Original Research Article

Wind Energy Production from Vertical Axis Wind Turbine on Offshore Production Platforms in Trinidad

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ABSTRACT

Aims: To estimate the available power that can be generated from wind on Oil and Gas production Platforms offshore Trinidad.
Place and Duration of Study: Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, University of the West Indies, St Augustine Campus. Data collected at a bpTT production platform offshore east coast Trinidad between January 2019 to November 2019.
Methodology: The East coast of Trinidad was chosen due to the presence of high yearly wind speeds. The wind data was collected 80 kilometers off Trinidad Southeast coast, east of the bpTT Cashima production platform for the year 2019. Wind speeds varied from 5.3 meters per second in October to 8.8 meters per second in June. The overall wind speed average for the year 2019 was 7.4 meters per second. The vertical axis wind turbine considered here was modeled using Parashivoiu's double multiple streamtube model concept. The VAWT modelled had 3 NACA0018 blade profile, a blade length of 2.5 meters and a diameter of 2 meters.
Results: The modeled vertical axis wind turbine monthly total power output varied from 5.43 KW to 20.34 KW. The daily average expected power output from the VAWT ranged from 175 Watts to 678 Watts. It can be observed that the months January to July gave higher daily and monthly average power generation due to these months having the highest wind speeds due to local weather conditions.
Conclusion: The VAWT modelled in this study can generate on average, 463 Watts of power per day with a peak average of 678 Watts of power per day in June from a single turbine. The total average power produced for the year 2019 was 151.11 KW. The turbine was sized as not to have a large footprint on the offshore platform. It is demonstrated here that substantial support and rationale is needed for the potential advancement of VAWT's for conditions that prevail offshore Trinidad, owing to their lower extraction costs and more robust geometry due to the use of existing offshore platforms.

Keywords: Coefficient of performance, Darrieus turbine, Double streamtube model, production platforms, Vertical Axis Wind Turbine (VAWT).

1. INTRODUCTION

The key driving force behind the development of wind energy is the rising cost of electricity. As a result of the lower cost advantage of Vertical Axis Wind Turbines (VAWTs) over Horizontal Axis Wind Turbines (HAWTs) has made the VAWT more attractive, although the HAWT has become more customary when compared with the VAWT [1].

VAWT blades usually employ symmetrical airfoils with a lower lift-to-drag ratio than cambered airfoils designed to maximize HAWT rotor power, which is one of the key drawbacks of the VAWT when compared to the HAWT. Another significant drawback is the mechanical simplicity of the active blade pitch control system for maximizing performance under various operating conditions. The drag losses caused by the Rotor's wake, are greater for the VAWTs than those losses experienced by the HAWTs. When compared to HAWTs, VAWTs are typically mounted lower to the ground, the power output of the turbine that can be absorbed is lowered due to wind shear. Because of its mode of operation, the VAWT is subjected to higher cyclic loads. VAWT rotors produce higher fatigue loads due to their highly cyclic strength and thrust on their structure from a structural standpoint. A VAWT operates at lower revolutions per minute mechanically, which saves energy.

At low altitudes, the winds are stronger and steadier off the coast over the ocean, VAWTs' lower operating height is less of a drawback (wind shear is reduced due to a lower surface roughness). The average height of the offshore production platforms in Trinidad are 36 meters to 49 meters. The amount and location of the offshore production platforms off Trinidad is a very cost-effective way of using them as support structures for VAWT to produce power offshore.

The proximity of the gearbox, generator, and other heavy equipment to the turbine's base is a major advantage for offshore operations. Because of its easy accessibility, installation and maintenance of essential parts is made even easier, reducing the need for high-lift operations offshore. The wind industry has a low failure rate, but when there is one, it can be devastating. [2]. Due to the inherent design of the VAWT blades, no blade pitch control or yaw mechanism is required to have the blade adjusting whilst in motion as in the HAWT, leading to a reduction of cost.

With the blade radius, gravitational loads on the HAWT edgewise blades appear to increase much more than aerodynamic loads. Due to the weight of the turbine causing fatigue loading of their blades, this can be an important limiting factor to turbine blade size [3]. Gravity does not affect the blades of VAWTs as it does the HAWT. HAWT blades' cyclic gravitational loading produces a greater fatigue load on the turbine blades and supporting structure as the size of the rotor increases, compared to the cyclic aerodynamic forces on the VAWT blades.

2. METHODOLOGY

2.1 VAWT Developments

There has been several Darrieus VAWT with curve blades that have emerged as a result of extensive research and development in the last three decades, more so in Canada and the United States.

The Éole Darrieus VAWT has a turbine height of 96 meters, actually was the biggest VAWT that was onshore, installed in 1986 at Quebec, Canada. This turbine produced 12 GWhr of electrical power since its 5 years of operation and has a rated power of 3.8 Megawatts before it untimely closure in 1993 due to a failed bearing. FlowWind limited of the United States tried to commercialize the VAWT in the 1980's. Some of the onshore VAWT that where constructed experienced some problems with fatigue failure, but the onshore wind farms worked efficiently [3].

During the 1980s and 1990s, Peter Musgrove pioneered the straight-bladed Darrieus turbine, also known as the H-rotor. The H-rotor was preferred to the curve blades (f-rotor) because of the lower costs associated with making the blade and the very simple supporting structure which has shorter tower, hence no need for guy wires [4]. In the UK, several onshore prototypes were designed, the largest of which was a 500kW computer built in 1990 [5]. However, after a few months of service, this prototype's blade failed due to a manufacturing flaw, delaying any further VAWT deployment efforts [6].

2.2 Offshore VAWT on Oil and Gas Production Platforms

Offshore wind energy and oil and gas offshore production platforms can be coupled to produce renewable energy in a symbiotic relationship. Indeed, as Musial and Butterfield [7] point out, that a large portion of the offshore wind turbine system will be defined by the oil

and gas industry's experiences and standards established over the last four decades. Existing offshore vessels and facilities can be used to mount and operate wind turbines.
This paper proposes the use of offshore production platforms in Trinidad as the offshore support structure for the installation of the VAWT, integrating wind energy conversion systems into existing offshore platforms. As a result, it would be possible to harness energy from the wind at locations with high average wind speeds, with that energy produced being used by the offshore facility as part of its energy needs. BpTT has the most offshore production platforms in Trinidad, 15 units as of 2021.

Installing a series of small Darrieus Vertical-Axis Wind Turbines (VAWTs) on offshore oil and gas extraction platforms could provide a substantial portion of the energy required by the platform's oil and gas processing facilities. In reality, the array will take advantage of the wind resource in places like the East Coast, Trinidad (and the Caribbean), where steady winds have a high average intensity (6-9 m/s), there is no need to spend money on building offshore foundations specifically for wind turbines.

The wind conditions experienced on a building's roof will be very similar or somewhat close to those found on a production platform offshore, the only exception being to the lack of obstacles on the sea surface, the average wind speed is higher.

Given the wind flow parameters will be similar, it's fair to assume that if a VAWT which is designed for use on top of a city building would perform significantly better if installed on a platform offshore. Furthermore, the smaller rotor sizes enable them to be installed in tight spaces, potentially taking up most of the platform's unused areas.

2.3 Wind Resource

The East coast of Trinidad was chosen due to the presence of high yearly wind speeds coupled with the fact that most of Trinidad’s offshore production platforms are located in this area (see figure 1).

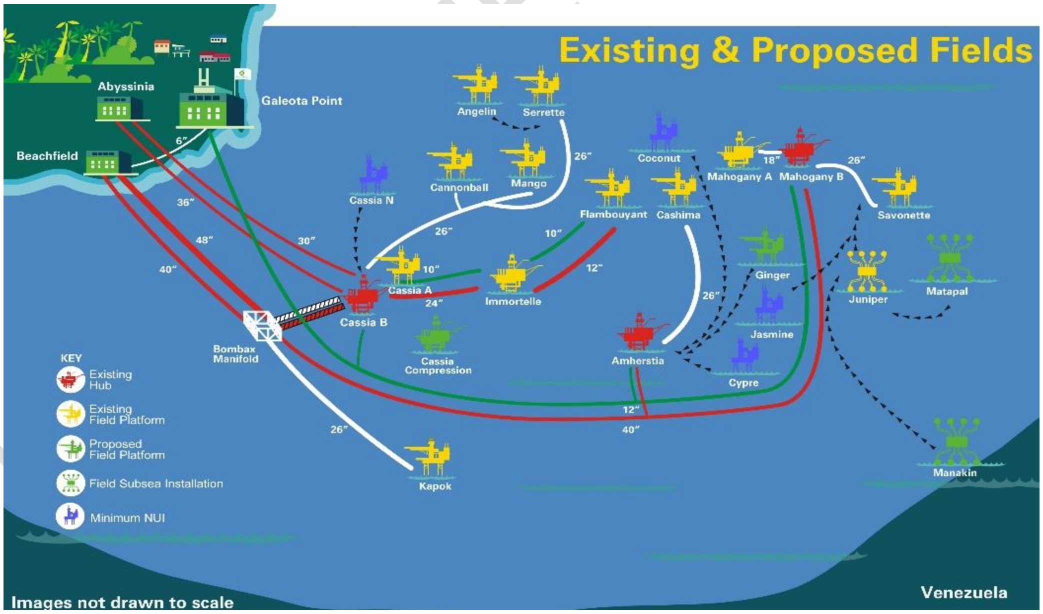

Fig. 1. Map of Trinidad Showing Offshore Production Platforms

The wind data was collected 80 kilometers off Trinidad Southeast coast, east of the bpTT Cashima production platform. Figure 2 indicates the average monthly wind speeds for the year 2019. Looking at Figure 2, it is noticed that the monthly average wind speeds vary from 5.3 meters per second in October to 8.8 meters per second in June. The overall wind speed average for the year 2019 was 7.4 meters per second.

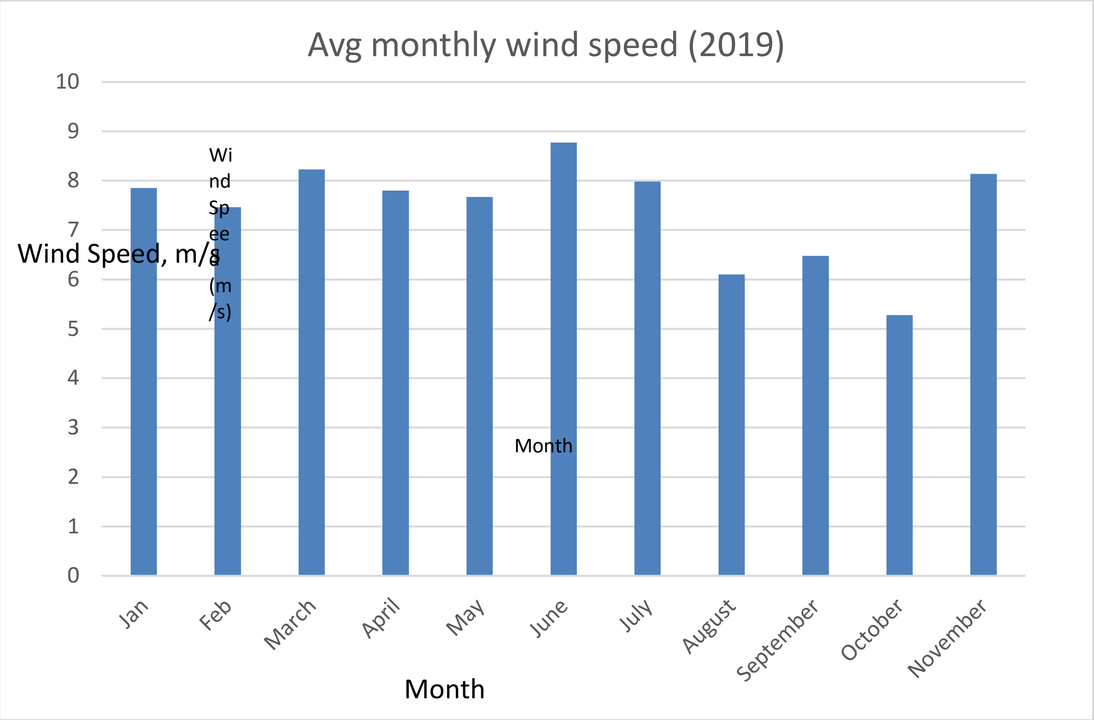

Fig. 2. Monthly Average Offshore Wind Speed in meters/sec

2.4 Offshore VAWT Modelling

The VAWT's structural simplicity is hampered by its extremely unsteady and fundamentally non-linear flow field aerodynamics, according to the wind energy research group [8]. As the turbine rotates, the blades' respective angle of attack (α) changes continuously, creating powerful unsteady effects in the flow sector as shown in figure 3.

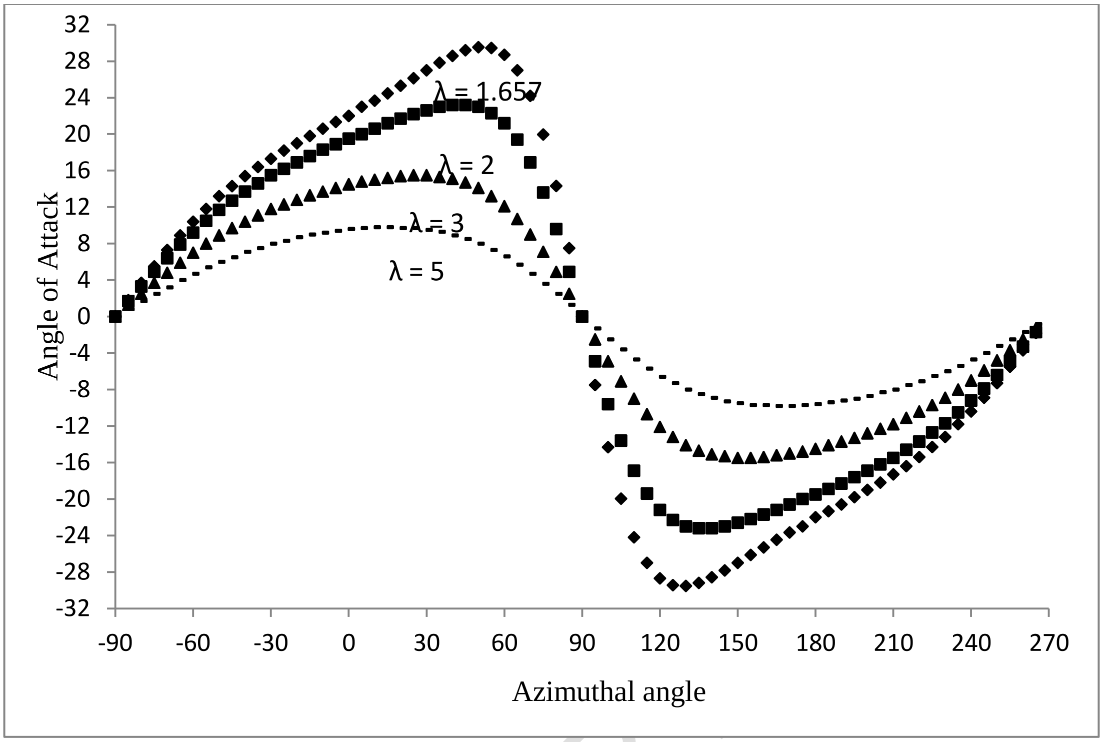

Fig. 3. Changing Angle of Attack with Rotation at different Tip Speed Ratios

The most important of these unsteady effects is the flow's continuous dynamic separation, which can significantly reduce the VAWT's efficiency. One of the major challenges in modeling the VAWT is the contact of the blade and the turbine's wake interaction [8].

The most commonly used mathematical models for analyzing VAWT efficiency are momentum models, which uses the streamtubes to measure the shift in momentum through the VAWT [9]. The single streamtube model was introduced by Templin [10], and then Glauert [11] tweaked it to form his theory for aircraft propellers.

Wilson and Lissaman [12] and Strickland [13] improved on the model by Glauert, by creating the multiple streamtube model, which used the single momentum model to form multiple parallel adjacent streamtubes for a more precise solution,

Parashivoiu [14], who expanded on the momentum model and developed his own double multiple streamtube model, solved the problem of inaccurate calculations for reducing free stream velocity.

All current design codes treat rotor aerodynamics using Glauert's well-known and well-established blade factor momentum (BEM) theory [15]. This theory is an extension of the Rankine–Froude actuator-disk model, with the goal of improving the model's accuracy performance predictions.

This vertical axis wind turbine was modeled using Parashivoiu's double multiple streamtube model concept. The multiple streamtube model and double actuator disc theory combined approach is a far more effective solution for modeling. Even though the two halves of the turbine are supposed to be aerodynamically independent of each other, it allows for velocity differences perpendicular to the flow direction and the ability to model parts of how the up-stream half affects the downstream half of the turbine (See Figure 4).

Since the blade's flight path is now split in half, the blade only encounters a single stream-tube once per revolution, implying that fraction $d\theta/2\pi$ is now the proportion of the stream-total tube's circumference occupied as shown in equation 1. Since the equations will be doubled and more precise, the relationship between the time averaged force and the instantaneous force will be halved.

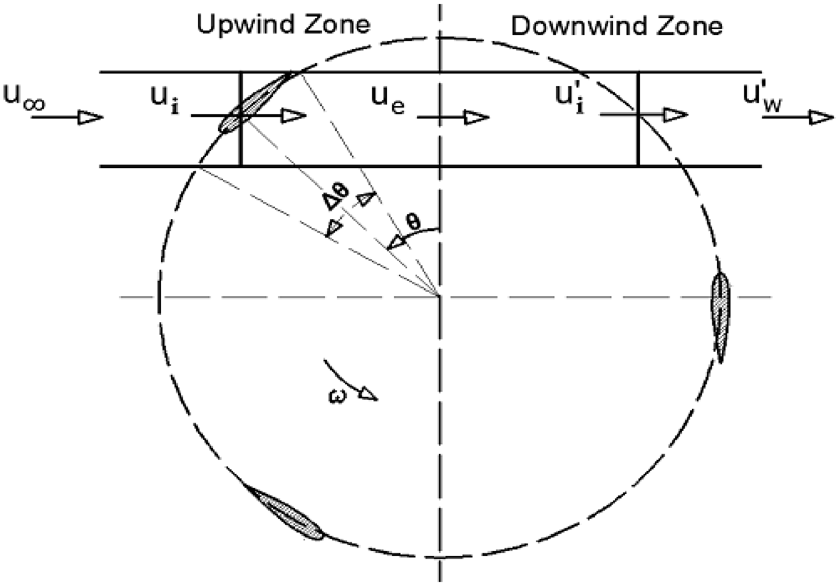

Fig. 4. Double Multiple Streamtube Model.

Since the blade's flight path is now split in half (equations 1 and 2), the blade only encounters a single stream-tube once per revolution, implying that fraction dθ/2π is now the proportion of the stream-total tube's circumference occupied.

$$Nd\emptyset/2\pi = T_{avg}/T_i \, \mathrm{N}d\emptyset/2\pi = \mathrm{T_{avg}}/\mathrm{T_i} \, \mathrm{N}d\emptyset/2\pi = \mathrm{T_{avg}}/\mathrm{T_i} \, \mathrm{N}d\emptyset/2\pi = \mathrm{T_{avg}}/\mathrm{T_i}$$

(1)

For the upstream half:

$$w = \sqrt{(u_\infty(1-a)\sin\emptyset)^2 + (u_\infty(1-a)\cos\emptyset + \omega r)^2}$$

(2)

For the downstream half

$$w = \sqrt{(u_e(1-a')\sin\emptyset)^2 + (u_e(1-a')\cos\emptyset + \omega r)^2}$$

(3)

The difference between the tangential components of the lift and drag forces is the tangential force coefficient (Ct). The difference between the normal components of the lift and drag forces is the natural force coefficient (Cn), (equations 4 and 5).

$$C_t = C_L \sin\alpha - C_D \cos\alpha$$

(4)

$$C_n = C_L \cos\alpha + C_D \sin\alpha$$

(5)

The net normal and tangential forces are calculated as follows:

$$F_t = 0.5C_t\rho CHW^2$$ (6)

$$F_n = 0.5C_n\rho CHW^2$$ (7)

Where ρ – air density, H – blade height and C – blade chord.

Since they refer to any azimuthal position, the tangential and normal forces are a function of azimuthal angle. The average tangential force (F_{ta}) on a single blade can be calculated from equation 8.

$$F_{ta} = \frac{1}{2}\pi \int_0^{2\pi} F_t(\theta)\, d\theta$$ (8)

For the number of blades (N), the total torque (Q) is calculated as

$$Q = NF_{ta}R$$ (9)

The total power (P) can be obtained from equation 10

$$P = Q\ x\ \omega$$ (10)

.
Where Q – torque, ω – rotational velocity, θ – azimuthal angle.

3. RESULTS AND DISCUSSION

The total rotor internal volume was chosen as a suitable objective feature to reduce its footprint on the production platform and low assembly costs, as the primary goal of the VAWT is to generate energy, primarily by lower cost manufacturing. When both blades of a 2-blade turbine are in a position where the wind does not facilitate rotation, this is known as the stall position. The stall condition is removed for a 3-blade turbine, such as the one chosen. Table 1 gives the VAWT design parameters that was used for the modelling of this turbine.

Table 1. Offshore VAWT specifications

Parameter	**Value**
Number of Blades	3
Blade Section	NACA0018
Blade Chord Length	0.15 m

Blade Length	2.5 m
Turbine Diameter	2 m
Inflow Velocity	7.37 m/s
TSR	2.556

The tip speed ratio versus the coefficient of performance is displayed in figure 5. The highest coefficient of performance modelled was 0.571. Using this value, the power output for the VAWT is shown in figure 5.

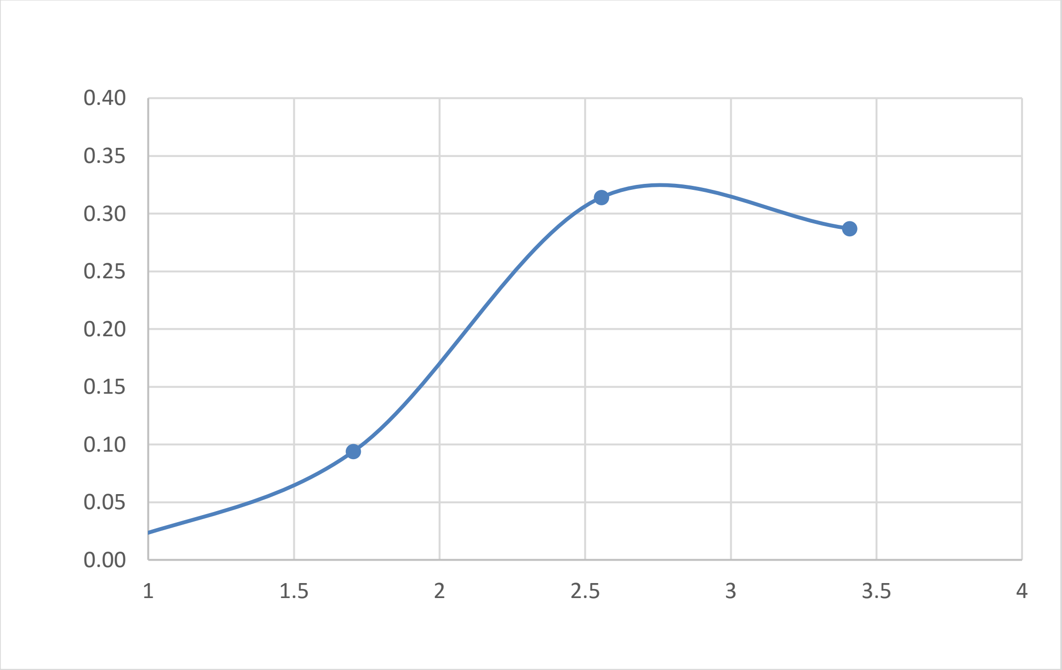

Fig. 5. Tip Speed Ratio Vs Coefficient of Performance

Efficiency of the straight bladed VAWT depends upon the reduction of fluid resistance and drag force values due to blade support arms, blades, gearbox types, generator and frequency convertor. For the most part, the efficiency provided by the aforementioned elements is consistent across all types of turbines. Hence, the theoretical efficiency of self-rotating vertical axis current turbine will be expected and increased due to blade's movement and arms and gearbox type as about 89% multiplied by the sum of all efficiency values [16].

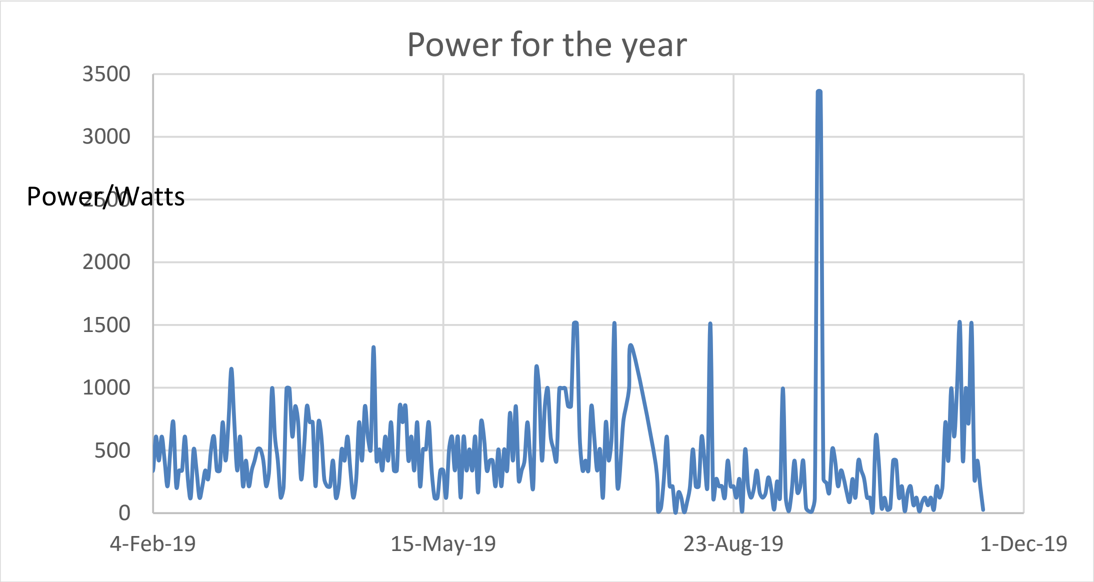

Fig. 6. VAWT power output.

The modeled vertical axis wind turbine total and average expected power output for the months for the year 2019 and is shown in table 2.

Table 2. Monthly total and average power values

Month	**Daily Average Power/Watts**	**Monthly Total/KW**
January	477	10.98
February	403	11.29
March	555	17.21
April	477	14.30
May	449	13.91
June	678	20.34
July	561	12.90
August	269	13.21
September	440	13.21
October	175	5.43
November	611	18.33

The modeled vertical axis wind turbine monthly total power output varied from 5.43 kW to 20.34 kW. The daily average expected power output from the VAWT ranged from 175 Watts to 678 Watts. It can be observed that the months January to July gave higher daily and monthly average power generation due to these months having the highest wind speeds due to local weather conditions.

The modeled vertical axis wind turbine total and average expected power output for the months for the year 2019 and is shown in table 3 for onshore data collected at the Metrological Office, Piarco, Trinidad.

Table 3. Monthly total and average power values for Onshore VAWT

Month	Daily Average Power/Watts	Monthly Total/Watts
January	27	827.08
February	44	1243.20
March	42	1291.46
April	52	1556.40
May	53	1638.35
June	27	818.40
July	21	650.69
August	20	625.27
September	12	353.10
October	17	539.09
November	18	528.90

There is considerable difference between the power produced offshore as compared to the power produced onshore. The table below indicates the percentage increase of power produced for the offshore VAWT as compared to the onshore VAWT, this can be attributed to the greater wind speeds that is experienced offshore.

Table 4. Monthly total and average power values for Onshore VAWT

Month	Percentage Extra Power Produced
January	1328
February	908
March	1333
April	919
May	849
June	2485
July	1983
August	2113
September	3741
October	1007
November	3466

3.1 Economic Considerations

Offshore wind energy costs vary greatly depending on the particular construction location, although it has been established that offshore wind turbines are considerably more expensive than those turbines operating on land (17,18). Higher costs for foundations, construction, service, and maintenance account for the bulk of the cost of offshore systems. The following are the key factors that influence wind energy economics [19]:

- The cost of the investment at the start of the project.
- Size of the turbine (Amount of Electricity produced).
- Costs of operation and maintenance (O&M).
- Lifespan of turbine power generation.

Of the major costs associated with the VAWT, the most important consideration is the amount of electricity produced and the initial investment cost. Since the amount of electricity generated is proportional to the cube of wind speed, selecting the best location is important for achieving economic viability. As a result, offshore wind energy development in recent years, it has become increasingly relevant. The main benefit of offshore wind energy is that, unlike on land, wind does not encounter ground irregularities that can stifle flow and cause turbulence.

The electrical and grid infrastructures, as well as the base and support systems, as well as its service and upkeep, account for the majority of the project’s overall cost. Furthermore, the cost of this service rises with the depth of the sea and, as a result, with the distance from the shore. The use of existing offshore oil and gas platforms will significantly reduce the costs associated with support structures, according to this report.

As a case study, the Ropatec 20 kW rotor [20] was used. The turbine, which has a diameter of 8 meters and a height of around 4 meters, can produce 20 kilowatts of power and was installed at a cost of € 50,000.00. The nominal power, like the investment cost, is low when compared to common offshore rotors.

Due to the small power produced, several VAWT can only provide a small portion of the power provided by the platform, utilization of the unused spaces on the offshore platform with VAWT’s, even if insignificantly, can contribute to the installation's energy output by using unused platform space. It's also worth noting that a wind turbine installed on an offshore platform will minimize the platform's carbon dioxide emissions, lowering not only its environmental impact but also the costs associated with gas emissions into the atmosphere.

The most significant drawback of installing offshore wind turbines on petrochemical platforms is the lack of space.

4. CONCLUSION

It has been demonstrated that small Straight Bladed vertical axis wind turbine mounted on offshore petrochemical platforms can generate wind energy.

The VAWT modelled in this study can generate on average, 463 Watts of power per day with a peak average of 678 Watts of power per day in June from a single turbine. The total average power produced for the year 2019 was 151.11 kW. The turbine was sized as not to have a large footprint on the offshore platform, having a diameter of 2 meters and blade length of 2.5 meters.

From the research done here, it demonstrates substantial support and rationale for the potential advancement of VAWT’s for conditions that prevail offshore Trinidad, owing to their lower extraction costs and more robust geometry due to the use of existing offshore platforms.

Further analysis needs to be done to prove the project's viability, beginning with an evaluation of the turbines' successful ability to be installed and operated on the particular offshore platform. A thorough examination of the construction and maintenance costs associated with particular extraction plant locations should also be carried out.

COMPETING INTERESTS DISCLAIMER:

AUTHORS HAVE DECLARED THAT NO COMPETING INTERESTS EXIST. THE PRODUCTS USED FOR THIS RESEARCH ARE COMMONLY AND PREDOMINANTLY USE PRODUCTS IN OUR AREA OF RESEARCH AND COUNTRY. THERE IS ABSOLUTELY NO CONFLICT OF INTEREST BETWEEN THE AUTHORS AND PRODUCERS OF THE PRODUCTS BECAUSE WE DO NOT INTEND TO USE THESE PRODUCTS AS AN AVENUE FOR ANY LITIGATION BUT FOR THE ADVANCEMENT OF KNOWLEDGE. ALSO, THE RESEARCH WAS NOT FUNDED BY THE PRODUCING COMPANY RATHER IT WAS FUNDED BY PERSONAL EFFORTS OF THE AUTHORS.

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