SINERGI Vol. 25, No. 1, February 2021: 27-32
http://publikasi.mercubuana.ac.id/index.php/sinergi
http://doi.org/10.22441/sinergi.2021.1.004

DESIGN MODELING OF SAVONIUS-DARRIEUS TURBINE FOR SEA CURRENT ELECTRIC POWER PLANT

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Abstract

Turbines convert the kinetic energy of ocean currents into electrical energy produced by the sea current electric power plant. This study aims to design a power generator turbine modeling that is carried out using the Computational Fluid Dynamic (CFD) approach by comparing the geometric performance based on the angle of attack and the Tip Speed Ratio (TSR) value of the Savonius-Darrieus Turbine. Having done several trials and errors during collecting the data, the value of the TSR 1.427; 2.853; 4.28; 5; and 5.7 is proposed. Here, the NACA 0018 series has been adopted on the current design of Savonius-Darrieus Turbine. The turbine has three blades, length of the span 357 mm, the diameter of turbine 428 mm, and length of the hydrofoil chord 40 mm. Effect of various angle of attacks from 0°up to 10° has been taken into account in the computational to obtain the coefficient power for each variation. The results revealed that the turbine with an angle of attack of 5°and TSR value of 5.0 has higher power coefficient value by 0.469 as compared with its angle of attack of 10°. It should be noted here that the increase of the angle of attack up to 10° resulted in a significant reduction of the power coefficient value of 0.206 as the value of TSR about 4.28. The addition of the Savonius Rotor results in increasing efficiency of the turbine for sea current applications.

Keywords:
Angle of Attack;
CFD;
Coefficient of Power;
Savonius-Darrieus Turbine;
TSR;

Article History:
Received: March 25, 2020
Revised: June 8, 2020
Accepted: June 20, 2020
Published: November 8, 2020

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INTRODUCTION

Indonesia is a maritime-based nation which is two-third of the area are high seas. Seas are one of the biggest resources than Indonesia has from its seafood to its energy potential. According to Paris Convention to reduce greenhouse gas emissions then Indonesia plans to achieve 23% of renewable energy use by 2025 and reach 31% by 2050. One of the sources is to use the sea as a source of targeted current energy reach 3.1 GW in 2025 [1, 2, 3, 4].

In 2017, BPPT Hydrodynamics Technology Center (BTH-BPPT) conducted a double shaft turbine performance test at Suramadu Bridge, which observed the amount of rotor rotation and the electric power generated as a function of the speed and direction of ocean currents. The results of the study are an initial reference for further research about sea current electric power plant in Indonesia [5]. Research by Kanyako & Janajreh shows the comparisons of NACA blades profile and the number of the profile power coefficient. By this research, NACA 0018 was chosen because of its best capability to provide the best starting torque compared to NACA 0015 and NACA 0021. Three blades configuration was used because of its better power coefficient compared to four blades, even though two blades are better for its power coefficient. Meanwhile, two blades provide least starting torque compared the other two [6, 7, 8].

In this research, an investigation to analysis Savonius-Darrieus Turbine design using Computational Fluid Dynamics (CFD) approach was presented. The CFD Analyze 2D Model of the Savonius-Darrieus Turbine with variations of velocity for the environment and the angle of attack of the hydrofoil. The Savonius-Darrieus Turbine was chosen due to overcome negative start off torque problem in the Darrieus Turbine [9] [10]. Basically, this research by changing the Darrieus Turbine to the Savonius-Darrieus Turbine aim for seeing the effect of Savonius Rotor addition with an angle of attack variation [11] [12].

METHOD

Geometry Modeling and Meshing

The geometry of the 2D model was created using Autodesk Inventor software and then exported to ANSYS Fluent to do the simulation. The geometry 2D model was used because of the unchanged surface towards height. The simplicity solution had done to minimalize the use of the computer's RAM when meshing activity, so the high accuracy of the mesh and data collecting can be obtained.

The Geometry consists of two parts, as depicted in Figure 1, which is an enclosure and rotating part. Separation of the two parts had done to turn one of the parts and keep the other part to not turning. In this case, the turning part is rotating, which is representing the turbine itself. The enclosure part represents the free stream fluid or sea current in terminology.

After doing trials and errors when collecting the data, variations of the geometry were determined to find the most optimum geometry. This research simulates the turbine with variations of Tip Speed Ratio (TSR) and the angle of attack of the hydrofoil. Details of the variations of the geometry that determined to find the most optimum geometry [13] [14], as explained in Table 1.

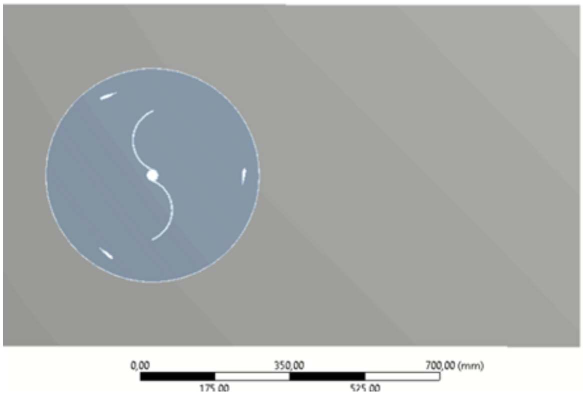

Figure 1. Turbine Model Geometry

From Table 1, the variations of velocity speed of the flow were put, while the rotational speed and the radius of the turbine remaining constant. From those variations, the optimum point for the TSR value was obtained.

Meshing or grinding is a discretization of the continuous fluid domain into discrete computation so the CFD numerical solution can be done using the ANSYS FLUENT software to obtain the solutions such as speed, pressure, fluid contour, and other solutions for each of the discrete domain [14, 15, 16].

Table 1. Variations of Velocity of Turbines for Simulation

v (m/s)	1.5	0.75	0.5	0.428	0.375
ω (rad/s)			10		
r (m)			0.214		
TSR	1.42	2.85	4.28	5	5.71

Where

- v : Speed of the free stream flow (m/s)
- ω : Rotational speed of the turbine (rad/s)
- r : Radius of the turbine (m)
- TSR : Tip Speed Ratio, calculated by v, ω, and r

Figure 2 shows the visualization of the meshing result. The meshing process settings use multi-zone (quad) to create the computation domain dominated by hexahedral or square mesh. This shape is ideal by its resolution and the efficiency when creating a detail mesh without using much element in total, so the use of the RAM will be saved [14]. While the dimension of the mesh, we choose maximum 3mm for the entire computation domain.

Computational Fluid Dynamic (CFD)

The numerical data solution using CFD method with ANSYS Fluent software had done to find each torque of the geometry variations. The input parameter is very important for the credibility of the data we obtained. For this research, the SST κ-ω models were used because of the ease of convergent data can be obtained with the flows that pressure gradients tend to be unnatural like compressors, pumps, turbine and other related things and details of the parameter shown in Table 2.

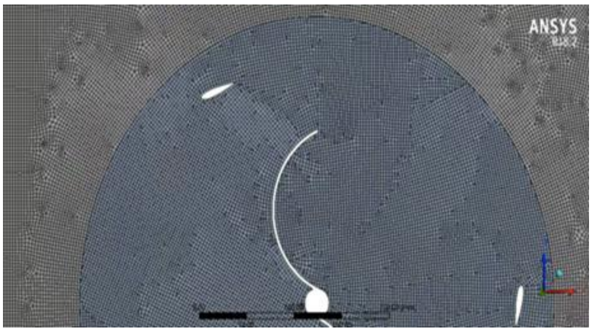

Figure 2. Meshing Visualization

Table 2. Parameter of Simulations

Time	Transient
Viscous	*SST* κ-ω [14]
Material	Water liquid (ρ = 1025 kg/m^3)
Cell Zone Conditions	Mesh Motion, (ω = 10 rad/s)
Inlet	Velocity inlet (V, free stream velocity)
Mesh Interface	Matching (Interface between the enclosure and rotating part)
Initialization	Hybrid
Time step size	0.01 s
Number of time step	50
Max iteration / time step	20, With total 1000 (50x20) iterations had done to obtain convergent data

RESULTS AND DISCUSSION

After the simulation process was finished, data solutions of the fluid were processed using ANSYS results. Taken parameters in this simulation are the velocity distribution plot, pressure distribution plot, and the torque obtained by the turbine every 0.04 s of time step to measure the performance of the turbine quantitatively.

From Figure 3, the Velocity distribution plot shows that fluid flows in the inner Savonius rotor area tend to be slower (±1.017 m/s) than the outer rotor. Slower speed shows stagnation area or an area with higher pressure that produces force linearly with the turbine turning direction. Higher velocity (±3.044 m/s) founded in the outer region of the rotor.

Pressure distribution from Figure 4 shows that stagnation phenomenon, as explained from the previous paragraph. In the inner rotor Savonius, the pressure tends to be higher (±560.968 Pa) that produces force to turn the turbine rotor. While at the hydrofoil, higher pressure produced at the lower area, which produces lift force of the hydrofoil to contribute extra torque for the turbine globally.

Modelling, design and simulation of the turbine geometry with variations of the hydrofoil angle of attack were analyzed using CFD software ANSYS Fluent. Because of behavior of the fluids, the torque of the turbine was obtained.

Torque data collected per 0.04s of the time step, which is represented as 22.5° of the turbine position angles. Whereas performance of the turbine was determined by average torque of the turbine itself.

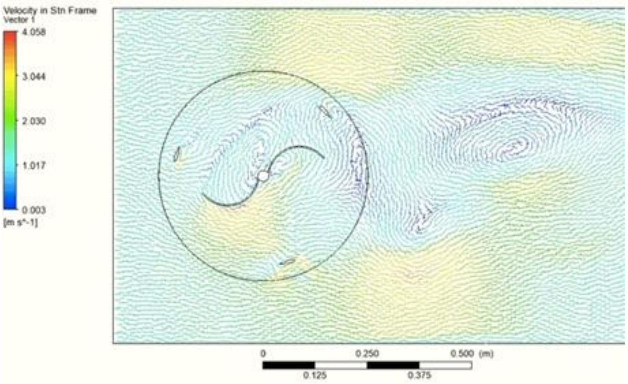

Figure 3. Velocity Distribution Plot

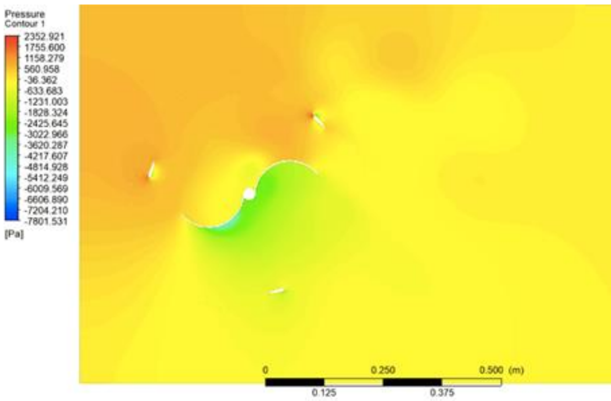

Figure 4. Pressure Distribution Plot

Torque values from Table 3, Table 4, and Table 5 concluded that the values changing related to its angle position. 180° turn of the turbine represents the torque values of the [17] turbine globally. The differences in torque values related to TSR values influenced by the parameter of the TSR itself as explained [17].

Table 3. Torque Values against Position Angle for 0° Angle of Attack

α (°)	T (N.m.) λ 1.427	2.53	4.280	5.000	5.707
0	58.766	11.484	0.440	-6.313	-10.476
22.5	53.347	8.081	1.666	-6.313	-7.809
45	40.779	-1.899	-2.283	-6.191	-6.009
67.5	-11.27	-11.60	-5.157	-2.926	-2.825
90	-22.41	-14.05	-2.692	0.666	0.902
112.5	13.477	-4.464	-0.638	0.263	0.994
135	35.288	10.195	2.734	8.730	3.738
157.5	46.152	17.415	10.081	13.470	8.532
180	33.153	20.737	15.833	13.470	11.692
Average	27.476	3.989	2.221	1.650	-0.140

Table 4. Torque Values against Position Angle for 5° Angle of Attack

α (°)	T (N.m.) λ 1.427	2.853	4.280	5.000	5.707
0	48.104	10.296	5.609	-0.271	-2.594
22.5	36.764	6.470	5.432	-1.243	-1.514
45	-5.161	-0.852	0.454	-1.556	-3.252
67.5	-25.54	-6.516	-0.773	-0.462	-2.035
90	-13.74	-6.182	0.393	2.503	0.066
112.5	20.469	3.869	0.507	9.045	-0.042
135	39.899	12.788	3.150	12.322	3.256
157.5	36.753	15.849	9.742	8.690	8.884
180	23.206	16.737	14.153	3.927	11.042
Average	17.862	5.829	4.296	3.661	1.534

Table 5. Torque Values against Position Angle for 10° Angle of Attack

α (°)	T (N.m.) λ 1.427	2.853	4.280	5.000	5.707
0	48.104	10.296	5.609	-0.271	-2.594
22.5	36.764	6.470	5.432	-1.243	-1.514
45	-5.161	-0.852	0.454	-1.556	-3.252
67.5	-25.54	-6.516	-0.773	-0.462	-2.035
90	-13.74	-6.182	0.393	2.503	0.066
112.5	20.469	3.869	0.507	9.045	-0.042
135	39.899	12.788	3.150	12.322	3.256
157.5	36.753	15.849	9.742	8.690	8.884
180	23.206	16.737	14.153	3.927	11.042
Average	17.862	5.829	4.296	3.661	1.534

Where
T : Torque obtained (N.m)
λ : Tip Speed Ratio
α : Position Angle (°)

The coefficient of power obtained by the power that the turbine produces against the potential energy that the fluid gives. Coefficient of power equations can be seen in (1) [17]. The results were expressed in Table 6.

$$C_{power} = T\,\omega \,/\, (½\, A v^3) \quad (1)$$

Where
C_{power} : Coefficient of power
ω : angular velocity (rad/s)
ρ : density of sea water (1025 kg/m^3)
A : Turbine Swept Area (m^2)
V : sea water flow speed (m/s^2)

From the coefficient power calculation results, the most optimum efficiency is from turbine geometry with a 5° angle of attack valued 0,469. Meanwhile, the turbine with the smallest efficiency was obtained by turbine geometry with a 10° angle valued 0,206. The comparisons between the results are shown in Figure 5.

Table 6. Calculation Results of the Power Coefficient

α (°)	Cp λ 1,427	2,853	4,280	5,000	5,707
0°	0.082	0.095	0.178	0.211	-0.027
5°	0.053	0.139	0.345	0.469	0,292
10°	0.026	0.082	0.206	0.183	0,034

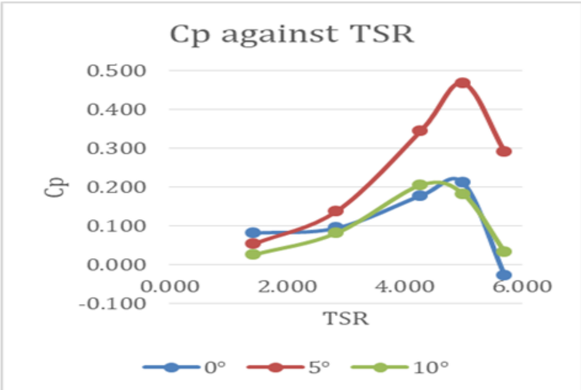

Figure 5. Comparations between Cp and the TSR for the Geometries

The addition of the Savonius Rotor results in increasing efficiency of the turbine for sea current applications and wind power [11, 16, 18]. From the same geometry and variations, the Darrieus Turbine obtained 0.228 of power coefficient when the TSR valued 5.7. Meanwhile, Savonius-Darrieus Turbine can obtain as high as 0.469 of power coefficient, which is almost twice as much power can be obtained with the same geometry. The comparisons between the two turbines can be seen in Figure 6.

The character of the power of that both turbines produces is the key why Savonius-Darrieus Turbine can be more efficient than the Darrieus Turbine. Figure 7 shows that Savonius-Darrieus Turbine produces power more evenly distributed when angle position at 90°-270°. Meanwhile, the Darrieus Turbine produce power when the angle position at 90°- 157.5° and then 202.5° - 270°.

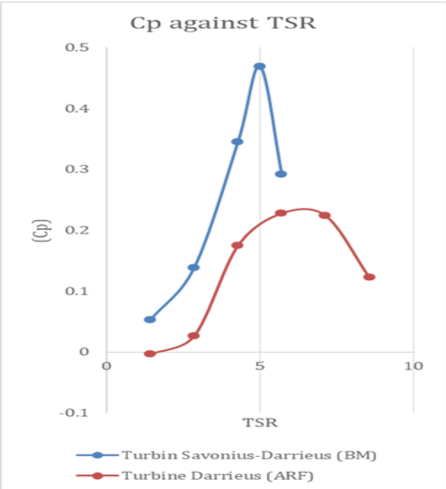

Figure 6. Cp against TSR for both Turbines

Maximum power coefficient valued 0.469 of turbine geometry with a 5° angle of attack with TSR valued five was used to be as a reference to calculate turbine power. Angular speed calculation affects the turbine to obtain maximum power. To simulate the potential turbine power, 1 - 2 m/s flow speed was used in the calculation. The calculation results of the power and the angular speed of the turbine shown in Table 7, using (2) and (3) respectively [17]. Table 7 shows the data that increasing flow velocity will have an impact on the increase in turbine power. The condition is following the results of Seno's research, which states the greater value of RPM and torque give the higher speed value and also gives the greater value of the power [19]. Meanwhile, overall design, according to this research, was explained in Table 8.

$$P_{turbine} = Cp \times \rho \times ½ Av^3 \quad (2)$$

$$TSR = \omega R/v \quad (3)$$

Where
$P_{turbine}$: Turbine Power
Cp : Turbine Power Coefficient
ρ : Sea Water Density
A : Swept Area of the Turbine
v : Fluid Flow Speed
R : Turbine Radius
ω : Turbine Angular Speed

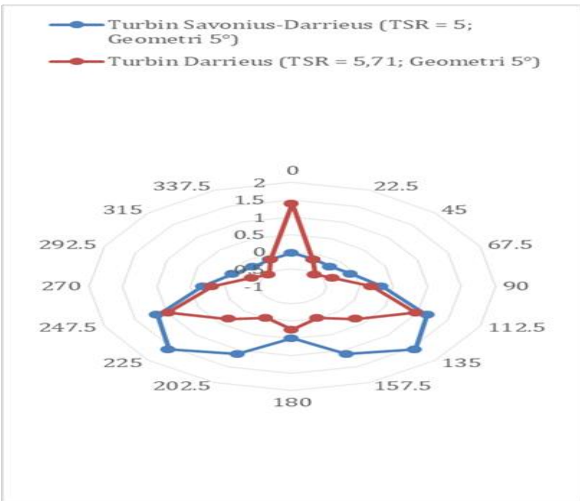

Figure 7. Cp Obtained from Various Angle Position

Table 7. The effects of the Flow Speed against Turbine Power

V = 1 - 2 m/s			
v (m/s)	ω (rad/s)	P_{water} (Watt)	$P_{turbine}$ (Watt)
1	23.364	338.137	158.507
1.25	29.206	660.424	309.584
1.5	35.047	1141.212	534.961
1.75	40.888	1812.203	849.498
2	46.729	2705.096	1268.055

Table 8. Dimensions of The Design

Dimensions of the Darrieus Rotor	
Diameter	428 mm
Span Length	357 mm
Angle of Attack	5°
Number of Blades	3
Hydrofoil Geometry Type	NACA 0018
Chord Length	40 mm
Dimensions of the Savonius Rotor	
Diameter	304 mm
Span Length	300 mm
Number of Blades	2
Bucket Spacing	0 mm
Design Results	
C_{power} Optimum	0.469
TSR	5
Turbine Area	0.66 m^2

CONCLUSION

This research concluded that the design of the Savonius-Darrieus Turbine has optimum power coefficient 0,469. Then the coefficient was achieved when the turbine TSR value is five, and the angle of attack is 5°. The drawings for this turbine are finished and ready for full-scale production.

ACKNOWLEDGMENT

We thank our institution Universitas Trisakti for supporting our research.

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