ISSN (Online): 2455-3662
EPRA International Journal of Multidisciplinary Research (IJMR) - Peer Reviewed Journal
Volume: 7| Issue: 12| December 2021|| Journal DOI: 10.36713/epra2013 || SJIF Impact Factor 2021: 8.047 || ISI Value: 1.188

PERFORMANCE ANALYSIS OF DIFFUSER AUGMENTED WIND TURBINE BY VARYING THE DIFFUSER BRIM ANGLE

Naveen Krishna P[1]

[1]*Research Associate at International Center for Technological Innovations, Alappuzha*

ABSTRACT

The power output of a wind turbine is directly proportional to the cube of the wind velocity. Even a marginal increase of wind velocity can result in exponential growth in power output. A Diffuser Augmented Wind Turbine (DAWT) is an improved version of ordinary wind turbine. With the help of diffusers, vortices are generated to form pressure difference and increase the wind velocity striking the rotor blades. The wind velocity enhancement depends on the geometry of the diffuser. This paper studies the impact of altering the brim angle of the diffuser on the diffuser efficiency and the power output. Four diffuser designs are generated with bring angles of 90, 75, 60 and 45 degrees and are analysed using flow simulation tool in SOLIDWORKS 2018 software. The best design with the most efficient brim angle can be identified from the result of analysis.

INTRODUCTION

Wind energy is a clean, abundant and renewable source of energy for generating electricity. For a long time, research has been going on for improvising the wind turbines to increase the production capacity of turbines. One of the major challenges faced by researchers is the Betz limit, which is the theoretical maximum efficiency for a wind turbine. According to the German physicist Albert Betz, only $^{16}/_{27}$ (59.3%) of the kinetic energy of wind can be used to spin the turbine and generate electricity. So even with the best design of turbine, only 59.3% of wind power can be utilized, this is when scientists began focusing on improving the kinetic energy of wind. The power output from a wind is proportional to the third power of wind velocity, even if the wind velocity can be increased by a small margin, the power generated will increase three times.

A Diffuser Augmented Wind Turbine (DAWT) is one in which the turbine rotor blades are placed within the diffuser. This configuration helps in increasing the efficiency of converting wind energy to electricity. The enhanced wind velocity produced by the diffuser helps improving the efficiency of turbine. DAWT is limited by Betz's law, which states that no more than 16/27 of total wind kinetic energy can be converted to electrical energy by a bare turbine in open wind. Because 59 percent isn't the most efficient rate, many designs have been developed to get around it. (Lokesharun *et al.*, 2019).

In this research, an attempt has been made to design different types of diffusers by altering their brim angle and to find the optimum design by performing Computational Fluid Dynamics analysis. Optimum design for diffuser is selected from literature review and the brim angle is altered from 90° to 45° by a margin of 15°, while all other design parameters remain unchanged. External flow simulation is performed by using SOLIDWORKS 2018 to find the optimum bring angle configuration.

LITERATURE REVIEW

2.1 PRINCIPLE OF DIFFUSER AUGMENTATION

The purpose of a diffuser is to boost a wind turbine's power production by increasing the wind velocity as it approaches the turbine. A lower pressure would form at the back of the wind turbine, acting as a vacuum to suck the wind and speed it towards the blades, increasing the wind velocity. The suction force will be generated by the vortex or in the area near the vortex, which will have lower pressure. As a result, it will operate as an accelerator, increasing the wind speed as it approaches the wind turbine.

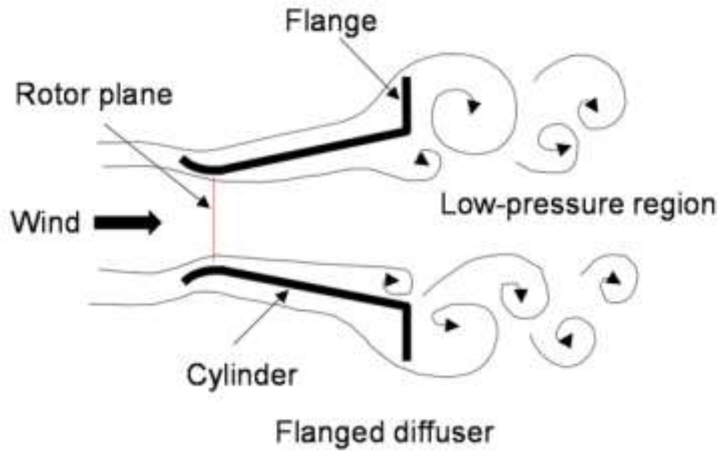

Fig 2.1 Principle of DAWT [4]

The pressure inside the diffuser may be lower than the pressure at the back of the wind turbine if vortices form inside the diffuser. The wind speed exiting the DAWT will be decelerated in this case, resulting in extremely low power coefficients. The pressure inside the wind turbine should not be lower than the pressure at the diffuser's wake in order to achieve optimal improved wind speed acceleration. This is accomplished by decreasing or preventing fluid flow separation on the inner diffuser wall, which causes vortices, while creating as many vortices as possible at the back.

The wind speed from an area is directly utilised to generate power in a conventional wind turbine. The diffuser in DAWT, on the other hand, increases the available wind speed to achieve high power output. Due to the concentration of wind energy density, the smaller diameter blade in DAWT generates the same power output as a typical "bare wind turbine." Only a few research have used computational models to investigate the effect of diffuser form on wind speed. (Lokesharun *et al.*, 2019)

2.2 POWER EQUATION OF DAWT

The various terms used for developing the wind power equation are

E = Kinetic Energy in J	ρ = Density in kg/m3	m = Mass in kg
A = Swept Area m^2	ν = Wind Speed in m/s	C_p=Power Coefficient
P = Power in W	dm/dt = Mass flow rate in kg/s	r = Radius in m
x = distance in m	dE/dt = Energy Flow Rate in J/s	t = time in s

At constant acceleration, the kinetic energy of an object having velocity (v) and mass (m) is equal to the work done (W).

$$\mathbf{E = W = Force \times Displacement = F \times s}$$

According to Newton's Law, we have:

$$\mathbf{F = m \times a}$$

Hence,

$$\mathbf{E = m \times a \times s \ldots (1)}$$

From the third equation of motion:

$$\boldsymbol{v^2 = u^2 + 2as}$$

We get:

$$\boldsymbol{a = \frac{v^2 - u^2}{2as}}$$

Since the initial velocity of the object is zero, i.e., u = 0, we get:

$$\boldsymbol{a = \frac{v^2}{2as}}$$

Substituting value of a in equation (1), we get the kinetic energy

$$\boldsymbol{E = \frac{1}{2}mv^2 \ldots (2)}$$

The power in the wind is given by the rate of change of energy:

$$P = \frac{dE}{dt} = \frac{1}{2}v^2\frac{dm}{dt} \ldots (3)$$

As mass flow rate is given by:

$$\frac{dm}{dt} = \rho A\frac{dx}{dt}$$

and the velocity is given by:

$$V = \frac{dx}{dt}$$

We get:

$$\frac{dm}{dt} = \rho Av$$

Hence, from equation (3), the power can be defined as:

$$P = \frac{1}{2}\rho Av^3 \ldots (4)$$

By applying the Betz limit, **Cp max = 0.59**. But this is the highest limit and is not practically possible. By taking into consideration of mechanical losses of bearings, generators and gearbox, only 10-30% of the wind power can be converted into electricity. Given by the equation.

$$\textbf{Pavailable} = \frac{1}{2}\rho Av^3C_P$$

2.3 PREVIOUS RESEARCH

A new wind turbine system was created, which includes a diffuser shroud with a broad-ring brim at the exit edge and a wind turbine inside. For a given turbine diameter and wind speed, a shrouded wind turbine with a brimmed diffuser has exhibited a power increase of around 2–5 times that of a bare wind turbine. (Ohya and Karasudani, 2010)

Under changing geometrical conditions, the performance of a flanged diffuser augmented wind turbine (FDAWT) structure is investigated. The five parameters that were changed for the study were nozzle angle, nozzle length, diffuser angle, diffuser length, and flange height. ANSYS FLUENT6.3 was used to investigate thirty random situations numerically. The impact of each parameter on the FDAWT structure's performance was explored. (Abdelrazek, M., *et al.* 2021)

Four different brim configurations are evaluated in the study, and CFD analysis is performed by altering the brim angle for each design while leaving the rest of the diffuser shape unchanged. Straight, bending, and stepped brims are employed, and fins are put over the final design brim to create a low-pressure region behind it, which enhances wind velocity at the diffuser's throat portion. The findings of the investigation revealed an increase in wind velocity at various brim angles. For 3D modelling of diffuser geometry, Ansys Design modeller is used. Ansys Fluent software is used for CFD analysis. (Bharath, N and Gautham MG, 2021)

Four configurations of diffusers were designed and tested to optimize the diffuser design. A remarkable 6.45 m/s wind velocity with 61.25% augmentation was obtained using a 16° diffuser opening angle coupled with a 0.5 m splitter and 4° splitter opening angle in the redeveloped design. This paper studies the different designs of Diffuser Augmented Wind Turbine using SOLIDWORKS and ANSYS Fluent. (Kannan, Mutasher and Lau, 2013)

2.4 SUMMARY

Diffuser Augmented Wind Turbine (DAWT) is an upgrade on the conventional wind turbines. It can increase the wind velocity intercepted by the turbine blade and thereby resulting in the exponential increase in the power output. The performance of diffuser can be further improved by reconfiguring the design. Studies were conducted for enhancing the wind velocity by altering design parameters of diffuser. The brim plays a crucial role in the vortex creation and hence in the overall performance. This paper attempts to find the effect of brim angle on the wind velocity.

METHODOLOGY

3.1 DESIGN PARAMETERS

The objective of the research is to find the optimum brim angle for the Diffuser Augmented Wind Turbine by performing flow analysis. After studying the literature, design parameters of the diffuser are selected including inlet diameter (D), diffuser length (L), diffuser angle (Φ), brim height (h), nozzle length (l), thickness (t) and nozzle angle (β). Meanwhile the brim angle (θ) is varied from 90° to 45°. The dimensions of the diffuser are given in the table

inlet diameter (D)	800 mm
diffuser length (L)	450 mm
diffuser angle (Φ)	7°
brim height (h)	480 mm
nozzle length (l)	100 mm
thickness (t)	20 mm
nozzle angle (β)	38.5°

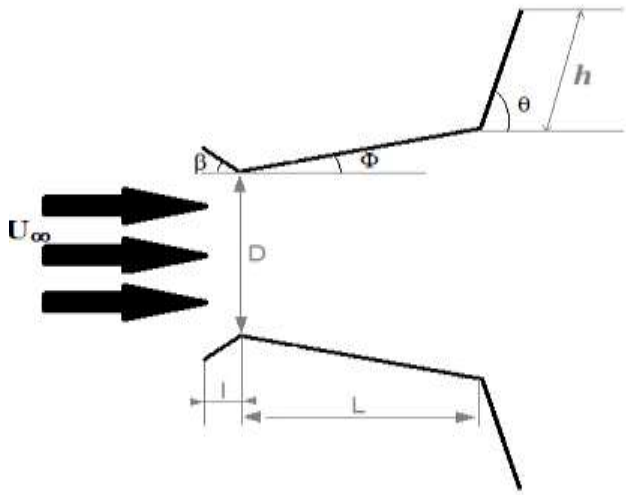

Fig 3.1 Geometry of DAWT

Four diffusers have been designed with every other parameter remaining same except for the brim angle. Brim angle varies from 45° to 90°.

3.2 CFD ANALYSIS OF THE TURBINE

The four diffusers designed with varying brim angle are then subjected to external flow simulation using SOLIDWORKS 2018 software. The CFD analysis will reveal the velocity and pressure profile. The design with maximum velocity can be easily identified. The four diffusers with their maximum and minimum velocities are shown below.

ISSN (Online): 2455-3662
EPRA International Journal of Multidisciplinary Research (IJMR) - Peer Reviewed Journal
Volume: 7| Issue: 12| December 2021|| Journal DOI: 10.36713/epra2013 || SJIF Impact Factor 2021: 8.047 || ISI Value: 1.188

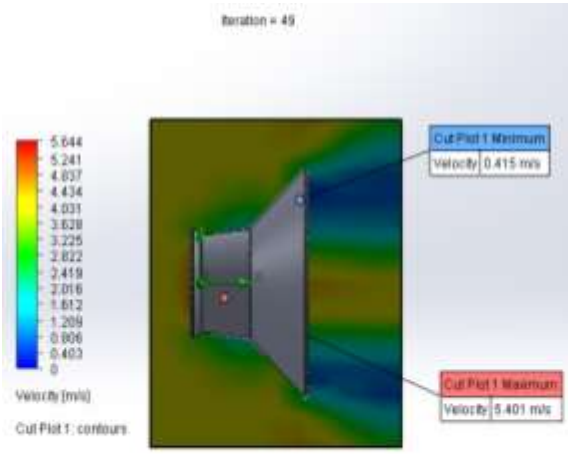

Fig 3.2 Diffuser with 45° brim angle

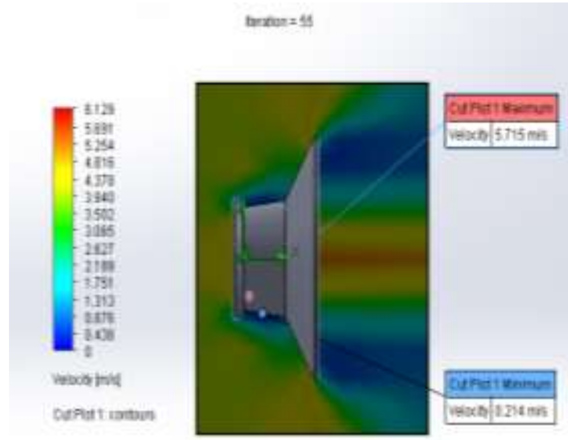

Fig 3.23 Diffuser with 60° brim angle

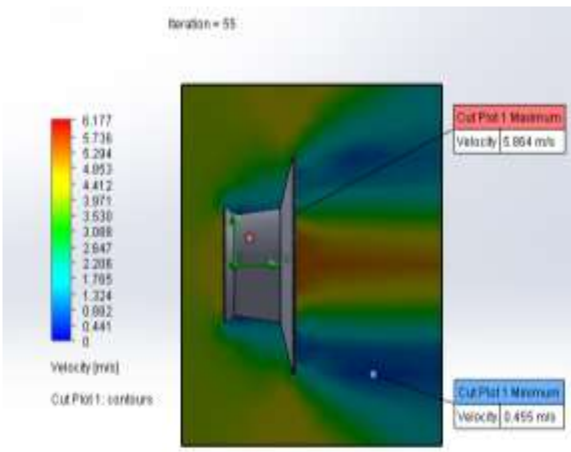

Fig 3.4 Diffuser with 75° brim angle

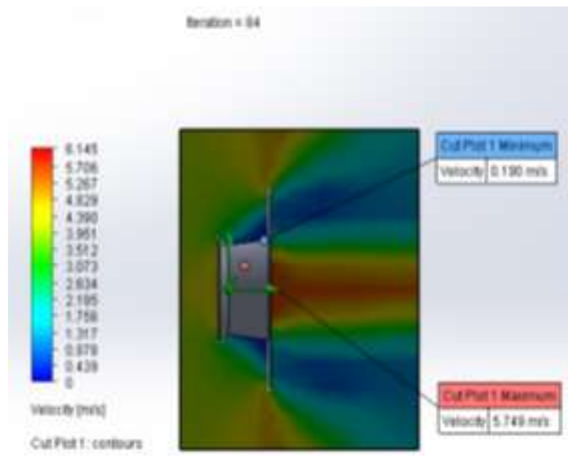

Fig 3.5 Diffuser with 90° brim angle

From the flow simulation using SOLIDWORKS, it is found out that out of these four diffusers, the one with brim angle 75° has registered the maximum velocity increment with 5.864 m/s. Followed by diffusers with brim angles 90°, 60° and 45°. From the CFD analysis, it is clear that the diffuser improves the wind velocity when incorporated with wind turbine.

RESULTS AND DISCUSSION

FLOW SIMULATION RESULTS

The external flow analysis proved the effectiveness of a diffuser in a DAWT. The four diffusers were analysed using the CFD tool. When tested with an inlet wind velocity of 4 m/s, a peak velocity of 5.864 m/s was obtained for the one with brim angle 75°. The diffuser with brim angle of 75° is the most efficient among the four models and the one with brim angle 45° being the least effective. The table shows the increment in power for each diffuser

Brim angle (degrees)	Inlet velocity (m/s)	Maximum velocity obtained (m/s)	Percentage increase in velocity	Increment in power
45	4	5.401	35.02	2.46
60	4	5.715	42.875	2.92
75	4	5.864	46.6	3.15
90	4	5.749	43.73	2.97

ISSN (Online): 2455-3662
EPRA International Journal of Multidisciplinary Research (IJMR) - Peer Reviewed Journal
Volume: 7| Issue: 12| December 2021|| Journal DOI: 10.36713/epra2013 || SJIF Impact Factor 2021: 8.047 || ISI Value: 1.188

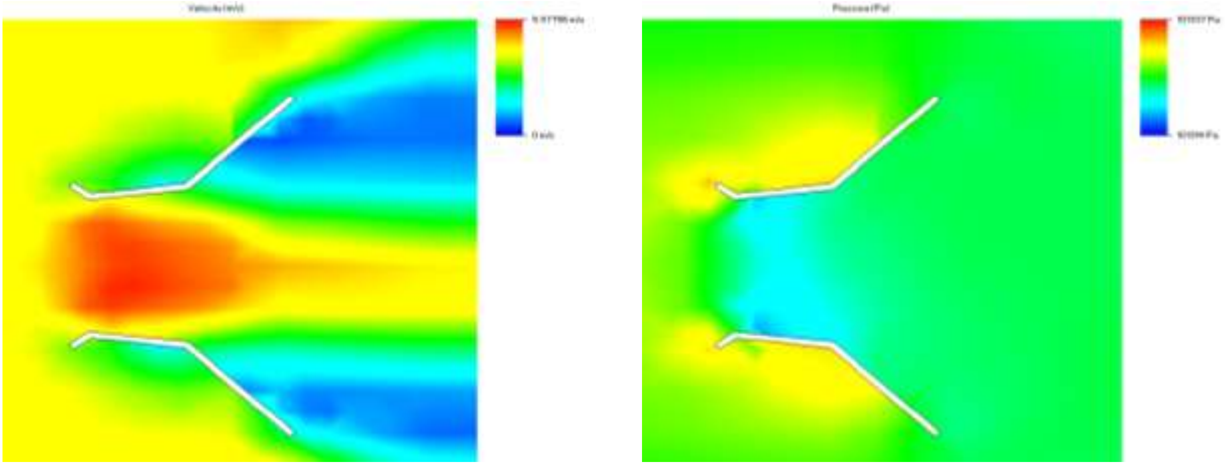

Fig 4.1 Velocity and Pressure profile of diffuser with 45° brim angle

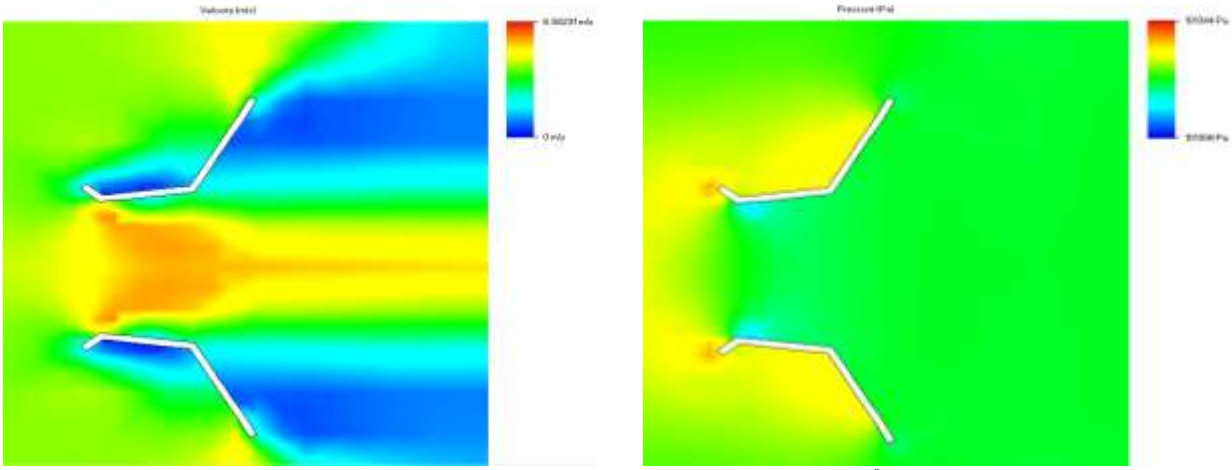

Fig 4.1 Velocity and Pressure profile of diffuser with 60° brim angle

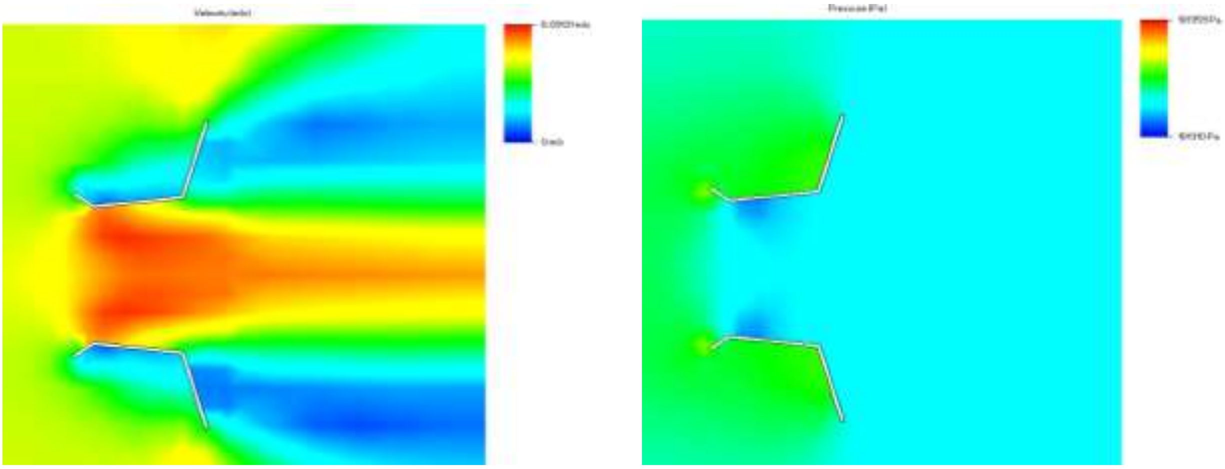

Fig 4.1 Velocity and Pressure profile of diffuser with 75° brim angle

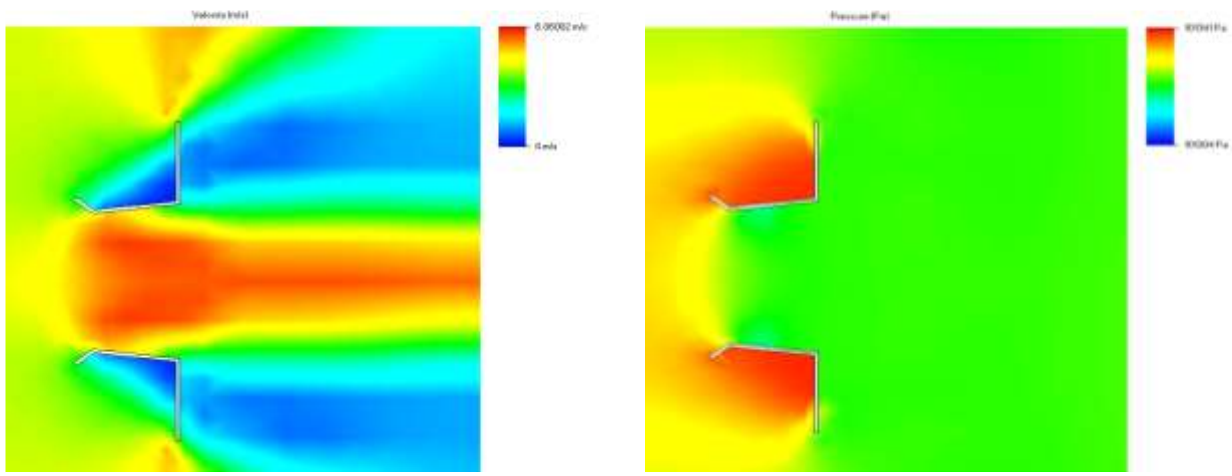

Fig 4.1 Velocity and Pressure profile of diffuser with 90° brim angle

CONCLUSIONS AND RECOMMENDATIONS

The Diffuser Augmented Wind Turbine (DAWT) can be considered as an ideal solution for overcoming the Betz limit barrier and can increase the electricity production capacity of turbines by many folds. It can significantly reduce the size of the wind turbine structures and can be incorporated with small scale wind turbines as well. The following observations were made from the research:

- A diffuser can be effectively used to improve the power output of a wind turbine as a Diffuser Augmented Wind Turbine.
- The geometry and dimension of the diffuser plays a crucial role in determining the effectiveness of a diffuser.
- By implementing a brim into the diffuser, the performance of a DAWT can be enhanced.
- The efficiency of diffuser in a DAWT is also affected by the brim angle.
- Among the four brim angles, 75° is the most efficient followed by 90°, 60° and 45°.

REFERENCES

1. *Abdelrazek, M., et al. (2021) 'Performance of a flanged diffuser augmented wind turbine structure under variable geometrical conditions', American Journal of Engineering Research, 10(1), pp. 142–152.*
2. *Bharath, N. and Gautham MG. (2021) 'CFD Analysis of Diffuser Augmented Wind Turbine with Various Brim Configurations', International Journal of Innovative Science and Research Technology, 6(2), pp. 593–598.*
3. *Kannan, T.S., Mutasher, S.A. and Lau, Y.H.K. (2013) 'DESIGN AND FLOW VELOCITY SIMULATION OF DIFFUSER AUGMENTED WIND TURBINE USING CFD', 8, p. 13.*
4. *Lokesharun, D. et al. (2019) 'Design and Analysis of Diffuser Augmented Wind Turbine using CFD', 7(1), p. 14.*
5. *Ohya, Y. and Karasudani, T. (2010) 'A Shrouded Wind Turbine Generating High Output Power with Wind-lens Technology', Energies, 3(4), pp. 634–649. doi:10.3390/en3040634.*