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Vertical Axis Marine Current Turbine Modelling

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Abstract: The development of alternative energy sources has attracted worldwide interest given the adverse effects of fossil fuels on the global climate as well as their unsustainability. This study examines the feasibility of marine power generation off the East Coast of Trinidad and Tobago and focuses mainly on the Vertical Axis Marine Turbine as the power generator. At this location where the data was collected, measurement depth varied between 3 to 10 m and an average marine current speed of 0.86 m/s suggests the possibility of generating power through submerged turbines. The modeled VACT produces an average of 2870 Watts of power from a single unit. After considering the technical and environmental factors, this study concludes it is feasible to utilize marine current resources off the East Coast of Trinidad for Power Generation.

Keywords: Darrieus, Double Stream-Tube Model, Marine Current Energy Devices (MCED), Marine Current Turbines (MCT), Ocean Energy, Ocean Renewable Energy, Vertical Axis Current Turbine (VACT)

Introduction

To reduce its reliance on fossil fuels, Trinidad and Tobago is promoting the use of renewable energy. Hydropower, wind energy, solar photovoltaic, biogas, biomass, geothermal, and solid waste are just a few examples of renewable energy resources that can be used to generate electricity. Due to the predictable nature of tidal currents compared to other renewable energy technologies, energy extraction from the ocean using Marine Current Energy Devices (MCEDs) can be a sustainable alternative to conventional sources. The exploitation of this renewable resource can help offset the expenses of electricity generation, especially in offshore facilities. This is not a new technology to Trinidad and Tobago; a previous investigation of tidal currents was undertaken on the West Coast of Trinidad, at the Serpent's Mouth, Columbus Channel (Hall and Shrivastava, 2017). The Guiana Current pours into the Gulf of Paria at the Serpent's Mouth, creating a Venturi effect. The researchers collected data for their investigation off the coast of Trinidad at latitude NS Indicator 10.068889 and longitude EW Indicator 60.346111. According to their research, the Marine Current Turbine (MCT) array could provide an average of 6 megawatts of power, with a maximum of 10 megawatts (at a current flow velocity of 1.5 m/s). The array of marine current turbines was modeled in the Serpent's Mouth at a depth of about 5 m below the surface of the ocean. Although there were physical difficulties due to the size of the Serpent's Mouth at this location, it is technically possible to place MCTs within the Serpent's Mouth.

The purpose of this article is to examine the possibilities of ocean renewable energy off Trinidad's east coast, namely a Vertical Axis Current Turbine (VACT), as a source of renewable energy for Trinidad. Its goal is to raise awareness of ocean renewable energy among the general public, industrial stakeholders, and municipal governments. It has the potential to be a significant source of renewable energy as well as an industrial opportunity for a more sustainable future.

The Status of Renewable Energy in Trinidad

Review Stage

Trinidad and Tobago is an oil and gas-producing country with a humid tropical climate with a land size of 5,131 square kilometers. Trinidad and Tobago's energy sector is the key cause for the country having one of the highest per capita incomes in Latin America, thanks to significant volumes of hydrocarbon resources. Between 2000 and 2007, annual economic growth averaged slightly more than 8%, which was slightly greater than the regional average of around 3.7%. The country's GDP declined somewhat from 2009 to 2012 due to lower oil prices, then increased slightly in 2013, before contracting again from 2014 to 2017. Trinidad and Tobago has significant foreign reserves and a sovereign wealth fund that is equivalent to one-and-a-half of the national budget. Even though the country is still in recession due to gas shortages and low prices, according to Moody's Analytics (Moody's Analytics, 2020), huge energy projects are alleviating the gas shortages.

Energy Supply

Trinidad and Tobago's hydrocarbon business transitioned from an oil-dominated to a primarily natural gas-based sector in the early 1990s, making it one of the top oil and natural gas producers in the Caribbean. According to the BP Statistical Review of World Energy 2015, Trinidad and Tobago was the world's sixth-largest LNG exporter in 2014. In 2014, the country was the leading LNG exporter to the United States, accounting for over 71% of US LNG imports. According to BP's Statistical Review, Trinidad and Tobago's total primary energy consumption in 2014 was 850 trillion British Thermal Units. Natural gas usage accounted for around 93 percent of total consumption, with petroleum products accounting for only 7%. According to the Oil and Gas Journal, Trinidad and Tobago has 728 million barrels of proved crude oil reserves at the start of 2016. (OGJ). In 2014, hydrocarbon output was 114,000 barrels per day of petroleum and other liquids, with crude oil accounting for 81,000 barrels per day, including lease condensates. The rest is made up of Natural Gas Liquids (NGL). Renewable fuels, such as biomass and trash, account for a small percentage of total energy use. Trinidad is ideally situated geographically, with plenty of sunlight and, as an island, easy access to ocean renewable energy.

Energy Policy

The country's significant reliance on petroleum resources has made it the country's primary source of revenue. There is currently a movement to diversify the economy and move away from its strong reliance on oil and gas. Natural gas has become the primary energy source for both fuel and feedstock since the establishment of Pt. Lisa's industrial estate and the construction of the Liquefied Natural Gas (LNG) plant in Pt. Fortin. The transportation industry is the sole user of refined petroleum products. The usage of alternative energy sources is becoming increasingly vital as local energy demand for this restricted resource rises. This could be solved by making use of Renewable Energy (RE) resources in both residences and cars. Increasing Energy Efficiency (EE) when using petroleum products, lowering energy demand, and employing alternative transportation fuels, such as Compressed Natural Gas (CNG). These measures would be in line with the National Draft Climate Change Policy now being developed, as well as worldwide mitigation and adaptation strategies to address climate change. In its national budget for 2020/2021, the Trinidad and Tobago government stated its commitment to the establishment of an energy policy for the country. The country's position is suitable for utilizing solar and wind energy, and legislation would encourage the country's Renewable Energy (RE) resources to be fully developed. A group was formed to investigate and develop policies, and a Framework was created. It is critical to expand the country's renewable energy resources and to educate the public about the benefits of using renewable energy in everyday life. The idea to construct a wind energy farm in Trinidad and connect it to the grid has a lot of potential for promoting and growing investment, enhancing research and development, offering fantastic job opportunities, and raising foreign exchange and revenue. Based on the country's current energy platform and expertise in energy sector development, including shown success in recruiting big investors and financiers (Renewable Energy Committee, 2020) Trinidad and Tobago is ideally positioned to face the task of effectively developing its renewable energy resources.

Ocean Renewable Energy

Tidal barrage, tidal current energy, wave energy, Ocean Thermal Energy Conversion (OTEC) power, and salinity gradient power are all examples of ocean energy.

In comparison to wave energy, OTEC power, and salinity gradient power, tidal turbines are commonly acknowledged as a cost-effective means of harnessing ocean energy (Khan *et al*., 2009). The proposed construction of the Severn Barrage in Wales, United Kingdom (REUK, 2020), demonstrates that tidal barrages are less environmentally benign than the other four approaches.

Tidal Barrage

Tidal barrages are massive, dam-like structures built across the mouth of a river or in a region with significant tidal range differences. The tidal barrages are based on the principles of hydroelectric generating from tidal current flows in both directions employing turbines, sluice gates, embankments, and ship locks (Etemadi *et al*., 2011). The height of the water controls the flow of water through the turbines. When the tides shift, a height disparity develops across the barrage. The turbines allow water to flow through the barrier, delivering power during tide shifts and flood tides. The potential energy of a tide can be recovered by impounding it with a barrage, or the kinetic energy can be collected straight from the tidal stream. A vertical-axis turbine (Darrieus turbine) has the advantage of being able to extract power from any direction without requiring any adjustments.

Tidal Current Energy

Trinidad, as a small island, has a lengthy coastline with a lot of potential for developing ocean energy-based electricity generation. Vertical-axis and horizontal-axis

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tidal turbines are the two types of tidal turbines (Fig. 1). The vertical-axis turbine can capture energy from various directions without changing its position, whereas the horizontal-axis turbine can capture more tidal energy but requires a control device to direct it in the direction of the oncoming current. In comparison to natural gas-fired power facilities, ocean energy is relatively new to Trinidad. The development of tidal currents is still in the research stage, despite efforts by the Institute of Marine Affairs (IMA) to accelerate tidal energy deployment. Trinidad's east coast is adjacent to the Guiana Current, the world's second strongest ocean current, with speeds ranging from 0.10 to 2.16 m per second, enough to power undersea turbines (Hall and Shrivastava, 2017). The Institute of Marine Affairs (IMA) is conducting research into the use of ocean currents to power submerged turbines. The IMA has begun work on a project that comprises a detailed study of ocean currents around Trinidad and Tobago, particularly in the Columbus Channel and the Galleons Passage on the island's south coast. Trinidad's eastern coast enjoys warm temperatures, making it warm at the surface yet cold enough at deep to support an OTEC plant. Ocean Thermal Energy Conversion (OTEC) plants can be a key asset in lowering reliance on oil and gas energy by providing a simple and reliable means to fulfill the population's expanding power needs. However, for the OTEC plant to be competitive as a power source, the technology needs to be treated similarly to other energy sources in terms of tax benefits and government subsidies.

Wave Energy

Because of the force that ocean waves exert, they might be used to generate electricity. The Northeast Trade Winds are a strong wind that blows across Trinidad and Tobago, contributing to the presence of waves around the islands, and allowing offshore energy farms to be built. Wave energy can be transformed into electricity in a variety of ways. The majority of wave energy technologies convert kinetic energy to electricity by using the kinetic motion of waves to generate electricity. The Pelamis Wave Energy Devices, which are located in Portugal, were the world's first wave farm (Palha *et al*., 2010). This gadget is made up of many large cylinders, usually four, that are connected but still move.

When fully completed, the device resembles a giant segmented sea snake. When the tubes bob up and down on the waves, their movements lob the joints, which is how the system works. Oil is pumped into the joints, which are subsequently moved by hydraulic motors.

To generate electricity, these motors are attached to generators. The Pelamis snake in Portugal is 182.88 m long and 3.96 m broad, and it can generate up to 0.75 megawatts of energy. The quantity of electrical energy extracted by this Pelamis Snake from the waves is mostly determined by the frequency and height of the waves. A key downside of the Pelamis Snake is that, due to its vast size and configuration, it may pose a navigational threat from collisions due to the wave energy device's low profile.

When compared to other wave devices, the Oscillating Water Column (OWC) may be a more cost-effective way to harvest wave energy in Trinidad. An air turbine is a convenient way to convert wave energy into mechanical energy. The OWC-type wave energy devices nearly exclusively utilize these air turbines (Heath, 2012).

The OWC is essentially an enclosed chamber with one or more air turbines on top and open to the sea waves at the bottom. The Wells Turbine is the most well-known design. It is a turbine with symmetrically shaped airfoils placed at 90 degrees to the airflow. Other turbine designs, such as variable-pitch turbine blades or varied airfoil shapes, could be used to maximize energy collected due to the Wells Turbine's design.

Ocean Thermal Energy Generation (OTEC)

Ocean Thermal Energy Conversion (OTEC) devices utilize the temperature difference between the warm ocean surface and the colder water layers below at a certain depth. The amount of energy given by solar seawater heating available via the temperature difference between hot and cold seawater can be significantly more than the power necessary to pump cold saltwater up from the ocean's bottom levels.

The warm water from the surface heats the turbine's operating fluid (the seawater itself under low pressure in open cycle systems). After that, the working fluid passes through a turbine before being condensed with cool saltwater injected from the depths. OTEC plants perform best at the equator, where intense sun radiation rapidly warms the surface of the seawater (Etemadi *et al*., 2011). In terms of harnessing ocean thermal energy, Trinidad has a lot of promise. At the surface, the temperature is around 26°C in February and 29°C in September. Recent discoveries in OTEC reveal that ammonia is an excellent choice for the organic Rankine cycle used in OTEC, allowing for higher production (Vega, 2002). The Atlantic Ocean on Trinidad's eastern shore is 760 miles north of the equator, with mild surface temperatures and cold enough depths to support an OTEC plant. OTEC has the potential to meet Trinidad and Tobago's expanding power needs while also reducing the quantity of energy generated from oil and gas. Cost estimates are difficult to anticipate due to the rarity of OTEC systems utilization and study. According to one study, power generation costs as little as $0.07 per kilowatt-hour, against $0.05 to $0.07 for subsidized wind systems (Shah, 2018).

Salinity Power Gradient

Because of the difference in salinity between fresh water and seawater, there is potential energy that can be utilized when they are mixed. Through a method known as "Pressure-Retarded Osmosis," the osmotic pressure created by the passage of water across a membrane due to a salinity gradient can be used to power turbines. The utilization of reverse electrodialysis ion-exchange membrane stacks in microbial reverse-electro dialysis cells is still being researched in this energy system. These cells are utilized to capture the salinity-gradient energy released by ammonium bicarbonate salt solutions, allowing for more energy production and energy recovery (Sun *et al*., 2012).

Resource Modelling

Because they have benefits over other mediums, tidal currents are particularly appealing to renewable energy providers. The density of a moving fluid is exactly proportional to the power extracted by a turbine. Because the medium, in this case, salt water, is approximately 800 times denser than air, the working fluid's necessary velocity might be lower than that of air. Although subject to weather-related variations, this energy source is rather steady, allowing tidal current flow to be predicted to within 98% accuracy for decades. In addition, tidal current chart forecasts are accurate to within minutes over some time. Weather fluctuations, such as wind speed and sea surges, cause second-order resource variations.

The impact of tidal currents is rarely affected by weather conditions such as wind, fog, rain, and clouds, as they are with other renewable energy predictions. Rain, clouds, and fog have a big impact on solar energy, and calm weather has a big impact on wind turbines, but tidal currents are quite reliable and predictable. This results in the main advantage of tidal current energy over solar and wind energy, which is its high predictability. Unfortunately, wind and solar energy do not have the same predictability as tidal energy. As a result, reliable energy generation from tidal power may be predicted with great certainty. This predictability is essential for the successful integration of renewable energy into the power grid.

Resource Potential

The total kinetic power in a marine current turbine has a similar dependence to that of a wind turbine and is governed by the following equation.

$$P = 0.5\,\rho A V^3 \tag{1}$$

where:

ρ = The fluid density
A = The cross-sectional area of the turbine, and
V = The fluid velocity

However, a marine energy converter or turbine can only harness a fraction of this power due to losses and equation 1 is modified as follows:

$$P = 0.5\,\rho Cp A V^3 \tag{2}$$

Cp is known as the power coefficient and is essentially the percentage of mechanical power that can be extracted from the fluid stream by the turbine and considers its efficiency. This coefficient is limited to 16/27 by the well-known Betz law. Wind generators have typical values in the range of 0.25-0.30. The upper limit is for highly efficient machines with low mechanical losses. For marine turbines, is estimated to be in the range of 0.35-0.50 (Myers and Bahaj, 2006).

Installation Site

The east coast of Trinidad was chosen because it has the biggest number of oilfield production platforms, as well as high-velocity current and sufficient depths for marine turbines.

The Orinoco River's current and the South Equatorial current are close enough to produce power using undersea turbines on Trinidad's east coast. Furthermore, the average marine current velocity distribution for 2019 is 0.86 m/s (Fig. 2a), which is lower than the minimum necessary for the economic deployment of marine turbines, which is expected to be 1.0 m/s (Energy-Joule, 1996; Myers and Bahaj, 2005). These economic deployment figures were calculated using a horizontal-axis marine turbine; the cost of a vertical-axis marine turbine should be lower, owing to reduced operation, maintenance, and support structure.

Turbine Modelling

The conversion of kinetic energy in a moving fluid to electrical energy, in this example seawater, into the motion of a mechanical system (marine turbine), which can subsequently drive a generator, is required to harness the current energy in a tidal flow. It's not surprising, then, that many developers advocate for utilizing technology similar to that which has been successfully used to capture wind, another flowing fluid.

The most effective tidal stream generator is the Horizontal Axis Turbine (HAT). The HAT must be properly aligned with varying streamlines to attain maximum efficiency, Fig. 2b shows the marine current direction at the modelled site. In comparison, a Darrieus Vertical-Axis Turbine (VAT) can collect fluid flow in all directions, however, it has a lower efficiency than the HAT (Shiono *et al*., 2002). However, there are a few key distinctions in the design and operation of maritime turbines. Changes in force loadings, immersion depth, stall characteristics, and the possibility of cavitation are the key differences in the configuration of horizontal versus vertical turbines. For a specific application, the hydrodynamic design characteristics include diameter (power required), pitch, and speed.

All current design codes treat rotor aerodynamics using Glauert's well-known and well-established Blade Element Momentum (BEM) theory (Glauert, 1963). This theory is an extension of the Rankine–Froude actuator-disk model, intending to improve the model's accuracy performance predictions.

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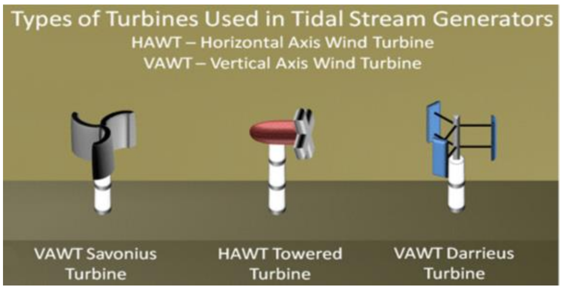

Fig. 1: Tidal Stream Generators (http://tidalpower.co.uk/tidal-stream-generator)

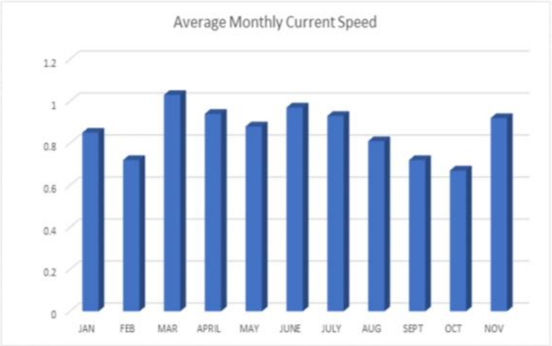

Fig. 2(a): Monthly marine current speed for the year 2019

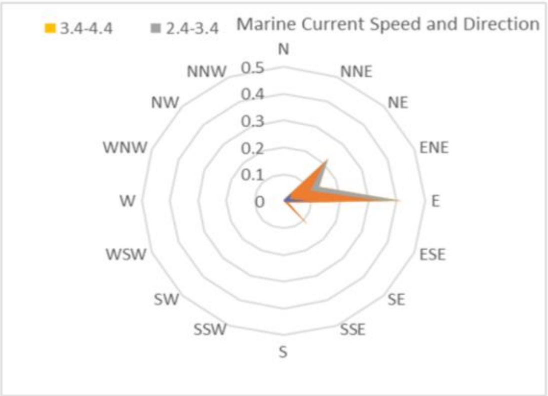

Fig. 2(b): Marine current direction for the year 2019

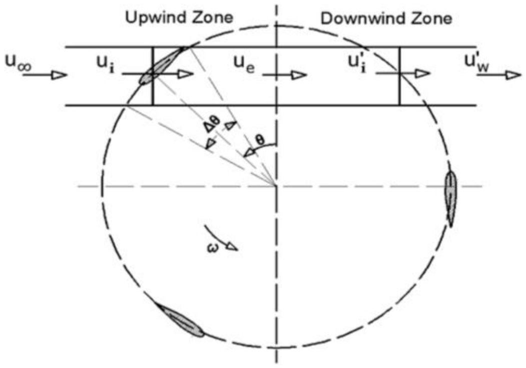

Fig. 3: Double multiple stream tube model

This vertical-axis marine turbine was modeled using the Double Multiple Stream-tube model (Fig. 3). A far more exact solution approach is the combination of the multiple stream-tube and the double actuator disc theories. Even though the two sides of the turbine are considered to be aerodynamically independent of each other, it allows for velocity fluctuations perpendicular to the flow direction and the ability to model sections of how the upstream half impacts the downstream half of the turbine.

Because of its configuration, the turbine's blade path is now divided into two halves; the blade only encounters a single stream tube once every rotation, implying that fraction d/2 is now the proportion of the whole circumference occupied by the stream tube. As a result of the doubled and more precise computations, the relationship between the time-averaged force and the instantaneous force will be halved.

The relation between the time-averaged force and the instantaneous force will be halved as the calculations will be doubled and more accurate:

$$Nd\O/2\pi = T_{ava}/T_i \quad (3)$$

For the upstream half:

$$w=\sqrt{\left(u_\infty(1-a)\sin\O\right)^2+\left(u_\infty(1-a)\cos\O+\omega r^2\right)} \quad (4)$$

For the downstream half:

$$w=\sqrt{\left(u_e(1-a')\sin\O\right)^2+\left(u_e(1-a')\cos\O+\omega r^2\right)} \quad (5)$$

The dimensionless coefficients for torque (C_Q) and power (C_P) can now be calculated and the performance of the turbine can be evaluated:

$$C_Q=\frac{Q_{avg}}{0.5\rho u_\infty^2 2rHr} \quad (6)$$

$$C_p=\frac{P}{0.5\rho u_\infty^2 2rH} \quad (7)$$

Power available in tidal currents is given by Eq. 8:

$$P_{avl}=0.5\rho AV^3 \quad (8)$$

where:
ρ = The density of seawater (1030 kg/m^3)
A = The frontal rotor blade area and
V = The water current speed

Incorporating the power coefficient

$$P=C_p 0.5\rho AV^3 \quad (9)$$

Since the straight blades have the same cross-section, the blade span effect can be ignored and two-dimensional simulations are chosen. In two-dimensional simulations, the blade has a unit span. A is the cross-sectional area (A = Diameter x Blade Height).

Results and Discussion

One of the most significant parameters to consider when analyzing the performance of a marine current turbine design is efficiency. The flow energy utilization factor and coefficient of power are commonly used to describe the efficiency of a Current turbine (*Cp*).

Table 1, gives the VACT physical dimensions that were used for the modeling using the Double Stream tube model.

Figure 4 shows the normal forces of the Double Stream Tube model simulation results for the VACT of the small model at 0.86 m/s current speed.

Figure 5 shows the tip speed ratio vs the coefficient of performance. The highest performance coefficient predicted was 0.571. Figure 6 shows the power output for the VACT with this number.

The theoretical efficiency of the straight-bladed VACT depends upon the reduction of fluid resistance and drag force values due to self-rotating blades, gearbox types, generators, and frequency converters. The efficiency of vertical-axis wind turbines is very similar to that of vertical-axis marine turbines. Hence, the theoretical efficiency of a self-rotating vertical axis current turbine will be increased due to the blade's movement, supporting arms, and type of gearbox by as much as 89% with the multiplication of all the values of efficiencies (Winter *et al*., 2011).

The modeled marine current turbine total and average expected power output for the months of the year 2019 and is shown in the table below.

Environmental Impact

Foreign things will be placed within their habitat, which will have an impact on marine life. Fishing and shipping, two of the most important activities, are projected to be negatively impacted. To create room for the marine VAWT, activities such as fishing and boating will have to be prohibited off the east coast of Trinidad. The VACT might be installed on the legs of an oil and gas production platform, reducing the impact on fishing and boating. The limited available knowledge on the impacts of acoustics on marine creatures from marine energy devices suggests that the operational sounds created by the marine current turbines are unlikely to kill or significantly hurt animals.

Marine life activity in the presence of marine current turbines from the "SeaGen" project in Strandford Lough has been claimed to have had no notable impacts. During the turbine's operation, the resident seals and porpoises were able to freely swim in and out of the Lough.

In addition, postmortem examination of Dead Sea mammals revealed no evidence of a deadly strike by the SeaGen device. No marine mammals have been recorded interacting with the turbines, according to observations at the European Marine Energy Center, but seals and porpoises have been seen traveling through the area around the turbine. While the turbine is spinning, no fish have been seen swimming through it. Except for the SeaGen turbine, which includes a manually operated shutdown function when marine mammals approach within 30 m of it. None of the others have taken any precautions to protect marine life, although they have all reported little to no interaction with the marine turbines.

Biofouling is projected to occur in the majority of the tidal energy installations that will be submerged in saltwater. Antifouling coatings are used to prevent the marine turbine from fouling (Delauney *et al*., 2010). Any coating, as expected, will affect the environment. Because some antifouling paints contain copper or Tributyltin (TBT), which have unfavorable effects on marine species, new ecologically friendly antifouling paints should be investigated to prevent environmental problems.

Table 1: Setting for Simulation

Parameter	Value
Number of Blades	3.000
Blade Section	NACA0018
Blade Chord Length	0.300 m
Turbine Diameter	4.000 m
Inflow Velocity	0.860 m/s
TSR	4.187

Table 2: Monthly total and average power values

Month	Power/Watts	Monthly Total/KW
January	2254	69.874
February	1642	45.976
March	4110	127.410
April	3759	112.770
May	2875	89.125
June	4496	134.880
July	3484	108.004
August	2277	70.587
September	2015	60.450
October	1697	52.607
November	2958	88.740

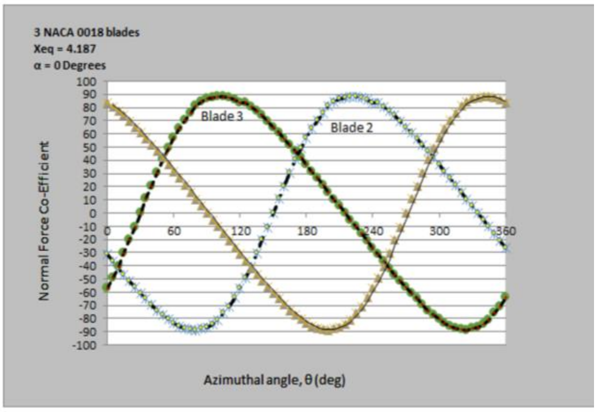

Fig. 4: Normal force co-eff on the 3 NACA0018 blades

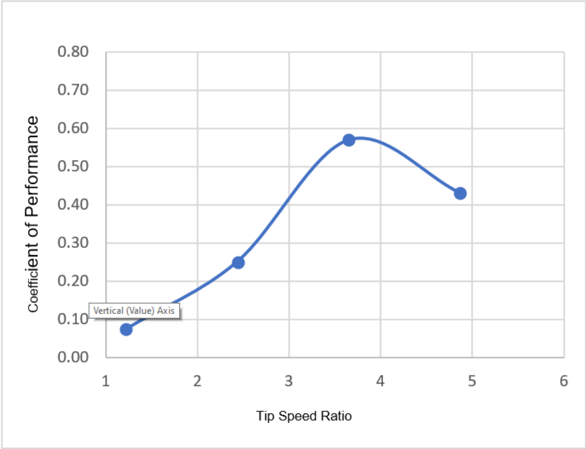

Fig. 5: Tip speed ratio vs co-eff of performance

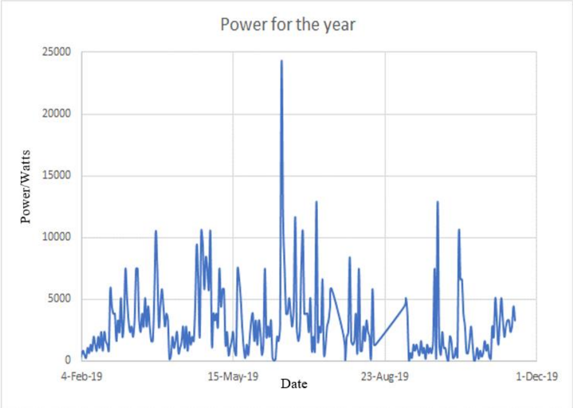

Fig.6: Simulated VACT power output

Conclusion

This is the first study that tried to model the Vertical Axis Turbine in the marine environment offshore Trinidad and Tobago. Marine current data offshore is very difficult to obtain and no simulation of a VACT was ever done before. The rotor diameter of the Vertical Axis Marine Current Turbines modeled was four (4) m. This rotor diameter was chosen so as to not interfere with the offshore platform design, these VACTs can be connected to the platform leg as a support structure, reducing the costs associated with them. From the modeling results, a single VACT can create 2,870 Watts of power on average, with a peak of 4,496 KW in June (Table 2) with an average current speed of 0.96 m per second, depending on the physical parameters of the site location. The average power output by a VACT array of four VACTs (connected to the four platform legs) is 11,480 Watts. Each VACT was modeled at a submerged depth of about 5 m under the surface of the water. Hydrodynamic interference between the VACT was not taken into consideration in this simulation. Since the offshore platforms are already built, a VACT model can be built and tested with the known platform dimensions and studied for Hydrodynamic interference.

A 15-kW direct-drive vertical-axis current turbine was created by DUT (Chen *et al*., 2021). This VACT uses a Permanent Magnet Synchronous Motor (PMSM) with a 65 rpm rated speed and a 380 V rated voltage. Two sets of blades, each with a diameter of 3.8 m and a span of 2 m, are used in the turbine, which features a coaxial three-blade double-rotor configuration. The blade uses NACA0018 and has a 0.5 m chord length. It produces 8 kW when the flow velocity reached 1.3 to 1.4 m per second.

This modeled VACT when compared with this similar VACT that was tested, can be seen that the power outputs are comparable. In our model, the VACT generates 4.5 KW at an average of 0.96 m/s. The VACT tested by DUT, produced 8 KW of power at 1.3 to 1.4 m/s. Bearing in mind this VACT by DUT has 2 sets of blades.

Taking environmental feasibility into account, the installation of the vertical axis current turbine array would have low environmental consequences, with compensatory measures in place for the most prevalent MCT impacts.

As a result, the VACT array is considered environmentally friendly. Overall, using the existing production platform structure, the Vertical Axis Marine Current Power Generation modeling on Trinidad's East Coast appears to be feasible. Only with time, as technological developments in the sector boost MCT efficiency, can a greater optimum power generation occur, yielding the greatest benefits of the Marine Renewable Energy technology.

Future Work

Turbine spacing: Two layouts, side-by-side and triangular, of closely spaced Vertical Axis Tidal Turbines, were subjected to a 2D CFD examination of the hydrodynamic interactions (Zanforlin, 2018). The consequences of obstruction on performance effects can be studied in the future.

Flexible blades: There was a study that recommended employing flexible blades that alter their shape during turbine rotation rather than stiff blades on VACTs (Bouzaher *et al*., 2017). According to their findings, the peak power Coefficient (Cp) for the flexible airfoil is significantly higher than that of the rigid blade turbine, an interesting parameter to investigate.

Blade Roughness: Due to the nature of their design, vertical axis turbines experience flow separation from the blade during times of stall during each revolution. According to the theory put forth by Priegue and Stoesser (2017), roughening turbine blades prevents flow separation.

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Author's Contributions

Rikhi Ramkissoon: Did the modeling and put the paper together.

Krishpersad Manohar: Provided the current speed data set and advised on the modeling and formatting of the paper.

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