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Review on Performance Evaluation of Helical Savonius Wind Turbine

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ABSTRACT

Large Scale Wind Turbines (LSWTs) have been extensively examined for decades but very few studies have been conducted on the small-scale wind turbines (SSWTs) especially for the applications where artificial wind speed is of order of few meters per second. Energy can be harvested with the help of helical savonius turbine where air is exhausted to atmosphere at high velocity. Such wind turbine is more efficient and economical compare to conventional which are based upon natural wind energy.
Keywords: Helical Savonius turbine, Vertical Axis Wind Turbine, Wind Energy

I. INTRODUCTION

Carbon dioxide plays important role in greenhouse effect (GHGs) that is a global concern about reducing carbon emissions. In this regard, to harvest energy form exit duct which exhaust air at high velocity can be used to generate electricity with the help of generator.

History of wind power starts from Persia (present-day Iran) about 500–900 AD ago. Finnish engineer Sigurd Johannes has invented Savonius turbine in 1922. However, Europeans had carried out experiment with curved blades on vertical axis wind turbine(VAWT). Two patent US1697574 and US1766765 have been registered earlier on 1925 and 1928 respectively.

II. WIND TURBINE

Wind Turbine is a device which converts kinetic energy of wind into mechanical energy which eventually into electric energy. There are two type of wind turbine based upon their axis configuration.

1. Horizontal Axis Wind Turbine (HAWT)
2. Vertical Axis Wind Turbine (VAWT)

Selection of wind turbine is highly depending on compatibility with available wind source. HAWT is based upon lift force, design of this type of blade is based upon air foil. HAWT is widely used on commercial level as they found more economical solution compare to VAWT on commercial level. While, VAWT is drag type wind turbine, such turbine is widely used where high velocity wind is available onsite during whole year. VAWT is very efficient in turbulence wind as well, while HAWT needs yaw system to maintain its performance.

Turbine is also classified based on power rating which are as follows:

1. **Non-Commercial**

1.1. Micro :- This type of wind turbine can produce electricity from 4 W to 250 W.

1.2. Mini :- This type of wind turbine can produce electricity from 250 W to 1400 W.

1.3. Household :- This type of wind turbine can produce electricity from 1400 W to 16000 W.

2. **Commercial**

2.1. Small Commercial :- This type of wind turbine can produce electricity from 25 KW to 100 KW.

2.2. Medium Commercial :- This type of wind turbine can produce electricity from 100 KW to 1000 KW.

2.3. Large Commercial :- This type of wind turbine can produce electricity from 1000 KW to 3000 KW.

III. SAVONIUS TURBINE

The Savonius turbine is one of the simplest turbines. It is a drag type turbine, consisting of two or three scoops. Its looks like "S" shape when viewed from top view. If it is swept over helix profile, it's called helical savonius turbine.

The effect of following parameter among the main parameters affect the performance of a savonius wind turbine.

A. Tip Speed Ratio (TSR)
B. No. of blade (n)
C. Aspect ratio (a)
D. Helix angle (α)
E. Overlap ratio (e)
F. No. of stage (N)
G. With or without endplate
H. Effect of Blade Curve Profile
I. Effect of with and without shaft
J. Reynold's No.
K. Turbulence model

A. Effect of Tip Speed Ratio (TSR)

Tip speed ratio (TSR) is defined as ratio of rotor tip speed (u) to the free wind speed (v).

Jae-Hoon Lee et al. [1] had concluded in numerical analysis C_T has highest value of 0.34 at a TSR of 0.45 for a twist angle of 45º, fluctuation of C_T decreases with increase in twist angle of 135º. In experimental result it has been found that C_T have negative value in range of 60º -150º and 240º - 330º for a twist angle of 0º, 45º and 135º with a TSR of 0.88. Konrad Kacprzak et al. [2] has carried out numerical investigation and found that the highest power coefficients are obtained at TSR ≈ 0.81 which reduces with further increment in Tip Speed Ratio as shown in figure 2. In computational model G. Ferrari et al. [3] concluded savonius rotor exhibits higher torque which values of 0.5 Nm at lower TSR of 0.6.

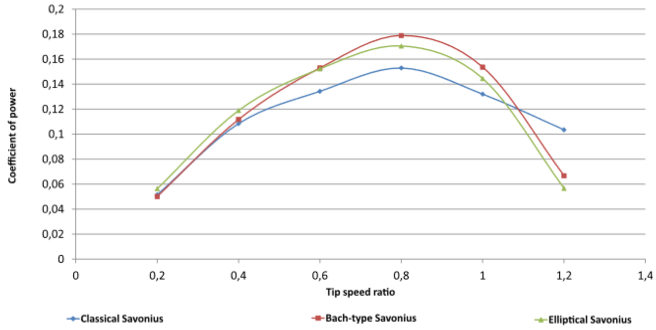

Figure 1. Comparison of the average coefficients of power obtained at different TSRs [2].

Whereas J.L. Menet et al. [4] has found in experimental analysis that rotor having overlap ratio of r/6, where r is radius of the rotor, having zero space between two opposite buckets have maximum coefficient of power is found 0.3 at TSR = 1, whereas maximum torque coefficient is found 0.425 at TSR = 0.4. M.A. Kamoji et al. [5] has experimentally found that, The Tip Speed Ratio (TSR) for maximum power coefficient is maximum for helical Savonius rotor having 90º helix angle and aspect ratio= 0.88 and overlap ratio = 0, then that of the conventional Savonius rotor.

B. Effect of No. of Blade (n)

Zhenzhou Zhao et al. [6] found in result of numerical analysis that power coefficient is 0.165 and 0.12 for two and three blade rotors respectively at TSR = 0.8, which is higher compare to conventional rotor in case of two blade rotor.

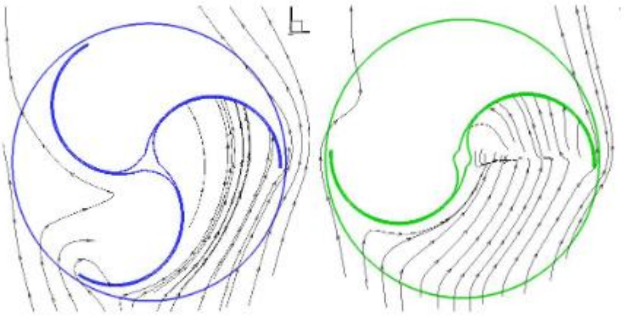

Figure 2. Air flow distribution of two and three blade [6]

U.K. Saha et al. [7] has carried experimental analysis considering two and three bladed rotors in which they found that coefficient of power is 0.32 and 0.28 respectively. From fig. 2 it can be visualized that air which strikes on a blade get reflected back to upcoming blade which create negative torque thus with increase in rotor diameter coefficient of power is decreased. Frederikus Wenehenubun et al. [8] has concluded that three blade savonius rotor produces higher rotational speed compared to two and four blades from their experimental study and simulation. They had also found that four blade rotor performs better at lower tip speed ratio while three blade rotor are best performing for higher tip speed ratio. Mohammed Ali et al. [9] also conclude in experimental analysis that the two blades Savonius wind turbine is more efficient, it has higher power coefficient under the same test condition than that of three blades Savonius wind turbine.

C. Effect of Aspect Ratio (a)

Aspect ratio is given by ratio of height to width of the turbine.

Parag K. Talukdar et al. [10] had reported rotor having lower aspect ratio is more preferable as it is easy to provide structural stability. Rotor having higher aspect ratio creates more bending moment on shaft which require heavy shaft which eventually increase inertia of the turbine which is unfavourable to its performance. Zhenzhou Zhao et al. [6] shows that performance of rotor (two blade, helical angle = 180º and overlap ratio = 0.3) is found optimum in CFD analysis having aspect ratio of 6 whose performance is Cpmax = 0.2 at TSR = 0.75. For lower aspect ratio coefficient of torque is considerably high at low RPM, while rotor having higher aspect ratio have higher RPM but its have lesser coefficient of torque. Rotor having higher aspect ratio would cause eddy airflow which leads to performance dropping.

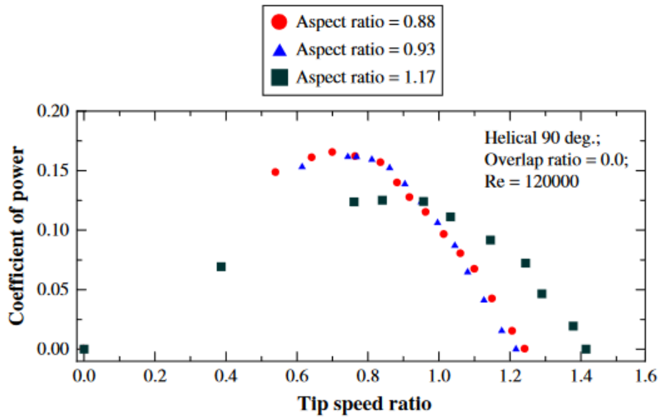

Figure 3. Variation of coefficient of power at aspect ratio of (0.88, 0.93 & 1.17) [5].

M.A. Kamoji et al. [5] found in experiment that, effect of aspect ratio on the coefficient of power for a helical Savonius rotor with a 90º twist at a Reynolds number of 120,000 shown in fig. 4. Performance of helical Savonius rotor with an aspect ratio of 0.88 is marginally higher (Cpmax = 0.165 at a TSR = 0.7) compared to the helical rotor with a rotor aspect ratio of 0.93 (Cpmax = 0.16 at a TSR = 0.74). Coefficient of static torque varies from 0.27 to 0.0038 for a rotor with an aspect ratio of 0.88 and from 0.17 to 0.04 for a rotor with an aspect ratio of 1.17. Coefficient of static torque varies from 0.08 to 0.33 for a helical Savonius rotor with an aspect ratio of 0.93.

D. Effect of Helix Angle (α)

Jae-Hoon Lee et al. [1] has concluded in numerical work that; in conventional savonius turbine helix angle is zero in that case rate of fluctuation of torque is considerably high. In order to overcome and to make turbine more stable helix angle is provided. For more than 90º twist angle, it was found that the torque coefficients stabilized and remained constant. Helix angle also reduce variation in projection area during its entire revolution as shown in figure 5.

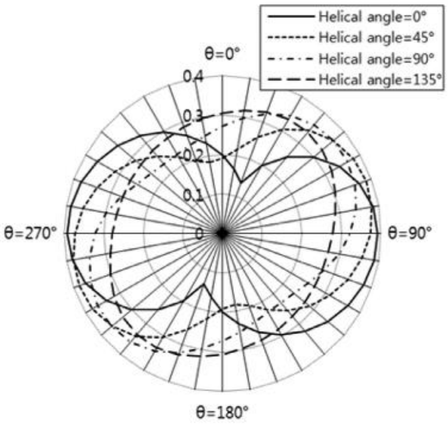

Figure 4. Variation of projection area at different azimuths angles [1].

A. Kamoji et al. [5] had concluded after performing several experiments that torque coefficient during complete revolution is positive, whereas in conventional rotor at several rotor angles torque coefficient is negative. In helical savonius rotor having 90º helix angle coefficient of power increases with increase in Reynold number.

E. Effect of Overlap Ratio (e)

Overlap ratio can be defined as ratio of distance between two blades at centre of the turbine to the diameter of the blade. Zhenzhou Zhao et al. [6] has found in numerical analysis that, overlap distance of savonius rotor also effects on the power coefficient pressure contour of savonius rotor having two blades with an overlap distance at rotating condition has been shown in Fig.6. It can be visualized that a pressure is high in the upwind rotor because of heading-on the wind or because of collecting the wind. Whereas pressure is very low on the counter blade, because of lacking of the air blowing. As the difference of pressure between two blades is more, it leads to higher push and power coefficient get lower. Passage between two buckets is provided to allow the wind to flow in counter blade so it will reduce pressure difference between two blade which eventually increase torque. If ratio is more it will not allow wind to thrust in a upwind blade and if ratio is too small it will not allow to flow the wind in counter blade. So, it requires optimum value which leads to a maximum power coefficient.

The maximum coefficient of power and the corresponding tip speed ratio with different overlap ratios modelled in this study. It may be seen that the tip speed ratio at which the maximum coefficient of power is observed decreases with the increase in the overlap ratio for helical Savonius rotors. Maximum coefficient of power for a helical Savonius rotor is around 0.18 for a 0.3 overlap ratio at a TSR of around 0.73. Joao Vicente Akwa et al. [11] has concluded rotor having overlap ratio of 0.15 gives averaged power coefficient equals to 0.3161 for tip speed ratio of 1.25 from CFD analysis.

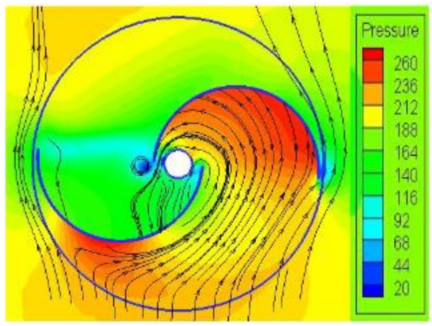

Figure 5. The effect of overlap on pressure around rotor [6].

F. Effect of No. of stage (N)

N.H. Mahmoud et al. [13] has found in experimental analysis that; the two stages rotor gives higher specific power than single stage rotor as shown in Fig.7. The specific power is defined as the power obtained from unit projected area of the rotor. In order to verify this result, the static torque affected on rotor blades for both single and double stages rotors is measured at the same angle of rotation and at different wind speeds. Double stages rotor has higher static torque and consequently higher static torque coefficient compared to the single stage rotor. Tsutumo Hayashi et al. [14] had found in experimental analysis rotor having three stage have almost same torque coefficient thorough out complete rotation of rotor at TSR = 0.043 at a wind speed of 12 m/s. But with increase of TSR of 0.259 again the variation in torque coefficient increase, with further increase of TSR variation in torque coefficients is again decreases.

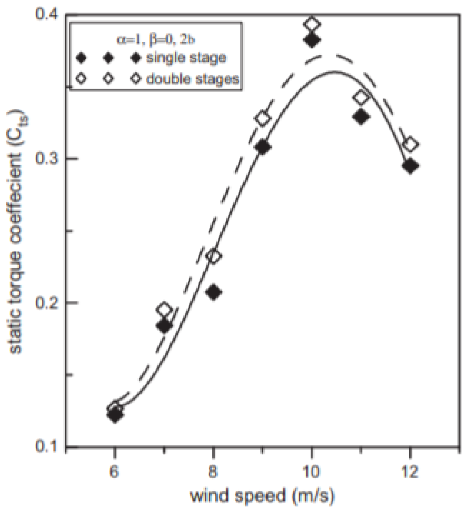

Figure 6. Variation of static torque coefficient with wind speed for single and double stage rotors [13].

G. Effect of with or without End-plate

N. H. Mahmoud et al. [13] has found in experimental analysis that, variation in mechanical power with wind speed for rotors with and without end plates is given in Fig. 8. Rotors with end plates give higher mechanical power than rotors without end plates. This is because the existence of end plates increases the amount of air which strikes the blades of Savonius rotor.

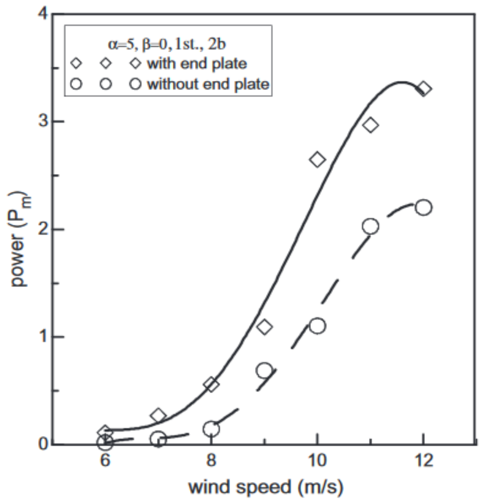

Figure 7. Variation of mechanical power with wind speed for rotor with and without end plates [13].

H. Effect of Blade Curve Profile

There are five turbines are considered for investigation as follows conventional semi-circular, semi-elliptic, benesh, modified bach type, newly developed.

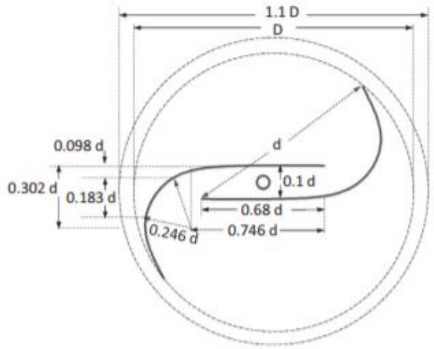

Figure 8. Savonius Wind Turbine Modified by Sukanta Roy [15]

Sukanta Roy et al. [15] has experimentally found that, with the newly developed SSWT, a noticeable improvement in the maximum power coefficient is observed over other tested models. Performance gains of 3.3%, 6.9%, 19.2% and 34.8% are achieved over modified Bach, Benesh, semi-elliptical, and conventional SSWTs, respectively.

They also found that, the CPmax values are experienced at an optimum range of TSR such as 0.75–0.82, 0.72–0.80, 0.72–0.80, 0.70–0.75 and 0.66–0.73 for the modified Bach, Benesh, semi-elliptical and conventional blades respectively.

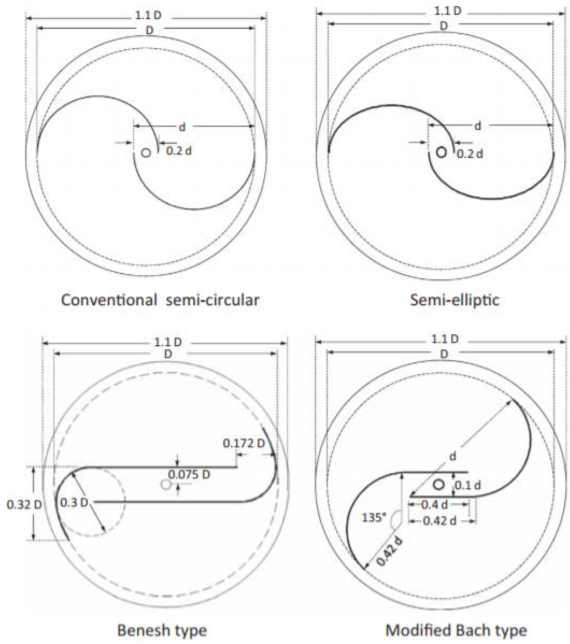

Figure 9. Different Type of Savonius Wind Turbine [15]

As shown in figure 1, Konrad Kacprzak et al. [2] has found that power coefficient the bach-type rotor is superior to the other tested geometries and at the same time the elliptical savonius turbine exhibits better power characteristics than the conventional one.

Wenlong Tian et al. [16] had modified curve profile of savonius blade, which exhibit higher average power of 0.2580 (4.41% higher than conventional) at high tip speed ratio of 0.7.

I. Effect of with and without shaft

In CFD analysis Rajat Gupta et al. [17] studied two-bucket helical Savonius rotor with shaft at 45º twist angle. From numerical analysis they concluded that the highest values of dynamic pressure and velocity magnitude were obtained at the chord ends with 45º bucket twist and 90º rotor angle, which would ensure improved performance of the rotor as a whole by increasing the aerodynamic torque production of the rotor. Bachu Deb et al. [18] has carried out numerical analysis which is designed in gambit software having rotor diameter of 17 cm, helical angle of 45º and diameter of blade is 17 cm. Blade is attached with each other with the help of end plate. In CFD analysis it has been found that helical savonius rotor without shaft obtained maximum power coefficient is 0.462 for 45º rotor angle at TSR of 1.636.

J. Effect of Reynolds No.

Reynolds no. can be defined as a dimensionless number used in fluid mechanics to indicate whether fluid flow past a body or in a duct is steady or turbulent.

In experimentally analysis it has been found that by A. Damak et al. [12] with increase of Reynold No. curve profile of coefficient of power increase as shown in figure. Kamoji [5] and Akwa et al. [11] had also reported the same trend of Reynold no. at different tip speed.

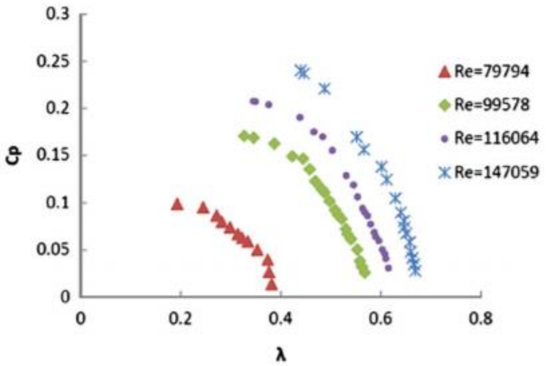

Figure 10. Effect of Reynolds No. on coefficient of Power with respect to Tip Speed Ratio [12]

K. Effect of Turbulence Model

Turbulence is considered as critical which should be accounted precisely in the case of air. There are a number of models available to take care of turbulence factor in the simulation. Reynolds number and flow geometry are the prevailing parameters to select an appropriate turbulence model.

M.H. Mohamed et al. [13] has carried flow simulation using various governing equation, as shown in fig. 11 it can be visualized that realizable k-ϵ model gives precious result compare to SST, standard k-ϵ and RSM model over wide range of speed ratio.

C Kang et al. [19] conclude that among the various turbulence models, the Spalart - Allmaras (SA) model is a simple one-equation turbulence model, where the near wall gradients of the transported variable are much smaller than the turbulent kinetic energy equation based (k - ϵ) models. This might make this model less sensitive in the near walls treatment around the Savonius rotor. However, a 3D CFD simulation using SA model was carried out to compare the performance of vertical-axis spiral rotor with two end plates and one middle plate with a conventional Savonius rotor. Results of the simulation depicted that torque performance of the spiral rotor was more favourable during its whole rotation cycle [6].

Anuj Kumar et al. [21] has considered Realizable k-ε turbulence model for CFD analysis as it demonstrates the excellent agreement with obtained experimental result. Realizable k-ε turbulence simulate better which involves the rotating behaviour of blades or air foil, a boundary layer, separated flows or flow through a channel.

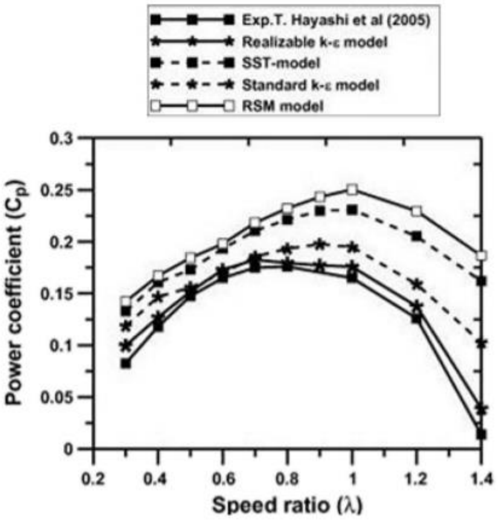

Figure 11. Effect of Governing Equation on results of CFD Analysis [21]

The results of their study are shown in Figure 11 which demonstrates the excellent agreement obtained between CFD and experiments results for the realizable k ε turbulence model. Accordingly, realizable k-ε turbulence model has been considered for the present study. It was suggested under earlier studies that Realizable k-ε turbulence model is better to simulate the rotating behaviour of blades or air foil, flow through the channel, a boundary layer or separated flows. Accordingly, the Realizable k-ε model has been employed as turbulence model under the present study to simulate the rotating behaviour of turbine blades. This model has two major differences from the Standard k-ε. It comprises a new formulation for the turbulent viscosity and a new transport equation for the dissipation rate ε, derived from an exact equation for the transport of the mean-square vorticity fluctuations. Further, this model does not rely on the assumed relationship between the Reynolds stress tensor and the strain rate tensor. In the realizable k-ε model, the coefficient of the model is expressed as a function of mean flow and turbulence properties, rather than assumed to be constant as in the standard model.

BE Launder et al. [20] says that, the standard k - ϵ model is the basic k–ε turbulence model and more suitable when flow is fully turbulent and has given better results than SA model for turbine analysis.

IV. SUMMARY OF LITERATURE REVIEW

From the literature, it can be concluded that helical savonius turbine is more efficient than conventional type wind turbine as the helical savonius turbine generates more power and torque coefficient. It is also observed form the literature that the turbine having helix angle of 180º makes the two blades rotor advantageous then the three-blade rotor. Savonius turbine having aspect ratio of about 0.88 having end plate with an overlap ratio in range of 0.15 to 0.30 are produces more torque and power. Sukanta Roy et al. has developed a modified blade profile which develops more drag force hence eventually improves the performance by 34.8% compare to conventional savonius wind turbine. For the numerical simulations, the researchers applied different models for the simulation to understand the physical behaviour and the flow conditions and it can be concluded from the literature that standard k - ϵ model gives the better results than the SA model for turbine analysis. The results obtained from the Standard k - ϵ model validates completely with experimental results.

V. CONCLUSION

Large Scale Wind Turbines (LSWTs) have been extensively examined for decades but very few studies have been conducted on the small-scale wind turbines (SSWTs). The performance improvement of a helical Savonius rotor is studied by using three dimensions CFD model & experimentally in the papers. Researches are carried out to study the influence of blade number, overlap ratio, helical angle, no. of stage and aspect ratio on the performance of helical Savonius rotors. Through the work in the papers, the coefficient of the power of Savonius rotor is dramatically improved from the conventional Savonius rotor.

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