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Jurnal Dinamis (*Scientific Journal of Mechanical Engineering*)
Journal homepage: https://talenta.usu.ac.id/dinamis/

Analysis of Deflector Variations to Improve Performance and Determine the Force of the Darrieus Turbine Using CFD Software

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ARTICLE INFO

Article history:
Received Novemner 12th 2024
Revised Novemner 17th 2024
Accepted June 29th 2025
Available online June 30th 2025

E-ISSN: 2809-3410

How to cite:
Edy Susanto. Hotdian Sinambela . Erwin Erwin, "Analysis of Deflector Variations To Improve Performance and Determine the Force of the Darrieus Turbine Using CFD Software" *Junal Dinamis (Scientific Journal of Mechanical Engineering)*, Vol. 13, No. 1, pp. 45-52, June 2025.

ABSTRACT

This research focuses on developing deflectors to improve the performance of Darrieus turbines, a type of vertical wind turbine known for its efficiency in the conversion of wind energy into mechanical energy. The main objective of this research is to test different deflector shapes to optimize the airflow entering the turbine blades and improve the efficiency and power output of the turbine. In this study, various deflector designs including semicircular, triangular, rectangular, hexagonal, and pentagonal shapes were examined to determine their effectiveness in directing and accelerating airflow to the turbine blades. The research method involved aerodynamic simulations using CFD software. The results showed that the semicircular-shaped deflector provided significant performance improvement compared to the other shapes. These deflectors successfully reduced turbulence and drag, and accelerated the airflow entering the turbine blades, thereby increasing the overall power output of the Darrieus turbine. In addition, the analysis shows that at 17.5, 10.5, and 8.5 m/s calculations, at 8.5 m/s wind speed calculation, the air speed can reach 30.1% with a force of 7.30344 N, and 10.5 m/s speed can reach 24.3390476% with a force of 11.361 N, and 17.8 m/s wind speed can reach 20.676% with 25.638 N force.

Keyword: *Deflector, Turbine, Simulation, wind energy, Darrieus*

ABSTRAK

Penelitian ini berfokus pada pengembangan deflektor untuk meningkatkan kinerja turbin Darrieus, jenis turbin angin vertikal yang dikenal karena efisiensinya dalam mengubah energi angin menjadi energi mekanik. Tujuan utama penelitian ini adalah untuk menguji berbagai bentuk deflektor untuk mengoptimalkan aliran udara yang masuk ke bilah turbin dan meningkatkan efisiensi dan daya keluaran turbin. Dalam studi ini, berbagai desain deflektor termasuk bentuk setengah lingkaran, segitiga, persegi panjang, heksagonal, dan pentagonal diperiksa untuk menentukan efektivitasnya dalam mengarahkan dan mempercepat aliran udara ke bilah turbin. Metode penelitian melibatkan simulasi aerodinamis menggunakan perangkat lunak CFD. Hasil penelitian menunjukkan bahwa deflektor berbentuk setengah lingkaran memberikan peningkatan kinerja yang signifikan dibandingkan dengan bentuk lainnya. Deflektor ini berhasil mengurangi turbulensi dan hambatan, dan mempercepat aliran udara yang masuk ke bilah turbin, sehingga meningkatkan daya keluaran keseluruhan turbin Darrieus. Selain itu, hasil analisis menunjukkan bahwa pada perhitungan 17,5, 10,5, dan 8,5 m/s, pada perhitungan kecepatan angin 8,5 m/s, kecepatan udara dapat mencapai 30,1% dengan gaya 7,30344 N, dan kecepatan angin 10,5 m/s dapat mencapai 24,3390476% dengan gaya 11,361 N, dan kecepatan angin 17,8 m/s dapat mencapai 20,676% dengan gaya 25,638 N.

http://doi.org/10.32734/dinamis.v13i1.18833

Kata Kunci: Deflector, Turbin, Simulasi, energi angin, Darrieus

1. Introduction

The increasing global demand for renewable energy has intensified research to optimize wind turbine technology [1]. Among the various designs, the Darrieus turbine—the vertical-axis wind turbine (VAWT) [2,3]—has attracted significant interest due to its omnidirectional operation, structural simplicity, and potential for urban integration [4]. However, the Darrieus turbine has inherent limitations, including poor self-starting capability, low torque generation, and highly variable aerodynamic performance under turbulent wind conditions [5]. These challenges have prompted investigations into flow control mechanisms, particularly deflector systems, to improve turbine efficiency by optimizing the oncoming wind flow [6].

The deflector serves as a passive flow control device that directs and accelerates the wind toward the turbine blades, thereby improving the effective wind speed and rotor torque characteristics [7,8,9] Its geometric configuration—including angle, curvature, and placement—plays a critical role in determining the degree of performance improvement [10]. Recent advances in Computational Fluid Dynamics (CFD) have enabled detailed analysis of deflector-turbine interactions, providing insight into flow separation, pressure distribution, and vortex dynamics that affect power output [11]. CFD simulations offer a cost-effective way to evaluate multiple deflector designs prior to experimental validation, significantly reducing development time and resources [12,13].

This study aims to systematically analyze the impact of deflector variations—including flat, curved, and multi-element designs—on the aerodynamic performance of a Darrieus turbine. Using transient CFD simulations with Reynolds-Averaged Navier-Stokes (RANS) turbulence modeling, we measure improvements in torque generation [14], power coefficient (Cp), and force distribution across the turbine blades. These findings will contribute to the optimization of deflector-augmented Darrieus turbines for low wind speed environments, especially in urban and coastal areas where conventional designs perform poorly.

1.1. Principles And Systems of Wind Farm

Wind turbines, or also known as wind farms, are one type of renewable energy source that is environmentally friendly and very efficient compared to other renewable energy sources. The working principle of wind turbines is to utilize the kinetic energy of the wind that enters the wind turbine area to rotate the rotor or wind turbine [15]. This rotational energy is forwarded to the generator which produces electrical energy. This renewable power plant utilizes wind to generate electricity. The main device is a generator that can generate power from the wind. This system is more efficient in producing electrical energy than solar power plants and has a superior stack size. This installation cannot be done in all locations, because the installation location must have a relatively high and stable wind speed. The process of generating energy from the wind begins when the wind moves towards the turbine blades. When the wind hits the turbine blades, the kinetic energy contained in the wind causes the turbine blades to rotate. This rotation of the turbine blades transfers kinetic energy into mechanical energy by moving the rotor. In some cases, an optional gearbox is used to adjust the rotor rotation speed to suit the needs. The rotating rotor then drives a generator, which converts the mechanical energy into electrical energy. The electrical energy produced by the generator is further boosted by a transformer. After this process, the voltage-enhanced electricity is fed into the grid for distribution to end users, allowing the energy from the wind to be used efficiently. To explain the wind farm system, it can be seen in Figure 1.

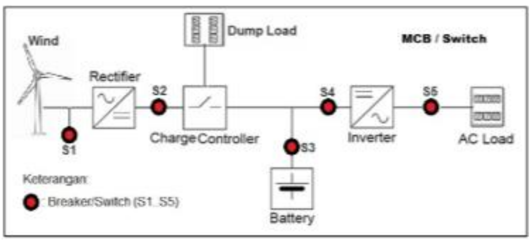


Figure 1. Wind Farm Cycle

All tables should be numbered with Arabic numerals. Every table should have a caption. Headings should be placed above tables, left justified. Only horizontal lines should be used within a table, to distinguish the column headings from the body of the table, and immediately above and below the table. Tables must be embedded into the text and not supplied separately. Below is an example which the authors may find useful.

1.2 Wind turbine power theory

Wind energy can define that the energy contained in the wind by movement, it is called kidnetic energy. It depends on the speed of the moving fluid and its mass; kinetic energy can be calculated by:

$$KE=\frac{1}{2}\cdot m\cdot U^2 \quad (1)$$

By: m = Fluid mass (kg)
U^2= Square of wind speed (m/s)

The level of kinetic energy in the flow is called wind force. As talking about wind (fluid fluid). The kinetic force can be calculated by:

$$P=\frac{dm}{dt}\cdot U^2 \quad (2)$$

By: ρ = Wind density (kg/m³)
dm = Turbine blade diameter (m)
dt = Time duration (s)
U^2= Square of wind speed (m/s)

In the test conducted, the number of blades checked was 3 blades. The calculation data carried out is actual public data from the PLN Institute of Technology.

Cross-Sectional Area (A)

$$A=D\cdot h \quad (3)$$

By : A = Cross-Sectional Area (m^2)
H = Blade height (m)
D = turbine diameter (m)

Loading Force (F)

$$F=m\cdot g \quad (4)$$

By : F = Loading Force (N)
m = massa / beban (kg)
g = Percepatan gravitasi (m/s^2)

Wind Power (Pw)

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

By : Pw = Wind Power (kg/m^3)
ρ = Wind density (m^2)
A = Cross-sectional area (m^2)
V = Wind speed (m/s^2)

Torque (τ)

$$\tau=F\cdot r \quad (6)$$

By : τ = Torque (N.m)
F= Loading force (N)
R= radius (m)

Angular Velocity (ω)

$$\omega = \frac{2\pi n}{60} \quad (7)$$

Dengan : ω = Angular velocity (rad/s)
n = Turbine rotation (rpm)
π = Environmental constant (3.14)

Turbine Power (P_T)

$$P_T = \tau \cdot \omega \quad (8)$$

By : P = Pinwheel power (Watt)
τ = Torque (N.m)
ω = Rotation of windmill rotation (Rad/s)

Turbine Efficiency (η)

$$\eta = \frac{PT}{PW} \times 100\% \quad (9)$$

Dengan : η = Turbine Efficiency (%)
P_T= Turbine power (Watt)
P_W= Wind power (Watt)

Renold (P)

$$P = \frac{1}{2} \cdot \rho \cdot A \cdot v3 \cdot Cp \quad (10)$$

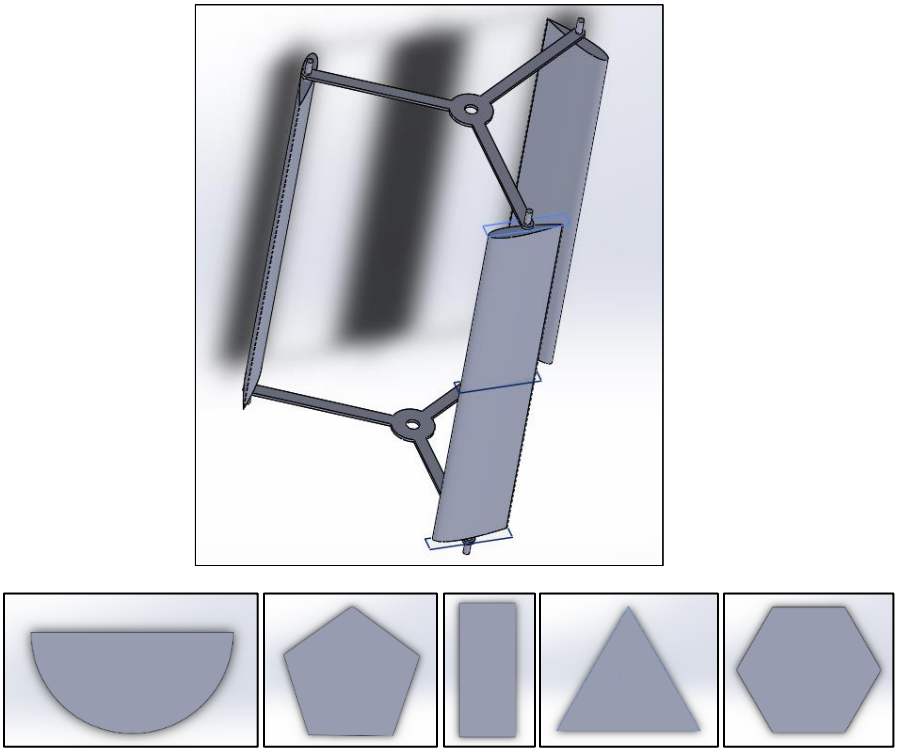
By :P = power generated (Watt)
P = air density (kg/m³)
A = cross-sectional area of the turbine rotor (m²)
v = wind speed (m/s)
Cp = turbine power coefficient (turbine efficiency, generally no more than 0.59 for an ideal turbine, known as the Betz limit)

2. Methods

In this method, the author gets data by taking data at the campus laboratory. Data obtained from observations and data collection will be processed using CFD software.

Table 1. Darrieus Turbine Spesification.

Turbine parameters	Description	Unit
Turbine diameter	0.54	m
Turbine height	0.71	m
Number of turbine blades	3	
Turbine blade width	0.125	m
Blade length	0.16	m
Cross-section area	0.1962	m



(A) (B) (C) (D) (E)

Figure 2. Deflector shapes of semicircle (A), pentagon (B), quadrilateral (C), Triangle (D), and Hexagon (E)

The placement of the deflector is in front of the wind turbine as far as ± 1433 mm against the turbine shaft. Thus, the flowing air will hit the deflector first before the wind turbine. The air flowed during the simulation has a speed of 17.5 m/s.

3. Results and Descussion

3.1. Simulation with tringular deflector

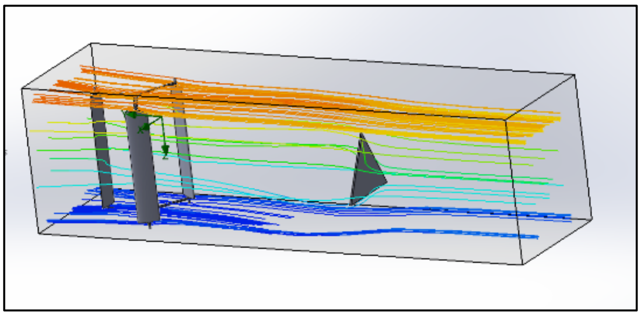


Figure 3. Simulation of Triangular Deflector

Table 2. Data Obtained for Triangular Deflector.

Name	Current value	Unit
Average Turbulance intensity	6.80382 %	%
Average velocity	16.0519 m/s	m/s
Force	36.5129 N	N
Maximum Velocity	19.3206 m/s	m/s
Torque (X)	-0.246 N*m	Nm
Torque (Y)	0.0238	Nm
Torque (Z)	0.792	Nm

In the simulation conducted with an airflow velocity of 17.5 m/s, there was an increase in the maximum airflow velocity by 10.4034286%. And the average turbulence intensity that occurs at that speed is 6.80382%

because it hits the rectangular deflector. The calculation of the percentage speed increase can be calculated:

$$\frac{19.3206\text{-}17.5}{17.5}\times 100=10{,}4034286\ \%$$

3.2. Simulation with Pentagon deflector

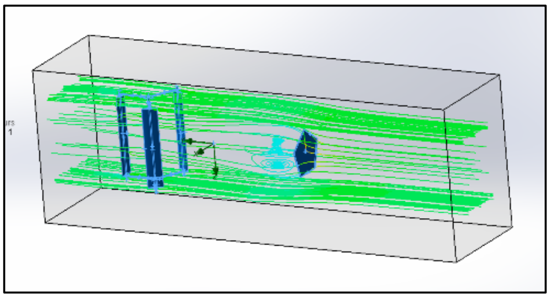


Figure 3.2 Simulation of the Pentagon Deflector

Table 3. Data Obtained for Pentagon Deflector.

Name	Current value	Unit
Average Turbulance intensity	12.5409	%
Average velocity	15.3551	m/s
Force	36.5817	N
Maximum Velocity	20.3778	m/s
Torque (X)	-0.221	Nm
Torque (Y)	0.413	Nm
Torque (Z)	0.712	Nm

In the simulation conducted with an airflow velocity of 17.5 m/s, there was an increase in the maximum airflow velocity of 16.4445714%. And the average turbulence intensity that occurs at that speed is 12.5409% because it hits the pentagon-shaped deflector. The calculation of the percentage speed increase can be calculated:

$$\frac{20.3778\text{-}17.5}{17.5}\times 100=16.4445714\%$$

3.3. Simulation with Hexagon Deflector

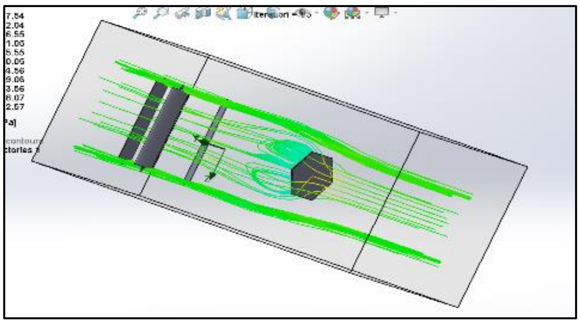


Figure 3. Simulation of the hexagon Deflector

Table 3. Data Obtained for Hexagon Deflector.

Name	Current value	Unit
Average Turbulance intensity	12.8536	%
Average velocity	15.4458	m/s
Force	38.1392	N
Maximum Velocity	19.2035	m/s
Torque (X)	-0.9381	Nm
Torque (Y)	-0.0969	Nm

Name	Current value	Unit
Torque (Z)	-1.346	Nm

In the simulation conducted with an airflow velocity of 17.5 m/s, there was an increase in the maximum airflow velocity of 9.7342857%. And the average turbulence intensity that occurs at that speed is 12.8536% because it hits the hexagon-shaped deflector. The calculation of the percentage speed increase can be calculated:

$$\frac{19.2035-17.5}{17.5}\times 100=9.7342857\%$$

3.4. Simulation with half-cicle deflector

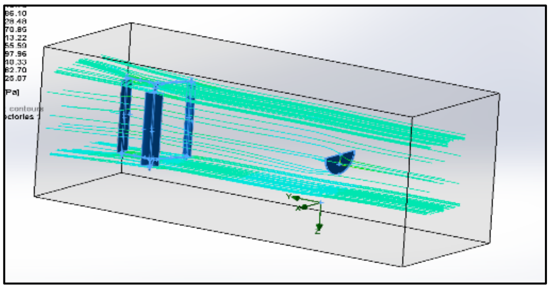


Figure 3. Simulation of the Half-Cicle Deflector

Table 3. Data Obtained for *Half-Cicle* Deflector.

Name	Current value	Unit
Average Turbulance intensity	5.08393	%
Average velocity	16.1928	m/s
Force	25.638	N
Maximum Velocity	21.1183 s	m/s
Torque (X)	-1.10046	Nm
Torque (Y)	-0.00061	Nm
Torque (Z)	-0.246	Nm

In the simulation conducted with an airflow velocity of 17.5 m/s, there was an increase in the maximum airflow velocity of 20.676%. And the average turbulence intensity that occurs at that speed is 5.08393% because it hits the semicircular deflector. The calculation of the percentage speed increase can be calculated:

$$\frac{21.1183-17.5}{17.5}\times 100=20.676\%$$

4. Conclusion

From the simulations conducted to analyze the effects of deflector shape and wind speed on airflow velocity enhancement, several key findings emerge. The deflector's geometry significantly impacts Darrieus turbine performance by optimizing airflow distribution, minimizing turbulence, and improving load efficiency. Through systematic simulations, the half-circle deflector design demonstrated superior effectiveness compared to other configurations. Specifically, at a wind speed of 8.5 m/s, this deflector increased airflow velocity by 30.1%. Similarly, at 10.5 m/s, the enhancement reached 24.33%, while at 17.8 m/s, a 20.67% improvement was observed. These results underscore the critical role of deflector shape in maximizing turbine efficiency across varying operational conditions, with the half-circle design proving consistently optimal.

5. Acknowledgements

The author would like to thank all parties who have supported and assisted in the preparation of this research, including the Faculty of Energy Technology and Business, Mechanical Engineering Study Program..

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