NTU Journal for Renewable Energy (2025) Vol. 8 (1): 51-56
DOI:https://doi.org/10.56286/fqtkxt88

IRAQI Academic Scientific Journals

ISSN: 2788-9912 (print); 2788-9920 (online)
NTU Journal for Renewable Energy
Available online at:
https://journals.ntu.edu.iq/index.php/NTU-JRE

Enhancement of small wind turbine efficiency by using nozzle at entrance

Zahra Adnan Shawket[1], Suad Hassen Danok[2]
[1]Northern Technical University, Technical Engineering College, Kirkuk, Iraq.
[2]Imam Ja'far al-Sadiq University, Kirkuk, Iraq.

Article Information

Received: 13 February 2025
Received in Revised form: 30 February 2025
Accepted: 23 March 2025
Published: 12 April 2025

Corresponding Author:
Zahra Adnan Shawket

Email:
zahra.adnangs2022@ntu.edu.iq

Keywords: Parabolic trough collector, Porous insert, Aluminum porous medium, The tracking system.

ABSTRACT

Wind energy is among the most economical energy sources available nowadays. Renewables, such as wind and solar energy, have become key elements of the global energy mix. Wind energy can generate large amounts of electrical energy through wind turbines that exploit the movement of air. In this study, a horizontal-axis wind turbine was simulated to measure its productivity according to the weather conditions of the city of Kirkuk and increase its efficiency when supported by a nozzle. the wind speed equation was applied to the entrance of a wind turbine, and the effect of narrowing the section area was described by a nozzle in front of the entrance to the turbine through pressure and speed distribution lines. The effect of turbine efficiency was studied after supporting it with a nozzle, narrowing the section area. The system was simulated using the ANSYS 2024 simulation program (Fluid Flow CFX). The turbine was designed in the form of a uniformly loaded engine disc to find the most efficient turbine.

1. Introduction

Wind turbines are rotating devices that convert wind energy into mechanical energy, and they are the most common way to use wind energy to generate electricity [1,2]. Researchers are currently working to increase wind power capacity so that it can be stored for use during low-wind periods [3,4,5,6].

Global wind capacity has grown significantly over the past decade, rising from 238 GW in 2011 to 845 GW in 2021. New capacity is being added to the grid every year, with 56 GW added in 2021 alone, as shown in Figure (1)[7]. This growth in wind capacity is attributed to a combination of factors, including falling costs, support for government policies, and growing demand for renewable energy.

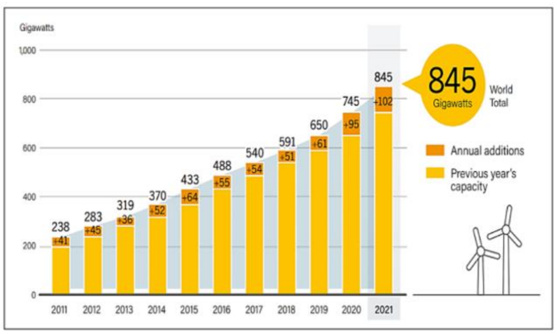

Figure (1) Grown of wind capacity

Wind energy

Wind arises as a result of the sun's uneven heating of the earth's surface. The Earth absorbs the sun's heat at different rates due to the diversity of its terrain between land and ocean. During the day, air over land heats up faster than air over water. As warm air expands over land and rises, colder, heavier air rushes in to replace it, resulting in wind. Wind is calmer at night because the air cools on land faster than water. Warming lands closer to the equator than lands near the North and South Poles lead to the formation of strong air currents orbiting the planet. Thanks to its infinite wind-blowing power, wind energy is one of many renewable energy sources[8].

The process of generating energy from wind is very simple, as kinetic energy is converted into mechanical energy. Wind turbines are commonly used to generate electrical power. Wind energy is one of the renewable and economical energies, and its impact on the environment is much lower compared to fossil fuels.

Wind flow is essential to the economy of this sector, in addition to the aerodynamic performance of turbines, as a turbine's output power is directly related to the cubic wind speed[9] .This indicates that a slight increase in wind speed results in a considerable rise in power production. Many researchers have, therefore, attempted to improve the turbine rotors' wind speed. The economic feasibility of the wind energy sector has shown intriguing results in ducted turbines, which have turbine rotors encircled by a chamber to funnel airflow into the system and boost the wind speed in the rotors [10,11,12].

In 1956, Lilly and Rainbird [13] conducted the first investigation into ducted wind turbines (DWTs). Taking into account the head loss through the diffuser, they were able to determine the power gain of shrouded turbines. Numerous numerical studies have examined the impact of adding a flange and different diffuser and nozzle (inlet) profiles [14,15,16].

Simulation of the nozzle and turbine model

In this part, the ANSYS-CFX software is used to simulate and analyze the aerodynamic performance of different models. The simulation involves a turbine independently, and the simulation of the nozzle with the turbine is performed at variable air speeds (0.5, 1, 3, 6 m/s). The simulation aims to study the air velocity and the distribution of speed and pressure in and around the nozzle and turbine and to analyze the improvement of the overall performance of the turbine as a result of adding a nozzle.

The nozzle is made of aluminum and has a total length of 4 m. The radius of the inlet air is 200 cm, while the radius gradually decreases to 100 cm at the outlet air.

The turbine model was designed using the SolidWorks 2023 software, relying on the NACA 4412 air wing section recommended by former researcher Yaumao [17]. The blade is 965 mm long, and it has been divided into multiple sections along it, where the geometric shape of each section is determined based on the design data of the turbine, as shown in Figure (2); each clip is precisely designed according to the data, and combined to create the final shape of the feather. After that, the hub was designed, and three blades were installed on it to complete the turbine completely as shown in Figure (3). This design aims to achieve maximum aerodynamic efficiency of the turbine when combined with a pre-designed nozzle, as shown in figure (4). This model is considered the basis for conducting aerodynamic simulations and analyzing the performance of the turbine in various conditions.

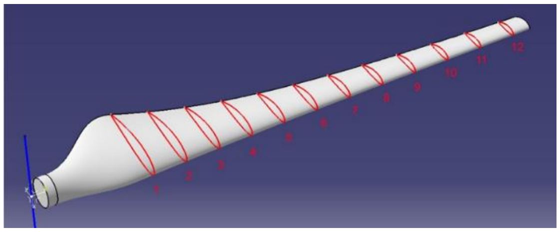

Figure (2) Blade design of turbine

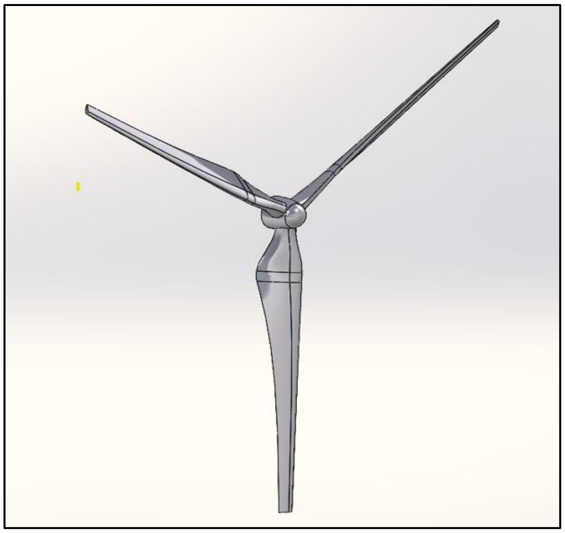

Figure (3) Designed turbine

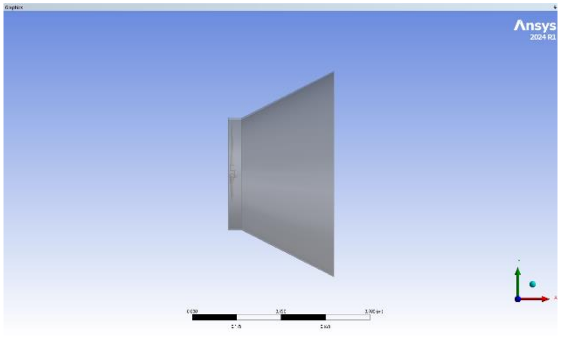

Figure (4) Nozzel design

Wind turbine performance and power calculations

The performance of wind turbines and the analysis of the resulting energy are key aspects of studying the efficiency of the turbine and the nozzle. Wind energy is a source of mechanical energy for turbines, and the energy produced can be determined using the relationship between angular torque and rotational speed, as shown in the equation below:

Pout = Tω

Where:

Pout: Output power (W)

T: Torque (N·m)

ω: Angular velocity (rad/s)

Power factor (CP) is a measure of the efficiency of a turbine in converting wind kinetic energy into mechanical or electrical energy. As shown in the equation below:

$$C_P = \frac{P_{out}}{0.5\ \rho\ A\ V_\infty^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:

ρ :density of air (kg/m³)

A: the area of the sectional surface of the rotor (m²)

V_∞ : Wind speed at the entrance (m/s)

The ratio of the velocity of the terminal λ is one of the most important measures for analyzing turbine efficiency, and the following relationship defines it:

$$\lambda = \frac{\omega R}{V_\infty} \quad \text{...(2)}$$

Where:

R: rotor radius (m).

For further analysis, the torque coefficient (CT) can be used as a measure of turbine performance, expressed as follows:

$$C_T = \frac{Actual\ torque}{Theortical\ torque} = \frac{T}{0.5\ \rho\ A\ R\ V_\infty^2} = \frac{C_P}{\lambda} \quad ..(3)$$

These equations represent the theoretical basis for analyzing the performance of wind turbines in this work. Power (CP) torque (CT), and tip velocity ratio (λ) are used to evaluate turbine efficiency

Results and Discussion

Turbine results without a nozzle

When simulating a turbine without a nozzle, the results showed that the power factor Cp and the output power Pout are significantly affected by different air velocities. At an entry speed of 0.5 m/s, the CP peaked at 0.24 at a tip speed ratio of 2.50, with an output power of 11.33 watts, while decreasing to 0.19 at 3.00. At 1 m/s entry speed, performance improved slightly, with a maximum CP value of 0.25 at λ=2.50 with an output power of 11.6 watts. At an entry speed of 3 m/s, the turbine showed the best performance, with (CP) peaking at (2.50) at a value of 0.27, with an output power of 12.72 watts, giving optimal efficiency at this speed. At 6 m/s, Cp peaked at λ=2.50 at 0.26, with an output power of 12.03 watts, but performance decreased at λ=3.00 to Cp=0.22. These results show that the turbine operates more efficiently at medium speeds (3 m/s), where the highest efficiency is achieved at λ=2.50, while the efficiency decreases at higher speeds due to the effects of aerodynamics.

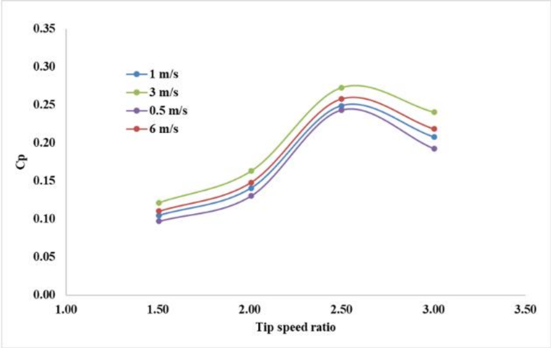

Figure (5) Curve Cp for turbine without nozzle

Turbine Results with Nozzle

When the nozzle is operated with the turbine without the influence of solar radiation, the results showed that different air velocities significantly affect the power factor Cp and the output power Pout. At an entry speed of 0.5 m/s, CP started with a low value of 0.10 at a terminal speed ratio (λ=1.51), gradually rising to a peak of 0.26 at λ=2.50, with an output power of 12.01 watts, and then decreasing to 0.20 at λ= 3.00.

At 1 m/s entry speed, performance improved slightly, with a maximum CP value of 0.26 at λ=2.50 with an output power of 12.09 watts, reflecting a slight increase compared to 0.5 m/s.

At an entry speed of 3 m/s, the turbine showed better performance, as Cp rose to a maximum value of 0.28 at λ=2.50 with an output power of 12.98 watts, giving higher efficiency at this speed.

At 6 m/s, Cp reached its highest value of all speeds, reaching 0.27 at λ=2.50 with an output of 12.72 watts, but Cp dropped to 0.22 at λ=3.00.

These results indicate that Cp and output power increase with increasing air velocity until the optimum speed is reached at λ=2.50, where the highest turbine efficiency is achieved, while Cp begins to decrease when the optimal ratio is exceeded due to aerodynamic effects that reduce turbine efficiency.

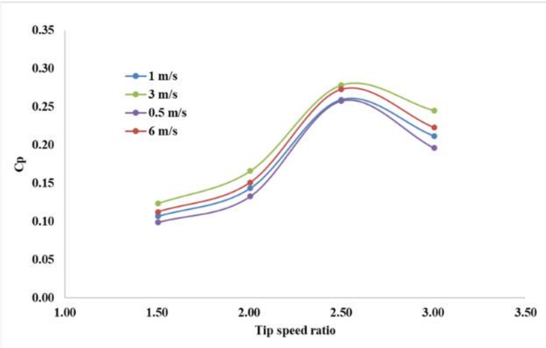

Figure (6) Curve Cp for turbine with

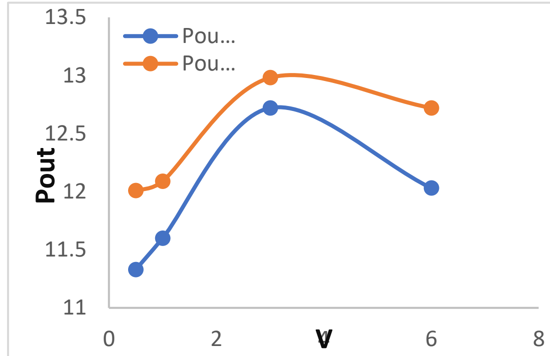

Figure (8) Curve Pout for turbine with nozzle and without nozzle

Comparison between wind turbine and wind turbine involved with a nozzle

After comparing the results of both simulation models, a clear difference in values Appeared between a turbine with a nozzle and a turbine without a nozzle, where the results showed that the best condition was reached in a tip speed ratio(λ =2.5), where a model with a nozzle recorded the power (12.98w) with a power factor of (0.28), while a model without a nozzle recorded (12.72) and with a power factor of(0.27).

An improvement was noted in the produced energy by (0.26) and in the efficiency of (0.01).As shown in the curves for Cp and Pout below.

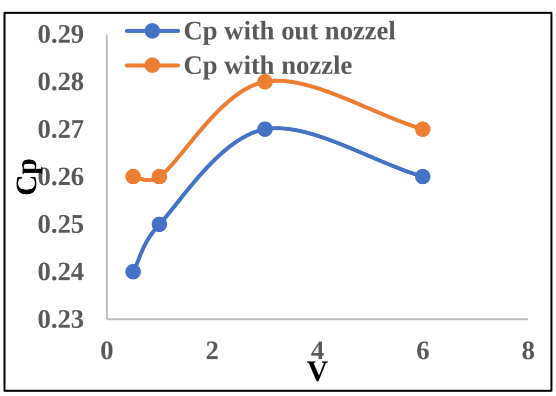

Figure (7) Curve Cp for turbine with nozzle and without nozzle

Conclusion

From the results, the effect of a nozzle on a wind turbine became evident. The highest efficiency of the turbine without a nozzle was achieved at a moderate air speed of 3 m/s and a tip speed ratio (λ) of 2.5, where 12.72W was produced. Efficiency decreased at higher speeds due to aerodynamic effects. However, it was noted that efficiency increased when the turbine was placed inside a nozzle at the same airspeed and tip speed ratio, achieving higher productivity than the previous state, reaching 12.98 watts. Thus, the difference between the two cases highlights the importance of using a nozzle to increase wind flow and improve the efficiency of wind turbines.

References

[1] J. N. Libii and D. M. Drahozal, "The influence of the lengths of turbine blades on the power produced by miniature wind turbines that operate in non-uniform flow fields," *World Trans. Eng. Technol. Educ*, vol. 10, no. 2, pp. 128–133, 2012.

[2] O. D. Vries, "Fluid dynamic aspects of wind energy conversion," Advisory Group for Aerospace Research and Development, 92-Neuilly-sur-Seine …, 1979.

[3] J. F. Manwell, J. G. McGowan, and A. L. Rogers, *Wind energy explained: theory, design and application*. John Wiley & Sons, 2010.

[4] M. K. Johari, M. Jalil, and M. F. M. Shariff, "Comparison of horizontal axis wind turbine (HAWT)

and vertical axis wind turbine (VAWT),” *Int. J. Eng. Technol.*, vol. 7, no. 4.13, pp. 74–80, 2018.

[5] S. I. Yannopoulos *et al.*, “Evolution of water lifting devices (pumps) over the centuries worldwide,” *Water*, vol. 7, no. 9, pp. 5031–5060, 2015.

[6] A. Raheem, M. Y. Hassan, R. Shakoor, and N. Rasheed, “Economic feasibility of stand-alone wind energy hybrid with bioenergy from anaerobic digestion for electrification of remote area of Pakistan,” *Int. J. Integr. Eng.*, vol. 6, no. 3, 2014.

[7] B. A. Jabbar, “Experimental and simulation study of a diffuser augmented wind turbine to enhance the performance by modifying diffuser and rotor.” Universiti Tun Hussein Onn Malaysia, 2019.

[8] C. N. Jones, “Blade element performance in horizontal-axis wind-turbine rotors,” *Wind Eng.*, pp. 129–137, 1983.

[9] R. Schaeffer *et al.*, “Energy sector vulnerability to climate change: A review,” *Energy*, vol. 38, no. 1, pp. 1–12, 2012.

[10] A. Grant, C. Johnstone, and N. Kelly, “Urban wind energy conversion: The potential of ducted turbines,” *Renew. Energy*, vol. 33, no. 6, pp. 1157–1163, 2008.

[11] A. Dilimulati, T. Stathopoulos, and M. Paraschivoiu, “Wind turbine designs for urban applications: A case study of shrouded diffuser casing for turbines,” *J. Wind Eng. Ind. Aerodyn.*, vol. 175, pp. 179–192, 2018.

[12] S.-Y. Hu and J.-H. Cheng, “Innovatory designs for ducted wind turbines,” *Renew. energy*, vol. 33, no. 7, pp. 1491–1498, 2008.

[13] G. M. Lilley and W. J. Rainbird, “A preliminary report on the design and performance of ducted windmills,” 1956.

[14] M. O. L. Hansen, N. N. Sørensen, and R. G. J. Flay, “Effect of placing a diffuser around a wind turbine,” *Wind Energy An Int. J. Prog. Appl. Wind Power Convers. Technol.*, vol. 3, no. 4, pp. 207–213, 2000.

[15] M. H. Ranjbar, S. A. Nasrazadani, and K. Gharali, “Optimization of a flanged DAWT using a CFD actuator disc method,” in *International Conference on Applied Mathematics, Modeling and Computational Science*, Springer, 2017, pp. 219–228.

[16] M. Kardous, R. Chaker, F. Aloui, and S. Ben Nasrallah, “On the dependence of an empty flanged diffuser performance on flange height: Numerical simulations and PIV visualizations,” *Renew. energy*, vol. 56, pp. 123–128, 2013.

[17] Y. Y. Maw and M. T. Tun, “Sensitivity Analysis of Angle, Length and Brim Height Of The Diffuser For The Small Diffuser Augmented Wind Turbin,” *ASEAN Eng. J.*, vol. 11, no. 4, pp. 280–291, 2021.