Simulation of Inlet Shroud and Diffuser Flange on Shrouded Wind Turbine Performance

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Abstract

The objective of this research is to enhance the diffuser parameters of shrouded Wind Turbine (Diffuser Augmented Wind Turbine DAWT). The study investigates different parameters of diffuser shape like inlet shroud curvature, diffuser flange height. The focus on these parameters are to develop the optimum condition of diffuser parameters for the aspect of power and thrust force coefficients. For that purpose, diffuser case-2 have been one of the recommended configuration as an effective design in increasing wind speed in the literature. In addition to the diffuser cases, a simulated model of wind turbine designed using blade element momentum (BEM) technique and has been validated with a Wind Turbine (AMPAIR-300). Diffuser case-2 has been simulated and analyzed using design software Solid-works and Computational Fluid Dynamic (CFD) Software Fluent-ANSYS-15. As per the study, diffuser case-2, adding inlet shroud directs the wind flow into the inlet of diffuser and the diffuser flange effect on the power enhancement was significant and also its induced axial load was significant, and it is recommended to modify the diffuser shroud shape to decreases the axial thrust effect with enhancing the power coefficient.

Keywords: Wind, CFD, DAWT, shrouded Wind Turbine.

Nomenclature

A	*Air Swept Area (m2)*
Cp	*Power Coefficient (Dimensionless)*
CT	*Thrust Coefficient (Dimensionless)*
D	*Rotor Diameter (m)*
D1	*Splitter Inner Diameter (m)*
Faxial	*Total Thrust Force Exerted On The DAWT (N)*
H1	*Diffuser Flange Height (m)*
P	*Power (Watt)*
R	*Distance From Tip Of turbine Blade To Hub Center (m)*
R1	*Inlet Shroud Curvature Radius (m)*
U	*Velocity Of Air (ms-1)*
α	*Diffuser Expansion Angle (Degree)*
α1	*Splitter Expansion Angle (Degree)*
λ	*Tip Speed Ratio (Dimensionless)*
ρ	*Air Density (kg m-3)*
T	*Torque Exerted On The Rotor (N.m.)*
ω	*Rotational Of Rotor Speed (Rad s-1) .*

1. Introduction

The growing worldwide energy demand is one of a few reasons to motivate energy markets to extend the usage of renewable energy [1].

The development and application of renewable, clean energy have become an important issue in recent years due to the serious effects of global warming and rapid depletion of fossil fuels [2].

Diffuser augmented wind turbine (DAWT) ideology is to increase the extracted power by generating a sub-atmospheric region at diffuser downstream which resulted in increasing wind flow speed passing through the turbine rotor [3].

They showed that the shroud shape and geometry parameters affect the shroud inlet efficiency, shroud pressure recovery coefficient and base pressure coefficient which accordingly affects the wind flow speed enhancement passing through the turbine rotor[4] [5].

He modeled the rotor using rotating reference frame and simulated different shroud configurations and found that a coefficient of power enhancement by a factor of 1.5 achieved using a diffuser shroud with 20o half open angle and exit area ratio of 1.56 [6].

He carried out experimental and numerical studies on diffuser shrouded turbines, with diffuser geometry of a 26o pitch angle airfoil shape and having an exit to throat area ratio of 1.7, which accordingly enhance coefficient of power by 2 [7].

They studied the effect of diffuser length and area ratio (outlet area / inlet area) using 3D-CFD simulations on the power augmentation of a small wind turbine (AMPAIR 300), after adding a shroud consists of a simple frustum diffuser. They stated that viscous loss in the inlet is negligible and separation of the diffuser boundary layer leads to a significant performance loss. They proposed a well-designed duct as a flanged diffuser that creates a large base pressure [8] [9].

He showed that the maximum wind speed increases 1.7 times with appropriate diffuser influenced by its length and expansion angle [10].

He investigated the effect of convergent – divergent scoop on the power output of a small wind turbine, and the Results showed that the power output increases by 2.2 times that of the same swept area [11].

Using CFD the effect of adding flange have been investigated at the diffuser exit plane, and have been examined the optimal form of the flanged diffuser, and found that power augmentation by a factor of about four to five, as the base pressure at the exit plane can be lowered further due to the vortex formation at the outlet plane, the pressure down-stream of the flanged diffuser turbine will be lower and hence greater flow rate is drawn into the rotor [12] [13].

He used CFD to study the cross section geometrical features of diffuser with airfoil (NACA-0015), and found that flow separation of diffuser wall and base pressure coefficient are the most influential parameters in power coefficient "Cp", while inlet efficiency has only small impact [14].

They studied the effects of flanged diffuser on small wind turbine for moving vehicles. The Results showed that the flanged diffuser significantly increased the torque and power outputs. To get optimum increased acceleration on the wind speed, the pressure downstream the turbine should not be lower than the pressure at the wake of the diffuser. Which can be achieved by reducing or avoiding separation of fluid flow on the inner diffuser wall and cause vortices. While creating as much vortices as possible downstream the diffuser [15] [10].

He showed that the power of a wind turbine doubled by means of a wing structure placed at some distance around the turbine. The wing structure size is the same as the turbine. Therefore this new method could result in an improvement of the ratio price to power for wind turbines [16].

Computational modeling has proved to be a valuable tool for Diffuser Augmented Wind Turbine (DAWT). It has been used to interpret full-scale field results from the Vortec-7 prototype DAWT, in an effort to find a diffuser design which is both aerodynamically efficient and can be manufactured at a reasonable cost [17].

A suggestion of Fiberglass Reinforced Plastics construction of the diffuser for the small (5-200 kW) rated output wind energy could lead to attractive and competitive cost of electrical generation by Diffuser Augmented Wind Turbine (DAWT) concept [18].

This paper parameterizes the power augmentation of a simulated model. This model has been designed using a blade element momentum technique, which then has been validated with experimental data of a turbine model (AMPAIR-300) [19], and also has been compared with simulation results presented in Ref [8]. This study aims to study and simulate the adding of inlet shroud and diffuser flange of diffuser shrouded wind turbine.

Which aims to find the optimized diffuser parameters. Which study the effect of various open angles of a diffuser shrouded wind turbine as shown in table- 1. A simple frustum diffuser shrouded wind turbine shape, which is recommended in Ref [2] as a wind speed enhancement design. It has been validated and simulated after adding a turbine rotor (diffuser case-2) in Ref [20].

It has been used to study the effect of various splitter open angle. The range of splitter open angle ranges from 8o to 44o in a 9o increment as presented in Ref [8], [22].

Various open angle has been simulated as recommended in Ref. [20], to study the optimized open angle of splitter that is used as a power augmentation of diffuser shrouded wind turbine [22].

To study the effect of various inlet shroud curvature ratio (R1/R) versus various diffuser flange height ratio (H1/R) as shown in Table-1. A simple frustum diffuser shrouded wind turbine shape, which is recommended in Ref [2] as a wind speed enhancement design and also validated and simulated after adding a turbine rotor (Diffuser Case-2) in Ref. [20]. It has been used to study the effect of various "inlet shroud curvature" radius ratio and various diffuser flange height ratio.

The range of "inlet shroud curvature" radius ratio (R1/R) from (0.05- 0.25) in an increment of 0.05, and the range of "diffuser flange" height ratio (H1/R) from (0.1-0.5) in an increment of 0.1.

To minimize the axial thrust force coefficient, which affect the body of the diffuser shroud wind turbine. The length of the diffuser shroud have been chosen as 15% of diffuser inlet diameter (L=0.15D) Ref [20].

In the present study a commercial small wind turbine selected was AMPAIR-300-Watt micro-wind turbine was shrouded with recommended diffuser case (Diffuser case-2) in CFD simulations, which have been presented in Ref. [20].

Diffuser case-2 has been used as a configuration to validate the effect of various radius ratio of "inlet shroud curvature" (R1/R=0.05, 0.1, 0.15, 0.2, 0.25) versus the various height ratio of "diffuser flange" (H1/R=0.1, 0.2, 0.3, 0.4, 0.5).

2. CFD and Model Description

Model and Shroud Geometry

The turbine model has been simulated and validated with commercial turbine "AMPAIR 300 [19], [20].

In Ref [20] the parameters of the shrouded wind turbine, its length shown by L , the difference between inlet and outlet radius of the shroud shown by its open angle "α", splitter length shown by L1 ,its inlet diameter shown by D1, splitter open angle α1, inlet shroud with radius R1 and a flange height H1. The validated model shrouded with each diffuser case have been"2 meter" from inlet of "10 meter" length of enclosure "outer cylinder".

The diffuser shrouded wind turbine was modeled with two configurations mentioned in Ref. [20] and parameterized in Tables 1 and 2. The distance between the rotor blade tip and the inner surface of diffuser "tip clearance" equals to one percent of turbine radius "R" as presented in Ref. [1], while the wall thickness of diffuser, splitter, inlet shroud curvature and diffuser flange equals to one percent of turbine rotor diameter as presented in Ref [1].

The CFD software calculates the torque directly. In the case of a bare turbine with or without its diffuser shroud the area is the turbine swept area.

The power coefficient "CP" and thrust coefficient "CT" of the Diffuser Augmented wind turbine "DAWT" to be calculated from the following equations:

$$C_p = P_{calculated} / P_{wind} = T\omega/(0.5\rho U^3((\pi((D/2))^2) \quad (1)$$

$$C_T = F_{measured}/F_{wind} = F/(0.5\rho U^2((\pi((D/2))^2) \quad (2)$$

Table 1. Dimensions of the Diffuser Case-1

Diffuser Case-1 [20] [22]						
Diffuser Open Angle "α"	Splitter Open Angle "α_1"					General Parameters
	8°	17°	26°	35°	44°	
8°	•	•	•	•	•	Splitter Length L_1=0.5 L.
17°	•	•	•	•	•	Splitter Inlet Diameter D_1=0.5 D.
26°	•	•	•	•	•	Diffuser Length L=0.4 D.
35°	•	•	•	•	•	No Inlet Shroud.
44°	•	•	•	•	•	No Diffuser Flange

Table (2): Dimensions of the Diffuser Case-2.

Diffuser Case-2 [20]						
Diffuser Flange Height "H_1/R"	Diffuser Inlet Shroud Curvature Radius "R_1/R"					General Parameters
	0.05	0.1	0.15	0.2	0.25	
0.1	•	•	•	•	•	Diffuser Open Angle A=16°,
0.2	•	•	•	•	•	Splitter Open Angle A_1=4°,
0.3	•	•	•	•	•	Inlet Shroud Radius R_1=0.1R,
0.4	•	•	•	•	•	Diffuser Flange H_1=0.5 R,
0.5	•	•	•	•	•	Splitter Length L_1=0.5 L, Splitter Inlet Diameter D_1=0.5D, Diffuser Length L=0.15 D.

2.2. Transition - Turbulence Model

Selection of an appropriate model for CFD simulation can predict precisely separation phenomenon [7]. While separation from diffuser surface greatly affects the performance of the diffuser. SST model has been validated extensively for separating 2D flows with Reynolds-averaged - Navier– Stokes (RANS) models [9].

It has been Shown that the SST model outperformed the 4-equation "$\upsilon 2$-f" (transition SST) has been predicted the separating velocity profiles for the NACA 4412 airfoil case and has been suggested that flow over the rotor blades can be subject to significant region of laminar– turbulence transition. And because the transition process can affect the separation behavior of the boundary layer on the blade surface, it has been agreed that the ($\upsilon 2$-f) model is the best model in case of separation, [21].

This model is a modified SST k–ω RANS turbulence model by the addition of two other transport equations for the intermittency (ɣ) and the transition onset criteria and the constants were kept as its default as in Ref. [11][20].

2.3. MESH and Boundary Conditions

This model has been created in Ref. [20] using ANSYS Fluent software and its meshing, been validated with the commercial wind turbine "AMPAIR-300".

The meshing of this model has been used in Ref. [20] was an unstructured mesh on blade surface, Fine tetrahedral grids within and around the inner cylinder, diffuser surfaces and the rest of the enclosure "outer cylinder", using minimum element size=2mm, proximity minimum size for edges =2mm, fine relevance center, medium smooth, tetrahedrons assembly meshing and the rest as default [20] [22]. This technique aims at generating very fine tetrahedral grid on the rotor surface and in regions far from the rotor, a one-third symmetric modeling of the bare blade before and after adding the diffuser cases have been effective as in Ref. [11] [20] to handle the high no. of mesh elements. So the full model grid size before adding diffuser cases becomes (650,000 tetrahedron element), while after adding the diffuser the mesh elements increased up to (3,600,000 tetrahedron element), without any change in the bare blade validation results after using the one third symmetry modeling for full model [20].

Moving Reference Frame (MRF) methodology is used in this study. MRF is a steady-state approximation in which individual cell zones are assigned different rotational and translational speeds. In MRF, two reference frames: (I) a stationary frame relative to the diffuser wall; and (II) rotating frame of the inner cylinder simulating the rotating turbine are used [20].

In this simulation, it was assumed to be a symmetric incompressible steady flow with the following boundary conditions, Inlet boundary condition is constant free stream velocity of 10 ms-1, outlet boundary of the domain was set to atmospheric pressure. In low-turbulence wind tunnels, the free-stream turbulence intensity is normally low.

But these models have been designed to simulate the shrouded small wind turbines in outdoor wind situations.

Turbulence intensity of 10% and turbulence viscosity ratios of 10% were set for both inlet / outlet boundary conditions, the standard pressure correction method / a first order upwind scheme was used. All walls were set to be no-slip boundaries.

The enclosure and the diffuser were set as moving walls with absolute rotational velocity of zero while the rotor blades and the hub were set as walls attached to moving frame.

In order to measure power coefficient "Cp" for various conditions, rotational speed of the MRF of the inner cylinder changed from approximately from 153 rpm (λ=1) to 1377 rpm (λ=9) with increment of 153 rpm (λ=1) [20].

2.4. Outcome Validation

Given the common use of commercial wind turbine "AMPAIR-300" by Ref. [8], the power coefficient "Cp" of the present model have been compared with Ref. [8] model in tip speed ratio λ from 1 to 9. The validation of the bare turbine with the commercial turbine has been mentioned in Ref. [20].

3. Results and Discussion

The present study continues with the same simulated and the two recommended diffuser shrouds mentioned in Ref. [20] as shown in Tables 1 and 2.

The two recommended diffuser shrouds were Diffuser case-1 which has been used to validate and study the effect of various open angles (8o, 17o, 26o, 35o, 44o) of the splitter versus the open angles (8o, 17o, 26o, 35o, 44o) of the diffuser shroud [22].

Diffuser case-2 has been used to validate and study the effect of various Radius Ratio of "inlet shroud curvature" (R1/R=0.05, 0.1, 0.15, 0.2, 0.25) versus the various height Ratio of "diffuser flange" (H1/R=0.1, 0.2, 0.3, 0.4, 0.5).

The shrouded turbine naturally causes extra vertical and horizontal load on the base of the turbine. Hence, the recommended shroud should be small and light in weight as much as possible to reduce these loads. In this study, all the shrouds were designed with length to diameter ratio "L/D" and height to diameter ratio "H/D" less than 50%.

3.1. Inlet Shroud Curvature Radius and Diffuser Flange Height Effect.

To optimize the diffuser configuration the diffuser parameters of inlet shroud curvature radius and diffuser flange height as shown in Figure 1 Thrust Coefficient (CT) increases after adding the inlet shroud and diffuser flange to the diffuser shrouded wind turbine, compared with diffuser shrouded wind turbine without inlet shroud and diffuser flange with the same open angle (α=16).

Figure 1 shows that diffuser flange (H1/R=0.5), the coefficient of thrust approximately the same with the inlet shroud curvature (R1) increased from (0.05 to 0.1).

But as the inlet shroud curvature increased from (0.1 to 0.25), the coefficient of thrust decreases sharply. It shows a positive effect in decreasing the axial thrust coefficient. But the thrust coefficient is still higher than the effect of diffusers only. It decreases from 225 % to 125 % of the diffuser only effect.

As shown in Figure 1 for diffuser flange (H1/R=0.4), the Thrust Coefficient (CT) decreases slightly as the inlet shroud curvature (R1) increases from (0.05 to 0.1), but as the inlet shroud curvature increases from (0.1 to 0.25), the thrust coefficient decreases sharply.

Which showed a positive effect in decreasing the axial thrust coefficient. But the thrust coefficient still higher than the effect of diffuser only. Thrust coefficient decreases from 275 % to 175% of the diffuser only effect.

As shown in Figure 1 for diffuser flange (H1/R=0.3), the coefficient of thrust decreases gradually as the inlet shroud curvature (R1) increased from (0.05 to 0.25).

Which showed a positive effect in decreasing the axial thrust coefficient. But the thrust coefficient still higher than the effect of diffuser only. It decreases from (225 % to 125%) of the diffuser only effect.

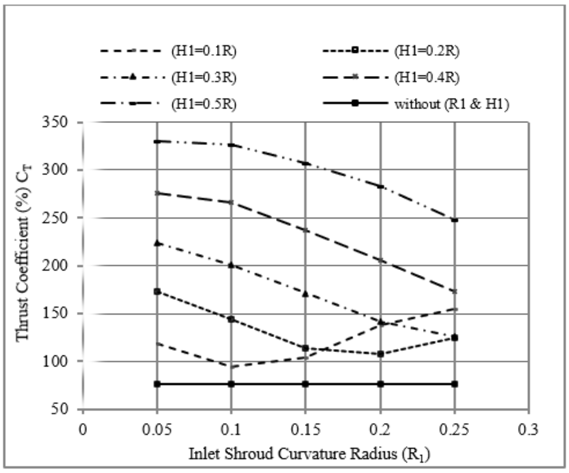

Figure 1. Thrust Coefficient (Ct) in percentage of Present Model shrouded with Diffuser Case-2 results with and without diffuser flange (H1) versus various inlet shroud curvature (R1) of diffuser open angle (α=16o) at optimum tip speed ratio (λ), of diffuser length (L=0.15D)

The diffuser flange (H1/R=0.2), the coefficient of thrust decreases sharply as the inlet shroud curvature (R1) increased from (0.05 to 0.15), but as the inlet shroud curvature increased from (0.15 to 0.2), the coefficient of thrust decreases slightly, and as the inlet shroud curvature increased from (0.2 to 0.25), the thrust coefficient increased from (105% to 125%) (see Figure 1).

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The diffuser flange (H1=0.1R), the coefficient of thrust decreases as the inlet shroud curvature (R1) increased from (0.05 to 0.1), but as the inlet shroud curvature increased from (0.1 to 0.15), the coefficient of thrust increased steadily, and as the inlet shroud curvature increased from (0.2 to 0.25), the coefficient of thrust increased gradually (see Figure 1). And as shown that the least increase in thrust coefficient (CT=95%) resulted at (H1=0.1R1), and as shown in Figure (3)A/B that the boundary layer of the inlet shroud curvature avoids the thrust coefficient effect of the diffuser flange at (H1=0.1R). as shown in Figure (3)C/D that as the inlet shroud curvature equals to or larger than the flange height, the effect of thrust coefficient decreases. As shown in Figure 1 That as the inlet shroud curvature increases the thrust coefficient decreases although the diffuser flange height increases. And as shown in Figures 1 and 2, that the Inlet Shroud Curvature could decrease the effect of Flange Height on Thrust Coefficient without affecting the Turbine Power enhancement due to the pressure recovery in the diffuser for the effect of using Diffuser Flange.

As shown in Figure 2, as the diffuser flange height (H1) increases, as the power generated of diffuser shrouded wind turbine with inlet shroud (R1=0.05R) increases steadily. Which have been shown in Figure 3 A and B of velocity contour and vectors of flange height (H1=0.1 and H1=0.5) respectively that the increase of diffuser flange has an enhancement effect on simulated power generated.

Figure 2 also shows the diffuser flange height increases (H1=0.1R), (H1=0.2R), (H1=0.3R), (H1=0.4R), (H1=0.5R) respectively, the maximum simulated power generated of diffuser shrouded wind turbine with inlet shroud (R1=0.1R), (R1=0.15R), (R1=0.2R), (R1=0.25R) respectively, gradually increases to the best point of mixture of inlet shroud curvature radius and diffuser flange height, which is using curvature radius (R1=0.05R) and (H1=0.5R) with simulated power enhancement and thrust coefficient equals 175% and 330% respectively .

In Figure 2 the maximum generated power of diffuser shrouded wind turbine with inlet shroud is (R1=0.1R) and diffuser flange height (H1=0.5R) higher than that of diffuser without inlet shroud and diffuser flange with 50% approx., but as mentioned in Figure 1 that the thrust coefficient of diffuser shrouded wind turbine with inlet shroud (R1=0.1R) and diffuser flange height (H1=0.5R) equals to 330% of ideal bare blade coefficient of thrust, while the thrust coefficient of the diffuser shrouded wind turbine without inlet shroud and diffuser flange equals to 80% of bare blade coefficient of thrust.

As shown in Figure 2, as the diffuser flange height (H1) increases, as the power generated of diffuser shrouded wind turbine with inlet shroud (R1=0.15R) increases.

As shown in Figure 2 the maximum generated power of diffuser shrouded wind turbine with inlet shroud (R1=0.15R) and diffuser flange height (H1 =0.5R) higher than that of diffuser without inlet shroud and diffuser flange with 50% approx., but as mentioned in Figure 1 that the thrust coefficient of diffuser shrouded wind turbine with inlet shroud (R1=0.15R) and diffuser flange height (H1 =0.5R) equals to 300% of ideal bare blade coefficient of thrust, while the thrust coefficient of the diffuser shrouded wind turbine without inlet shroud and diffuser flange equals to 80% of ideal bare blade coefficient of thrust, which make it not feasible for the required supporting base.

As shown in Figure 2 as the diffuser flange height (H1) increases, as the power generated of diffuser shrouded wind turbines with inlet shroud (R1=0.2R) increases.

As shown in Figure 2 the maximum generated power of diffuser shrouded wind turbine with inlet shroud (R1=0.2R) and diffuser flange height (H1 =0.5R) higher than that of diffuser without inlet shroud and diffuser flange with 50% approx., but as mentioned in

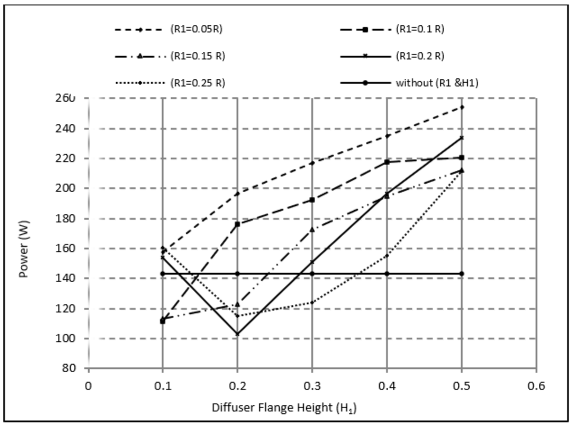

Figure 2. Power W of present model shrouded with diffuser case-2 results with and without inlet shroud range (R1= 0.1 to 0.25D) versus various diffuser flange height range (H1=0.1 to 0.5 D) of diffuser open angle (α=16o) and diffuser length (L=0.15D), at optimum tip speed ratio (λ=6)

In Figure 1, the thrust coefficient of diffuser shrouded wind turbine with inlet shroud (R1=0.2R) and diffuser flange height (H1 =0.5R) equals to 280 % of ideal bare blade coefficient of thrust. while the thrust coefficient of the diffuser shrouded wind turbine without inlet shroud and diffuser flange equals to 80% of ideal bare blade coefficient of thrust.

As shown in Figure 2, adding diffuser flange heights as the diffuser flange height (H1) increases, as the power generated of diffuser shrouded wind turbine with inlet shroud (R1=0.25R) increases.

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As shown in Figure 2, the maximum generated power of diffuser shrouded wind turbine with inlet shroud (R1=0.25R) and diffuser flange height (H1=0.5R) higher than that of diffuser without inlet shroud and diffuser flange with 50% approx. but as mentioned in Figure 1, that the thrust coefficient of diffuser shrouded wind turbine with inlet shroud (R1=0.25R) and diffuser flange height (H1 =0.5R) equals to 250 % of ideal bare blade coefficient of thrust. While the thrust coefficient of the diffuser shrouded wind turbine without inlet shroud and diffuser flange equals to 80% of ideal bare blade coefficient of thrust.

The effect of increasing of the diffuser flange (H1) as shown in Figure 2, the increase of power for the diffuser with inlet shroud curvature (R1=0.05R) from 10% to 50% compared with the power of diffuser (without inlet shroud and diffuser flange) with the increase of diffuser flange height from (H1=0.1R) to (H1=0.5R), and as mentioned in the Figure (3)A/B the vortex on the boundary layer on the diffuser flange external surface increases with the increase of Diffuser Flange Height, which accordingly enhance the vacuum effect on the diffuser downstream which increase the mass flow rate passing through the turbine rotor.

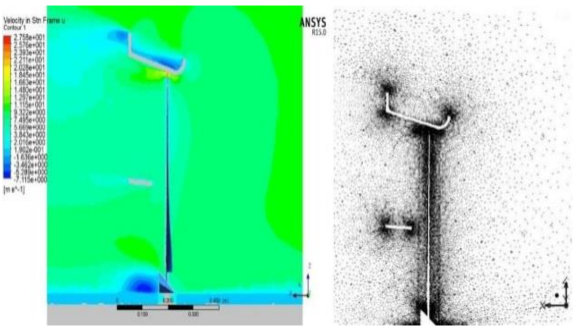

Figure 3 A. Velocity Contour and Velocity Vectors of Case-2 with Length (L=0.15R), Inlet Shroud Curvature (R1=0.05R) and Diffuser Flange Height (H1=0.1 R)

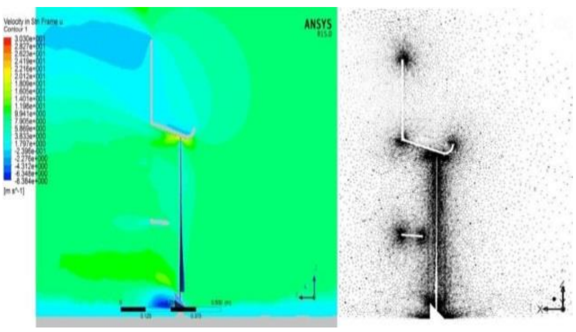

Figure 3 B. Velocity Contour and Velocity Vectors of Case-2 with Length (L=0.15R), Inlet Shroud Curvature (R1=0.05R) and Diffuser Flange Height (H1=0.5R)

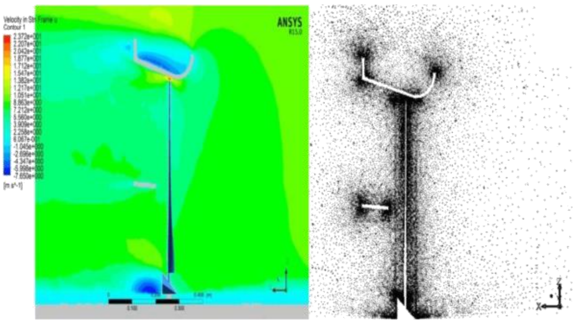

Figure 3 C. Velocity Contour and Velocity Vectors of Case-2 with Length (L=0.15R), Inlet Shroud Curvature (R1=0.1R) and Diffuser Flange Height (H1=0.1R)

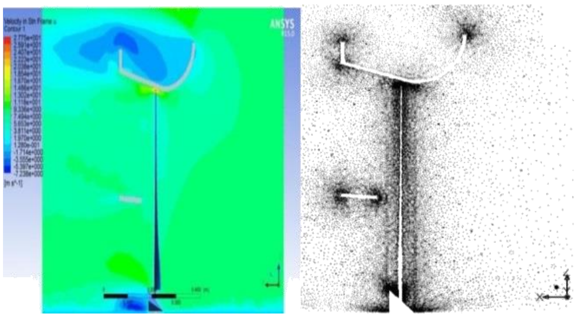

Figure 3 D. Velocity Contour and Velocity Vectors of Case-2 with Length (L=0.15R), Inlet Shroud Curvature (R1=0.2R) and Diffuser Flange Height (H1=0.1R)

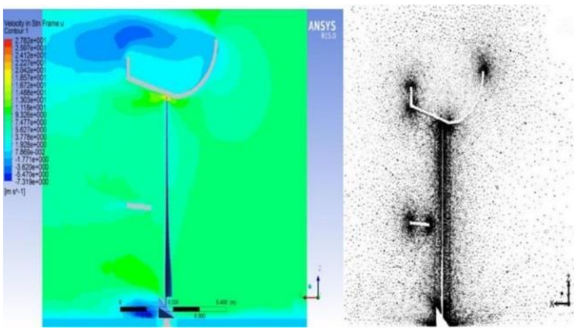

Figure 3 E. Velocity Contour and Velocity Vectors of Case-2 with Length (L=0.15R), Inlet Shroud Curvature (R1=0.25R) and Diffuser Flange Height (H1=0.1R)

Figure 3 (ABCDE). Velocity Contour and Velocity Vectors of Case-2 with Length (L=0.15R), various Inlet Shroud Curvature and Diffuser Flange Height

The effect of increasing of the diffuser inlet shroud (R1) as shown in Figure 2, the power decrement of the diffuser with Diffuser Flange Height (H1=0.1R) from +10% to -22% with the Inlet Shroud Curvature from (R1=0.05R) to (R1=0.15R), but the power enhanced with 12% using Inlet Shroud Curvature (R1=0.2R and

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R1=0.25R), compared with the Power of Diffuser (without Inlet Shroud and Diffuser Flange) and as mentioned in Figure 3C using the velocity contour and velocity vectors which showed that, the tip of the inlet shroud height become higher than the starting point of the diffuser flange which make an negative effect on the usage of diffuser flange which is obvious with increasing the inlet shroud curvature, as showed in Figure 3 D and E that the flow vortex formed behind the inlet shroud and diffuser flange.

Figure 3 C to E shows that the increase of the inlet shroud curvature for small diffuser height decreases the effect of diffuser flange, until the inlet shroud effect neglects the flange effect which make an power decrement effect to -22% compared with (diffuser without inlet shroud and diffuser flange).

As shown in Figure 3 D, the velocity contour and velocity vectors showed the formation of vortex behind the inlet shroud curvature higher than the diffuser flange, which neglect the effect of diffuser flange and further increase in the inlet shroud curvature make a decrease in the power decrement from -12% to -7% compared with diffuser (without inlet shroud and diffuser flange), which showed the effect of inlet shroud in increasing and guiding the flow into the diffuser inlet but with less effect than the diffuser flange and with a limit of not to decrease the effect of the diffuser flange.

Figure 3 E shows the velocity contour and vectors of inlet shroud curvature (R1=0.25R) and after comparing the results of its usage with diffuser flange heights from (H1=0.1R to 0.5R), resulted that using the curvature (R1=0.25R) with flange height (H1=0.5R) decreases the thrust coefficient as shown in Figure (5) From (330% to 250%) and decreasing the power generated about (20%) only.

But comparing its results with flange height (H1=0.1R) showed that using the inlet curvature (R1=0.25R) enhance the power generated only by +12% compared with diffuser (without inlet shroud and diffuser flange) and approximately equal to the power generated by inlet shroud (R1=0.05R), which showed that the inlet shroud is not only a tool to enhance power generated but also a guiding for the flow.

And as shown in Figure 3 B to E, the reason for its effect of decreasing the thrust coefficient and increasing diffuser flange height effect, by guiding the flow away from the diffuser flange. The latter increases the boundary layer formed behind the diffuser flange, and accordingly its effect of low pressure at the turbine downstream.

4. Conclusions and Future Recommendations

A simulated model designed and validated using Blade Element Momentum (BEM), which then shrouded with the recommended diffuser cases [20] using ANSYS-15 and SOLID-WORKS software as CFD tools to get the following results:

Effect of Inlet Shroud and Diffuser Flange

The low diffuser length (L=0.15D) and high-speed flow at blade tip decreased the effect of boundary layer existing on the diffuser surface as shown in the vector and contour figures but not measured or simulated its effect on simulated turbine power or turbine axial thrust coefficient.

Curvature radius ratio for the inlet shroud to be lower than the diffuser flange height ratio, to enhance the thrust coefficient effect and to enhance the power coefficient, and to avoid being interfere with the effect of the diffuser flange.

The inlet shroud curvature is a good parameter to guide the flow into the inlet of the diffuser, especially when added to the diffuser flange parameter. The usage of inlet shroud curvature only would augment slightly the diffuser configuration to enhance the turbine power generated.

The maximum coefficient of thrust after usage of inlet shroud and diffuser flange increased in a percentage up to (CT=200%), while the percentage of increase of wind turbine generated power equals to (CP=75%).

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