

# “CFD Analysis on Two Bladed Savonius Wind Turbine With and Without Splitter”

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**Abstract** - Recent uncertainties in the world's energy market due to reduction of fossil fuel sources, global warming threats and increasing the price of fossil derivatives impose the need of harnessing the clean and renewable source of energy. In this context research in the field of wind energy is becoming particularly important hence the main reason of considering Savonius wind turbine is because of its high starting torque at low wind velocity. Many modifications have been made on conventional Savonius wind turbine rotor blades; even though there is a problem of negative torque exists. In the present work experimental conventional savonius wind turbine is considered as a reference to validate the result. CFD analysis is carried out by ANSYS FLUENT 14.5 software with different inlet wind velocity 2.2, 3.7, 4.9 and 6.5 m/s in different angular position of 0, 45, 90 and 135 degree orientation to obtain the static torque and analyze the pressure and velocity distributions are studied. The modification is done on conventional savonius rotor by introducing splitter. Splitter savonius wind turbine which is helpful for proper pressure and velocity distribution in rotor, thereby increasing the 5% improvement in power coefficient as compared with conventional Savonius wind turbine. In order to reduce the negative torque three different stationary guide vanes are analyzed in terms of velocity and pressure distribution with different velocity conditions and finally optimized Curved stationary guide vane selected for the splitter savonius rotor and there is a 15 % improvement of power coefficients ( $C_p$ ) is achieved.

**Key Words:** Splitter Savonius Wind Turbine, Stationary Guide Vanes, Power, Power Coefficient.

## 1. INTRODUCTION

Wind energy has been in use since the earliest civilization to grind the grain, pump the water from deep wells, and power sail boats. Wind mills in pre-industrial Europe were used for many things, including irrigation, saw milling of timber. The stimulus for the development of wind energy in 1973 was due to rising price of oil and concerned over limited fossil fuel resources. Wind energy has been the fastest growing renewable energy sector in India. Energy is vital for the country's economic growth and improving the life standard of its citizen. India has spent lots of resources on increasing

its energy capacity since independence. As a result, country's generation capacity has increased considerably. Nevertheless, meeting growing energy needs through conventional sources such as coal, gas, etc. creates environmental problems. Hence, the government embarked on exploring new and clean energy sources. The main driver for use of wind turbine to generate the electrical power is the very low CO<sub>2</sub> emission. The main driver for use of wind turbine to generate the electrical power is the very low CO<sub>2</sub> emission. The wind turbine is used to convert power of the wind into electricity has many advantages. It is modular and can be installed relatively quickly, so it is to match electricity supply and demand. The fuel, the wind is free and plenty full which eliminates the cost of purchase of fossil fuels, and its storage. Wind Energy Conversion System (WECS) which are broadly classified as two types they are of Horizontal Axis Wind Turbines (HAWT) which are widely used because of its higher power rate. And Vertical Axis Wind Turbines (VAWT) these turbines are used because it is more beneficial due to its low starting torque characteristics as well as other advantages like being in-expensive to build and of simple design. Other than that, the aerodynamics of a horizontal-axis wind turbine is complex. Many Researches are going on VAWT as that can be used in domestic power generation they provide wide ranges of benefit from recoverable wind energy in buildings, facade and in any urban area where low altitude winds are remarkable and the construction of a conventional wind farm is unfeasible. The most basic type of vertical axis wind turbine is Savonius Wind Turbine (SWT). This class of wind turbine was introduced by a Finnish engineer Savonius in the 1920s and was named after its inventor (Savonius, 1929). The outlook of this turbine analogous to an 'S' shape, when viewed from top surface. These turbines are designed to be driven by the wind drag forces on the turbine blades. The turbines have very low cut in speed and operate in low wind velocity.

## 2. METHODOLOGY

Because of more energy demand there are many researches are going on wind energy because it is renewable and eco friendly. Many developments are going on drag type device especially in Savonius wind turbines. In this work it is mainly concentrated on conventional savonius wind turbine of

single stage two bladed Savonius rotors. Here experimental model has to be taken as reference and CFD analysis to be done for the validation by ANSYS FLUENT 14.5 software. A new concept of splitter arrangement is made in conventional savonius wind turbine in order to get proper air channelization and proper pressure distribution. In order to reduce the negative torque the guide vanes are introduced as stator part in savonius turbine. The analysis carried out with different angle of rotation that is 0, 45, 90 and 135 degrees in low wind velocities of 2.2, 3.7, 4.9, 6.5 m/s, to analyze the velocity and pressure distribution and obtaining average torque.

### 2.1 Conventional Savonius Wind Turbine (CSWT)

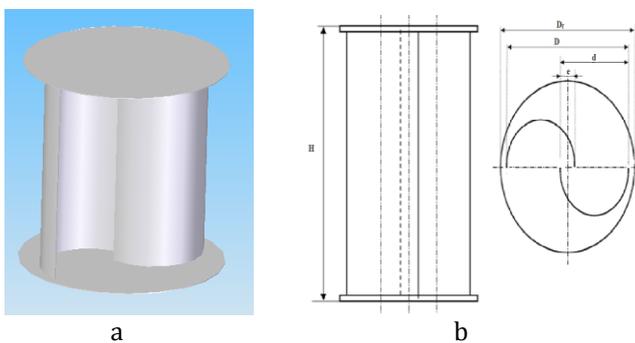


Fig-1: (a) CSWT model (b) Schematic diagram of CSWT

The CSWT is designed as per experimented model dimensions [8].

Table-1: Geometry parameters of CSWT model

Total height of the rotor (H)	400 mm
Nominal radius of the rotor (d)	200 mm
Diameter of the rotor (D)	400 mm
Overlap ratio ( $\beta$ )	20%
Aspect ratio ( $\alpha$ )	1
Main overlap (e)	40mm
Thickness of the model (t)	2mm

The aspect ratio considered as 1 and the overlap ratio of 20% taken in order get better performance. The importance of giving overlap is to reduce the negative torque in lesser extent that developed in convex blade, the wind that hitting to concave blade that directly traverse into convex blade to impact to reduce the negative torque in it.

#### 2.1.1 Theoretical calculation of conventional Savonius wind turbine

The electrical current produced by a wind turbine is quantified in terms of power, usually in units of watts. Equations have been developed for the purpose of predicting

the amount of power a wind turbine will generate.

Swept area of the wind turbine ( $A_s$ ) =  $(D \times H)$

Free wind power ( $P_{wind}$ ) =  $\frac{1}{2} \rho A_s V^3$

$P_{rotor} = C_{p \max} \times P_{wind}$

Table-2: Analytical Power and power coefficient of Savonius rotor

Free wind velocity 'V' (m/s)	Power 'P' (W)	Coefficient of power (Cp)
2.2	0.23	0.296
3.7	1.08	0.296
4.9	2.51	0.296
6.5	5.85	0.296

Table-3: Results of experimented conventional Savonius wind turbine

Wind Velocity 'V' (m/s)	Speed of wind turbine 'N' (rpm)	Power 'P' (W)	Coefficient of Power (Cp)
2.2	89	0.087	0.093
3.7	121	0.527	0.118
4.9	195	1.442	0.139
6.5	289	3.85	0.159

### 2.2 Splitter Savonius wind turbine model design (SSWT)

In order to channelize the air and for proper velocity and pressure distribution a splitter device is attached to the conventional Savonius wind turbine.

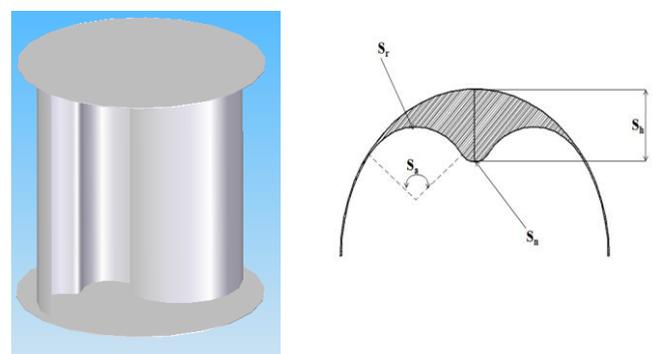


Fig-2: (a) SSWT model (b) Schematic diagram of Splitter geometry

### 2.2.1 Splitter Geometry

As earlier mentioned because of more turbulence there is no proper pressure distribution and hence it reduce the torque which ultimately reduces the performance of the wind turbine hence in order to eliminate this problem splitter element is attached to conventional SWT

Where,

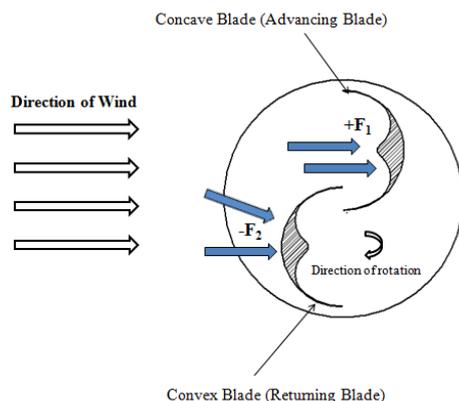
- $S_h$  Splitter Height
- $S_n$  Splitter Nose radius
- $S_r$  Splitter Curvature radius
- $S_a$  Splitter Curvature angle

**Table-4:** Splitter geometry dimensions

Splitter Height	$S_h$	46.40 mm
Splitter Nose radius	$S_n$	11.89 mm
Splitter Curvature radius	$S_r$	44.70 mm
Splitter Curvature angle	$S_a$	99.4°

Here the splitter nose which made into blunt edge which is given of fillet radius of 11.89 mm in order to distribute the air properly and the blunt edge which acts as aerofoil structure which speed up the air and channelize the air smoothly. Here splitter height is reduced because in order to increase the swept area of the turbine to catch the air.

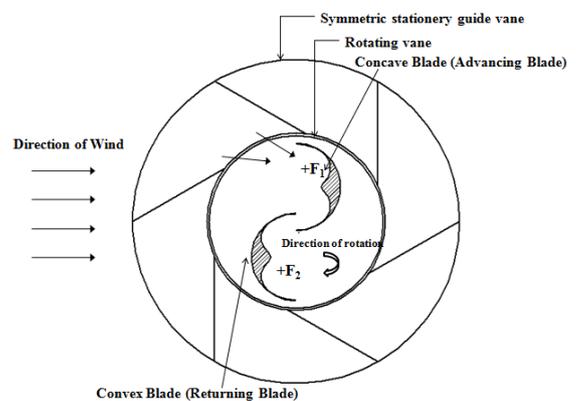
### 2.3 Negative Torque development in Savonius wind turbines



**Fig-3:** Negative torque development in split Savonius wind turbine

The major problem that is faced by the drag type vertical axis wind turbine i.e. in case Savonius wind turbine is negative torque. The wind hitting the Savonius wind rotor at a certain speed creates a positive wind force that constitutes a positive torque (+ $F_1$ ) on the concave blade and a negative wind force that constitutes a negative torque (- $F_2$ ) on the convex blade. Since the torque on the concave blade is higher than the torque on the convex blade, a rotation movement is

secured. But the negative torque developed in the convex blade which restricts the acceleration of the moving or advancing blade, this leads to decrease in speed of the rotor and also reduces the performance of the rotor. From the above Fig-3 it can be noted that the concave side of the blade drag coefficient is of 2.3 and it adds a necessary force of (+ $F_1$ ) to rotate the blade but in case of convex side the drag coefficient is 1.2 which creates negative force (- $F_2$ ), it slowdown the rotation. By this negative torque development which restricts the rotor movement. Hence many researches are going on to reduce negative torque in Savonius wind turbine by introducing wind shield, curtains, nozzle arrangement, V shaped deflectors are used. In this work stationary guide vanes are using to reduce the negative torque to get efficient work. In order to reduce the negative torque guide vanes are used which restricts the wind force that develops on the convex blade which leads to decrease in the negative torque development in the rotor



**Fig-4:** Method to reduce the negative torque by guide vane

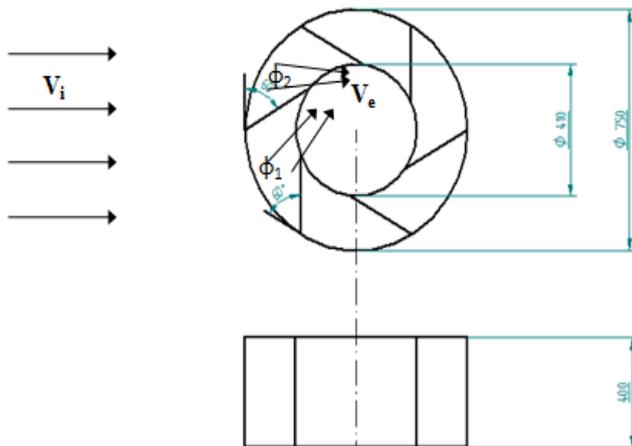
From the Fig-4 it is observed that the wind pressure on the concave side is more which + $F_1$  development which creates the blade to rotate in clock wise direction, while the convex side barrier developed by guide vanes in which negative force vanished and it gives + $F_2$ , the returning blade moves easily without any restriction. Guide vanes also increase the velocity of air at the outlet and pointing towards the rotating blade to increase the speed of the rotor and hence there is improvement in the efficiency and performance the rotor.

### 2.4 Study of different types of guide vane

Guide vane is one of additional device that its function is for directing wind stream onto concave blade and deserves as obstacle of the wind that flowing onto convex blade. That way it increased wind speeds to strike the rotor, consequently it produced higher power coefficient thus Savonius rotor performed to get better performance. Here circular geometry guide vanes are adopted instead of rectangular curtain arrangement deflectors.

### 2.4.1 Symmetric Stationary Guide Vanes (SSGV)

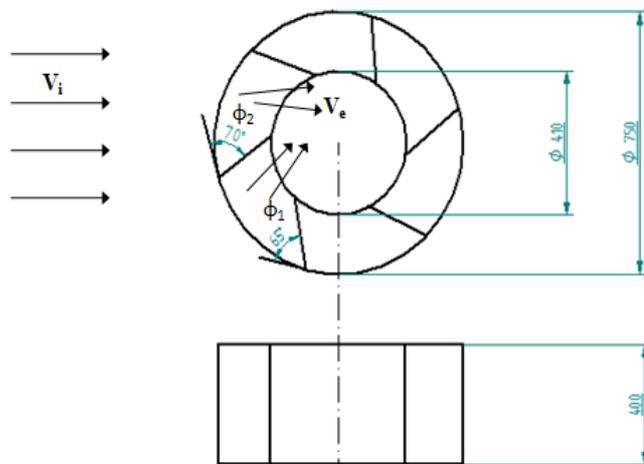
This is one type of SGV it consist of 6 vanes in which; symmetric straight guide vanes with angles  $\phi_1 = \phi_2$  are situated. Free wind with velocity  $V_i$  hits the SSGV as shown in Fig-5 and there will be increase in wind speed  $V_e$  inside the guide vanes as a result of venture effect created by SSGV.



**Fig-5:** The geometry of symmetric stationary guide vanes (SSGV)

### 2.4.2 Asymmetric Stationary Guide Vanes (ASGV)

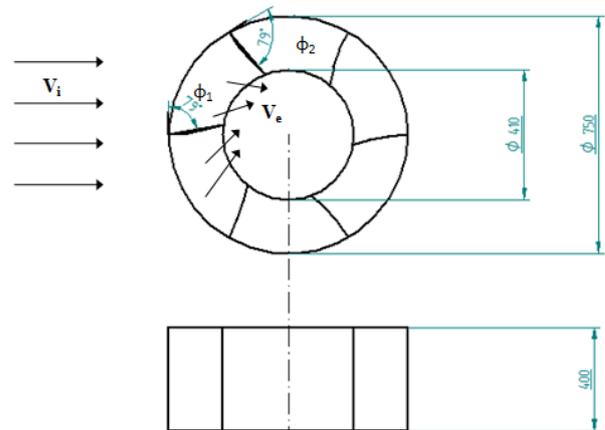
This is one type of SGV it consists of 6 vanes in which; a pair of two asymmetric straight guide vanes with angles  $\phi_1$  and  $\phi_2$  is situated. Free wind with velocity  $V_i$  hits the ASGV as shown in Fig-6 and there will be increase in wind speed  $V_e$  inside the guide vanes as a result of venture effect created by ASGV



**Fig-6:** The geometry of asymmetric stationary guide vanes (ASGV)

### 2.4.3 Curved Stationary Guide Vanes (CSGV)

This is one type of SGV consists of 6 vanes in which; symmetric curved guide vanes with angles  $\phi_1 = \phi_2$  are situated. Free wind with velocity  $V_i$  hits the CSGV as shown in Fig-7 and there will be increase in wind speed  $V_e$  inside the guide vanes as a result of venture effect created by CSGV. The curved geometry is made in such a way that air tangentially hits the pitch circle diameter ( $d_p$ ) of rotating vane.



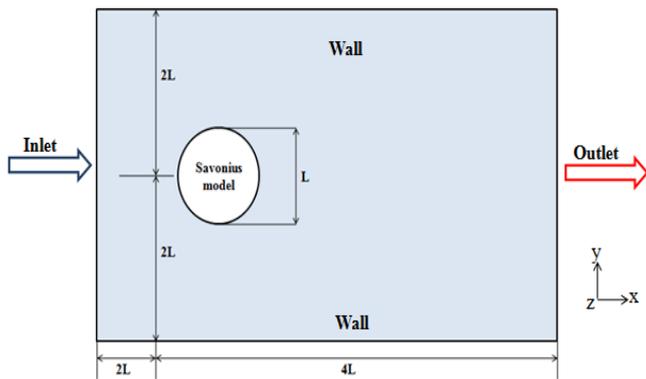
**Fig-7:** The geometry of curved stationary guide vanes (CSGV)

## 2.5 CFD Analysis

In this paper the computational analysis is conducted using ANSYS FLUENT 14.5 software which is one of commercial CFD (computational Fluid Dynamics) tool. Fluent is an analysis program utilizing finite volume method (FVM) based on the Navier-Stokes and energy equation, which is suited for resolving ambient flow and heat transfer problems for complicated shapes. Numerical domain and meshes were generated using ICEM CFD software which is inbuilt in ANSYS. The  $k-\epsilon$  RNG turbulence model has been preferred for the analysis. The  $k-\epsilon$  model is very popular for industrial applications due to its good convergence rate and relatively low memory requirements.

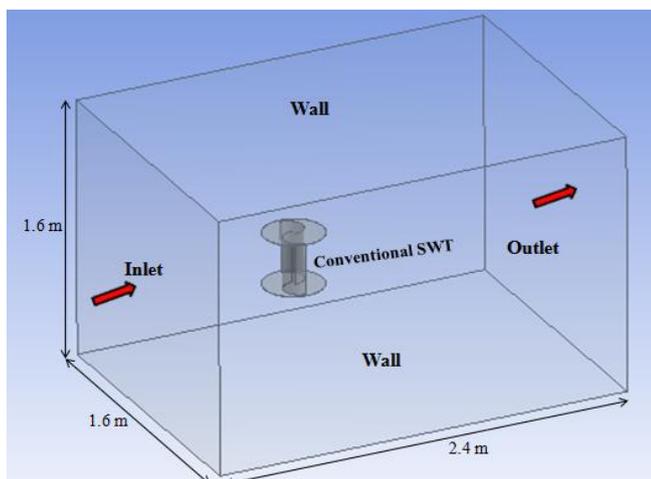
### 2.5.1 Method of domain generation

It is common practice to conduct aerodynamic performance tests for products like a Savonius wind turbine inside wind-tunnels. However, methods exist for purely numerical studies using Computational Fluid Dynamics or CFD simulators. They are sensitive to domain size (or the size of fluid/solid meshes in the simulator), turbulence models used, and the complexity developed by the air flow.



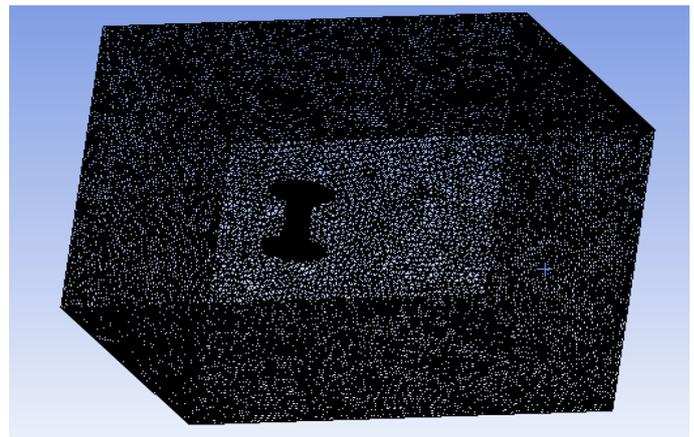
**Fig-8:** Method of domain generation for Savonius turbine models

The domain generation is the part of pre processing which is the important step in CFD analysis. Here the Savonius wind turbine model is considered as external flow condition. as that of wind tunnel experiment flow domain. The flow domain should be filled with air, enclosed by inlet, outlet, and walls. In Fig-8 it is shown that the domain should be generated for savonius rotor with its size 'L' as reference. The inlet of the domain at a distance of 2L from the model and where as for outlet distance from model is 4L from the model in x direction for to reduce wake formation in back side of the rotor and remaining y and z distances are maintained 2L. The same procedure is followed for creating domain for conventional and splitter Savonius wind turbines and for different types of guide vanes according to their dimension "L"



**Fig-9:** Domain generation for CSWT

In Fig-9 the two bladed CSWT is having outer diameter of 0.4 m and of height of 0.4 m. The outer diameter with endplate is the longest diameter of the model which is taken as reference length L accordingly the domain has been generated. The free wind velocity 2.2 m/s enters through inlet of the domain region.



**Fig-10:** Mesh generation for CSWT

Now this domain acts as tube through which air is made to pass. Now the initial conditions as shown in Table-5 have to be incorporated into preprocessing.

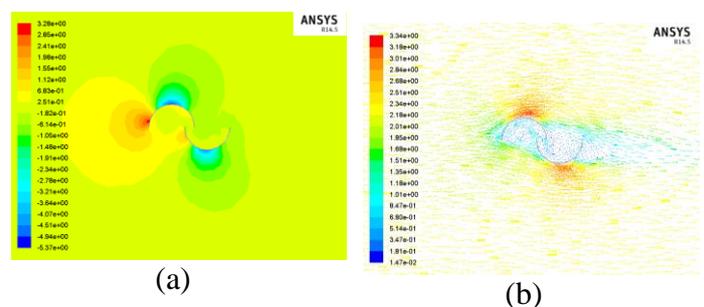
**Table-5:** Initial conditions incorporated into preprocessing

Properties		Values
Fluid Type		Air
Density of fluid	( $\rho$ )	1.225 kg/m <sup>3</sup>
Fluid Viscosity	( $\mu$ )	1.789 x 10 <sup>-5</sup> Ns/m <sup>2</sup>
Specific Heat	( $\gamma$ )	1.4
Reynolds Number	(Re)	242247
Analysis Model		k-e

The same computational procedure is adopted for analysis of SSWT, Guide Vanes and Guide Vanes with SSWT.

### 3 RESULTS AND DISCUSSIONS

#### 3.1 Results of CSWT



**Fig-11** (a) (b): Pressure Contour (a) and velocity vector (b) of conventional SWT at 0°

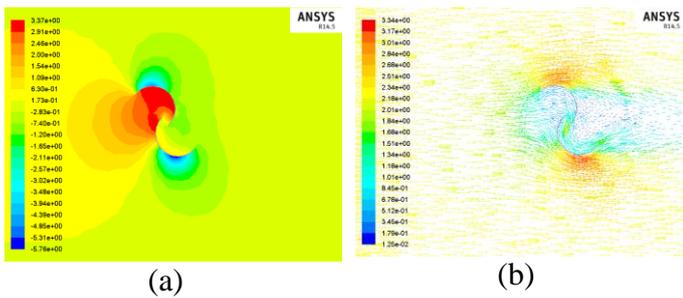


Fig-12 (a) (b): Pressure Contour (a) and velocity vector (b) of conventional SWT at 45°

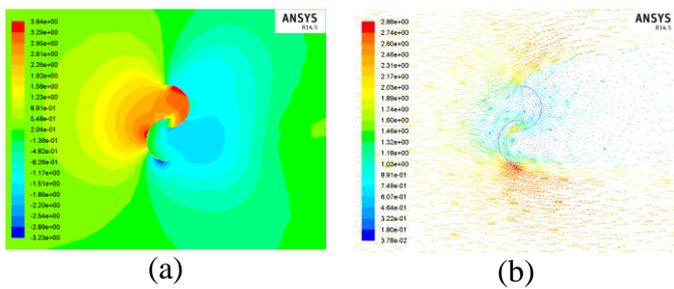


Fig-13 (a) (b): Pressure Contour (a) and velocity vector (b) conventional SWT of at 90°

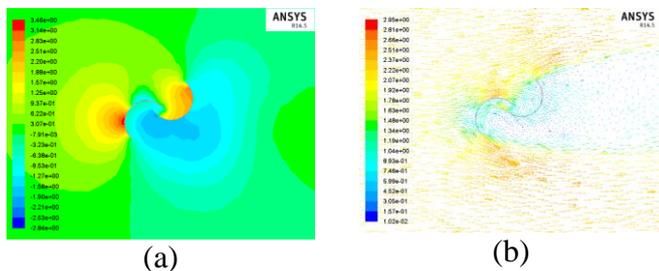


Fig-14 (a) (b): Pressure Contour (a) and velocity vector (b) of Conventional SWT at 135°

The flow analysis conducted on experimented CSWT model with different angle of rotation i.e. 0, 45, 90 and 135 degree. Fig-11 to Fig-14 shows the variation of pressure and velocity distribution for 2.2 m/s inlet wind velocity. While examining this result it has been noted for 0 degree angle of rotation, the depression region that created behind advancing and returning blades where the pressure is low. But in concave surface of the blade, the pressure is more that tends the blade for motion. For 45 degree the pressure developed on the concave (advancing) blade is more hence torque developed also more and less pressure on returning blade it has been observed that there is a depression region in returning blade hence negative torque is less. Where maximum torque development is observed from Fig-12. For 90 degree angle of rotation the pressure on both concave and convex side of the blade which is more hence there is restriction in blade movement because there is negative torque which developed on the returning blade that opposes the advancing blade movement. In 135 degree angle of

rotation the pressure developed on the returning blade is more as compared to advancing blade hence the negative torque development is more, hence minimum torque developed. The same variation followed for the rotation of 360 degree. In case velocity vectors it is observed that the advantage of main overlap is air after striking the advancing blade that enters returning blade to reduce negative torque.

Table-6: Experimented and CFD values for CSWT

Wind Speed 'v' (m/s)	Power (W)		Coefficient of Power (Cp)	
	EXP	CFD	EXP	CFD
2.2	0.087	0.0917	0.093	0.098
3.7	0.527	0.549	0.118	0.122
4.9	1.442	1.508	0.139	0.145
6.5	3.85	4.034	0.159	0.167

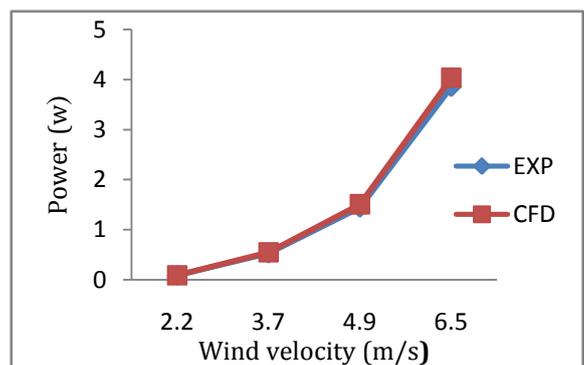


Chart-1: Variation in Experimental and CFD values of Power for CSWT

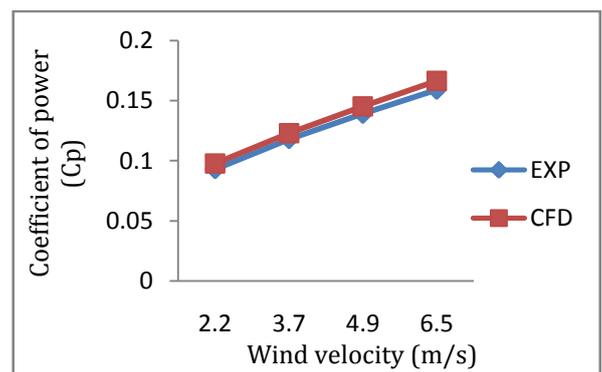


Chart-2: Variation in Experimental and CFD values of Coefficient of power (Cp) for conventional SWT

From Chart-1 and Chart-2 both power and coefficient of power increase with wind velocity and it can be justify that for experimented result is comparable with CFD results except the percentage error occurred nearly 5%.

### 3.2 Results of SSWT

#### For 2.2 m/s wind velocity

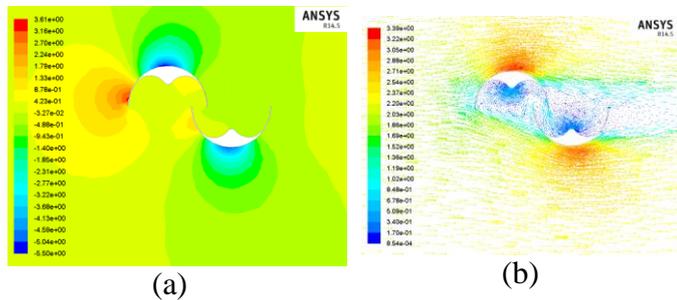


Fig-15 (a) (b): Pressure Contour (a) and velocity vector (b) of Splitter SWT at 0°

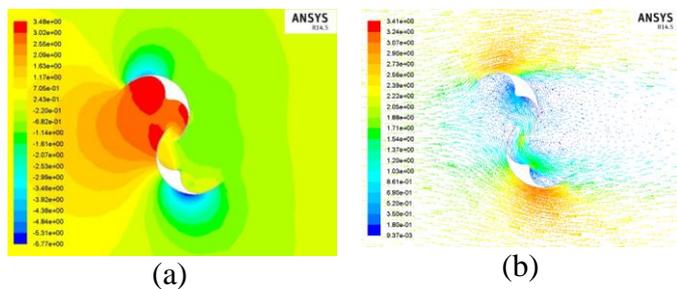


Fig-16 (a) (b): Pressure Contour (a) and velocity vector (b) of conventional SWT at 45°

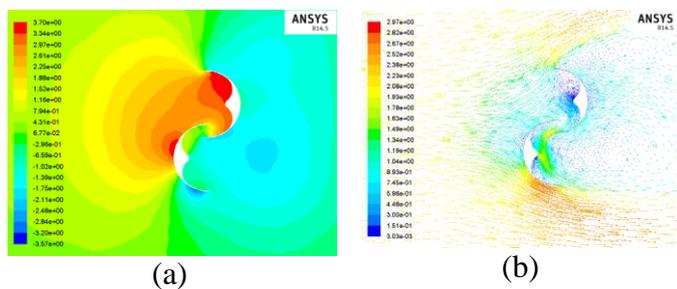


Fig-17 (a) (b): Pressure Contour (a) and velocity vector (b) Splitter SWT of at 90°

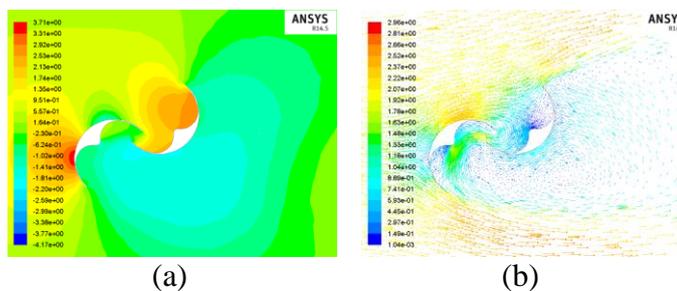
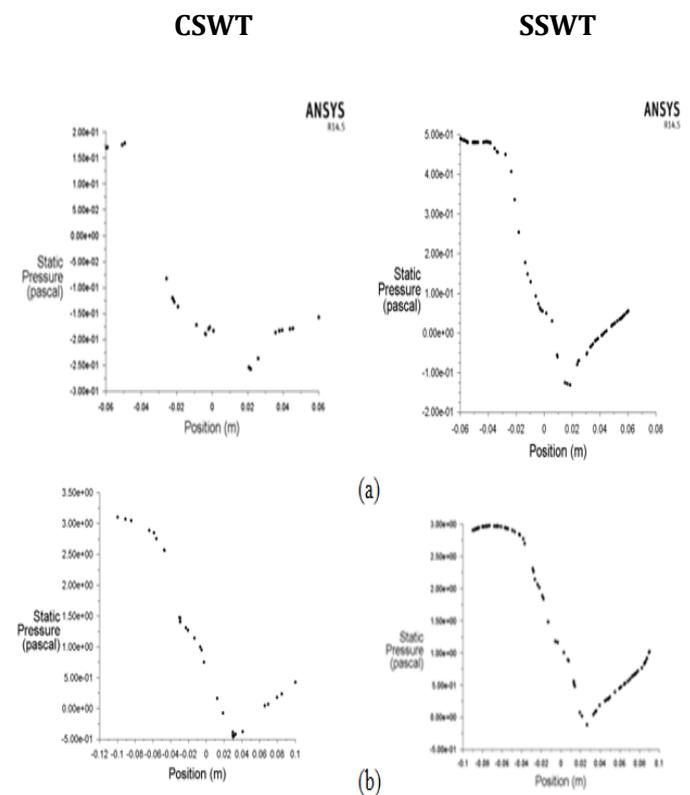


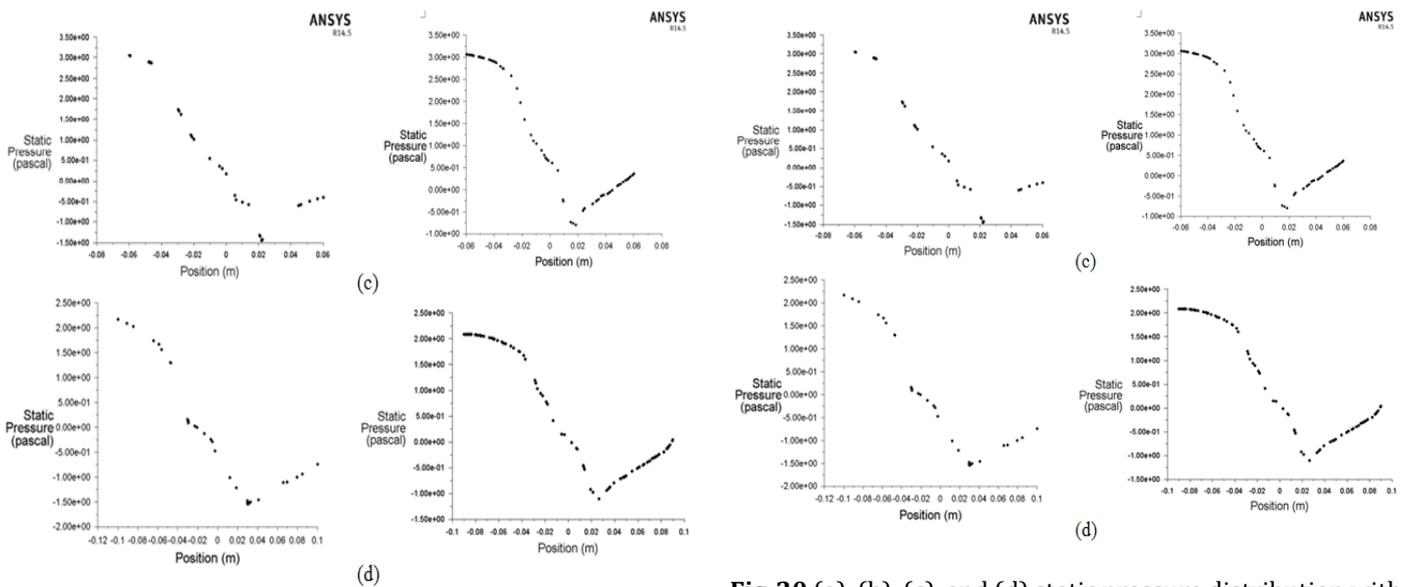
Fig-18 (a) (b): Pressure Contour (a) and velocity vector (b) Splitter SWT at 135°

The flow analysis conducted on “SSWT” model with different angle of rotation i.e. 0, 45, 90 and 135 degree. Fig-15 to Fig-18 explains the variation of pressure and velocity distribution for 2.2 m/s inlet wind velocity. From the above plots it is noted that there is striking pressure is more in SSWT. For 0 degree the pressure on the concave (advancing) blade is increasing and behind the advancing blade the depression region created where the pressure is very low. Hence the blade is easily rotate with less negative torque. For 45 degree orientation the pressure on the concave blade is more and depression region behind the advancing blade and behind the returning blade is very less hence the negative torque is less, and the blade movement is easier. But in case of 90 degree angular position both the side of (advancing concave) and returning (convex side) of the blade the pressure is more hence the negative torque which produced on convex side is more that leads to restriction of advancing blade movement. For 135 degree angular position pressure on the returning blade is more because it faces towards the wind direction that obviously creates negative torque much more in this position.

#### 3.2.1 Comparison of CSWT and SSWT

##### Pressure distribution at 2.2 m/s wind velocity

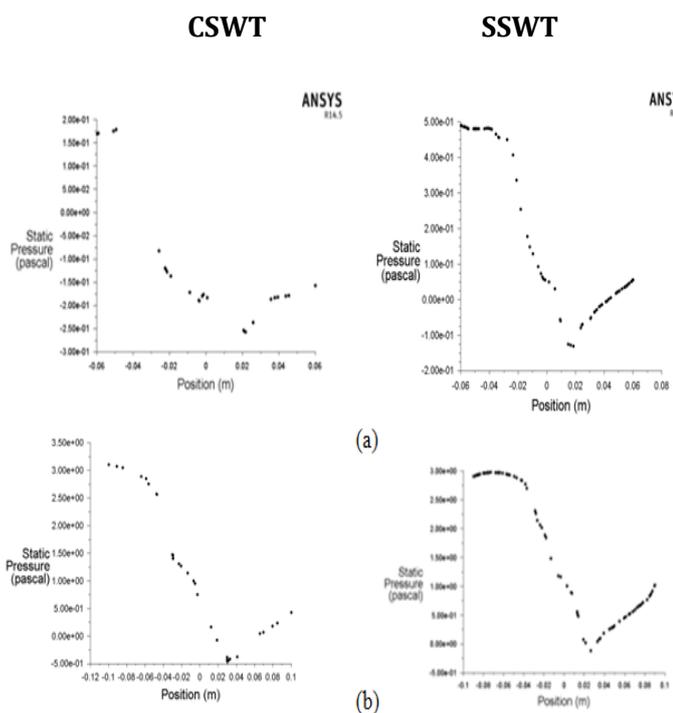




**Fig-19** (a), (b), (c), and (d) static pressure distribution with 0, 45, 90, and 135 degree angle of rotation in conventional and splitter SWT at 2.2 m/s wind velocity.

The main advantage of introducing splitter in savonius wind turbine is for proper air channelization that leads to proper striking pressure on rotor. In case of C SWT the pressure and velocity distributions on the concave side (advancing) of the rotor are not uniform from the above Fig-19 and Fig-20 it is noted that air distribution to the rotor not

**Velocity distribution at 2.2 m/s**



**Fig-20** (a), (b), (c), and (d) static pressure distribution with 0, 45, 90, and 135 degree angle of rotation in conventional and splitter SWT.

taking place properly. From the above Fig-19 and Fig-20, it is noted that velocity and pressure is in x direction and position in y direction, where the 'position' refers to the line drawn to study the effect of pressure and velocity effect, the line traverse the distance from inner radius of advancing blade to the radius of returning blade. The position line represents from -0.1 m to +0.1 m shows that negative sign that indicates line inside the advancing blade and positive sign indicates the line that inside the returning blade. In case of CSWT the air hitting the concave side of the blade where the pressure is initially high and decreases by loosening its energy. When it traverses to the returning blade through main overlap there is improvement in pressure increasing for certain level and decreases when it strikes returning blade. This can be observed by the above shown graph, it is important to note that in conventional SWT the pressure and velocity distribution is not uniform. But in case of SSWT the pressure on the striking surface is more as compared to CSWT and there is a proper velocity and pressure distribution can be seen by the obtained plots.

**Table-7:** Comparison between CSWT and SSWT

Wind Speed 'v' (m/s)	Power (W)		Coefficient of Power (Cp)	
	CSWT	SSWT	CSWT	SSWT
2.2	0.0917	0.0967	0.0977	0.1029
3.7	0.5494	0.5823	0.1229	0.1303
4.9	1.508	1.5941	0.1454	0.1536
6.5	4.034	4.29	0.1665	0.177

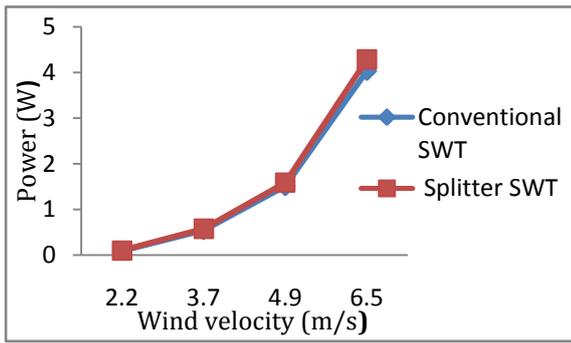


Chart-3: Variation of power in conventional and splitter SWT

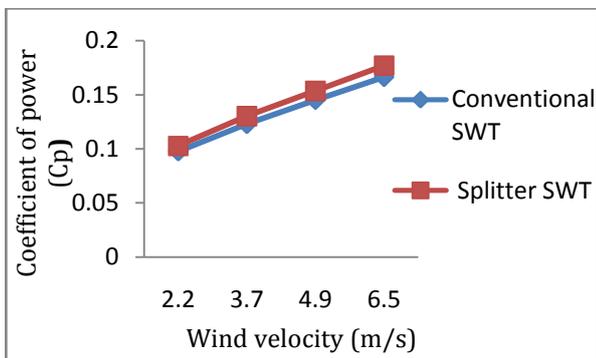


Chart-4: Variation of coefficient of power in conventional and splitter SWT

From Chart-3 and Chart-4 it is noted that there is an improvement in power and power coefficients of 5% as compared to that of CSWT

### 3.3 Computational Results of Stationary Guide Vanes

#### 3.3.1 CFD analysis of Symmetrical Stationary Guide Vanes (SSGV)

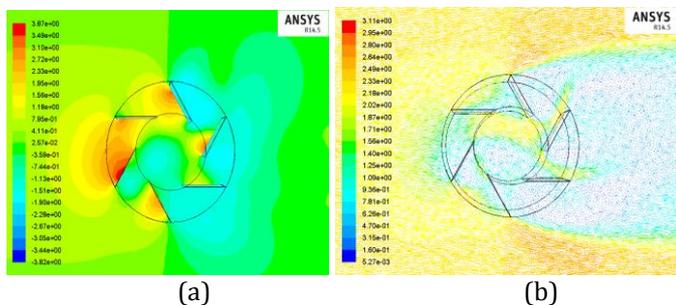


Fig-21 (a) (b): Pressure Contour (a) and velocity vector (b) of SSGV at 2.2m/s

#### 3.3.2 CFD analysis of Asymmetrical Stationary Guide Vanes (ASGV)

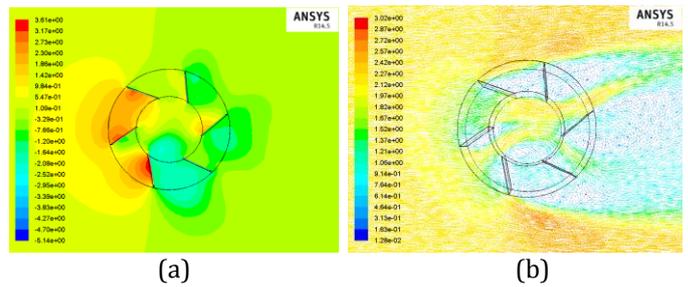


Fig-22 Pressure Contour (a) and velocity vector (b) of ASGV at 2.2m/s

#### 3.3.3 CFD analysis of Curved Stationary Guide Vanes (CSGV)

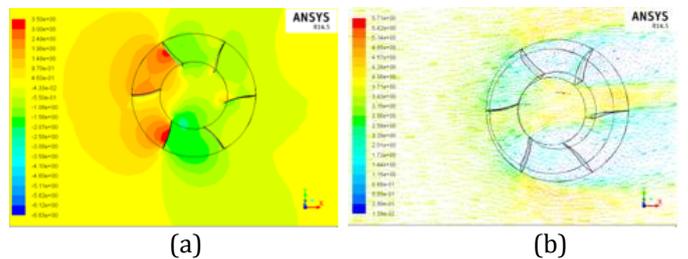


Fig-23 Pressure Contour (a) and velocity vector (b) of CSGV at 2.2m/s

Table-8: Variation of wind speed in three different guide vanes

Free wind speed 'V <sub>i</sub> ' (m/s)	Wind speed past guide vane 'V <sub>e</sub> ' (m/s)			
	Without GV	SSGV	ASGV	CSGV
2.2	2.2	2.45	2.51	2.56
3.7	3.7	3.89	3.92	3.97
4.9	4.9	5.24	5.32	5.39
6.5	6.5	6.82	6.9	6.95

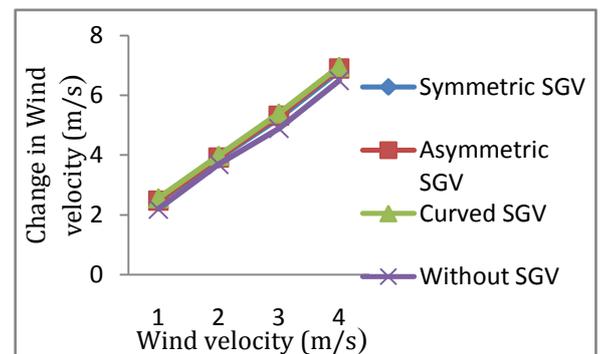


Chart -5: Variation of wind speed in SGV

The guide vanes which are not only decrease the negative torque it also increases the speed of the wind at the inlet position because of pressure difference in the stationary

vanes. Table-8 it is noted that the velocity at curved SGV is more as compared to that of other two guide vanes. In case of the curvature in the guide vane that properly deflects the air towards the rotor blades.

### 3.4 Computational Results of CSGV with SSWT

#### For 2.2 m/s wind velocity

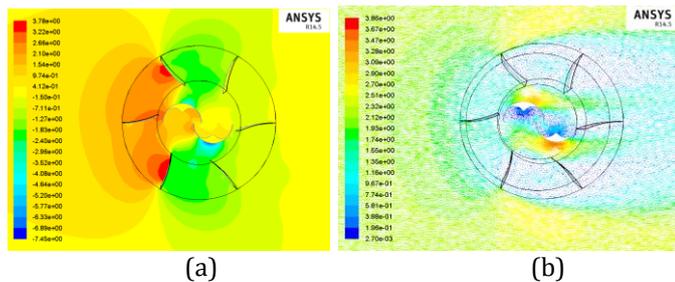


Fig-24 Pressure Contour (a) and velocity vector (b) of Splitter SWT with CSGV at 0°

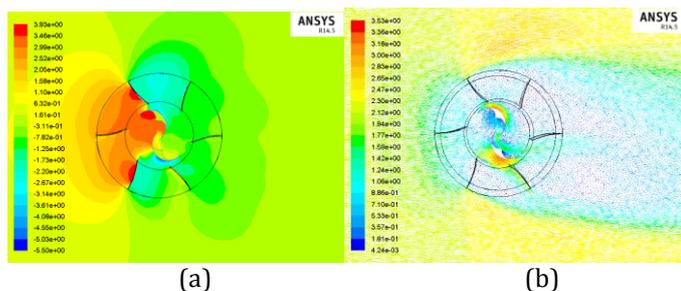


Fig-25 Pressure Contour (a) and velocity vector (b) of Splitter SWT with CSGV at 45°

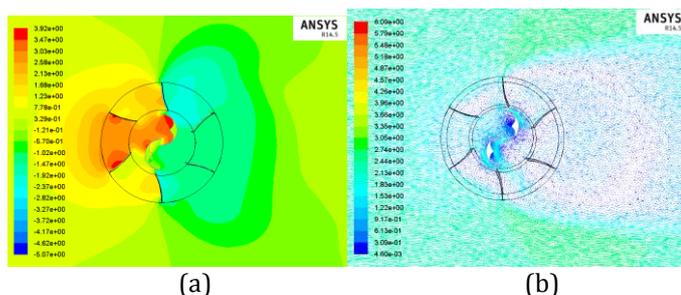


Fig-26 Pressure Contour (a) and velocity vector (b) of Splitter SWT with CSGV at 90°

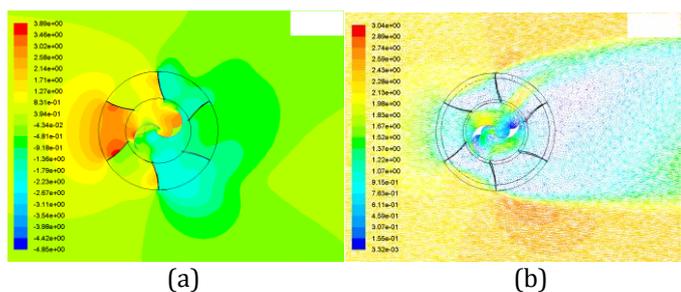


Fig-27 Pressure Contour (a) and velocity vector (b) of Splitter SWT with CSGV at 135°

The final stage of CFD analysis work carried out on SSWT with CSGV, where an assembly of rotor and curved guide vane is analyzed statically by keeping SSWT which is making different angles such as 0, 45, 90 and 135 degree for incoming free wind. Fig-24 to Fig-27 shows the pressure contour and velocity vectors at different angle of rotation respectively at 2.2 m/s. The main advantage of stationary guide vane in rotor is reduction in the negative torque in different angle of rotation and increase in wind speed by guide vane improves the performance of the rotor. From the above plots it is observed that for 0 degree angular position the pressure development is increased in the advancing blade because of the effect of guide vane where the curved guide vane which restricts wind flow on returning blade and it deflects the air towards the advancing blade and the depression region created on returning (convex side) of the blade hence blade easily rotate from Fig-24 it is observed that starting torque is increasing. For 45 degree of orientation the negative torque development is almost less because the advancing (concave side) of the blade area is more prone to wind direction then returning blade hence negative torque development is less on returning blade and also the guide vane creates barrier to the wind flowing on returning blade hence the maximum torque development is observed for 45 degree of rotation. For 90 degree angular position there is more negative torque in case of without guide vane rotor this can be eliminated by the guide vane as earlier case the negative torque on returning blade is more hence there is restriction in blade movement and average torque development is less this can be eliminated by guide vane which restricts the wind flow on returning blade hence pressure on advancing blade increases hence from Fig-26 for 90 degree it is observed that static torque is more compared to that of 0 degree orientation. For 135 degree of angular position the pressure on the advancing blade is increased by adopting the curved guide vane but comparative to the other rotor angle the torque development is less because the returning blade (concave side) is more prone wind pressure. For the previous analysis as observed negative torque development is reduced as compared to that of conventional and splitter SWT.

#### 3.4.1 Torque variation in Splitter SWT with CSGV for different angle of rotation

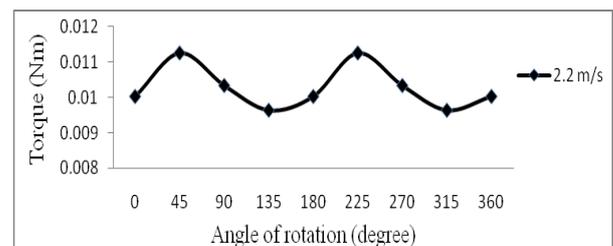


Chart-5: Torque variation of SSWT with CSGV for different angle of rotation at 2.2 m/s

**Table-9:** The average torque generated at different wind speeds.

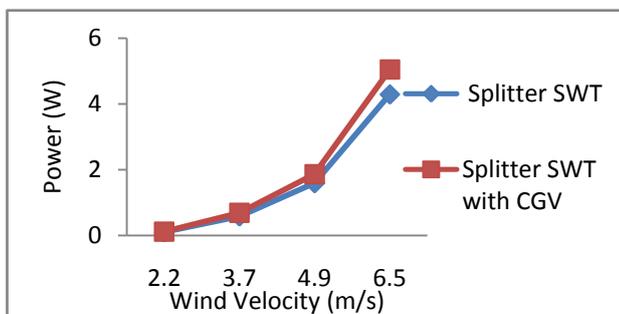
Orientation of Rotor (degree)	Torque 'T' (Nm)			
	2.2 m/s	3.7 m/s	4.9 m/s	6.5 m/s
0°	0.01003	0.0411	0.0732	0.1332
45°	0.01126	0.0604	0.0925	0.1724
90°	0.01034	0.0454	0.0771	0.1402
135°	0.00964	0.0353	0.0647	0.1175
Avg. Torque	0.01032	0.0456	0.0769	0.1408

From Table-9 which shows static torque at different angle of rotation and average static torque with different wind speed. The torque value is maximum for 45 degree of angular position and minimum for 135 degree orientation and as introduction of guide vane which increases the torque value at 90 degree as compared to that of without guide vane there is more improvement observed. The average torque for with guide vane rotor is high as compared to that of conventional rotor.

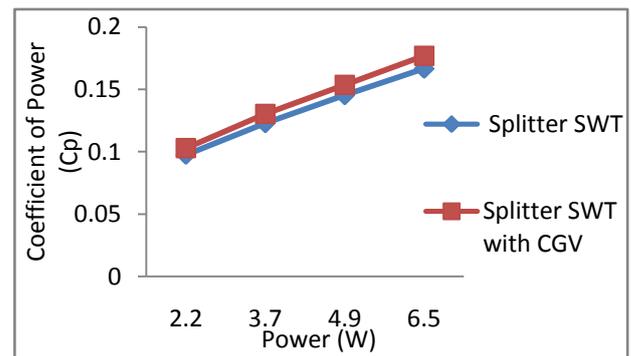
**Table-10:** Variation of rotor power and power coefficient with and without CSGV at different wind speeds

Wind Speed 'V' (m/s)	Power (W)		Coefficient of Power (Cp)	
	SSWT	SSWT with CSGV	SSWT	SSWT with CSGV
2.2	0.102	0.1124	0.1029	0.1197
3.7	0.58	0.682	0.1304	0.1527
4.9	1.59	1.859	0.1536	0.1792
6.5	4.29	5.044	0.177	0.2082

The Table-10 which represents the power and power coefficient values for splitter SWT (without guide vane) and for splitter SWT with CSGV (curved stationary guide vane) with different inlet wind velocity.



**Chart-6:** Variation of Power with different wind velocities



**Chart-7:** Variation of Power Coefficient with different wind velocities

From Chart-6 and Chart-7 represents the variation of power and power coefficient with different wind velocities. The power and power coefficients increase with wind velocities in case of splitter SWT with CSGV the power and power coefficient is more as compared to that of splitter SWT without guide vane. Because of curved guide vane that is not only helpful for the deflects the air at the mean time the negative torque which reduced and that crated venturi-effect to increase the wind velocity these all improvement leads to increase the power development up to 14% as compared to that of without guide vane savonius rotor.

#### 4. CONCLUSIONS

The Savonius wind turbine a class of vertical axis wind turbine can be viable option for small scale, low cost of grid energy conversion in certain cases of confined space and low wind speed region, where the other turbines cannot work efficiently. However the existing design of conventional Savonius wind turbine is yet a matter of research to make it more useful in situations. In this context the present study attempts to improve the performance of CSWT by evolving a new concept of splitter arrangement and stationary guide vanes. The present work shows Savonius wind turbine having enormous potential in extracting power at low wind speeds for 2.2, 3.7, 4.9, and 6.5 m/s. The Savonius wind turbine has few drawbacks such as negative torque development by returning blade of the rotor and improper pressure distribution on the advancing blade. In this work importance given for proper distribution of pressure and velocity by introducing splitter and the negative torque which is eliminated by stationary guide vanes. The CFD analysis carried out in ANSYS FLUENT 14.5 using steady state, k-ε model and it is compared with experimented conventional model which taken as reference.

- The Savonius wind turbine is simple in design so it can easily fabricated and maintain at low cost, the cut in speed of this turbine is very low these devices are insensitive to the wind flow direction and thus

are useful for specific location of variable wind speed.

- The introduction of splitter in conventional savonius wind turbine which is helpful for proper pressure and velocity distribution in rotor surface. There is 5% improvement of power coefficient in SSWT as compared to that of CSWT.
- The main drawback concerned with Savonius wind turbine is negative torque that can be reduced by different types of guide vanes which are analyzed in CFD software.
- Curved stationary guide vane (CSGV) with 6 vanes which gives better result in reducing the negative torque as compared to that of symmetric stationary guide vane (SSGV) and asymmetric guide vane (ASGV).
- There is increase in rotor power and power coefficient up to 14% by incorporating Curved guide vane to the splitter Savonius rotor.

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