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Performance Augmenting of a Vertical Axis Wind Turbine using Adaptable Convergent Ducting System

Abdullateef A. Jadallah[**] **Sahar R. Farag** [***] **Jinan D. Hamdi**[***]
[, **, ***]Department of Electromechanical Engineering / University of Technology / Iraq*
*Email: abdullateef.aljad@gmail.com
**Email: dr saharalsakini@yahoo.com
***Email: jenanjenan780@yahoo.com

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Abstract

Developments are carried out to enhance the performance of vertical axis wind turbines (VAWT). This paper studies the performance of the ducted wind turbine with convergent duct (DAWT). Basically, the duct technique is utilized to provide the desired wind velocity facing the turbine. Methodology was developed to estimate the decisive performance parameter and to present the effect of the convergent duct with different inlet angles. The ducted wind turbine was analyzed and simulated using MATLAB software and numerically using ANSYS-Fluent 17.2. Result of both approaches were presented and showed good closeness for the two cases of covering angles 12° and 20°, respectively. Results also showed that the convergent duct with an inlet angle 12° and 20° improved the coefficient of performance at a specified tip speed ratio by 25.8% and 33.33% respectively in the productivity of wind turbine.

Keywords: *Coefficient of performance, DAWT, MATLAB, VAWT, wind Turbine.*

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1. Introduction

The development of renewable energy has become one of the most important goals due to global warming and the high consumption of energy, in addition to the fossil fuel waste and its impact on the environment in order to deal with these problems by resorting to alternative means of obtaining energy. Wind energy has become one of the fastest growing sources of energy. In recent years [1]. There have been many attempts to improve the performance of wind turbines and wolves by adding a tunnel to the torpedo called the shroud [2]. Grant and Kelly [3] developed and tested a mathematical model of a ducted wind turbine and described the integrations of the turbine according to various domain of building simulation. The study was investigated the concept of ducted wind turbine, and the integration of the wind turbine model mounted inside the building using the simulation tools. Abdullateef et al. [4] designed and fabricated vertical axis wind turbine (VAWT) are revealed in this work. Six different geometries of the VAWT rotors were designed and manufactured. These geometries are: two straight bladed (2HB) VAWT, three straight bladed (3HB) VAWT, Savonius rotor (SI), Savonius rotor (SII), Savonius rotor (SIII) and Savonius rotor (SIIII). They compared their results with an adopted methodology and attained reasonable agreement. A number of researches have been interested in studying this concept [5-8]. Performance of wind turbine can be improved just in case of good alignment between the channel and the wind, and the flow is no so gusty. Deterioration and other phenomena related to the wind turbine is demonstrated by Sörensen [9], where various, models to portend aerodynamic forces, design of rotor-blade airfoils, analysis of wind ranch, and wind turbine wake simulations, are also considered. One of the most important issue with duct wind turbines is the bulk of the wake, which can give rise to wake interference, which can cause fatigue loading of down wind turbines and also reduce the efficiency of wind farms. These are some of the reasons why wind turbine wake structure has been studied extensively [10-11]. Turbines built up inside small enshroud entries are also used to transfer power to the sensing system in ducts and pipes as shown in Howey et al. [12]. Hansen et al. suggested that the augmentation is limited to the relative speed-up under zero thrust. Based on inviscid 1D analysis of pressure variation through the duct [13]. The convergent duct system is considered in this paper and a comparative performance has been carried out on the convergent ducted turbine and the traditional turbine. The convergent duct turbine has the ability to accelerate the air flow through a converging intake and increasing the power that can be extracted from the air flow.

2. Design of the Convergent Ducting System Wind Turbine

The flow is assumed to be one dimensional steady and incompressible thus, flow the one dimension of governing equations are:

$$\frac{d}{dx}(\rho AV) = 0 \quad \text{... (1)}$$

$$\text{v}\frac{dV}{dx} + \frac{1}{\rho}\frac{dp}{dx} = 0 \ldots \quad \text{... (2)}$$

It will be noted that because the flow variables depend only on x in steady flow, these equations do not involve partial derivatives. Analytical solutions to equations 1 and 2 are easily obtained purpose here is not, therefore, to imply that it is necessary to solve this set of equations numerically. It is simply to illustrate some of the consideration that are involved in obtaining numerical solution to the equations governing incompressible fluid flows. The iterative finite–difference procedure used for the designed duct is shown in figure (1) [14]. This domain is divided into series of segment of length each of length Δx thus:

$$\Delta x = \frac{L}{N-1} \quad \text{... (3)}$$

Where N is the number of grid points and L the length of the solution domain

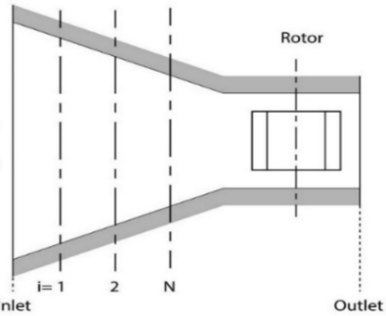

Fig. 1. Convergent duct system.

Area at each section may be calculated as:

$$\text{A}_i = A_1 - 2(A_1 - A_n)\frac{x_i}{L} + (A_1 - A_n)\frac{{x_i}^2}{L^2} \quad \text{... (4)}$$

Where $x_i = x_{i-1} + \Delta x$.

The density is constant because the flow is incompressible so the velocity at each section may be calculated as:

$$V_i = \frac{V1\,A1}{Ai} \quad \text{... (5)}$$

The pressure at point 2,,…n are then found using a first order finite difference approximation to eq.(2).using

$$\frac{dV}{dx} = \frac{Vi - V_{i-1}}{\Delta x} \quad \text{...(6)}$$

$$\frac{dp}{dx} = \frac{P_i - P_{i-1}}{\Delta x} \quad \text{...(7)}$$

The pressure is then calculated

$$P_i = P_{i-1} - \rho_i V_i (Vi - V_{i-1}) \quad \text{...(8)}$$

Applying this equation sequentially from points i= 2,…,n allows the values of P_i at each of these points . Power coefficient can be calculated from [15]

$$Cp_u = Ct * \lambda \quad \text{... (9)}$$

3. Numerical Analysis of the Convergent Duct Wind Turbine

The flow inside the duct and over the VAWT blade is solved numerically using ANSYS-LUENT 2017.The following section include.

3.1 Governing Equations

The dynamics of computational fluids include the differential governing equations and the nature of the flow which determines the possibility of the application for governing equations. Mathematical representations of these equations can be used in a group or individually depending on the uses of the output desired. Equation include the properties for any fluid which represent the conservation for mass and momentum. In such case, we are using with the equation of continuity with the application of the model K-Ω .The continuity equation or maintaining the mass provided as follows:

$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho u}{\partial x}+\frac{\partial \rho u}{\partial y}+\frac{\partial \rho u}{\partial z}=0 \qquad \text{... (10)}$$

Momentum Equation for incompressible flow is given below:

$$\rho\left[\frac{\partial u_i}{\partial t}+\frac{\partial u_k u_i}{\partial x_k}\right]=-\frac{\partial \rho}{\partial x_i}+g_i+\mu\frac{\partial^2 u_i}{\partial x_k x_k}=0 \qquad \text{... (11)}$$

3.2 Geometry

A 2D analysis for NACA 0012 air foil is treated by Ansys design. The convergent duct system for different geometry formed after create the geometry of airfoil. Three airfoils are creating for bladed and separated by 120 ° .

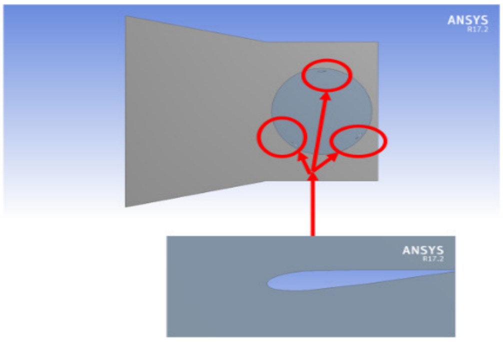

Fig. 2. 2D Geometries of convergent duct.

3.3 Mesh Generation

Solutions by using the numerical methods demand accurate meshing for the geometry. The quality for the mesh depending on the accuracy for the solution of the numerical. The precision of numerical solution depending on the mesh size. the smaller mesh size needed to produce more accuracy result. The reduction mesh size need more computer memory and processing time.

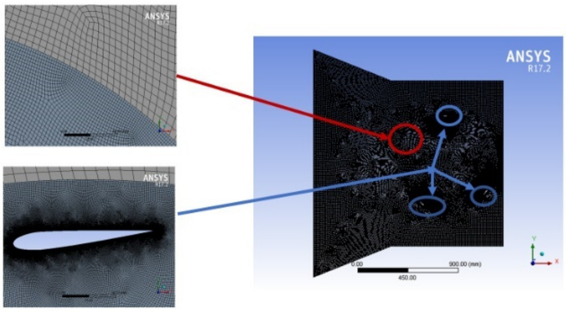

Fig. 3. 2D Meshing of convergent duct.

Table 1,
Meshing characteristics.

Statistics	
Nodes	67582
Elements	66704
Mesh Metric	Skewness
Min	2.4379e-005
Max	0.67156
Average	6.1832e-002
Standard Deviation	6.7663e-002

3.4 Boundary Condition

The performance inlet conditions and the design choices of the present study were set basing on experience. Boundary condition for convergent duct wind turbine summarized in table (2).

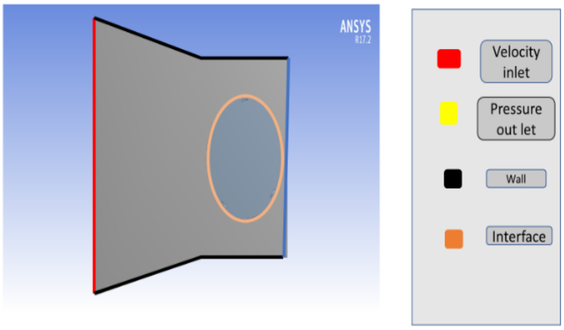

Fig. 4. 2D Boundary condition for ducting vertical axis wind turbine.

Table 2,
Boundary conduction

Viscous Model	
Model	K-omega
K-omega	SST
Model constants	Default
Inlet boundary condition	
Type	Inlet velocity
Velocity magnitude(m/s)	10
Reference Frame	Absolute
Turbulent method specification	Ratio of intensity and viscosity
Out let boundary condition	
Type	Pressure outlet
Gage pressure(Pa)	101325
Back flow direction specification method	Normal to Boundary
Turbulent specification method	Magnitude normal to boundary

3.5 Turbulence

In this study modeled SST (K-ω) used for wall bounded turbulent flow around the vertical axis wind turbine The Two equation of SST (K-ω) turbulent model is: [16]

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho u_j k)}{\partial x_j}=\mathrm{P}-\beta\rho\omega K\ \frac{\partial\left[(\mu+\sigma_k\mu_t)\frac{\partial k}{\partial x_j}\right]}{\partial x_j} \qquad \ldots(12)$$

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho u_j k)}{\partial x_j}=\frac{\gamma}{v_t}\mathrm{P}-\beta*\rho\omega^2\ \frac{\partial\left[(\mu+\sigma_\omega\mu_t)\frac{\partial k}{\partial x_j}\right]}{\partial x_j}$$

$$+2(1-F_1)\frac{\rho\sigma_\omega}{\omega}\frac{\partial(k)}{\partial x_j} \qquad \ldots(13)$$

3.6 Reference Values

Chord length = 0.1 m
Reference Length = Radius of the rotor = 0.5 m.
Enthalpy = 0 Jule /kg
Pressure = 101325 pa at the velocity inlet
Density = 1 kg/m^3
Temperature = 288.16 k

4. Result and Disscusion

The convergent duct is firstly designed to attain the desired velocity at the inlet of turbine. The duct is converged by 12° and 20° angles. The velocity is increased by 47% and 50% respectively shown in figure (5). However, the static pressure decreases in both cases the benefit of enhanced velocity was achieved as shown in figure (6). The velocity contours show that velocity at the inlet duct equal 10 m/s, it increases gradually until the turbine entry as shown in figures (7&8). This increase in speed causes an increase in the rotation speed of turbine. This will increase the power and power coefficient of the wind turbine. Figure (9) and (10) show the pressure contour pressure being to reduce at the convergent duct between the inlet duct and the out let of the duct. The maximum pressure at the inlet duct this gradually decreased toward the throttle. The high energy that can be obtained from the feathers is due to the height of the lifting coefficient, which is produced by the pressure differential on both sides of the wing. Figure (11) Show the power coefficient against tip speed ratio calculated by Ansys. To describes how to use wind energy and convert it into turbine power through a factor called a performance factor. Performance coefficient the wind turbine depends on the type of airfoil, the thickness of the blade and the Reynold number. Figure (12) reveals the power coefficient with tip speed ratio for different inlet angle 12° , 20 °. Respectively. Results showed that the larger the converging angle, the higher is the power coefficient Cp at a certain range of TSR. This is because the increase in the velocity with increase the inlet angle of the duct System. The power coefficient enhanced at a tip speed ratio equal 1.5 for convergent duct when the converging angles 12° , 20 ° by 25.8%, 33.33% respectively. Figure (13& 14) show a little difference in the power coefficient value between analytic and numerical solution this difference. This is due to the limitation in numerical solution and that 2D solution does not take into account secondary flow and vortex generated at tip. Pressure and velocity distribution along 3D blade there for a good agreement is observed for all cases.

5. Conclusions

Utilization of wind turbines with different configurations are facing the restriction of intermittent and low wind speed. Ducted system; convergent, divergent and convergent divergent even with reflectors were employed to enhance the productivity of wind turbines. In this paper, a convergent duct with two converging angles are considered. It was concluded that, increasing the angle of convergence lead to enhance the productivity of the wind turbine regarding less to the drop-in pressure because of the dependency of power on the cubic wind speed. This privilege assist installing wind turbine system in converging gates of buildings and in manufactured adapted ducts and consequently alleviating the use of DAWT systems in low wind speed regimes like Iraq.

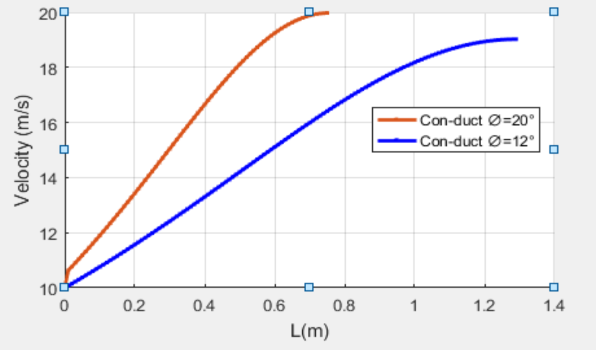

Fig. 5. Velocity distribution along the different convergent duct .

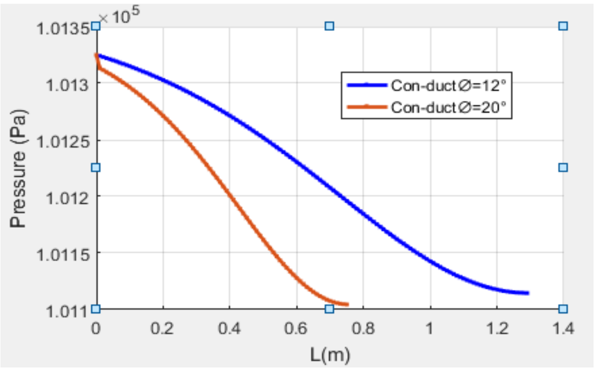

Fig .6. **Pressure distribution along the different convergent duct .**

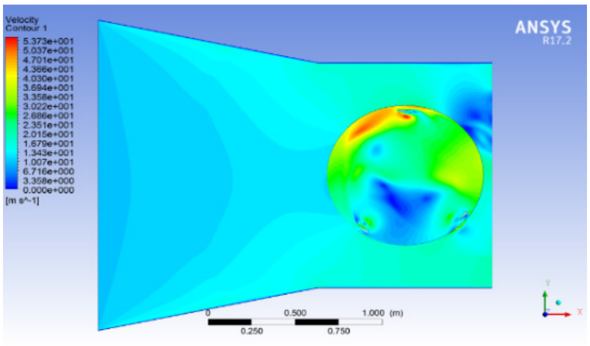

Fig. 7. **Velocity distribution along the convergent duct inlet angle 12° .**

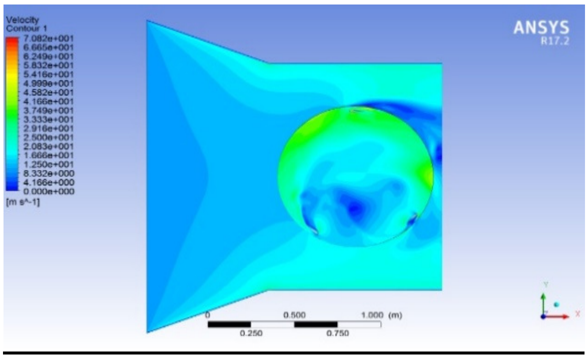

Fig. 8. **Velocity distribution along convergent duct inlet angle 20° .**

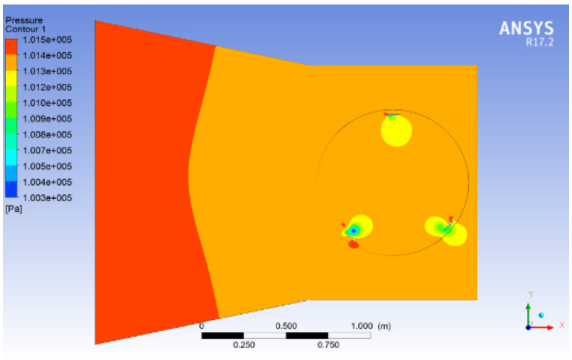

Fig. 9. **Pressure distribution along convergent duct inlet angle 12° .**

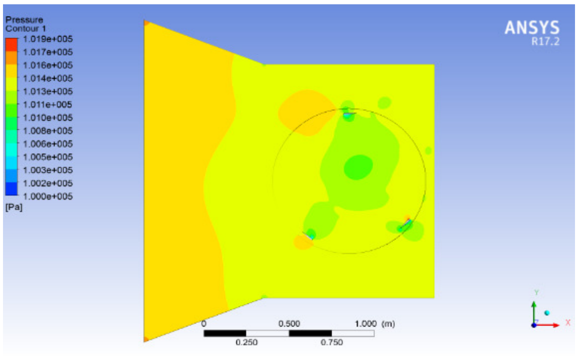

Fig. 10. **Pressure distribution along convergent duct inlet angle 20° .**

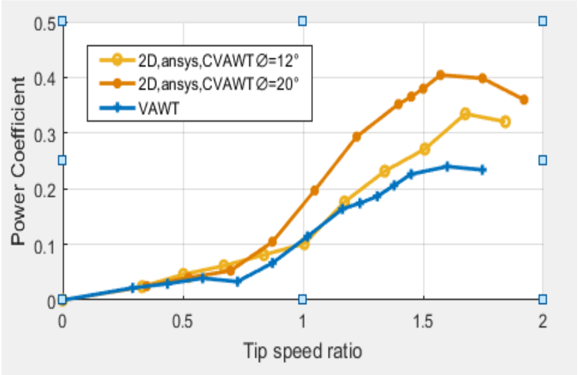

Fig. 11. **Power coefficient for convergent duct wind turbine with tip speed ratio.**

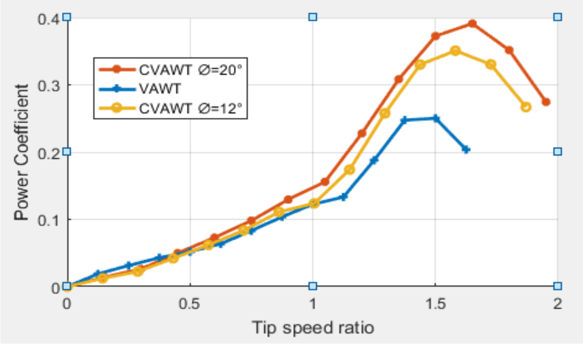

Fig. 12. **Power coefficient for convergent duct wind turbine with tip speed ratio.**

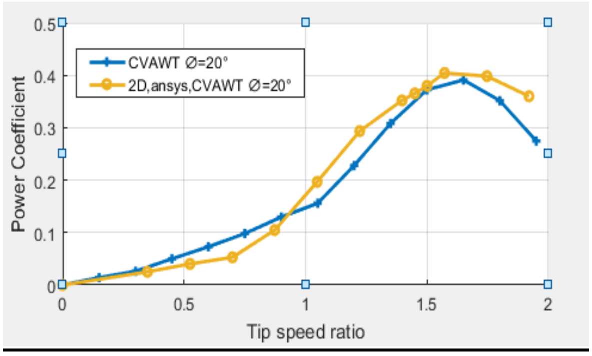

Fig. 13. **Power coefficient for convergent duct wind turbine with inlet angle 20° .**

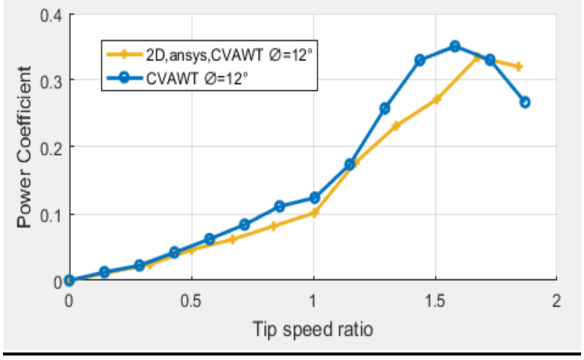

Fig. 14. Power coefficient for convergent duct wind turbine with inlet angle 12° .

Notation

A	Area $[m^2]$
Cp	Power Coefficients
Ct	Torque Coefficients
D1	Inlet Diameter of Duct [m]
D2	Out let Diameter of Duct [m]
K	Turbulent Kinetic Energy $[m^2/sec^2]$
L	Duct length [m]
P	Pressure (Pa)
R	Turbine Radius [m]
t	Time [sec]
V_∞	Free Stream Velocity [m/sec]

Greek letters

ϕ	Duct Angle [degree]
ε	Turbulent dissipation rate$[m^2/s^3]$
ρ	Air Density [Kg / m3]
λ	Tip Speed Ratio (TSR)
ω	The Angular Velocity [rad/sec]

Abbreviations

CFD	Computational Fluid Dynamics
SI	Conventional Savonius rotor
SII	First modified Savonius rotor
SIII	Second modified Savonius rotor
VAWT	Vertical axis wind turbine
TSR	Tip Speed Ratio
CVAWT	Convergent vertical axis wind turbine
Con	Convergent duct

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تعزيز أداء التوربين الريحي عمودي محور الادارة باستخدام منظومة معبر هواء تقاربي

عبد اللطيف أحمد جاد الله* سحر راضي فرج جنان دخيل حمدي*****

*،**،*** قسم الهندسة الكهروميكانيكية /الجامعة التكنولوجية / بغداد / العراق

*البريد الالكتروني:abdullateef.aljad@gmail.com

*البريد الالكتروني:dr saharalsakini@yahoo.com

***البريد الالكتروني: jenanjenan780@yahoo.com

الخلاصة

أجريت دراسات عديدة لتحسين اداء التوربين الريحي العمودي. تناول هذا البحث دراسة تحسين اداء التوربين الريحي عمودي محور الادارة باستخدام معبر هوائي تقاربي. تم تطويع منهجية رياضية تحليلية وعددية باستخدام ANSYS 17.2 لتمكين حساب معامل القدرة والعزم والمتغيرات الحاكمة الاخرى باستخدام زاويتين لمعبر الهواء وبواقع ١٢° و ٢٠°. ان استخدام المعبر بالزاويتين المذكورتين آنفا حقق زيادة في معامل القدرة بواقع ٢٥,٨% و ٣٣,٣٣% على التوالي. تم تمثيل تصرف الجريان وحساب معامل القدرة من الحل العددي ومقارنته بنتائج الحل التحليلي واظرهت تطابقا جيدا.
