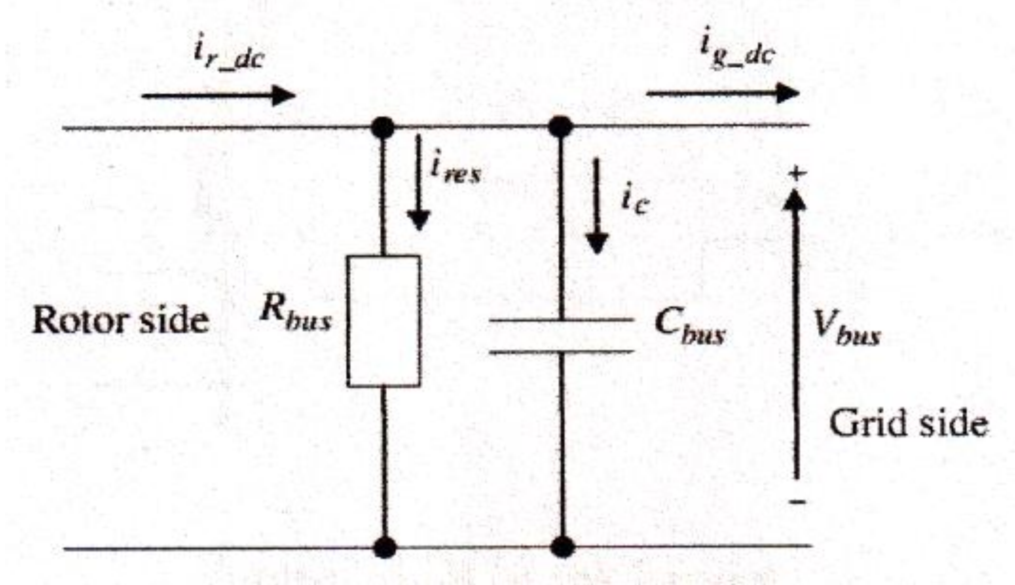


Figure 7 DC-link Power Converter

The DC bus voltage can be calculated

$$V_{bus} = \frac{1}{C_{bus}} \int i_c \, dt \tag{21}$$

The DC current can be calculated as follows from the output AC current of the converters:

$$i_{g\_dc} = S_{a\_g}\, i_{ng} + S_{b\_g}\, i_{bg} + S_{c\_g}\, i_{cg}$$
$$i_{r\_dc} = S_{n\_r}\, i_{nr} - S_{b\_r}\, i_{br} - S_{b\_r}\, i_{c\_r}\, i_{cr} \tag{22}$$

The current through capacitor can be found as

$$I_c = i_{r\_dc} - i_{g\_de} - i_{r\_res} \tag{23}$$

Where:

$i_{res}$ : current through the resistance (A)

$i_{g-dc}$: DC current flowing from the DC link to grid (A)

$i_{r-dc}$: DC current flowing from the rotor to the Dc link (A)

The current through the resistance is

$$i_{res} = \frac{V_{bus}}{R_{bus}}$$

Hereafter, the model of the DC link system illustrated in figure 3.31.

PI (Proportional Integral) Controller

A PI controller has proportional and integral actions. Which is a special case of the PID controller in which the derivative (D) of the error is not used. To control the amount of mechanical power captured, a pitch controller was used. The purpose of the pitching mechanism is to ensure at all times that the output power does not exceed its rated value during periods of high flow velocity Thus, the transfer function of such a regulator is:

$$k_P + \frac{ki}{s} \tag{24}$$

With:

Kp: Proportional constant

Ki: Integral constant

S: Laplace variable

Suppose current need to be regulated such as:

$$i = \frac{v}{R + Ls}$$

With:

V: Supply voltage

R and L: Respectively resistance and inductance.

The regulation loop is described as:

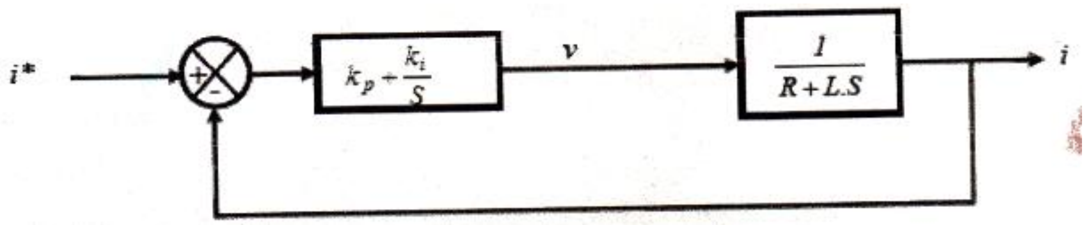


Figure 8 Close Loop Transfer Function of a PI Controller

Open loop transfer function is:

$$G_0 = \left[k_P + \frac{ki}{s}\right] \cdot \left[\frac{1}{R+LS}\right] \quad (25)$$

Closed loop transfer function is

$$G_c = \frac{\left[kP + \frac{ki}{s}\right] \cdot \left[\frac{1}{R+LS}\right]}{1 + \left[kP + \frac{k'}{s}\right] \cdot \left[\frac{1}{R+LS}\right]} \quad (26)$$

Multiply and divide Equation 3.60 by: $\frac{S}{R+L.S}$

Then it becomes:

$$G_c = \frac{k_P \cdot s + ki}{LS^2 + [R + k_P] \cdot S + ki} \quad (27)$$

Multiply and divide Equation 3.61 by $\frac{1}{Ki}$ then we have:

$$G_0 = \frac{\frac{k^p}{ki} \cdot s + 1}{\frac{1}{L} s^2 + \left[\frac{R+kp}{ki}\right] \cdot s + 1} \quad (28)$$

If filter is used at the input of the system, then its transfer function is:

$$\frac{1}{\frac{kP}{ki} s + 1}$$

Then closed loop transfer function becomes:

$$G_c = \frac{1}{\frac{L}{k_i} s^2 + \left[\frac{Rt \cdot k_P}{\kappa i}\right] s} + 1 \quad (29)$$

It is noticed from the above transfer function (equation 29) that it is a second degree. Indeed, the transfer function of second-degree system is written in the following formula:

$$G_c = \frac{1}{\frac{1}{\omega_n^2} S^2 + \frac{2.\varepsilon}{\omega_n} .S + 1} \quad (30)$$

With:

$\omega_n$: Natural Pulsation

Ɛ: Damping.

By identification, we can determine the parameters of the PI regulator.

$$\frac{L}{ki} = \frac{1}{\omega_n^2} \rightarrow ki = \omega_n^2 . L$$

$$\frac{R + kp}{ki} = \frac{2.\varepsilon}{\omega_n} \rightarrow kp = \frac{2.\varepsilon}{\omega_n} . ki - R \rightarrow kp = 2.\varepsilon.\omega_n . L - R$$

We considered:

$$\omega_n = \frac{2.\pi}{T} \; Where \; T \leq \frac{\tau}{10}; with \; \tau = \frac{L}{R}$$

$$\varepsilon = 0.707$$

Modelling of Power Converter

The power converter is implemented to supply the rotor of the DFIG. It is possible to control the wind turbine to operate at variable speed, delivering energy from the wind to the grid and meeting the grid code requirements. Recent development in computer-aided design and semiconductors have enormous contribution to the modelling of power converters, and are commonly used on the rotor side of DFIG.

Power converter is composed to two main parts namely; rectifier and inverter, these two components are made up of power electronic device such as diodes, transistors in addition to the DC- Link which is used as storage unit and point of decoupling and stabilization between the two main parts of the power converter. This configuration allows obviously bidirectional flow of power that is from the machine to the grid and vice versa. Furthermore, the three phase Pulse Width Modulator (PWM) boost rectifier has some advantages such as nearly sinusoidal waveform input currents, unity of input power factor, and low harmonic distortion of line currents, adjustment and stabilization of DC link voltage, reduce capacitor size and minimized pulsations of the torque. The three-phase rectifiers and inverters used for this hybrid system are bidirectional and controlled power converters. This type of converter can therefore operate both inverter and rectifier, depending on the direction and type of electrical energy that passes through them.

Mathematical Modelling of Power Converter

It is considered as modelling hypothesis that the Insulated Gate Bipolar Transistor (IGBT) and diode

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are all ideal: zero resistance in closed and infinite resistance in open position, and instantaneous response to control signals.

Rotor Side Converter Model

Each phase of the DEIG's rotor coils can be represented by an electromotive force (e.m.f) in series with an inductance and resistance and currents crossing each phase with i= a, c, b.

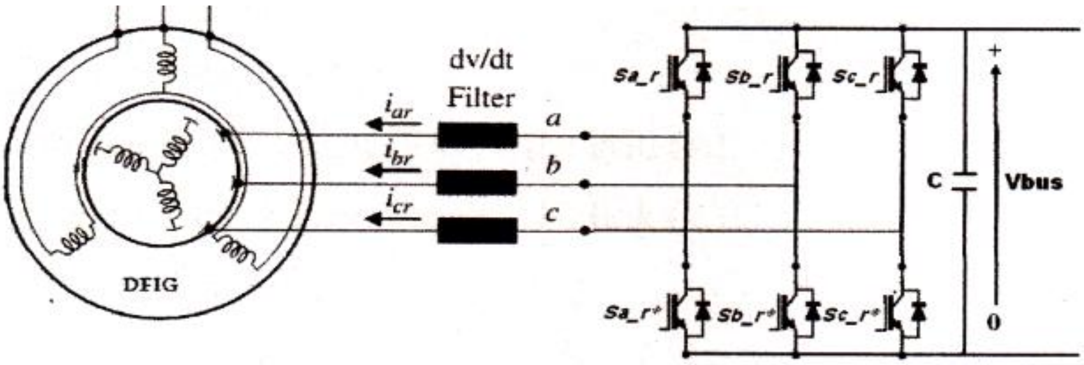


Figure 9 Schematic of Power Converter Rotor Side (rectifier)

Fixed Speed Control

From figure 4.20 and 4.21, we can see that the rotation speed of the rotor is constant although the tidal speed is altered. This demonstrates the robustness of the PI Controller which let the actual values track the set point. Generated mechanical power and mechanical torque increase and decrease according to the tidal speed.

2.5.7 Grid Side Converter Model

The grid side system is composed of converter, filter and grid voltage. As illustrated in figure 10

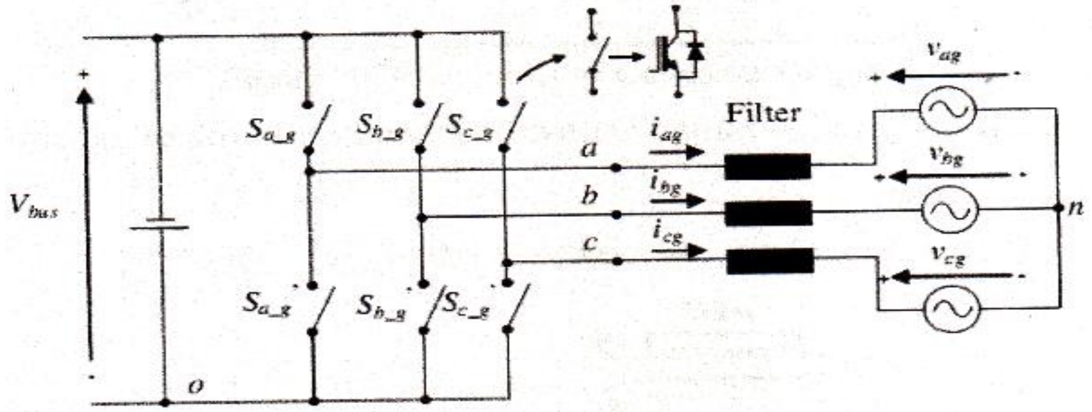


Figure 10 Grid Side Converter

Two- level converter is modelled with ideal switches, where the current can flow in both directions. Switches are commanded by triggers denoted by Sa-g, Sb.g, Sc-g which are generated by pulse width modulation (PWM) method. Under ideal situation the converter switches hold this command condition:

$$s_{a\_g} = s_{a\_g} \quad (31)$$

$$s_{b\_g} = s_{b\_g}$$

$$s_{c\_g} = s_{c\_g}$$

For instance, the voltage $V_0$ referenced to the zero point of the DC bus:

$$V_{jo} = V_{bus} S_{j\_g}$$

$$S_{j\_g} = \in \{0,1\} \quad (32)$$

J = a, b, c

Note that, it is not possible to have two switches connected in the same time on the same leg. Also, by manipulating switch position, it is possible to have different wave forms and amplitudes at the output of the converter.

## III. SIMULATION RESULTS AND ANALYSIS

The objective of the simulation is to develop and evaluate a hybrid wind and tidal energy generation system in which the electrical outputs of a wind turbine and a tidal turbine are integrated through power electronic converters and a common electrical bus. The simulation investigated the power output, voltage, current, efficiency and dynamic response of the hybrid system under varying wind speeds and tidal velocities. The study also determines whether the complementary characteristics of wind and tidal energy can improve the reliability and stability of electricity generation compared with using wind energy alone. A simulation of a hybrid wind and tidal energy system can be developed to model how wind and tidal resources are converted into electrical power and combined to supply a common load or grid.

Simulation Models of the Wind and Tidal Turbines

Figure 11 shows the simulation model of the combined wind turbine and tidal turbine respectively carried out in a Simulink environment. The objective of the simulation is to develop a hybrid wind

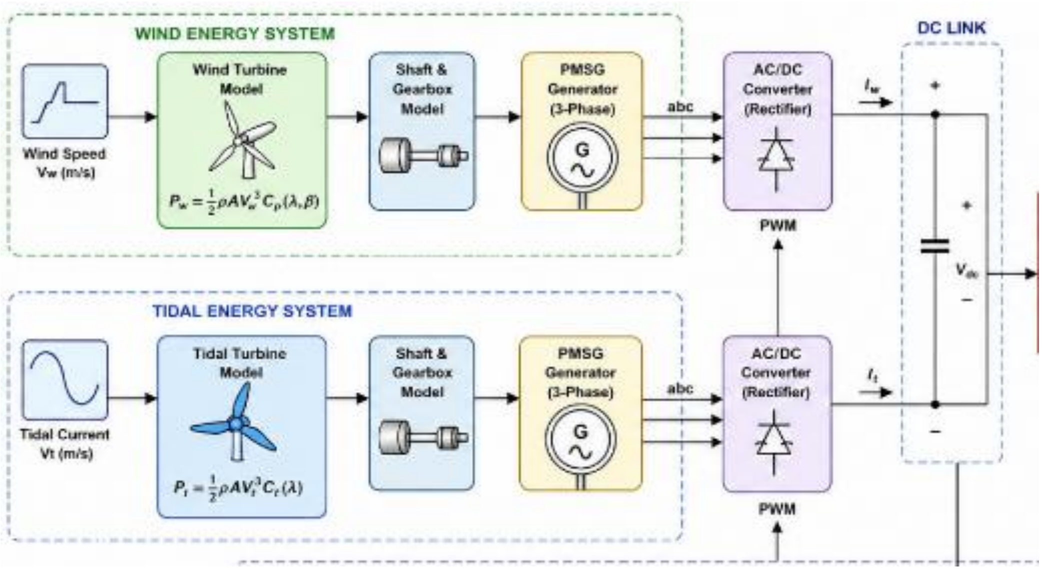


Figure 11 Simulink Diagram: Hybrid Wind- Tidal Energy System

and tidal energy generation system for Dawes Island in which the electrical output of a wind turbine and tidal turbine are integrated through a common electrical bus. The simulation shows power output, voltage, current and the response of the hybrid system under varying wind speed and tidal currents.

3.1 Result of Wind Turbine Simulations

Wind speed in a hybrid wind tidal energy simulation is normally modelled as a time varying input to the wind turbine. For MATLAB/SIMULINK, Simulation was conducted using measured wind speed data by obtaining hourly or 20 minutes wind speed data over 24 hours, the data is then imported into Simulink using a from file block.

Suggested Parameters

| Parameter | Value |
|---|---|
| Rated wind Power | 540KW |
| Rotor Radius | 8m |
| Air density | 1.225 kg/m$^3$ |
| Maximum $C_p$ | 0.42 |
| Cut-in-speed | 3m/s |
| Rated Speed | 12m/s |
| Cut-out-speed | 25m/s |
| Generator | DFIG |

In Simulink, implement $C_p$ is implemented as a 2-D lockup table with inputs λ and lade pitch $\beta$

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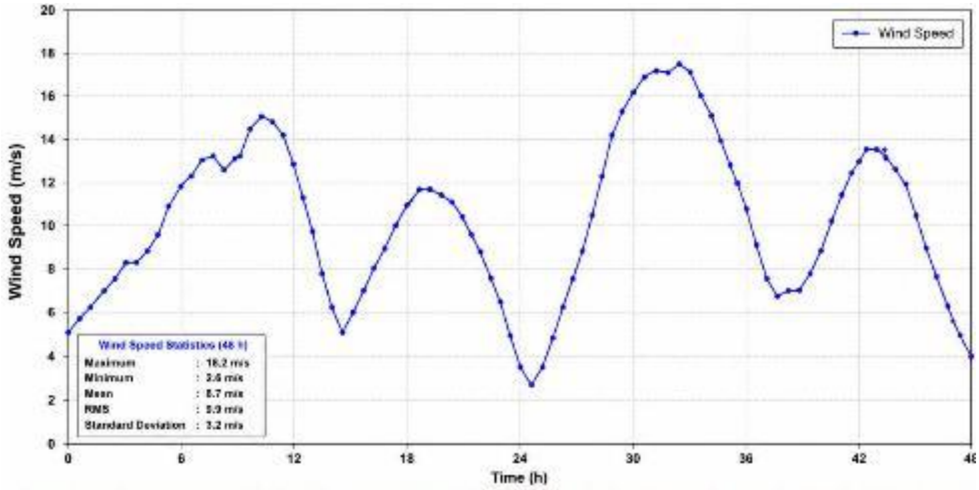


Figure 12 Simulation of Wind Speed versus Time

Figure 13 displays the wind turbine output power at different wind speeds. At the base wind speed, the turbine achieves maximum power output peaking at approximately 540KW. However, as the wind speed decreases, the wind power output also diminishes. Again, when the wind speed increases, the power increases to its maximum, the simulation show that the wind turbine works correctly.

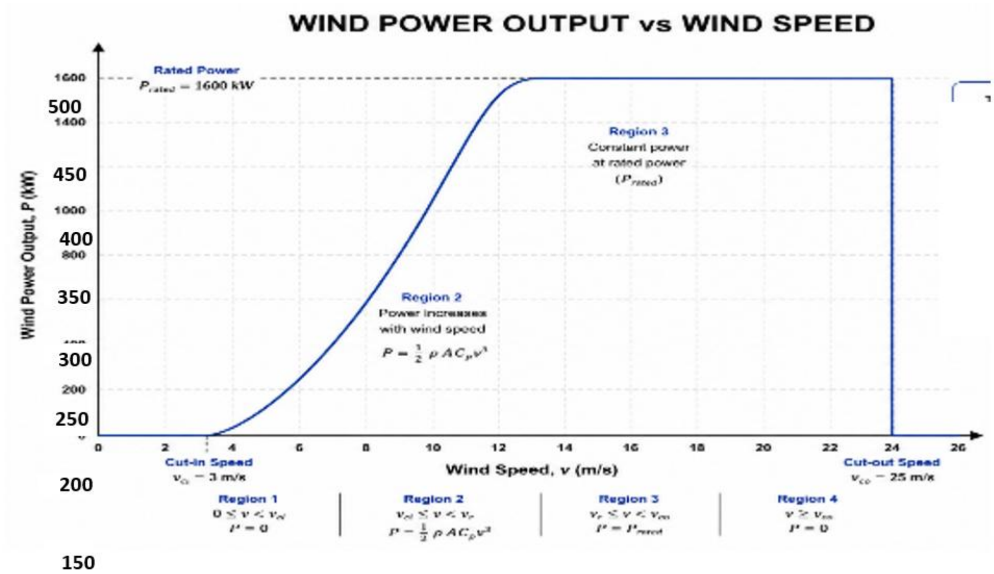


Figure 13 Power Curve of the WES 30 Wind Turbine

Simulation Results of Tidal Turbin

The tidal energy is being analysed by giving a stream of frequencies applied as input
source of turbine to behave like a tide. The tidal simulation as shown in figure 15 indicates a high predictable rate of the tides, therefore the energy expected at every given time can be obtained. the initial pick-up performance of the tidal turbine is comparatively low because it takes some time to get in synch with the tidal current and afterwards the turbine reaches its maximum generation capacity. It is clear that the output reaches steady state within a very short time resulting power equal to the rated value.

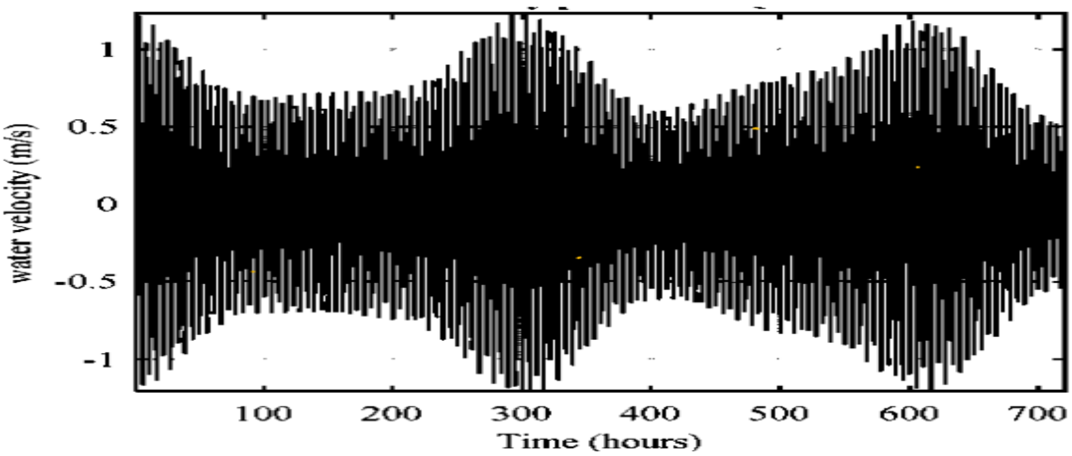


Figure 15 Tidal Generation Output Power

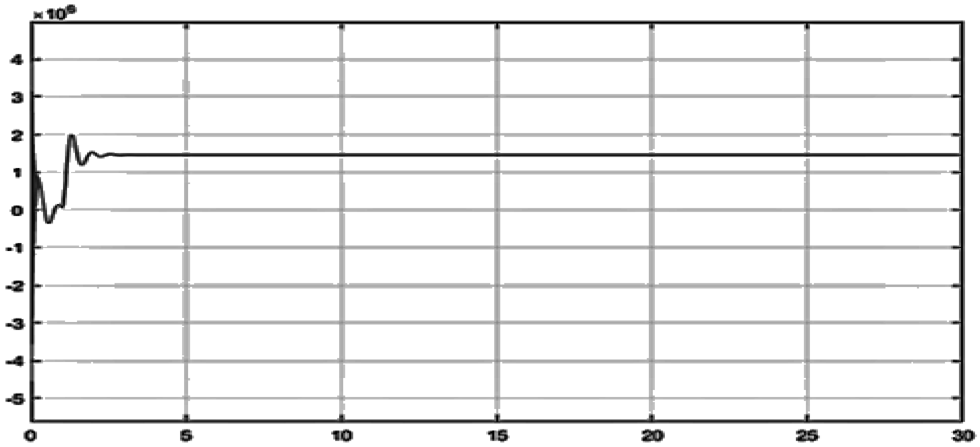


Figure 14 Tidal Turbine Power Output

3.3 Simulation Result of Hybrid Wind Tidal Generation

Figure 16 shows a 24 hours simulation graph of the hybrid wind-tidal power system. It shows wind power, tidal power and the combined output.

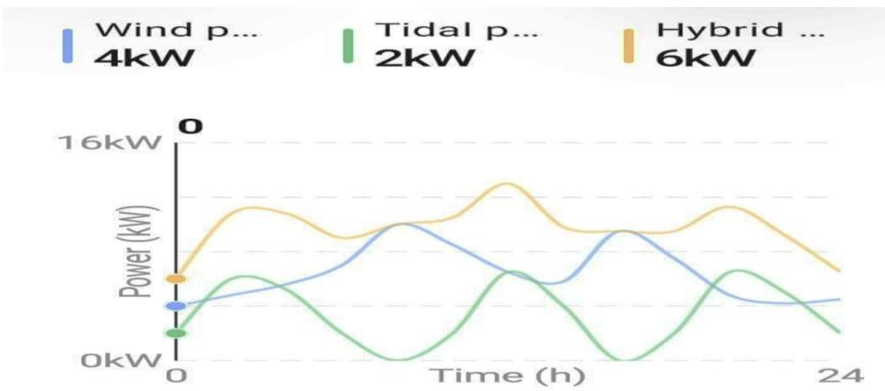


Figure 16 Simulation showing individual wind and tidal generation and their combined output.

The hybrid output is smoother than the individual sources as the wind and tidal resources vary differently. At time 12.00hours, the tidal output is 0.6MW, with a wind output of 3.7MW which gives a hybrid generation of 4.3MW.

3.4 Simulation and Control of Doubly-Fed Induction Generator-based Tidal Turbine.

To avoid repetition, and due to the similarity between wind and tidal turbines, in terms of design, their operation principles are very similar. Although the water Speeds are low, however the density difference between fluids where water density is much greater than the density of air, which creates the real difference in production between the turbines.

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3.4.1 Control of Rotor Side-Converter (RSC)

i. Fixed Speed Control

From figure 17 and 18, we can see that the rotation speed of the rotor is constant although the tidal speed is altered. This demonstrates the robustness of the PI Controller which let the actual values track the set point. Generated mechanical power and mechanical torque increase and decrease according to the tidal speed as seen in figure 19 and 20.

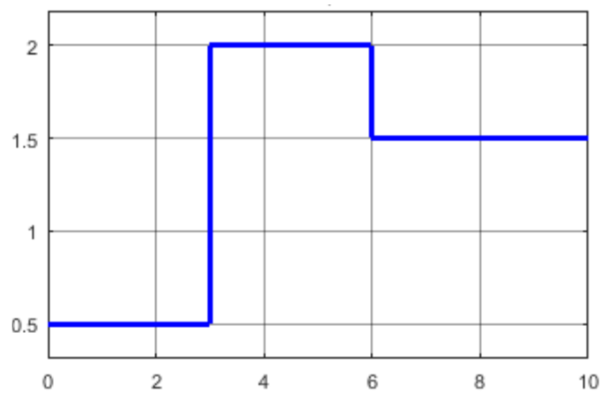



Figure 17 Tidal Speed

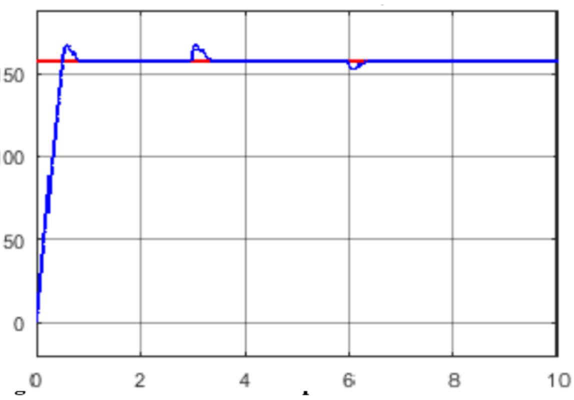



Figure 18 Generator's Rotor Speed

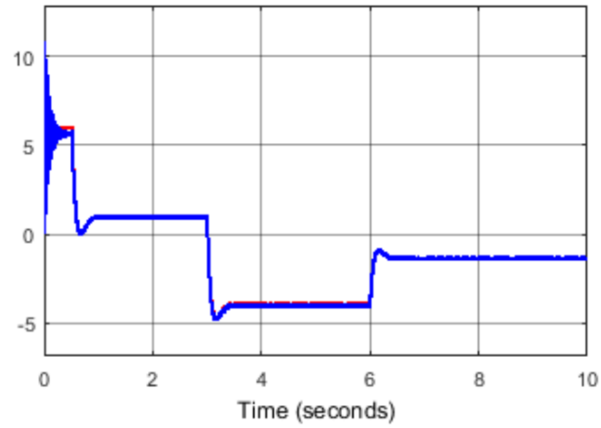



Figure 19 Measured and Reference Torque

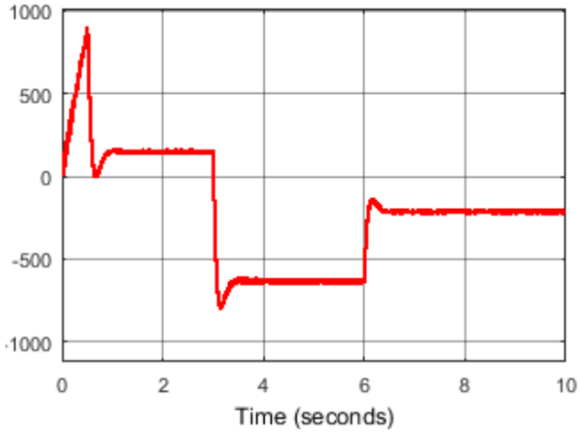
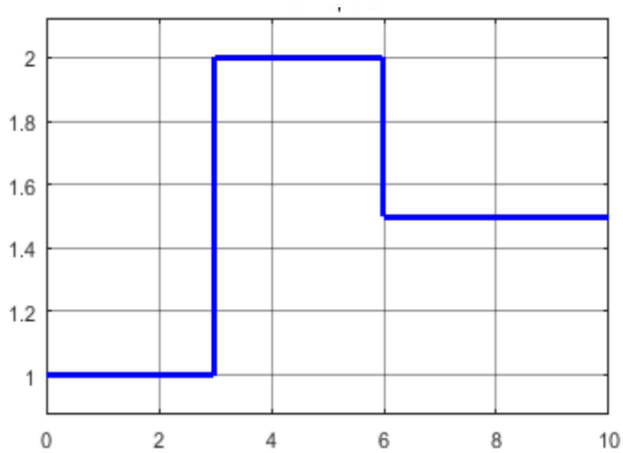
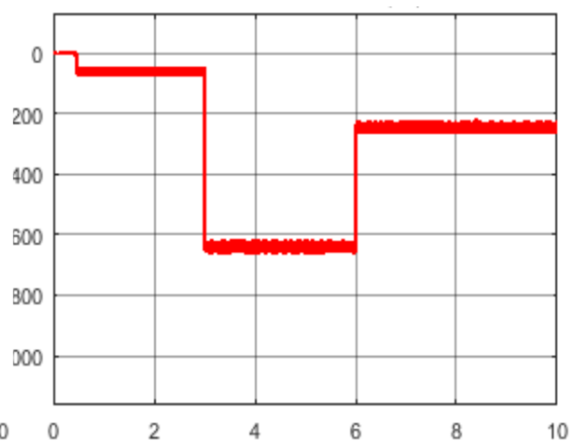



Figure 20 Generated Power

ii. Variable Speed Control

In figure 21 and 23, we can observe the response of the rotor speed to the tidal speed changer, as well as the other variables such as rotor current and mechanical torque, again the robustness of the PI regulator is demonstrated.



DOI: https://doi.org/10.64388/IREV10I3-1722805

Figure 21 Tidal Speed

Figure 22 Mechanical Power

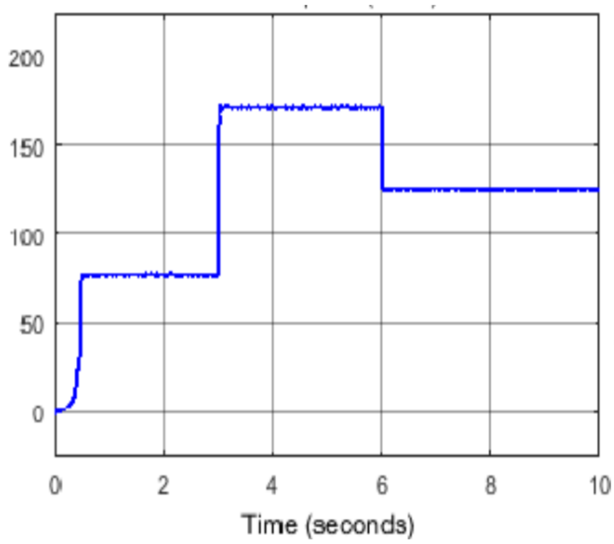



Figure 23 Rotor Speed

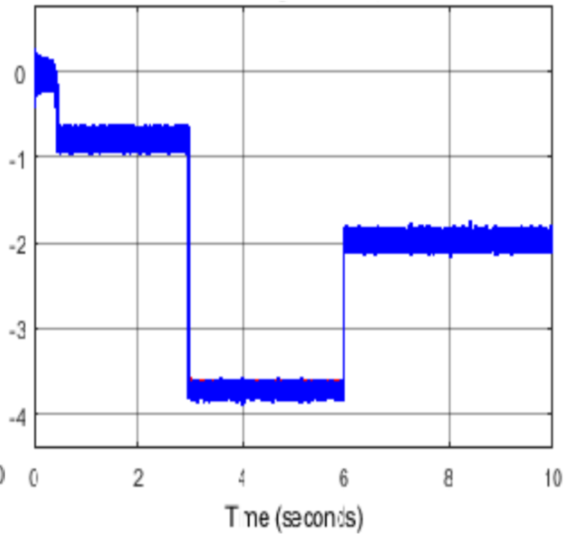


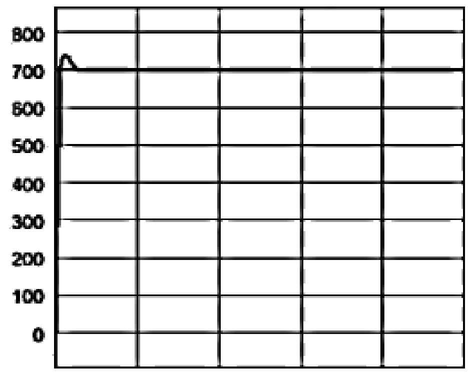

Figure 24 Electromagnetic Torque

3.5 Simulation Result of Grid Side Converter (GSC)

The hybrid system consists of induction generators having 2MW, 11KV and 540KW, 11KV for tidal and wind turbines respectively. Their outputs are separately connected to three phase bridge rectifiers (MSC) and connected to three phase bidirectional inverter (GSC) through a DC link.

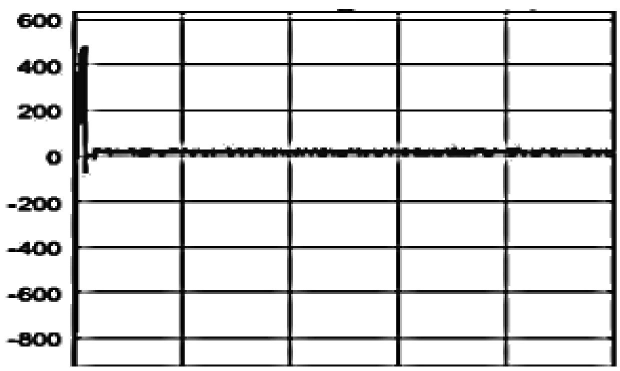
The GSC is a two level, three phase PWM rectifier that interfaces with the AC grid in the renewable energy system. It converts power from the DC link to AC for the grid, controls both active and reactive power flow, and ensures that grid voltage and current are sinusoidal and in phase.

Figure 25 DC bus voltage, it is maintained constant due to the PI controller; Figure 26 and Figure 27 reactive grid side converter currents, Figure 28 and the three-phase grid side converter output voltage and current Figure 29 measured current transmitted to the grid, Figure 30 reactive power exchange with the grid as demanded by the grid side.




Time (Seconds)

Figure 25 Controlled DC Bus Voltage




Time (Seconds)

Figure 26 Controlled Direct Voltage/Current

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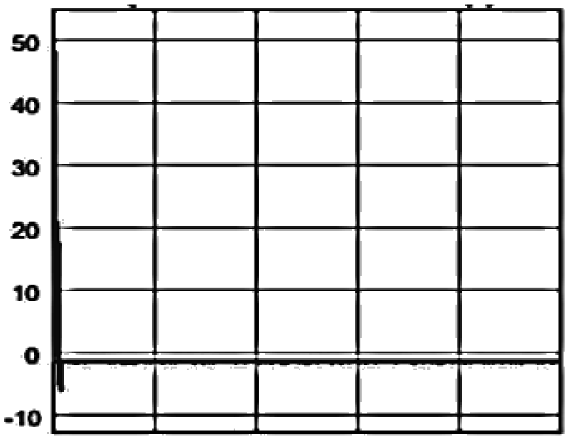



Time (Second)
Figure 27 Controlled Quadrature Grid Current

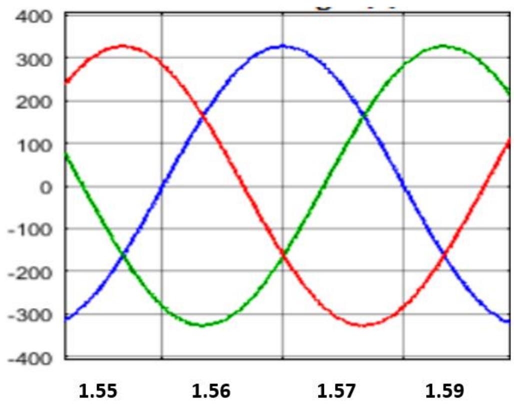
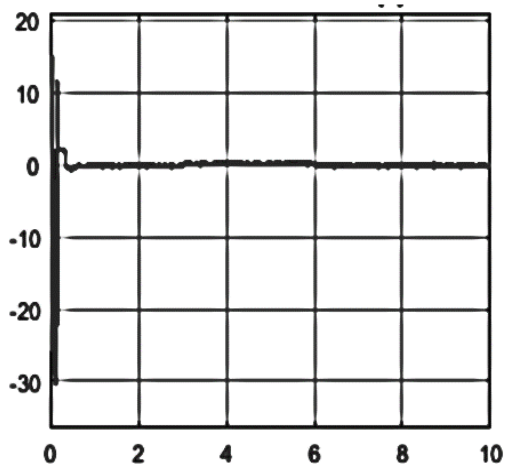
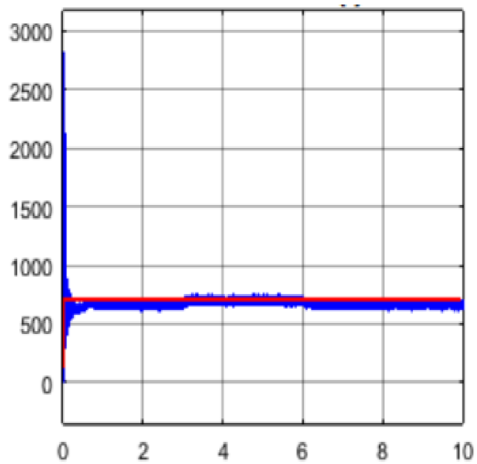


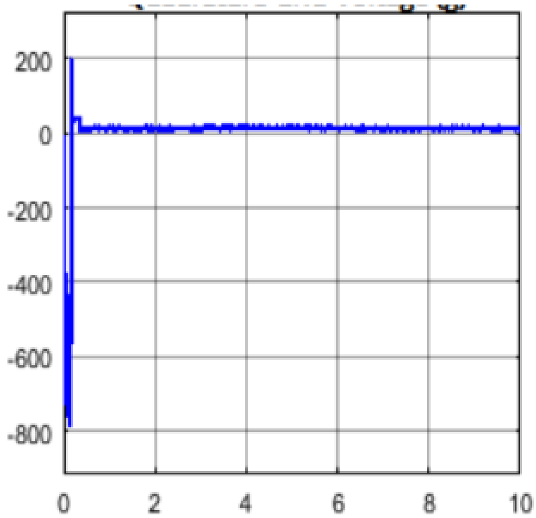

Figure 28 Controlled Voltage (d)



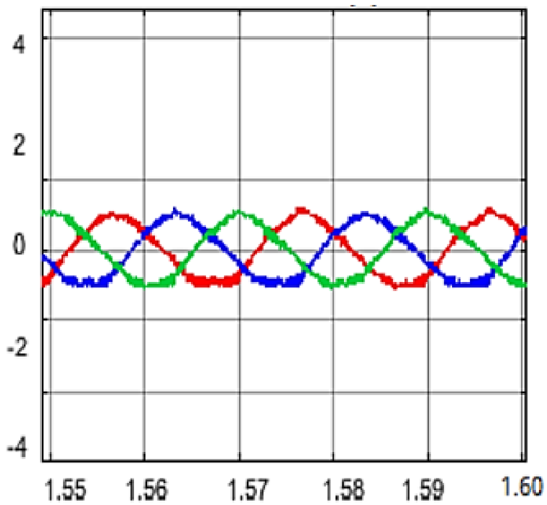

Time (Seconds)
Figure 29 Direct-Grid Current




Time (Seconds)
Figure 30 Control Reactive Power




Time (Seconds)
Figure 31 Quadrature Grid Voltage




Time (Seconds)
Figure 32 Controlled Grid Current

3.6 Complementarity

From the monthly/annual average wind velocity of Dawes Island, wind power is more abundant in the months of April to August, and lowest in the months of October to January. While tidal current energy is more with highest monthly mean tidal height in October, with lowest mean tidal height in July. Wind turbine generates more energy during peak wind hours which translates to increase in electricity production from May to September due to high wind velocity, but decreases in the later months as a result of drop in wind speeds. Unlike tidal turbines which operates optimally around a lunar day/year, wind turbines performance fluctuates throughout the day without a predictable pattern, hence wind generation contributes about 18% of the total annual energy production. This complementarity ensures that the two energy sources can balance each other. This combination guarantees the stability and the reliability of the system.

## IV. DISCUSSION

The tidal velocity profile for Dawes Island showed significant motion, and hence a capacity factor favorable for use as a tidal resource. For 2015 and 2016, both years have peak flood and peak ebb velocities of 10m/s and 20m/s respectively. The year 2017 also had a peak flood velocity of 10m/s, however it has indication that tidal energy resources are not completely predictable. The year 2017 and 2018 both have peak flood and peak ebb velocities of 10m/s and 20m/s respectively. A comparison of the tidal highs and lows of each site over the five-year period (2015-2020) clearly indicates ebb speed dominance over flood speeds which affirms more generation during ebb tides.

The highest monthly mean tidal height (2.48m) for Dawes Island is in October, and the lowest value of 2.00m is in July. It is obvious that for any particular year, the probability that the mean annual tidal height will exceed 1.90m is above 90%.

Also, water speed exceeds the cut-in speed (0.7m/s) of the Atlantis AR2000, 2MW tidal turbine for all through the year makes it an appropriate choice for tidal energy generation at Dawes Island.

Using the Atlantis AR2000 tidal turbine with a turbine rotor diameter of 18m, a swept area of $254.47m^2$ and a velocity estimate of 2m/s, the annual energy output would be 391.0MWh.

Table 5 Annual Production of each component

| Component | Production KWhr/yr | Percentage |
|---|---|---|
| WES 30<br>540 KW | 1.18 GWhr/year | 18.73% |
| AR 2000 | 5.26 GWhr/year | 81.6% |

A540 KW Wind turbine with capacity factor of 30% typical for areas close to the coast. It could generate 3.240 MWhr/day (Rated power x Capacity factor x 8760hrs) and 1.18GWhr/year. AR2000 tidal turbine (2MW), with a capacity factor of 30%, could generate 14.4MWh/day and 5.26GWhr/year. The average daily load consumption of Dawes Island is estimated at 2.9 MWhr/day. With an annual consumption of 25,404MWhr/year from table 4 the tidal turbine is well suited to provide the base load demand of Dawes Island although the year, while the wind turbine effectively provides for peak loads. It should be noted that the choice of 540KW wind turbine and 2MW AR2000 tidal turbine is an optimistic selection for Dawes Island. This futuristic choice is for scalability of the system, to adequately accommodate an imminent surge in the population of Dawes Island as a result of the provision of a reliable electricity supply with the activities of OML 54.

## V. CONCLUSION & RECOMMENDATION

A good number of Nigeria's coastline communities are concentrated in the Niger Delta which depend on fire wood and small petrol generators to satisfy their energy demand. Consequently, government policy against deforestation and hike in fuel prices would have negative impact on the socio-economic life of these communities.

This study strongly suggests the utilization of energy resources that are readily available within the environment of these communities to provide an efficient, reliable, cost effective and environmentally friendly energy system. The integration of an onshore wind and tidal energy system would be the best option to meet the energy demand of these communities. In addition, it has the potential to ameliorate climate change and substantially reducing $CO_2$ emission.

Even if the plan by the Federal Government of Nigeria to increase generation capacity by 35,000MW (Dumuodeke, et al 2020) by the year 2025-2030 is realized, the possibility that these communities would benefit from the National grid will remain a wishful thinking due to the rugged terrain. It is envisaged that the implementation of the suggested energy system for Dawes Island would no doubt support the Niger Delta Communities whose livelihoods have been negatively affected by the combined effect of oil and gas exploration to attain their needed economic and environmental potentials which is driven by availability of electricity.

Recommendation

An intelligent battery management system that can optimize charge and discharge cycles would also be beneficial to the system since it would lengthen battery life and improve performance during prolonged period of low wind speed.

Technologies for predictive maintenance and real-time monitoring which may anticipate possible system breakdown and enable preventive measures are equally crucial. When combined, these steps would strengthen the system's robustness and dependability, protecting the energy supply from unpredictable occurrences.

Conclusion:

The adopted onshore wind and tidal generation system in conjunction with a bidirectional grid inverter showed good performance and ensure stability of the system. Modeling and Simulation of the wind and tidal turbines each separated coupled to a doubly-fed induction generator and power converter are carried out in MATLAB/Simulink environment. Simulation result showed that the system is well designed and the PI controller functioned well in most situation.

It promotes green energy production with very little ecological impacts to the ocean life. A 2.00MW tidal turbine is implemented to capture tidal energy and one 540KW onshore wind turbine are installed at the same coast. previous literature were only concerned with the apparent benefit of using a single structure for tidal turbine and the offshore wind turbine, while ignoring the huge cost of maintenance and the imminent complexity of the design.

The integration of HRES in Dawes Island is more than an academic exercise, it is a strong demand for a paradigm change in the way similar isolated communities in the Niger Delta would see the future of their energy usage.

The study underscores the need for sustainable energy solutions to balance environmental conservation and socio-economic growth of the numerous Island communities. It is an indication that the use of renewable energy as a foundation for sustainable development is essential to building a resilient, self-sufficient, and peaceful societies in the now volatile Niger Delta Region of Nigeria.

Contribution to Knowledge

- Location-Specific Contribution for a Nigerian Costal Environment (Dawes Island): The research provides site-specific evidence on the technical potential of combining wind and tidal resources for electricity generation in the selected coastal area. (Dawes Island).
- Resource Complementarity Assessment: The research established the temporal complementarity between wind and tidal resources and determines ow the predictable nature of tidal energy can compensate for variation in wind generation.
- Integration of a Tidal Barrage Power Generation with an on-shore wind turbine: The integration of a tidal barrage generation with an onshore wind turbine with separate structures located on the same coast eliminates the complexity of design which accompanies the single structure tidal offshore wind system.

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