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Comparison of Horizontal and Vertical axis tidal turbine with a new design to the renewable energy production of marine currents

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ABSTRACT

This study is a new design of a vertical axis turbine that generates renewable energy from low-speed currents tidal. Tidal Energy is one of the most important available resources among the renewable and environmentally friendly energy resources in oceans and seas. Tidal turbines are used to produce renewable energy. Some types of tidal turbines widely used and studied are vertical axis tidal turbines (VATT) such as Savonius, Darrieus, Gorlov, Lucid, etc., in which the flow direction is not essential for them. And some types of tidal turbines are Horizontal axis tidal turbines (HATT) which the flow direction is important and often have good performance than vertical axis turbines. These turbines are well suited for absorption of high-speed current, but most ocean areas have tidal flow at low speed. The main purpose of this research is a numerical study of tidal turbines with a horizontal and vertical axis rotor and designing and modeling VATT to increase the power efficiency in low-speed currents. In numerical modeling, the HATT at high speeds has high efficiency, and C_P to TSR is more than 0.4, but with the design of the vertical Savonius turbine, with the focus of the flow on the concave blade and the removal of force from the convex blade, almost equality in speed Less than 2m/s. In the modern design of the Savonius turbine, the ratio of C_P to TSR has been increased three times and reaches more than 0.3 in compare the simple Savonius classic turbine. Therefore, due to advantages such as easier installation and lower maintenance costs of Savonius turbines, and with the new design, the use of these turbines in renewable energy will be appropriate.

1. Introduction

nowadays, with the reduction of underground resources and fossil fuels, researchers are trying to use clean and renewable energy. The use of renewable energy in addition to economic savings brings good conditions for the environment [1]. One of these sources is the use of current energy generated by the tide. The use of tidal currents is of interest to researchers in the extraction and production of energy because this energy is available intermittently and regularly. This feature of tidal energy is contrary to wind force or solar radiation because it cannot be interrupted due to environmental conditions [2]. The use of tidal currents is of great interest to researchers in the extraction and production of energy because this energy is available intermittently and regularly. This feature of tidal energy is contrary to wind force or solar radiation because it cannot be interrupted due to environmental conditions. The power density of the ocean is about 832 times greater than that of the air, making it potentially a much more efficient energy source [2].

In general, there are various methods for extracting tidal current energy, such as tidal dams, tidal kites, oscillating hydrofoils, and tidal turbines. One of the tidal energy extraction options is hydrofoils and kites with limited installation depth.[3] Research also shows Tidal turbines have less harmful effects on the environment.[4] Therefore, the use of this type of technology (tidal turbines) is much more efficient than other methods of tidal energy extraction. As shown in the below graph, the most commonly used technology is current and wave energy extraction, indicating these energies' importance and superiority. [5]

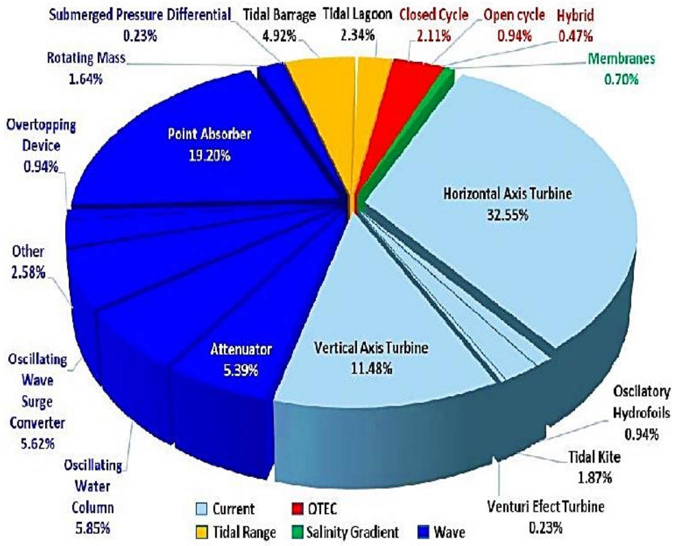

Fig 1. Technology distribution among projects [5]

Nowadays, research, design, and construction of tidal turbines are increasing rapidly. Many places have potential extraction and use of this energy.

Generally, the tidal turbine has two categories, horizontal and vertical. [6] Horizontal axis turbines convert fluid energy into mechanical energy by passing a current through a system of fixed and moving blades. And operates according to the drag system. Horizontal axis turbines are parallel flow turbines that are similar in concept to horizontal axis wind turbines. Vertical axis turbines are the same as horizontal axis turbines, except the vertical axis connects the turbine blades. This indicates the rotation performance of the blades due to the torque caused by the water force inside the blade. These types of turbines operate on the basis of a lift system [7].

Much research has been done on selecting horizontal and vertical axis tidal turbine types. Each of these types of turbines has its unique characteristics. The vertical axis turbine is easier to start and can rotate on both sides [8]. These turbines are also being developed for wind energy extraction and are less expensive to build and easier to install than vertical axis turbines [9]. Another feature of these turbines is that in the marine environment, especially for hydrokinetic applications, the equipment is exposed to water. As an electrical component, the generator needs to be sealed, so this becomes one challenge. In a horizontal axis turbine, gear and generator must be placed underwater.

In contrast to a vertical-axis turbine, the generator can be coupled to one end of the shaft. So, it can be placed on top and at one end of the shaft. So, it can be placed on top and reduce the cost of arranging water-sealed technology [10].

The equipment is exposed to water in the marine environment, especially for hydrokinetic applications. As an electrical component, the generator needs to be sealed, which has become one challenge. In a horizontal axis turbine, gear and generator must be placed underwater.

On the other hand, the most critical challenges of vertical axis turbines, compared to horizontal axis turbines, can be mentioned as follows:

Irregular current velocity: Irregular current velocity is a typical challenge for all hydrokinetic turbine types. The current movements of seawater are dominantly driven by changing tides. Tides have predictable velocity according to tide time or ebb time. However, tidal currents velocity are irregular and fluctuate depending on location and specific time. [11]

Fatigue loading: The variation of radial force can effect on shaft or bearing. The closest effect is friction on the bearing, and the other impact is broken in the shaft. It happened experimentally in towing tank Shaft cannot resist fluctuation force with a big peak.

Vibration: The variation of radial force also can effect the supporting structure and other equipment. It is known as vibration. Some components like the generator are susceptible to vibration. On the other hand, if this vibration frequency coincides with the natural frequency of the support structure, it can be destructive. [12].

Cavitation: Cavitation is always to be a challenge in the hydrokinetic turbine. It can be defined as the formation of water bubble or voids when the local pressure falls below the vapor pressure. Slowly it can damage turbine material. Rough blade surface will decrease the performance. [12].

A tidal current turbine rated at 2–3 m/s in seawater can results in four times as much energy per year/m2 of rotor swept area as similarly rated power wind turbine. Although accessing tidal stream energy may be costly, the high energy availability if exploited will more than compensate for the higher costs as a result, the use of this energy is useful and practical and research on the performance of tidal turbines is important.

According to the advantages and disadvantages of tidal turbines, There are many types of research about the modeling of tidal turbines and the new designs of them in both horizontal and vertical axis types to increase efficiency, angular velocity, and output power of the turbines.

For example, Nachtane et al. (2020) studied the hydrofoil designs of horizontal axis tidal current from the technology development point of view. Also, the newest marine tidal current turbine technologies and its historical development were reviewed. Besides, they reviewed CFD models used to investigate the performance of tidal turbines and their optimization methods [13]. Gaurav and Prasad Saini (2019) studied the several rotor configurations of the vertical axis hydrokinetic turbines (VAHT). This research help researchers in selecting, performance-enhancing, and design optimizing the design of cross-flow hydrokinetic turbines [8]. Qian et al. (2019) reviewed the control methods and configuration of tidal turbines, with a focus on horizontal axis tidal turbines [14]. Li et al. (2016) present a review of the technological developments of the tidal turbine blade structure and hydrodynamics design. Subsequently, the key technologies to be researched for the tidal current turbine blade design were concluded and forecasted [15].

Many tidal turbines broadly studied and used are vertical axis tidal turbines such as Darrieus, Gorlov, Savonius, Lucid, etc., which work in any flow direction.

In another study, Payambourpour et al. (2020) investigated a turbine with a flow deflector as a laboratory and numerical analysis. The studied turbine has 2 blades with a large number of semicircles with different diameters and an axis perpendicular to the flow direction. In this study, the researchers examined various parameters. Finally, they evaluated the turbine's efficiency, and as a result, the best deflection criteria obtained the collision current with the turbine to produce more efficiency. [16].

Gorle et al. (2019) introduced a method based on kinematic relations in the Darrieus turbine [17].

Kerikous and Thevenin (2019) improved the blade profile of a water current Savonius turbine for maximizing the output power of the turbine with a particular thick blade. They introduced 12 geometrical terms to shape optimization. Their optimum blade leads to considerably higher efficiency than common blades in Savonius turbines [18].

Elbatran et al. (2017) presented a new system for increasing the turbine efficiency with a ducted nozzle around Savonius rotor (6 different duct nozzle designs). Their design increased the maximum power coefficient by 78% compared to the commonly modified rotors [19].

Derakhshan et al. (2017) introduced a movable blade VATT and studied it numerically and experimentally. They achieved higher efficiency with their new design [20].

In this research, horizontal axis and VAT of Savonius type are modeled under the same conditions, and their output power results are compared. Then, the obtained results are compared with the newly designed Savonius turbine, and the results of each Will be examined.

In this research, a Savonius turbine has been designed that has the ability to generate energy in low tidal currents. Most Savonius turbines can't produce good energy, but, with the changes in the turbine, the conditions for energy production for this model of the turbine have been provided. The performance of the designed turbine will be evaluated using numerical modeling. And the results will be discussed

2. Material and method

For modeling, it should be noted that the height of the turbine installation, temperature changes and water salinity, viscosity effect, the effect of disturbances in the course of all of the influential parameters in the turbine production energy [6] hence all the influential variables in the model It is considered the same.

In the Horizontal axis of one blade and two blades, according to the deviation and torque of swing, they produce significant alternate load. Rotors with more than two blades, rotor moment during a rotor rotation round, almost completely in general balance. Therefore, the horizontal axis of the 3 blade and the Airfoil in the design are used. In the design of the horizontal turbine, the choice of a profile in the form of Airfoil should have important criteria.

The profile should have a high lift coefficient, while keeping the drag coefficient low. As a result, the coefficient of C_L/C_D should have a high value before the pre-design of the blade should be examined for the selective profile. The production of blades should be easy and began to resist environmental conditions.

Also, the selected profile should be effective for the stability of the blade against the accumulation of marine and dirty plants .[21]

The optimal tip speed ratio depends on the number of turbine rotor blades. The smaller number of blades, the turbine should rotate faster than the maximum capable. The optimal tip speed ratio is obtained depending on the number of rotor blades.

$$\lambda_{OPT} = \frac{4\pi}{n} \tag{1}$$

In the above relationship, n number of rotor blades.

By applying the momentum theory of Betts and the strip's theory, the blade form's optimal form can be calculated. If producing a coefficient of lift and local length, follow a hyperbolic pathway during the blade radius, the flow rate of flow on the plate is not high, and the coefficient of the lift in its highest value is noted. In calculating the amount of chord on the airfoil, the mechanical power of the rotor from the wind flow or water is affected by the geometric form of rotor blades. With certain simplification and by ignoring the profile of the blade profile and tip vortices, a mathematical formula that can be solved analytically can result in the optimal aerodynamic distribution during the blade:

$$C_{Opt} = \frac{2\pi r}{Z}\frac{8}{9C_L}\frac{v_{WD}}{\lambda v_r} \tag{2}$$

In the above formula, the optimum local length of the blade in meters C_{opt}, design flow speed in meters per second, v_{WD}, local effective flow velocity in meters per second, $v_r = \sqrt{v_w^2 + u^2}$, peripheral speed Meters per second, u, local tip speed ratio, λ, local distribution coefficient, C_L, local length of blade, r, the number of rotor blades, Z, are.

Many studies have been investigated in terms of a variety of horizontal turbine airfoils, and their various characteristics are discussed. This study uses a horizontal axis turbine expression to use airfoil Naca 63-415 because it has good aerodynamic properties. Also, the naca63 airfoil series has a lot of time and less sensitivity to roughness and friction compared to other airfoils. [22]

In the vertical turbine modeling, the conventional Savnious turbine, which includes two half-cylindrical sections, will be modeled. The turbine, which has been proven to be a shaft, absorbs a portion of flow due to the collision of flow, and another part prefers to move in the opposite direction.

In the CFD modeling, Flow3D software is used. This software uses the first and second-order accuracy methods in solving equations

2.1. Theoretical consideration

The rules governing the flow of an incompressible fluid, expressed by the continuity equations and the size of the motion in the coordinate axes known as the equations of Navier Stokes, represent the sustainability of mass and size of movement to mathematical expression. If the fluid element is considered a constant volume in the computational atmosphere,

in this case, the forces of which and the principle of survival of the mass in this element are represented as partial derivative equations .

$$\frac{\partial \mathrm{u}_i}{\partial \mathrm{x}_i} = 0 \quad (3)$$

$$\frac{\partial \mathrm{u}_i}{\partial_i} + u_i \frac{\partial \mathrm{u}_i}{\partial \mathrm{x}_i} = \frac{-1}{\rho}\frac{\partial \mathrm{p}}{\partial \mathrm{x}_i} + \mathrm{g}_\mathrm{i} + v\nabla^2 u_i \quad (4)$$

In the relationships expressed Ui, the instantaneous speed component in the direction of i (m/s), V dynamic fluid (Ns/m^2), ρ density fluid (kg/m^3), g gear acceleration component in the order i (m/s^2), And P pressure at any point of the fluid. In the CFD modeling, the equations governing the non-density flow are expressed as the following relationships [23]

$$\frac{\partial}{\partial \mathrm{x}}(uA_x) + \frac{\partial}{\partial \mathrm{y}}(vA_y) + \frac{\partial}{\partial \mathrm{z}}(wA_z) = 0 \quad (5)$$

$$\frac{\partial \mathrm{u}_i}{\partial \mathrm{t}} + \frac{1}{V_F}\left(u_i A_{i1}\frac{\partial \mathrm{u}_i}{\partial \mathrm{x}_i}\right) = \frac{1}{\rho}\frac{\partial \mathrm{p}}{\partial \mathrm{x}_i} + \mathrm{g}_i + f_i \quad (6)$$

In the relationships expressed 5 and 6 u,v,w, fluid velocity components in the direction of x,y,z (m/s), V_F Volume fraction of Chase (m^3), A_x, A_y, A_z Surface in the direction of x,y,z (m^2), ρ density (kg/m^3), P pressure at any point of fluid (Pa), g_i accelerated gravity component in the direction of i (m/s^2) and fi represents Reynolds stress (Pa).

2.2. Turbulence modeling

Researchers develop much disturbed models to simulate turbulent currents. The number of differential equations used for disturbing quantities to different categories, including alternate models, single equation models, second model models, models It has a tension equation and large vortex simulation, models. The simulation of turmoil in the Flow-3D modeling software using one of the five models of parental mixing length, a kinetic energy equation, the two equivalents of the K-ε model of the groups and the simulation model of large facial vortices It takes

The momentum and continuity equations with k-ε turbulence model are the governing equations of this study which are used to CFD simulation [24] with the volume of fluid (VoF) model for simulating free-surface flow according to the following equations [25].

$$V_f\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u A_x) + \frac{\partial}{\partial y}(\rho v A_y) + \frac{\partial}{\partial z}(\rho w A_z) = 0 \quad (7)$$

Momentum equations for the fluid velocity components (u,v,w) in the three coordinate directions:

$$\frac{\partial u}{\partial t} + \frac{1}{V_f}\left\{uA_x\frac{\partial u}{\partial x} + vA_y\frac{\partial u}{\partial y} + wA_z\frac{\partial u}{\partial z}\right\} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + G_x + f_x \quad (8)$$

$$\frac{\partial v}{\partial t} + \frac{1}{V_f}\left\{uA_x\frac{\partial v}{\partial x} + vA_y\frac{\partial v}{\partial y} + wA_z\frac{\partial v}{\partial z}\right\} = -\frac{1}{\rho}\frac{\partial P}{\partial y} + G_y + f_y \quad (9)$$

$$\frac{\partial k_T}{\partial t} + \frac{1}{V_f}\left\{uA_x\frac{\partial k_T}{\partial x} + uA_y\frac{\partial k_T}{\partial y} + wA_z\frac{\partial k_T}{\partial z}\right\} = P_T + G_T + DiffK_T - \varepsilon_T \quad (10)$$

Turbulence transport equation in the three coordinate directions:

$$\frac{\partial k_T}{\partial t} + \frac{1}{V_f}\left\{uA_x\frac{\partial k_T}{\partial x} + uA_y\frac{\partial k_T}{\partial y} + wA_z\frac{\partial k_T}{\partial z}\right\} = P_T + G_T + DiffK_T - \varepsilon_T \quad (11)$$

Where P is the pressure, V_f Is the open volume fraction of the flow, ρ is the fluid density, and the components of velocity (u, v, w) are in the directions about x, y, and z. A_x, A_y and A_z are the open surface fraction in the x,

y, and z directions. K_T, P_T, G_T, Diff K_T, and ε_T are turbulent velocity fluctuations in the flow, the turbulent kinetic energy, the buoyancy production term, diffusion term, and the turbulent energy dissipation rate, respectively.
To evaluate the efficiency and output power of turbines from dimensionless coefficients, power factor (Cp) and blade tip speed ratio (TSR) is introduced as the ratio of blade tip speed to free flow velocity. The mentioned coefficients are introduced below. [6]

$$C_P = \frac{P_{rotor}}{P_{available}} + f_x \tag{12}$$

Where P_{rotor} and $P_{available}$ are the power generated by the rotor (W) and incident flow power passes from the cross-section area of the turbine, respectively. $P_{available}$ is obtained as follows:

$$P_{available} = \frac{1}{2}\rho A U^3 \tag{13}$$

In which U and ρ are the free stream speed (m/s) and fluid density (kg/m^3), respectively.

$$TSR = \frac{R\omega}{U} \tag{14}$$

ω is the rotational speed of the rotor (rad/s), and R is the radius of the turbine rotor (m). Therefore, the last power that can be exploited is obtained as:

$$P_{rotor} = \frac{1}{2} C_P \rho A U^3 \tag{15}$$

3. Verification of the model

To ensure the accuracy of the modeling process and control the software outputs, the articles Bhuyan and Biswas have been used. Due to the laboratory and numerical model of this research and the design of a new hybrid turbine model, this research has been used for validation. In that research, a Savonius Hybrid Turbine is in the below table. It was investigated in two cases, laboratory and numerical. [26]

Table 1. Turbine's parameters Bhuyan and Biswas [26]

Parameter	Dimensions
Dimensions of H rotor	
Blade profile	NREL S818
Number of blades	3 (120° apart)
Blade chord length	0.1 m
Blade height	0.3 m
Diameter of H-rotor	0.3 m
Dimensions of Savonius rotor	
No. of Savonius blades	2
Height	0.25m
Diameter	0.08m
Thickness	0.005m

According to the specification provided in Table 1, first, the turbine is modeled in solid work software and then the model designed in numerical modeling software.
Figure 2, a show the experimental model of the Biswas and figure b and c represents turbine modeling

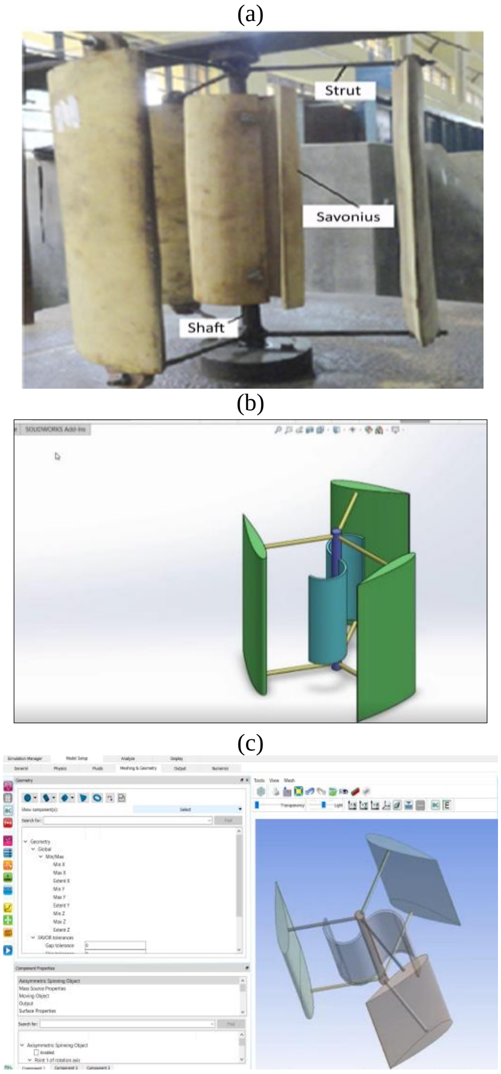

Fig 2. a: Bhuyan and Biswas laboratory turbine, b: design turbine in solid work, c: analysis model in software

Based on the figure shown in Fig 3, the values obtained from the proportion of torque coefficient to TSR have a good matching; therefore, the classical Savonius turbines and new design Savonius turbine and horizontal turbine are modeled and analyzed.

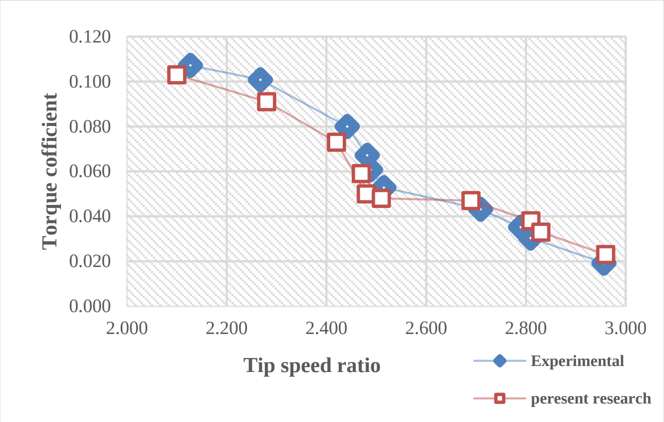

Fig 3. Comparison of the experimental and numerical model

4. Turbine model

In this section of research, Turbine modeling is done.

4.1. Simple Savonius turbine

The turbine model of this study is shown in Fig. 4, and Table 2 shows the quantities of parameters of that turbine. The overlap coefficient of the blades is defined by the following equation effects on the turbine's performance. Yaakob et al. show that the maximum turbine power coefficient relationship is obtained at β of between 0.2 and 0.25 [27]. Hence, this ratio in this study was selected at 0.23 approximately.

$$\beta = \frac{e}{d} \tag{16}$$

Table 2. Dimensions of turbine used in CFD simulation

Specification	Input Data
Rotor diameter	3.00 m
Turbine height	3.00 m
Hub diameter	0.80 m
thickness of blades	0.30 m
Overlap ratio	0.22

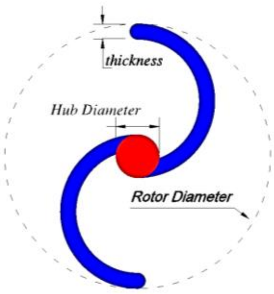

Fig 4. Schematic top view of simple savonius turbine

4.2. Horizontal turbine

The horizontal turbine model was used to model three blades with Airfoil Naka 43-415. To prevent long time and computational space are avoided by modeling the turbine body. Also, for the same modeling conditions, the surface of the fluid surface is identical in both turbines. Therefore, in modeling, the turbine characteristics are following Table 3.

Table 3. Dimensions of horizontal turbine used in CFD simulation

Specification	Input Data
Rotor diameter (d)	3.65
thickness of blades(m)	3 Blades-Airfoil Naka 43-415

Fig. 5: Airfoil Naka63-415

4.3. New Savonius turbine

The blades used in this research are designed inspired by the study blades of Tian et al. [28]. The turbine design of this study with its obstacles is shown in Fig. 6, and Table 4 shows the quantities of parameters of that turbine and its obstacles.

Table 4. Dimensions of turbine and its obstacles used in CFD simulation

Specification	Input Data
Rotor diameter	3.00 m
Obstacle diameter	2.20 m
Hub diameter	0.80 m
Turbine and obstacles height	3.00 m
Maximum thickness of blades and obstacle	0.3 m
Minimum thickness of blades and obstacle	0.10 m
Overlap ratio	0.22

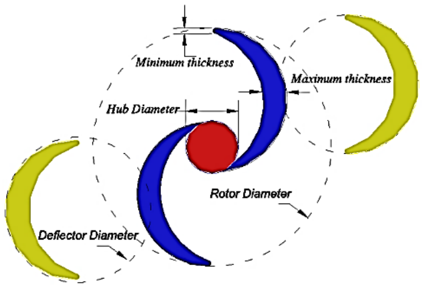

Fig 6. Schematic top view of turbine and obstacles

5. Results and Discussion

CFD simulation was done for four models (simple savonius turbine, horizontal turbine, new savnious turbine and Savonius Hybrid Turbine that had been done modeling for validation) in Constant and identical inlet current velocity. Computational fluid dynamics is a branch of fluid mechanics that uses numerical analyses to solve problem involving fluid flows. Computational Fluid Dynamics (CFD) is a computer solution of the governing equations for fluid flows (the conservation of mass, momentum, and energy) in up to three dimensions. This research has used Flow-3D software for CFD. FLOW-3D provides a complete and versatile CFD simulation platform for engineers investigating the dynamic behavior of liquids and gas in a wide range of industrial applications and physical processes.

FLOW-3D focuses on the free surface and multi-phase applications, serving a broad range of industries, including microfluidics, bio-medical devices, civil water infrastructure, aerospace, consumer products, additive manufacturing, and inkjet printing, laser welding, automotive, offshore, energy, and automotive.

The boundary condition and solution domain are the same selected. Fig. 7 shows the two and 3D time frames of CFD models.

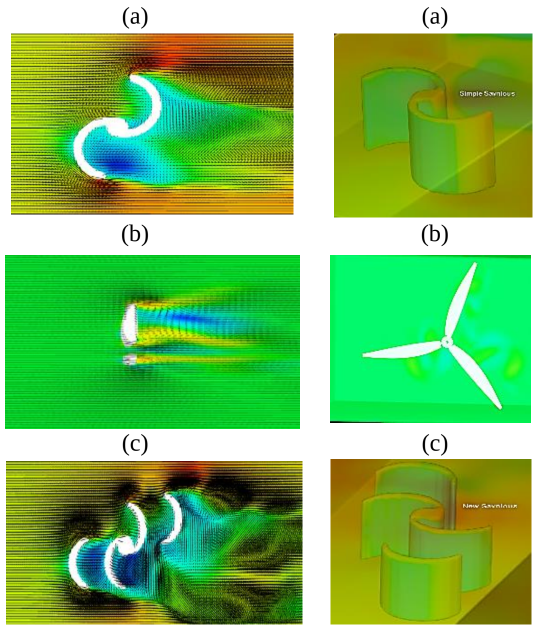

Fig 7. 3D view of the turbine a: simple savonius b: horizontal c: new savonius

In the modeling performed, C_p-TSR ratio is displayed in the following graphs. It is observed new turbine design savonius had low slippage than the horizontal turbine when the current velocity below 2m/s. In continuing with raise the current speed, the ability both Savonius turbine decreased. This is important, mostly, sea current is accompanied low speed, so use of horizontal turbine at the low velocity isn't a good choice.

One of the reasons for raising C_p-TSR in the horizontal turbine is turbine area motion. Obviously, with increasing the diameter of the Savonius turbine, the turbine efficiency will be high.

The considerable results of modeling show that C_P has an upward trend by increasing the speed of water flow in the Simple savonius turbine. However, C_P has an upward trend till 2m/s current speed and after that unexpectedly, has a downward trend in rotors with a new turbine.

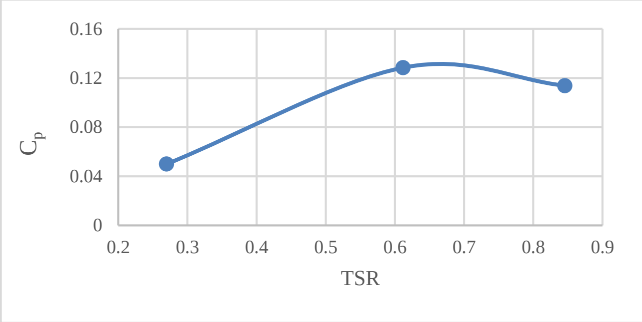

Fig 8. Cp-TSR Classic Savonius Turbine

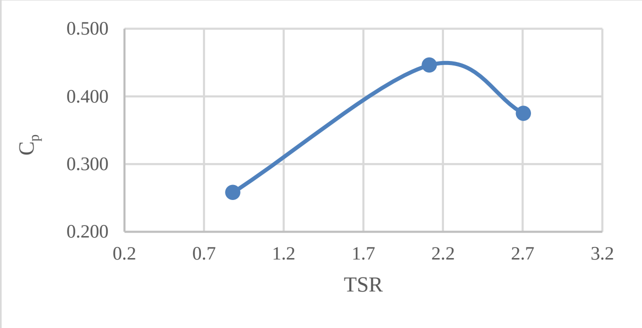

Fig 9. Cp-TSR New design Savonius Turbine

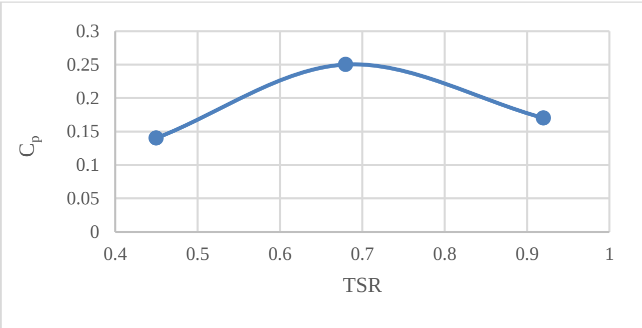

Fig. 10: Cp-TSR Hybrid H-Savonius Turbine

In the modeling performed, the C_p-current velocity ratio and power-current velocity ratio are displayed in the following graphs. It is observed new turbine design savonius had low slippage than the horizontal turbine when the current velocity was below 2m/s.

This issue is vital because marine currents often have low velocity. And since savonius turbine has fewer installation costs and the ability to rotate from both sides, it has suitable conditions for exploitation. And the other hand, the process of changes in two other turbines indicates a significant difference at high speeds that represents the horizontal turbine is better than the vertical turbine.

With consideration, the power graph can be concluded that the design of new turbines and the use of combined turbines will increase the turbine efficiency. So in Table 5, the amounts of the obtained capabilities are displayed and well-increasing the power of combined turbines compared to the simple Savonius turbine. The amount of turbine designed at a speed of 1m/s is almost equal to the horizontal turbine and drops 40% at speeds of 2m/s. In other words, it can be concluded from Table 5 that at low flow velocities, a good power can be achieved by selecting a designed Savonius turbine. And due to the low cost of installation and operation of this turbine, it is a more suitable choice than the horizontal axis turbine. On the other hand, as the flow rate increases, the ability of the horizontal axis turbine is well increased, so it can be concluded that turbines designed for high-speed flows are not suitable.

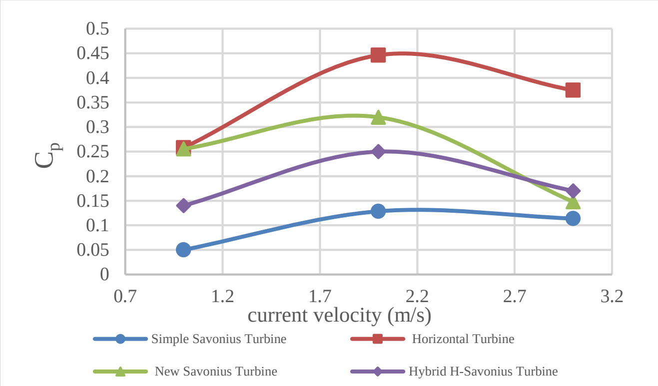

Fig. 11: C_p-current velocity ratio

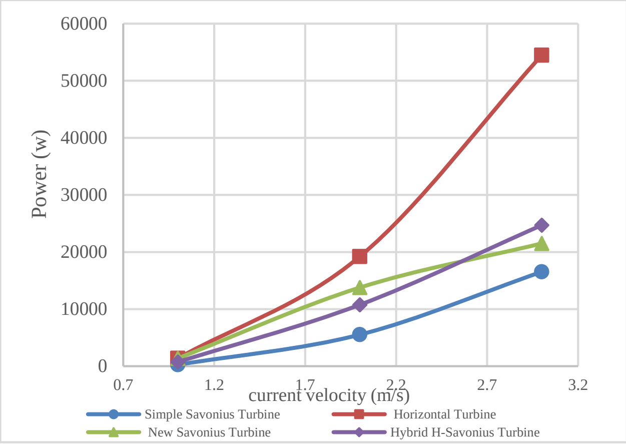

Fig. 12: Power-current velocity ratio

Table 5. Power Amounts

Turbine	Simple Savonius	Horizontal	New Savonius	Hybrid H-Savonius
Power in velocity= 1m/s	269	1388	1375	754
Power in velocity= 2m/s	5530	19209	13776	10763

6. Conclusions

The typical tidal turbine can absorb the tidal flow of the ocean at a relatively high speed. But some areas with the tidal flow are low speed. VATT, due to its low power coefficient, is not popular, while they have got less cost installation and have a good situation for maintenance. If this power increases, this turbine will be suitable for energy extraction. Using CFD modeling and designing a new turbine in this study has increased the ratio of Cp to TSR. The base of this design was focused on the current blade and the removal force from the convex blade. Simple Savonius turbines are not suitable for water currents less than 2m/s at all. Putting the semi-cylinder barriers as a manner in the turbine, front and back of the Savonius rotor, has a significant increase in the output performance. According to the obstacle that has been designed in this research, the result has shown that the power has risen to 2.50 times.

Also observed from numerical modeling, hybrid turbines and new VATT have increased their power near to HATT's performance

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