Semarak Engineering Journal

Journal homepage: https://semarakilmu.my/index.php/sej/index
ISSN: 3036-0145

Performance Enhancing of A Savonius Wind Turbine with an Adaptable Convergence Ducting System

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ARTICLE INFO

Article history:
Received 20 July 2025
Received in revised form 29 November 2025
Accepted 10 December 2025
Available online 25 December 2025

Keywords:
Power coefficient; vertical axis wind turbine; ANSYS; TSR; Savonius; Convergent duct system.

ABSTRACT

A ducting system is a practical means of perhaps improving wind turbine productivity. This paper is aimed to investigate a potential strategy for enhancing the performance of vertical-axis wind turbines. It is distinguished by the addition of a convergent duct, which makes it easier to impart higher flow rates. The system was methodologized and simulated analytically and numerically as well. To do so, a computer program written in MATLAB is adapted to simulate the viability of the system. The performance was numerically processed utilizing ANSYS-FLUENT 17.2. The result shows that the average power coefficient and velocity enhanced for a convergent duct with a converging angle of 20º by 32.2 % and 47.7% respectively for the Savinus wind turbine. Also, the result shows that slight pressure decreased by 0.2077% compared with velocity increase. Results revealed an acceptable impact on the wind turbines. This technology may be effectively employed in gates and urban sites with a roughly low wind speed regime.

1. Introduction

Due to the effects of global warming, increased energy use, and the waste from fossil fuels, which has a negative influence on the environment, the development of renewable energy technologies has taken on a major role [1-3]. This forces the use of these alternative fuels in the production of energy. In recent times, wind power has emerged as one of the energy sources with the quickest rate of growth [4,5]. One of the vertical axis wind turbines (drag type) is the Savonius turbine, which was invented in 1922 by Finnish engineer Sigurd Johnson Savonius. It is a dragtype aerodynamic device with two or three scoops [6,7]. The "S"-shaped cross-section will be visible when viewed from above. The Savonius wind turbine is turned by a drag force, and its beginning torque is maximum [8-10]. Ilham Satrio Utomo *et al*., [11] experimental study modifications Savonius wind turbine by using fins to rise the inline drag force by producing a flow that can emit the overlapping ratio of the gap. The power generator, power coefficient, and torque coefficient are among the parameters that came about as a result of the experiment. Variations in fin area, or horizontal finning, will be used to gather

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https://doi.org/10.37934/sej.11.1.122134

experimental data at wind speeds ranging from 3 to 4.85 meters per second. 2 According to experimental findings, adding fins can increase a wind turbine's performance by 11%. Kannan and Jaganath [12] investigate the best blade geometry and flow augmentation device combinations to increase turbine efficiency and lower negative torque. By CFD analysis, nine trial configurations of the blade shape are created, and numerical results are produced. The combination of the AR-0.5, OR-0.2, and HA-12.5 turbines yielded the highest torque generation of 1.7520 Nm out of 9 trials, with a Cp value of 0.31. Additionally, the combination case is changed for design enhancement research using guide vanes to improve the torque and power coefficient to 1.9487 N-m and Cp of 0.34 respectively. Numerical and analytic assessment of a zooming in wind turbine's performance (three-bladed Darrius wind turbine) by Abdullateef Ahmed *et al.*, [13]. The capability of the VAWT installed in an adaptable duct is improved by 24.2% and 9.09%, respectively, when an adjustable diverging duct is used for opening angles of 20° and 12°. This is because it is possible to apply a higher flow rate. Majid Eshagh Nimvari et al. [14] investigate enhance and improve performance of wind turbine by joining a deflector (porous) in face of the Savonius WT. It was specifically proposed to reduce the strong effects of the complex wake-zone generated aft the traditional solid-deflector that hadn't been interpretated yet. Numerical solutions were found for the equation of the unstable Reynolds-averaged Navier-Stokes and the SST k-ω turbulence model. The outcomes showed that the maximum torque and power coefficients can be obtained by selecting the proper porosity value. According to a study by Rochman *et al.*, [15] on the impact of extra flanges on convergent ducts, the addition of a flat flange at the end of the duct increases wind speed in the duct's throat region by 29% when compared to the situation in which there is no flange. Mohammad *et al.*, [16] numerical investigation of adding diffuser augmented wind turbine to the rotor. Three major parts make up the chosen duct: a diffuser, a flange, and a nozzle. These elements work together to give the rotor placed in the duct throat an enhanced upstream velocity. A code was created to facilitate all the numerical processes, such as simultaneously producing meshes, altering geometries, and configuring the numerical solver. Ultimately, the ideal duct geometry that permits a doubling of the flow velocity has been determined. The findings indicate that the DAWT's power coefficient can be increased by up to 2.9 times. This research examines the adaptable ducted Wind turbine system and compares the performance of the convergent ducted turbine with that of the conventional turbine. The airflow through a converging intake can be accelerated by the convergent duct turbine, which increases the amount of power that can be recovered from the flowing air.

2. Shaping and Analysis of the Converging Duct System

The one-dimensional steady and incompressible flow is assumed, and the governing Eq. (1) and Eq. (2) for the one-dimensional flow are [17, 18]:

$$\frac{d}{dx}(\rho A V) = 0 \tag{1}$$

$$v\frac{dV}{dx} + \frac{1}{\rho}\frac{dp}{dx} = 0 \tag{2}$$

Note that in a steady flow, the flow variables only rely on x, hence partial derivatives are not included in these equations. Equations 1 and 2 have simple analytical solutions. Consequently, this is not intended to suggest that solving this system of equations numerically is required. Its purpose is only to provide an overview of some of the factors to be taken into account while trying to solve the equations controlling incompressible fluid flows numerically. Figure (1) illustrates the planned duct's iterative finite-difference process. This domain is split up into the following series a length of Δx segments in Eq. (3):

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

The section area at every can be evaluated in Eq. (4) [19]:

$$A_i = A_1 - 2(A_1 - A_n)\frac{x_i}{L} + (A_1 - A_n)\frac{{x_i}^2}{L^2} \quad (4)$$

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

Since the flow is incompressible and the density is constant, the velocity at each segment may be computed as follows Eq. (5):

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

The pressure on sections 2 to N is then determined by a 1st order finite difference approach to Eq. (2). using follows Eq. (6) and Eq. (7):

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

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

The pressure is then calculated in Eq. (8)

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

Eq. (8) is then applied in sequence from points i= 2,…,N permit the context of P_i at any of these points.

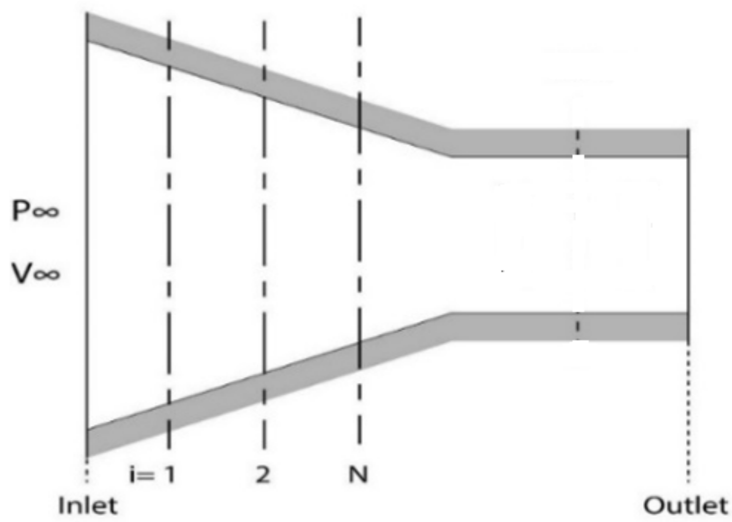

Fig. 1. Convergent duct system

3. Numerical Investigation of The Proposed Turbine Performance

The flow enclosed in the duct and on the vertical Savonius blades is processed numerically by ANSYS-FLUENT 2017. The following sections are included.

3.1 Dominant Equations

Mathematical representations of the governing equations can be grouped or separately employed basing upon the usage of the outcome prescribed. Eq. (9) of the properties of any fluid present the conservation of mass, energy and momentum. The continuity equation is used to implement the model K-Ω. Continuity equation may be given as [20]:

$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho u}{\partial x}+\frac{\partial \rho u}{\partial y}+\frac{\partial \rho u}{\partial z}=0 \tag{9}$$

While the momentum equation for incompressible flow is given as follows Eq. (10):

$$\rho\left[\frac{\partial u_i}{\partial t}+\frac{\partial u_k u_i}{\partial x_k}\right]=-\frac{\partial \rho}{\partial x_i}+g_i+\mu\frac{\partial^2 u_i}{\partial x_k x_k}=0 \tag{10}$$

3.2 Geometry and Mesh Generation

A two dimensional analysis for the VAWT is dealt using Ansys analysis. Figures (2 and 4) show the geometry of Savonius without and with ducts. The diameter of the wind turbine is 1m and 1m in height. In a convergent duct, the cross-sectional area smoothly decreases from a larger value where the duct diameter of (2 m) to a smaller one where the outlet diameter (1.45 m). The duct length is (0.75 m) for a duct angle of 20°.

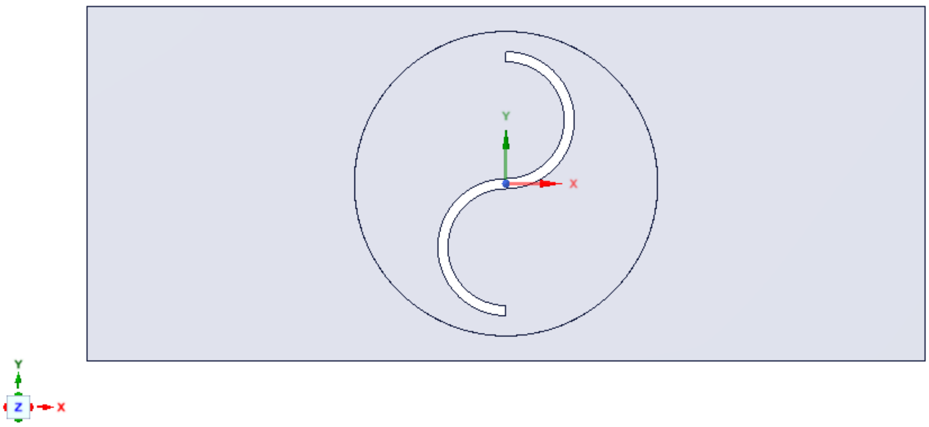

Fig. 2. Geometry of Savinus wind turbine

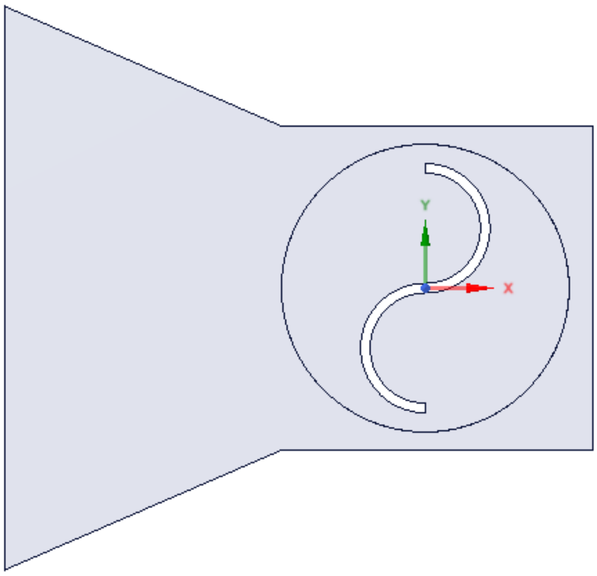

Fig. 3. Geometry of convergent duct wind turbine

3.3 Mesh Generation

A mesh is a discretized representation of the geometry of a physical system. It divides the computational domain into small, manageable elements or cells. The purpose of the mesh is to achieve a linearization of a system by a modelling that represents the system, with a view to simulations of calculations or graphicl presentations. Figure (3.13) shows the mesh generation for ducted and inducted wind turbines.

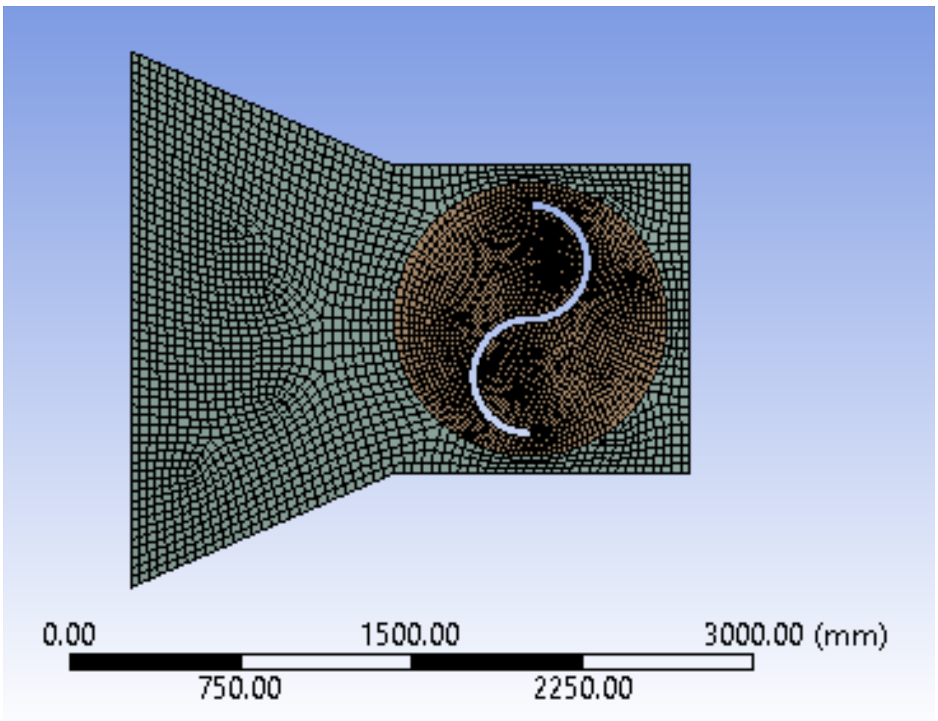

Fig. 4. Mesh generation of convergent duct wind turbine at inlet angle 20°

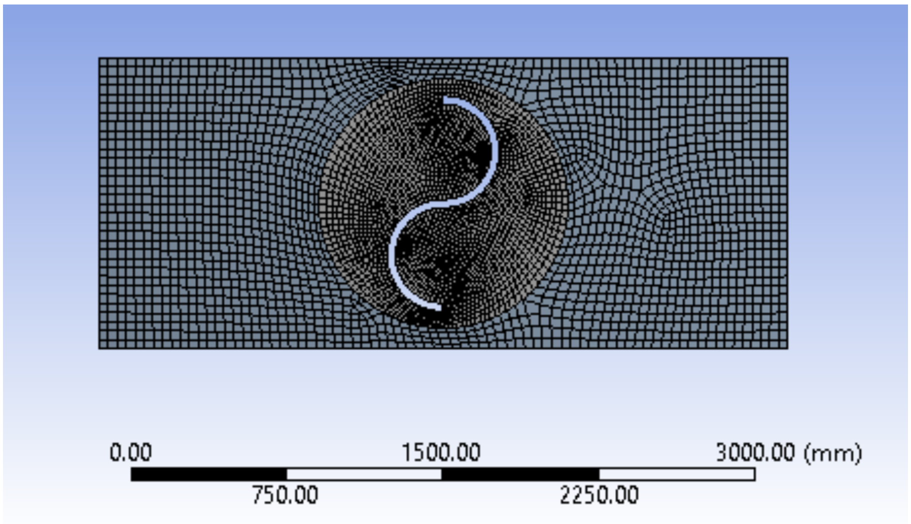

Fig. 5. Mesh generation of VAWT

Table 1
Characteristics of mesh

Statistics	
Nodes No.	67,582
Elements	66,704
Metric of Mesh	Skewness
Minimum	$2.4379*10^{-5}$
Maximum	0.67156
Average	$6.1832*10^{-2}$
Standard Deviation	$6.766*10^{-5}$

3.4 Boundary Circumstance

The aerodynamic performance of the Savonius wind turbine with adaptable duct is conducted numerically. Airflow Parameters at every location of the selected plane are prescribed. Findings are highly influenced by the conditions at circumferences**.** Several stated boundaries exist in the FLUENT package like pressure inlet, entry velocity, mass of airflow rate, pressure outlet, etc. In the present work, the B. Cs are employed in the path of the blade considered for setting the moving and airfoil location [21]. Wind speed at inlet was set as an inlet and a pressure at exit with the value of ambient pressure is dealt the exit. The working zone is prescribed by the ducted system. The boundary conditions of the outflow are synchronized for simulation. The value of the velocity with orientation should be known. The boundary conditions of the C-D wind turbine are briefed in Table (1).

Table 2
Boundary condition

Zone	Boundary Conditions
Inlet velocity	10 m/s
Inlet pressure	101325 Pa
Airfoil	Solid rotating Wall
Rotating domain	Air
Flow domain	Airflow

4. Turbulence

Result of the flow is affected by the Reynolds number. Working with a high Reynold number required more accuracy and precision. In this work, wall-rounded turbulent flow over the wind turbine rotor is employed using SST (K-ω). The Eq. (11) and Eq. (12) of the SST (K-ω) turbulent model are [22] :

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho u_j k)}{\partial x_j} = P - \beta * \rho\omega K + \frac{\partial\left[(\mu+\sigma_k\mu_t)\frac{\partial k}{\partial x_j}\right]}{\partial x_j} \tag{11}$$

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho u_j k)}{\partial x_j} = \frac{\gamma}{v_t} P - \beta * \rho\omega^2 \frac{\partial\left[(\mu+\sigma_\omega\mu_t)\frac{\partial k}{\partial x_j}\right]}{\partial x_j} +2(1 - F_1)\frac{\rho\sigma_\omega}{\omega}\frac{\partial(k)}{\partial x_j} \tag{12}$$

5. Result and Disscusion

Distribution of the velocity as well as pressure through the converging duct can be analyzed and optimized through computational fluid dynamics (CFD) simulations. A convergent duct with a vertical axis wind turbine (VAWT) refers to a structure that is designed to accelerate and direct the incoming wind towards the turbine blades. The convergent duct helps to direct the wind flow more precisely towards the turbine blades, ensuring that a larger portion of the wind energy is captured and converted into rotational motion. This can lead to improved efficiency and performance of the VAWT. Figure (6) shows the velocity distribution along the converging duct. The Figure shows that the wind enters the converging duct, and the narrowing cross-sectional area causes a reduction in the available volume for the wind to flow through. In view of the principle of continuity in fluid dynamics, any reduction in area will deduce to an increase in velocity to maintain the same mass flow rate. This Figure shows that the velocity enhanced by 47.7 %. Figure (7) shows the pressure distribution along the convergent duct in VAWT the pressure distribution is primarily influenced by the acceleration of the wind as it flows through the narrowing cross-sectional area. Generally, the pressure decreases as the wind travels through the converging section of the duct according to Bernoulli's principle. The pressure distribution along the convergent duct can be approximated by a profile where the pressure is highest at the entrance of the duct and gradually decreases as the wind approaches the narrower section. The rate of pressure decrease depends on various factors such as the design of the duct, the wind speed, the specific operating conditions, the presence of turbulence, boundary layer effects, and the interaction between the rotor blades and the airflow. These factors can introduce additional complexities and variations in the pressure distribution. Figure (7) shows that slight pressure decreased by 0.2077% compared with velocity increase. Velocity change and the combined variation of the pressure contour for the non-ducted wind rotor are presented in Figures (8 and 9). Contours of velocity contours reveal that velocity at the entry of the duct equal 10 m/s, it increases step by step until the turbine inlet (vis figure 10). The velocity distribution can be approximated by a velocity profile that is highest at the centerline of the duct and decreases towards the walls. This profile is often assumed to be relatively uniform, especially in the axial direction. However, it's important to note that the actual velocity distribution may be affected by factors such as turbulence, boundary layer effects, and the specific design and shape of the duct. The interaction between the rotor blades and the airflow causes variations in the velocity distribution along the duct. The rise of the speed leads to an increase in the rotational speed of the wind turbine rotor. This will in turn rise both the power and power coefficient of performance of the wind turbine. Figure (11) shows that the contour of pressure being reduced along the convergent duct between the inlet and outlet of the C-duct. The maximum pressure at the inlet duct gradually decreased toward the throttle. Figure (12) shows the power coefficient against the tip speed ratio calculated by ANSYS. The Figure shows that the average power coefficient enhanced for a convergent duct with a converging angle of 20º by 32.2 %.

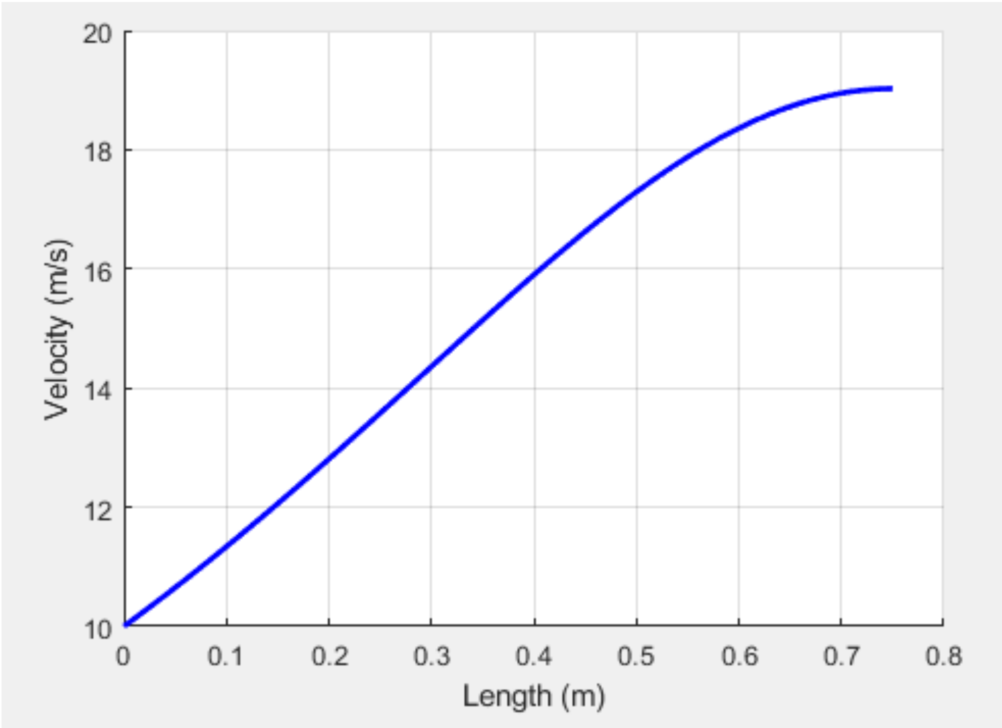

Fig. 6. Velocity variation along the C-duct

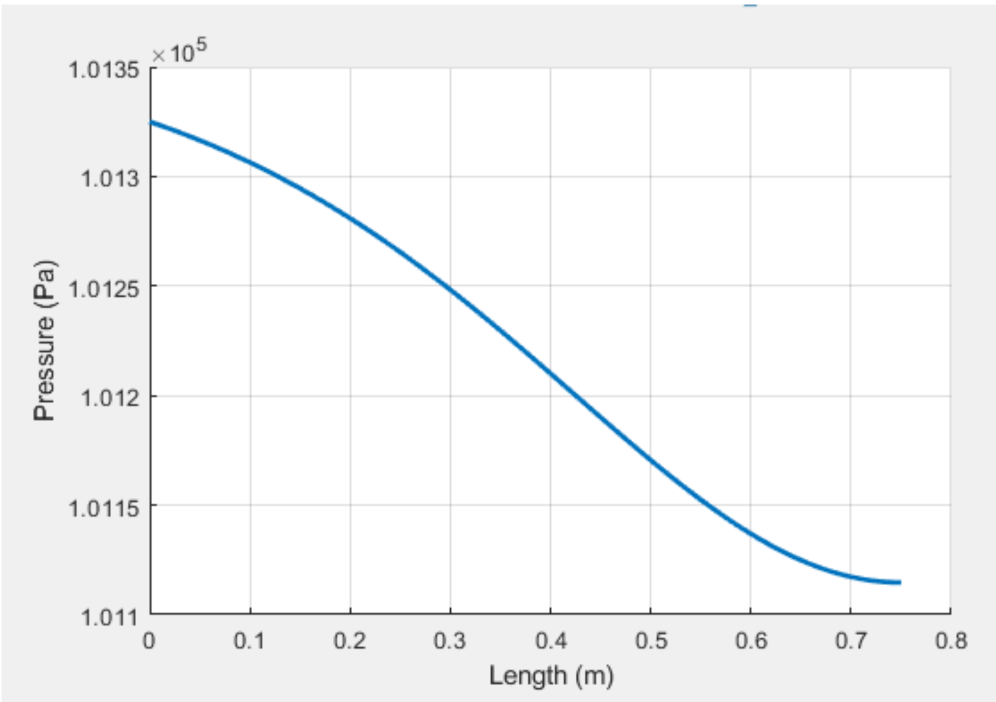

Fig. 7. Pressure reduction through the convergent duct

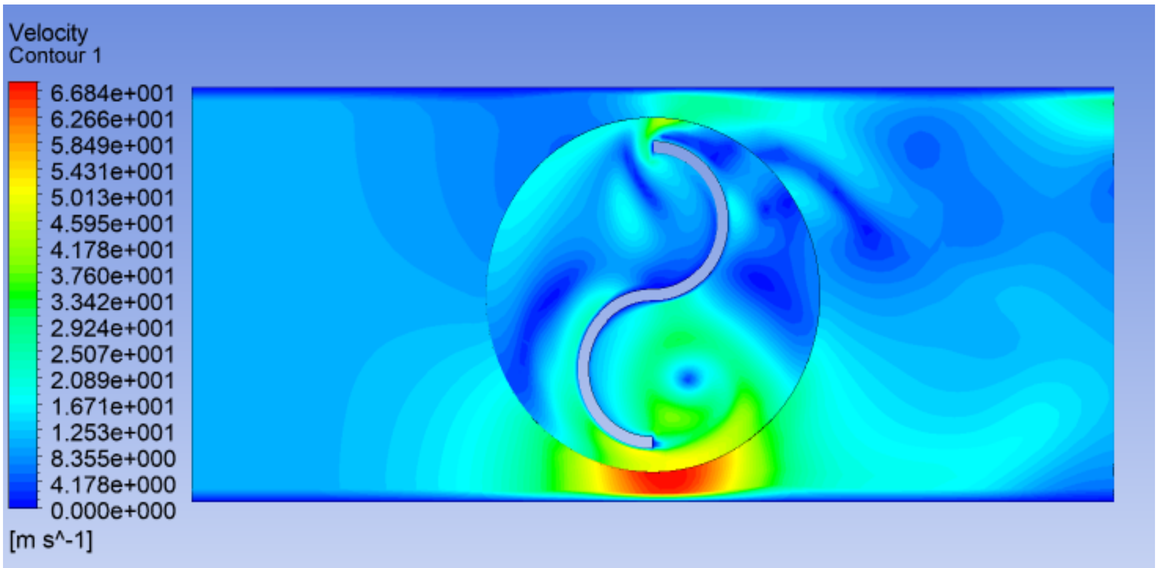

Fig. 8. Distribution of velocity in the Savonius VAWT without duct

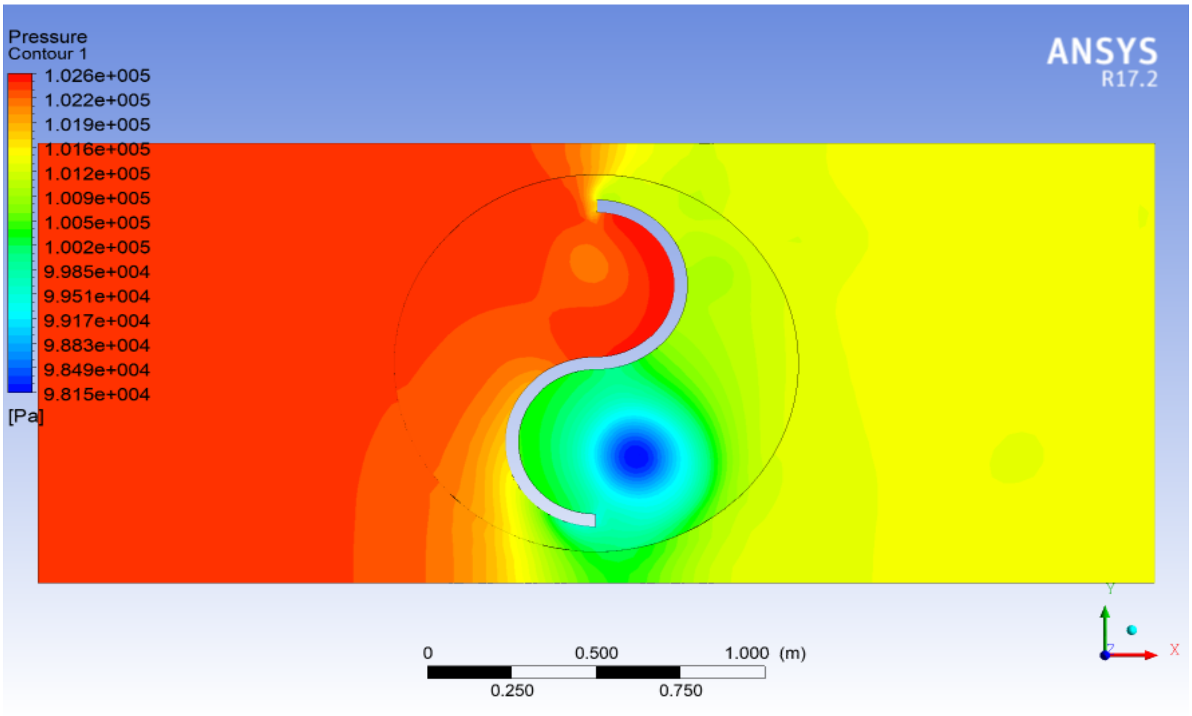

Fig. 9. Distribution of velocity in the Savonius VAWT without duct

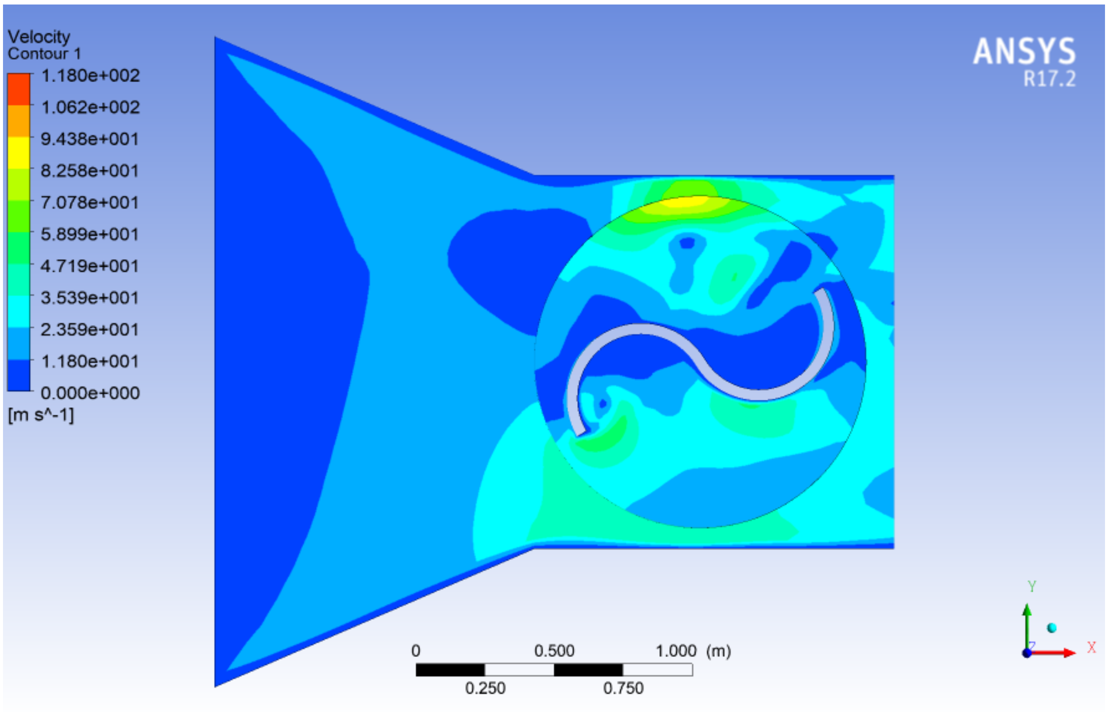

Fig. 10. Velocity of the flow in the C-duct for an inlet angle of 20°

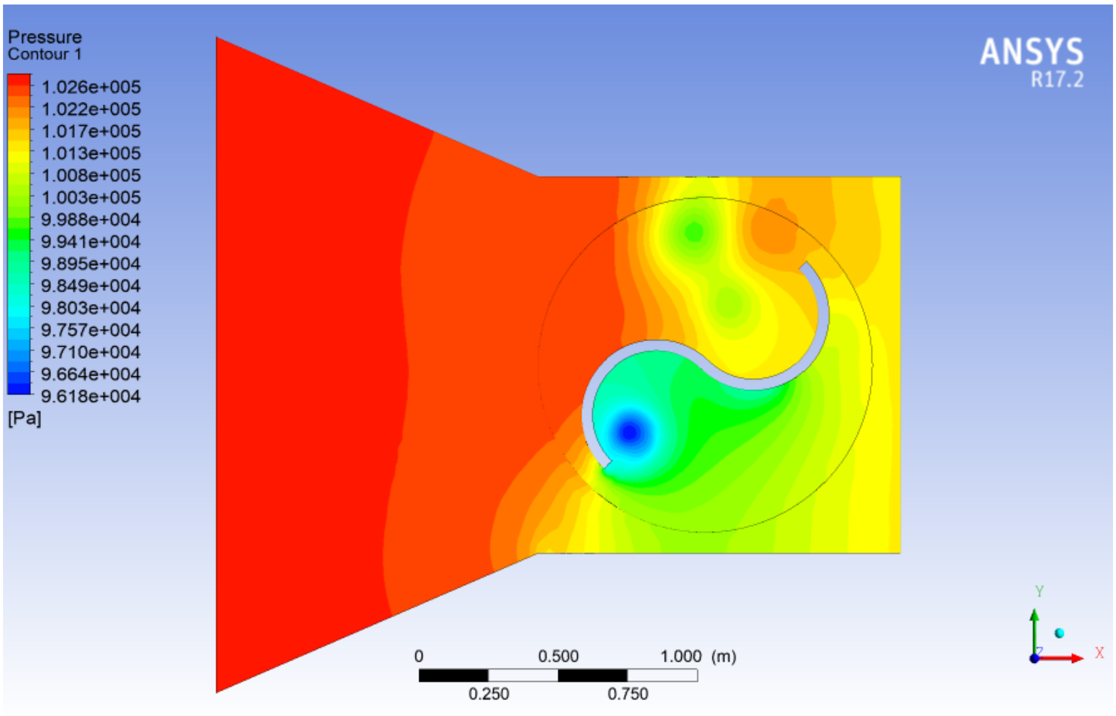

Fig. 11. Pressure variation in the C-duct for an opening of 20°

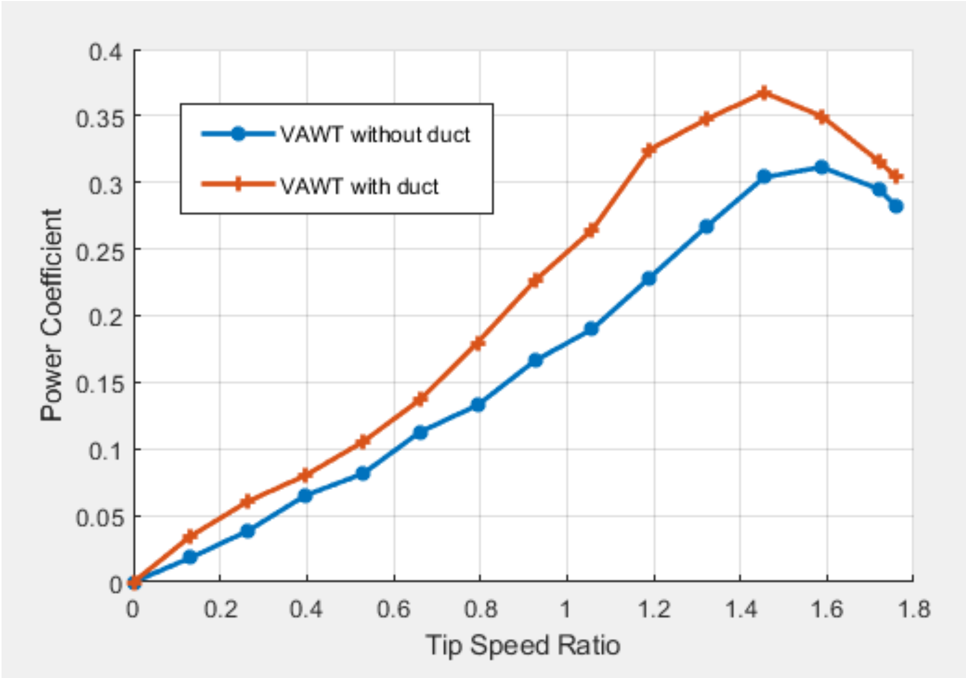

Fig. 12. Relationship between Cp and TSR for C-D Savonius VAWT

6. Conclusions

Numerical and analytic prediction of the productivity of the DVAWT was achieved in this work. Savonius wind turbine with ducted system used to augment the energy produced of the vertical axis wind turbines. Because power depends on cubic wind speed, it was determined that employing convergence duct lead enhanced wind turbine productivity with respect to drop-in pressure. The result show that.

1. The wind enters the converging duct, the narrowing cross-sectional area causes a reduction in the available volume for the wind to flow through. Basing the principle of continuity in fluid dynamics, any reduction in wind turbine rotor area gives an increase in velocity by 47.7 %.
2. Average power coefficient enhanced for a convergent duct with a converging angle 20º by 32.2 %
3. According to Bernoulli's principle, the pressure distribution along the convergent duct slightly decreases by 0.2077% with a decreased cross-section area.

Nomenclature

Cp	Coefficient of Performance
D1	Entry Diameter of the adaptable Duct [m]
D2	Exit Diameter of the Duct [m]
K	Kinetic Energy (Turbulent) [m^2/sec^2]
L	length of the duct [m]
N	Number of section number
P	Static Pressure (N/m^2)
R	Turbine Rotor Radius [m]
V_∞	Upstream Velocity [m/sec]

Greek letters

ϕ	Duct Opening [degree]

ρ Air Density [Kg / m3]

Abbreviations

CFD Computational Fluid Dynamics
VAWT Vertical axis wind turbine
TSR Tip Speed Ratio

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