International Journal of Soft Computing and Engineering (IJSCE)
ISSN: 2231-2307, Volume-3, Issue-2, May 2013

Investigation of Overlap Ratio for Savonius Type Vertical Axis Hydro Turbine

Patel C.R., Patel V.K., Prabhu S.V., Eldho T.I.

Abstract- ***Hydropower from the river is one of the best renewable sources. Hydropower source is predictable compared to wind or solar energy. For generation of electricity using the kinetic energy of natural water resources, Savonius rotor is one of the best types of turbine. The Savonius turbine is more popular as wind turbine. However, in present work, attempt is made for use of Savonius rotor as hydro turbine application. A 3D computational model built and analyzed using a Computational Fluid Dynamic (CFD) analysis using ANSYS. The effect of overlap ratio is investigated for performance enhancement Savonius turbine. In present investigation three different overlap ratios, 0.0, 0.1 and 0.2 are studied, at different angular speeds of rotor. It is found that the maximum torque can be obtained at overlap ratio of 0.2.***

Index Terms— Overlap ratio, Savonius Turbine, CFD Simulation, Micro hydro turbine, Coefficient of torque, Coefficient of power.

I. NOMENCLATURE

α Aspect ratio
β Overlap ratio
ρ Density *[kg/m^3]*
ω Angular velocity *[rad/s]*
θ Angle of attack *[rad]*
d Diameter of the Blade *[m]*
D Diameter of rotor *[m]*
e Gap between two paddles *[m]*
F Force of turbine *[N]*
G Coefficient of gravity *[m/s^2]*
H Height of turbine *[m]*
i Number of angle of attack
n Number of force on the rotor
N Rotation velocity *[rpm]*
P Power *[watts]*
r Radius *[m]*
T Torque of model *[Nm]*
V Current velocity *[m/s]*

SUBSCRIPT

r Rotor
s Shaft

II. INTRODUCTION

The recent increase in the price of crude oil has reminded many quarters on the transient nature of fossil fuel. On the other hand, environmental issues are forcing governments to consider the incentives for development of alternative clean sources of energy.

One of the potential sources of clean energy is the ocean or hydro kinetic energy. The Savonius type vertical axis wind rotor was first invented by S. J. Savonius in 1929. The design was based on the principle of Flettner's rotor. The rotor was formed by cutting a Flettner's cylinder from top to bottom and then moved the two semi-cylinder surfaces sideways along the cutting plane so that the cross-section resembled the letter 'S'. It can be directly placed in flowing stream of water to generate mechanical power from kinetic energy of flowing fluid. Applications of Savonius rotor, in general, includes ventilation pumping water, driving an electrical generator.[1]

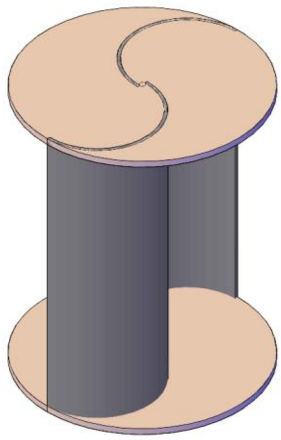


Fig. 1 Savonius Rotor

Different designs of water current turbine are available for the extraction of energy from the river water or canals. Based on the alignment of the rotor axis with respect to water flow, turbine can be classified as (1) horizontal axis turbine (axial turbines) and (2) vertical axis turbine (cross flow turbines). The commonly used vertical axis turbines are Savonius turbine, helical turbine, Darrieus turbine and H-shaped Darrieus turbine. [3]

Figure 2 indicates comparision of coefficient of power of some of the hydro kinetic turbines, at different Tip Speed Ratio (λ).

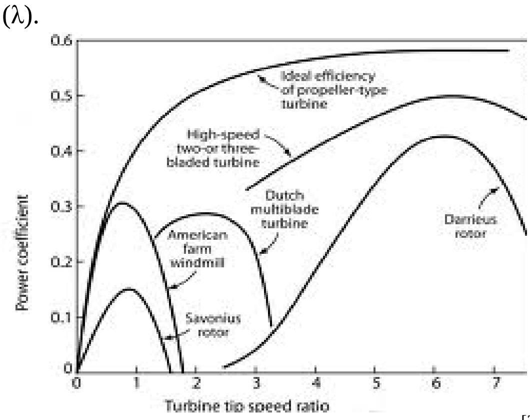


Fig. 2 Comparison of Cp-λ performance curves [3]

However, coefficient of performance of Savonius rotor is comparatively low, but it has excellent starting capability. Performance of Savonius type turbines is critically affected by 3 particular parameters, (1) Aspect ratio, (2) Overlap ratio

Manuscript received on May, 2013.

Patel C. R, Mechanical Engineering Department, SVMIT, Gujarat Technological University, Bharuch, Gujarat, India.
Patel V. K., Mechanical Engineering Department, Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat, India.
Prabh S. V., Mechanical Engineering Department, Indian Institute of Technology, Bombay, Maharastra, India.
Eltho T.I., Civil Engineering Department, Indian Institute of Technology, Bombay, Maharastra, India.

and (3) Stacking configuration. Present work focused on study of the effects of overlap ratios on the performance of the Savonius turbine in relation to its output torque.

III. PERFORMANCE PARAMETERS OF SAVONIUS ROTOR

Figure 3 indicates schematic diagram of Savonius rotor with nomenclatures used. Three parameters, (1) aspect ratio α, (2) rotors stack and (3) Overlap ratio, β, are predominantly affecting performance of Savonius turbine. Present work mainly focused on performance enhancement by variation of overlap ratio.

A. Aspect ratio:

The aspect ratio represents the height of rotor relative to diameter. The relation is shown by

$$\alpha = \frac{H}{D} \quad (1)$$

B. Stacking Configuration:

The starting torque of the turbine is high but it is not consistently constant. One way of overcoming this fluctuating torque is to stack the rotors. The starting torque of double stack rotor is never negative, whatever the direction of the current.

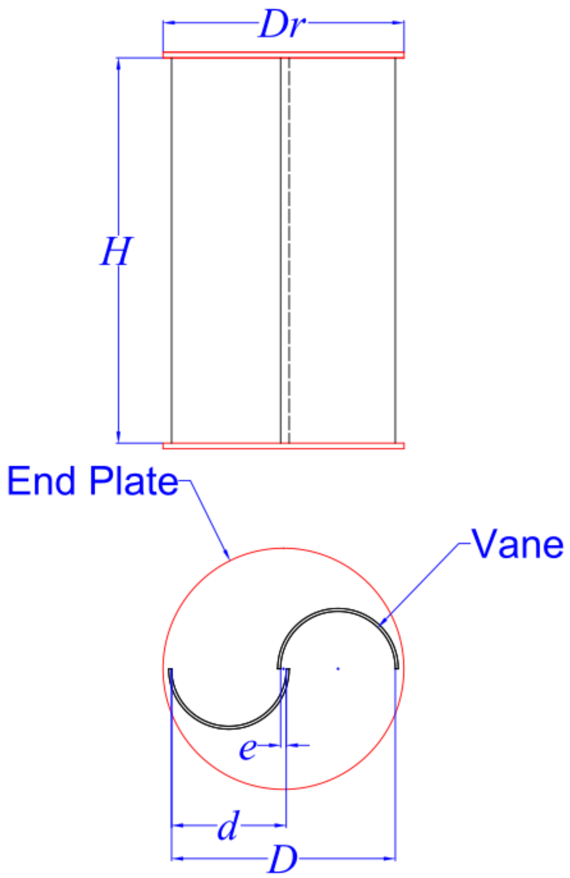


Fig. 3. Schematic diagram of a Savonius rotor.

C. Overlap Ratio

The equation for the overlap ratio is given by

$$\beta = \frac{e}{d} \quad (2)$$

Overlap ratio is one important factor affecting the performance of the turbine.
In present study, effort is made to find optimum overlap ratio to get best coefficient of performance.

IV. CFD ANALYSIS

The dimensions, operating parameters and fluid properties used in simulation are shown in Table 1.
The present simulation is done using ANSYS 12. This software is based on advanced Computational Fluid Dynamics (CFD) techniques and allows the user to analyze a wide range of complex problems including two and three dimensional analyses, external and internal flows, incompressible liquid and compressible gas flows, etc. In present work, 3D modeling was made using PRO-E CREO and CFD analysis done using ANSYS 12.

TABLE 1 Dimensions and conditions for model simulations.

Sr. No.	Input data	Value
1	Height of Rotor, H	370mm
2	Diameter of Rotor, D	245mm
3	Nominal speed, V	0.6m/s
4	Fluid	Water(ρ=1000kg/m^3)

A. Design Configuration of Model for Simulation

In present work, two blade single stacking Savonius-rotor turbine model used as it provides smoother rotor fluctuation force to the turbine blades. Figure 4, indicates geometry used for Computational Fluid Dynamic (CFD) analysis.

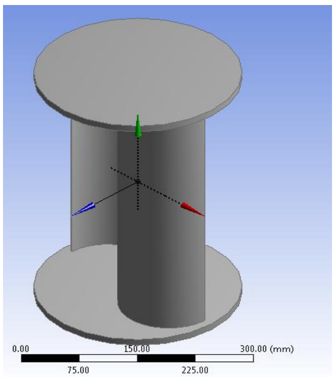
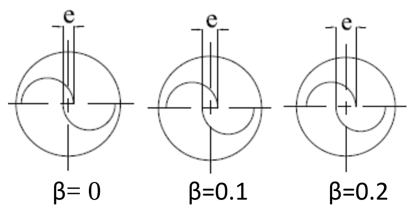
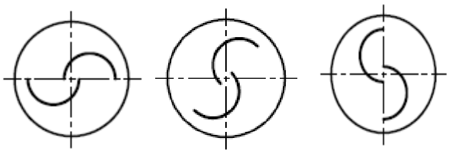


Fig. 4 Geometry of Rotor





(b)

Fig. 5. (a) Overlap ratio configuration and (b) Angle of attack.

Three different overlap ratios are studied, i.e. β= 0, 0.1, and 0.2, as shown in Fig. 5(a). All configurations are evaluated for four different orientations as shown in Fig. 5 (b).

B. Computational Domain and Initial Mesh

The computational domain used in simulation is shown in Fig. 5. Fig. 6 indicates initial mesh for one of the configuration (β=0.2). Other computational parameters used in study is shown in Table 2.

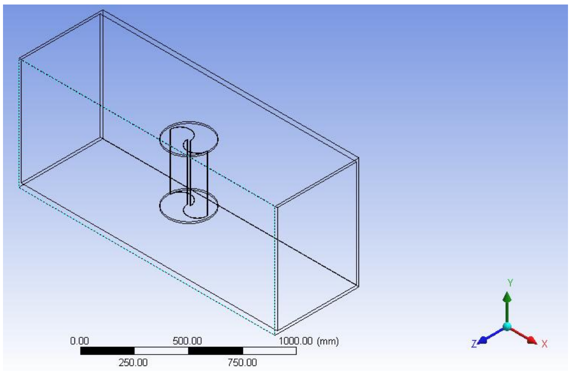


Fig 5 Geometry view of region of Savonius rotor

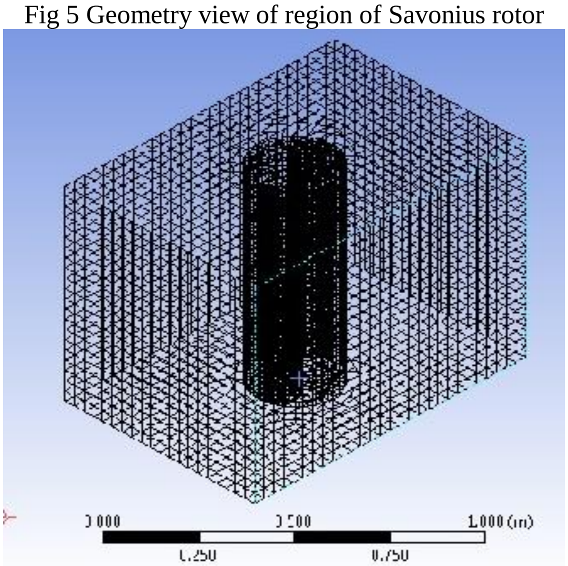


Fig 6 Meshing of model

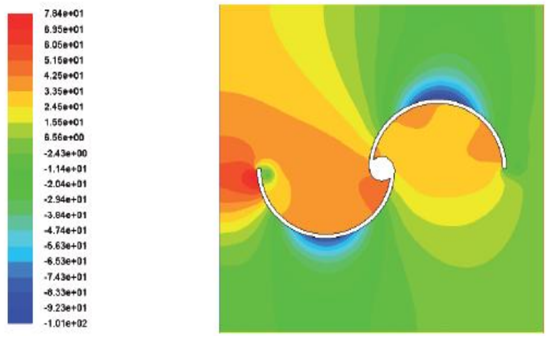
TABLE 2 Input Data for CFD Analysis

SR.NO	INPUT	VALUE
1	Domain motion	Rotating
2	Angular Velocity	30 to 60 RPM
3	Boundary Condition inlet flow	Subsonic
4	Normal velocity	0.6 m/s
5	Outlet pressure	1 atm
6	Angle of Attack	0,45˚,90˚ & 135˚
7	Turbulence model	K epsilon

C. Simulation Results

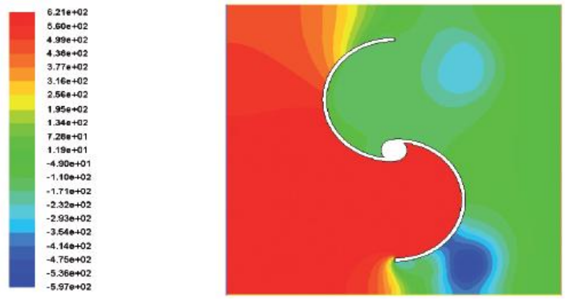
The analysis is done using above parameters β= 0, 0.1, and 0.2 and for four different configurations. Figure 7 (a to d) shows pressure contour of simulation condition at 0°, 45°, 90°, and 135°.

From the simulation results, forces on the blades are found from which the torque on turbine is calculated. The forces on every rotor blade for every angle were calculated to provide the resultant force, based on Figure 7.



(a) θ = 0˚

(b) θ = 45˚



(c) θ = 90˚

(d) θ = 135˚

Figure7. Contour of pressure for different angle of attack

Figure 7 shows the direction and distance of force from the center of the turbine-shaft. The torque at every angle of attack (T_θ) can be determined by the following formula:

$$T_\theta = \sum_{n=1}^{n} F_n \cdot d$$

$$= F_1 \cdot (r - \beta \cdot r) \cdot \cos\theta - F_2 \cdot (r - \beta \cdot r) \cdot \cos\theta$$

$$= (F_1 - F_2) \cdot (1 - \beta) \cdot r \cdot \cos\theta$$

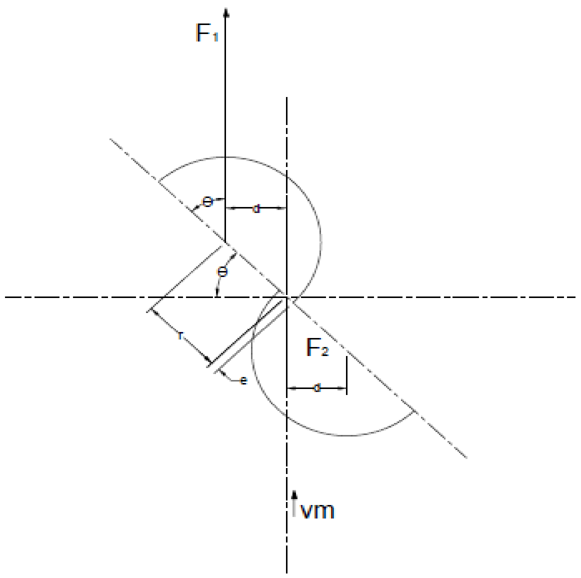


Fig.7 Force direction on the paddle turbine for θ = 45°

The average torque (Tm) is calculated as follows:

$$T_m = \frac{\sum_{\theta=0}^{\theta} T_\theta}{i} \quad (3)$$

Results of the simulation are given in Table 3 to 6 and variations of *Cp* with reference to TSR are shown in Fig. 8, 9 and 10.

IV. RESULTS AND DISCUSSIONS

The calculated instantaneous torque for different overlap ratios and at different angular positions is shown in table 3. The calculation is done for velocity of 0.6 m/s and at angular velocity of 3.14 rad/s. On the base of instantaneous torque, average torque and developed power is calculated.

TABLE 3 Torque and power developed on Turbine blades with V = 0.60 m/s and ω = 3.14 rad/sec

Sr. No.	Overlap Ratio *(β)*	Angular position of vanes *θ*	Torque developed T_θ (Nm)	Average Torque T_m (Nm)	Power developed (W)
1	0	0	1.1351	1.056	3.321
		45	1.898		
		90	0.42004		
		135	1.056		
2	0.1	0	1.0731	1.3064	4.102
		45	1.9842		
		90	1.2006		
		135	0.9676		
3	0.2	0	0.97684	1.3781	4.327
		45	1.4029		
		90	1.6439		
		135	1.4885		

TABLE 4 Torque and power developed on Turbine blades with V = 0.60 m/s and ω = 4.188 rad/sec

Sr. No.	Overlap Ratio *(β)*	Angular position of vanes *θ*	Torque developed T_θ (Nm)	Avg. Torque T_m (Nm)	Power (W)
1	0	0	1.014	0.9331	3.908
		45	1.5133		
		90	-0.2146		
		135	1.4199		
2	0.1	0	0.99727	1.0131	4.243
		45	1.6909		
		90	0.8902		
		135	0.4742		
3	0.2	0	0.95301	1.0777	4.5133
		45	1.1349		
		90	1.0956		
		135	1.1272		

TABLE 5 Torque and power developed on Turbine blades with V = 0.60 m/s and ω = 5.235 Rad/sec

Sr. No.	Overlap Ratio *(β)*	Angular position of vanes *θ*	Torque developed T_θ (Nm)	Avg. Torque T_m (Nm)	Power (W)
1	0	0	0.90153	0.6107	3.947
		45	0.5379		
		90	0.03517		
		135	0.9682		
2	0.1	0	0.8964	0.8724	4.567
		45	1.1689		
		90	1.0778		
		135	0.3465		
3	0.2	0	0.94622	0.9096	4.762
		45	0.7121		
		90	1.1834		
		135	0.7969		

TABLE 6 Torque and power developed on Turbine blades with V = 0.60 m/s and ω = 6.28 Rad/sec

Sr. No.	Overlap Ratio *(β)*	Angular position of vanes *θ*	Torque developed T_θ (Nm)	Avg. Torque T_m (Nm)	Power (W)
1	0	0	0.86705	0.6416	4.029
		45	0.5054		
		90	-0.0271		
		135	1.2209		
2	0.1	0	0.79796	0.7489	4.7034
		45	0.99505		
		90	0.83604		
		135	0.3667		
3	0.2	0	0.85248	0.7825	4.914
		45	0.6687		
		90	1.0064		
		135	0.6024		

V. CONCLUSIONS

The most recommended overlap ratio for this type of turbine is β = 0.20 and with increase TSR, coefficient of power increases and coefficient of torque decreases. This is similar to the results of studies on Savonius turbine for wind turbine applications. The results obtained from simulation are plotted for different overlap ratio as shown in Fig.8, Fig. 9 and Fig. 10. The results indicates that overlap ratio of 0.2 provides highest *Cp* and *Ct* among all studied overlap ratios. From analysis it can be concluded that, maximum *Cp* of nearly 0.5 can be achieved at Tip speed ratio of 1.2 for overlap ratio of 0.2. This simulation study shows that vertical axis Savonius turbine has good potentials for low head hydro turbine velocity application.

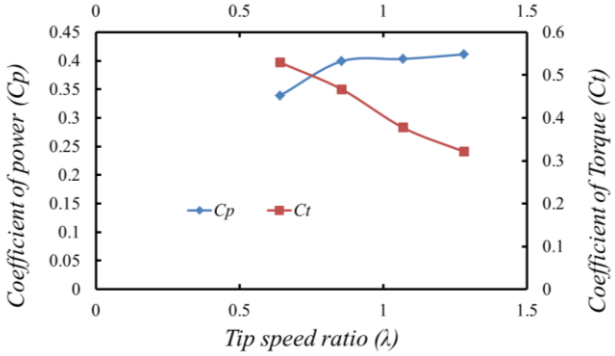


Fig. 8 C_P & C_T at overlap ratio β= 0

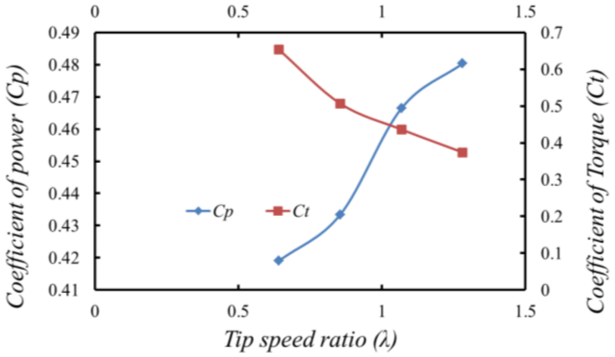


Fig. 9 C_P & C_T at overlap ratio β= 0.1

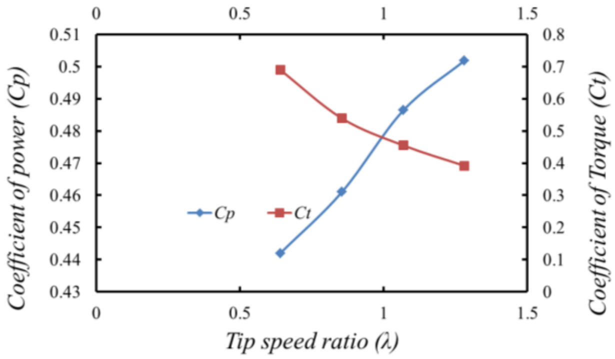


Fig. 10 C_P & C_T at overlap ratio β= 0.2

From pressure contours of Fig. 7, at angular position of θ = 90^0, the maximum pressure arises on the vane surface. It implies that higher structural strength requires for maintain structural stability of turbine. In contrast with Darrieus turbine, not much structural strength is necessary for same outer diameter, which is the one disadvantage of Savonius turbine.

REFERENCES

[1] Nakajima M; Iio S, Ikeda T (2008), "Performance of Double-step Savonius Rotor for Environmentally Friendly Hydraulic Turbine", J. of Fluid Sci. and Tech. 3(3):410-419
[2] Ali Arslan , Rizwan Khalid, Zohaib Hassan and Irfan A. Manarvi, "Design and Manufacture of a Micro Zero Head Turbine for Power Generation", international journal of multidisciplinary sciences and engineering, vol. 2, no. 7, 2011
[3] Kailash Golecha, T.I. Eldho, S.V. Prabhu, "Influence of the deflector plate on the performance of modified Savonius water turbine", Applied Energy, Vol. 88, N. 9, pp. 3207-3217, 2011.
[4] Saha U.K., Rajkumar M., "On the performance analysis of Savonius rotor with twisted blades". J Renew Energy 2005:0960–1481
[5] Md. Imtiaj Hassan, Tariq Iqbal, Nahidul Khan, Michael Hinchey, Vlastimil Masek, "CFD analysis of a Twisted Savonius Turbine", Memorial University of Newfoundland St. John's, NL, A1B 3X5, Canada
[6] Jean-luc menet, nachida bouraba, "Increase in the savonius rotors efficiency via a parametric investigation", Valenciennes Cedex 9 FRANCE.
[7] Sargolazei J, "Prediction of power ratio and torque in wind turbine Savonius rotors using artificial neural networks" , Proceedings of the WSEAS International Conference on Renewable Energy Sources, Arcachon, France, Page (14-16),2009.
[8] Burcin Deda Altan, Mehmet Atılgan , Aydogan Ozdamar, "An experimental study on improvement of a Savonius rotor performance with curtaining", Experimental Thermal and Fluid Science 32 (2008) 1673–1678
[9] Gupta, R., Biswas, A., Sharma, K. K., "Comparative study of a three bucket savonius rotor with a combined three bucket Savonius –three bladed Darrieus rotor". Renewable Energy, 33, Page (1974-1981),2008
[10] M.A. Kamoji, S.B. Kedare, S.V. Prabhu, "Experimental investigations on single stage modified Savonius rotor", Applied Energy, Vol. 86, 2009, pp. 1064-1073
[11] Vinay p v, "Modified savonius rotor for Domestic power production", International Journal of Engineering Science and Technology (IJEST) ISSN : 0975-5462 Vol. 4 No.07 , 2012
[12] Dobrev I, Massouh F (2011), "CFD and PIV investigation of unsteady flow through Savonius wind turbine". Energy Procedia, Vol. 6, 2011, pp. 711-720
[13] Shamsun nahar, md. Quamrul islam, mohammad ali, "Design, fabrication and its performance test of a six bladed Savonius rotor", international journal of advanced renewable energy research vol.1, issue. 5, pp. 276-282, 2012
[14] Sanjay W. Rukhande, Shami Pathan,Aditya Kamble, Pratik Kale, Pankaj Daga and Sagar Pandita, " Design and development of micro savonius type vawt", Proceedings of the NCNTE-2012.