CFD ANALYSIS OF SAVONIUS VERTICAL AXIS WIND TURBINE: A REVIEW

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Abstract - *This paper presents review on performance and testing methodology of savonius vertical axis wind turbine. Savonius wind turbine is suffering from poor efficiency. Many of researchers proposed different configuration of savonius wind turbine to increase the efficiency. In this paper various factors such as aspect ratio, overlap ratio, number of blade, interference of shaft, influence of stator, influence of Reynolds number, shape of rotor, how affects the performance of turbine are discussed . Experimental method is expensive and time consuming. But numerical method provide good result compared to experimental method which is less expensive and less time consuming for testing of savonius wind turbine. Intension of this paper to gather information and bringing it into discussion about their performance of savonius wind turbine for future studies.*

Key Words: *savonius vertical axis wind turbine,coefficient of power,cfd analysis.*

1 Introduction

Fossil fuels are conventional energy source which are limited. Intensive use for energy generation from fossil fuel will diminish in several upcoming decades. By burning fossil fuels like natural gas, crude oil, coal etc. generate heat energy which will utilize for power to vehicle, generation of electricity for domestic & industrial purpose. Burning of fuel causes environmental pollution which is harmful for eco-system day by day. It is necessary to use renewable energy source such as wind. A device which converts kinetic energy of wind into electricity is as called wind turbine. Wind turbines are two types such as horizontal axis wind turbine & vertical axis wind turbine. Horizontal axis wind turbines are not suitable for mounting on roof of house & building. Because it generates vibration, noise also harmful for birds due to high speed rotation of blades. Vertical axis turbine has two categories such as darriues vertical axis turbine (D-VAWT) & savonius vertical axis turbine. The savonius wind turbine has suffering from poor efficiency. Many of researchers had proposed different savonius configuration to increase the performance. D-VAWT is lift- drive which has more efficiency than savonius VAWT, but savonius turbine has some advantageous over darriues vertical axis turbine like self starting capacity at low speed wind, simple in construction, independent on wind direction, reduced wear & tear of moving parts. Savonius wind turbine was discussed by S.J.Savonius. The concept of conventional savonius turbine was cutting a cylinder into two halves along the central plane & then moving the two half cylinder sideways along the cutting plane so that the cross-section of seems like 'S' letter [8].

Fig.1 shows Savonius wind turbine, which has concave and convex section. In concave section wind strike and get trapped into it, the wind has some kinetic energy which exert pressure on concave section of blade exactly at a same time wind get deflect on convex section of blade, so that pressure difference arise between concave & convex section from upstream to downstream due to that turbine get rotates about its central axis shaft [10].

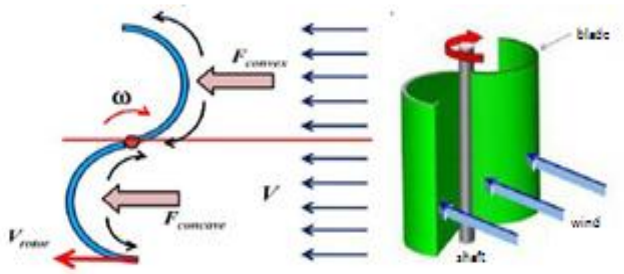

Fig.1 forces on simple savonius wind turbine[10].

2 Methods

Various configuration were proposed by many of researcher & verified using different techniques such as experimental, computational fluid dynamics

2.1Experimental Study

In experimental study U.K.Saha et al [6], Frederikus Wenehenubun et al [5], M.A.Kamoji et al [14], Mohammed hadi Ali et al [10], the experiments carried out on proposed dimensional savonius wind turbine in open or closed wind tunnel for testing the performance. In wind tunnel axial flow fan was mounted & encased in a circular mouth casing, when the wind tunnel starts then anemometer measures the velocity of wind, when wind is produced by fan it pushes the blade of turbine, then turbine will rotate. Rotation will measured by tachometer & torque of turbine measured by torque meter corresponding wind speed. This method gives accurate results but it is costly and time consuming method.

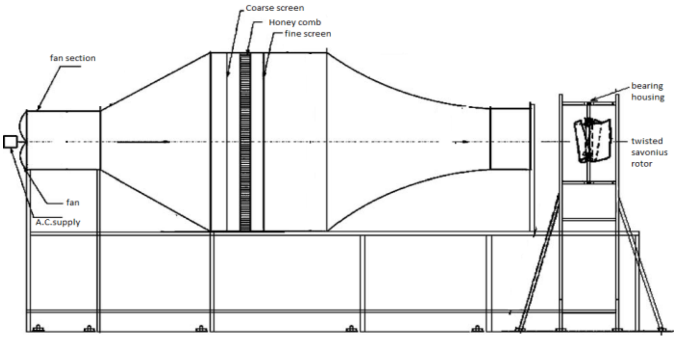

Fig.2 wind tunnel with twisted savonius wind turbine [6]

Coefficient of performance (Cp):- it is ratio of maximum power (p_t) obtained from wind and total power available (p_a) from wind. Cp can be calculated

$$C_p = \frac{P_t}{P_a} = \frac{P_t}{\frac{1}{2}\rho A V^3} \quad (1)$$

Where ρ is air density (1.225kg/m^3), U is wind speed (m/s),A is swept area of rotor (m^2).

Maximum power (P_t watt) of wind turbine can be calculate.

$$P_t = T\,\omega \;\; (Watt) \quad (2)$$

Swept area (A):- it is product of height and rotor diameter

$$A = H * D \quad (3)$$

Tip speed ratio (λ):- it is ratio of speed of tip blade (Vrotor) and wind speed through blade. It is calculated by

$$TSR = \lambda = \frac{V_{rotor}}{V} = \frac{\omega.d}{V} \quad (4)$$

where *Vrotor* is the tip speed

Coefficient of torque (C_t):- It is ratio actual torque of rotor to theoretical torque of wind (T_w)

$$C_t = \frac{T}{T_w} = \frac{4\,T}{\rho\, A_s\, d\, V^2} \quad (5)$$

2.2 Computational Fluid Dynamics

yan-Fei Wang et al[7], Maosheng Zheng et al[2], Wenlong Tian et al, S.Mctavish et al[4], bachu deb et al[16], R. Gupta et al[11], pinku debnath et al[1], Cfd became a powerful tool for testing of wind turbine, because it is economical as well as less time consuming, CFD provides a fluid mechanics which analyze & solve the problem related to fluid flow physics so that it provides good result as compared to experimental results if boundary conditions are well defined.

2.2.1 Numerical Method

Any commercial Cfd software ANSYS, COMSOL, FLOW3D, CFDESIGN, using such software S.Mctavish et al [4] unstructured finite element method Cfd code that applies prismatic layers near the wall of rotor, there are two turbulence model K-e & RNG used for wind turbine which is very popular to give accurate result using the semi-implicit method for pressure-linked equation (SIMPLE) algorithm for pressure-velocity coupling [12]. A second order upwind scheme is employed for spatial discretization & first order scheme is used for transient discretization. In rotating simulation the rotor geometry is surrounded by cylindrical volume which is rotates at any desired angular velocity, the flow is solved using the sliding mesh mode (SMM) [2].

2.2.2 Computational Domain and boundary Condition

2.2.3 Two-Dimensional Domain for Steady Simulations.

Domain is rectangular region which may vary according to geometry which is under simulation, S.Mctavish et al [4] in rectangular region in which fluid flowing & rotor geometry at the center of domain remain stationary. The domain size should be in multiples to rotor diameter, boundaries of domain according to fluid flow, flow is entering called inlet and at the exits of domain means at outlet zero gauge static pressure boundary condition was applied. Free slip boundary conditions are applied to remaining external boundaries. The RNG turbulence model is used with 1% to 5% turbulence intensity. RNG turbulence model provides artificial flow behavior in rotating simulation [4].

2.2.4Three Dimensional Domain for Rotating Simulation

S.Mctavish et al [4], Maosheng zheng et al [2], Yan-Fei Wang et al [7], Fig.3 shows that three dimensional computational domain, the domain size was decided using by multiple of rotor diameter including a cylinder which represents the rotating zone of the domain. Inlet of domain fluid entering with certain uniform velocity, Outlet had a zero static pressure boundary condition applied. Wall of rotor had a no-slip boundary condition applied. The reaming outer four walls free slip boundary condition applied. The turbulence model K-e with1% to 5% turbulence intensity was used which is suitable for rotating simulation. For transient calculation, using sliding mesh model flow is solved but it is time dependent. In rotational zone the grid and geometry is moving using some constant time step and blades changes the position at every time step. When simulation completes the output in the form of coefficient of torque obtained. Using Ct, p and cp can be calculated.

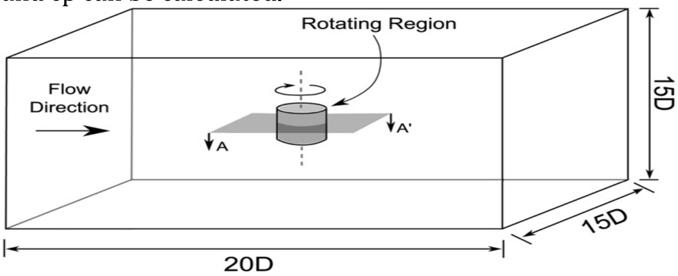

Fig.3. three dimensional domains for rotating simulation [4]

3 Factors That Affects Performance of Savonius Wind Turbine

There are many factors that affect the performance of savonius wind turbine such as overlap ratio, aspect ratio, shaft interference, number of blades, rotor stage, rotor shape, Reynolds number, effect of stator.

3.1 Effect of Aspect Ratio.

Aspect ratio is defined as it is a ratio of height and rotor diameter (h/d).while swept area (A), bearing friction, weight of rotor, wind velocity, keeping constant. Mohamed et al.[3] Increment in aspect ratio it also increase the power coefficient. While keeping high aspect ratio gives better coefficient of performance due to effects of tips of bucket. In many of studies shows that aspect ratio should not be less 2 which give best results. M.A. Kamoji et al [14] if helical rotor compared with conventional savonius rotor shows good results for aspect ratio of 0.88 which has coefficient of power 0.165 at γ=0.7.when aspect ratio increases angular acceleration also increase & inertia of turbine decreases.[3, 14]

3.2Effect of Overlap Ratio

Many of studies show that zero (without) overlap ratio has better performance than non zero (with) overlap ratio with semi circular savonius rotor. Because of when wind strikes to concave portion of rotor wind will escape from gap between the blades, reduction in performance may arise. Zied Driss et al [17] In this study author conclude that internal overlap ratio has an effect on the power & torque rpi=0 overlap ratio gives improved cp & ct, the increase in internal recovery value. A progressive decrease of the power value is observed at the same speed. For rpi=0 maximum cp is 0.324 at TSR=0.392 was obtained.

3.4 Effect of Blade Number & Rotor Stages.

Most of studies show that increase in number of blade will increase drag force against the wind so that reverse torque will increase & leads to reduce the net torque of savonius wind turbine. Because blade deflects the wind flow which is a strike on next blade after it while turning, each blade affects the performance of previous blade is called as cascade effect. Due to this less power will generate when number of blade increases. Mohamed et al [3] they perform an experiment to reduce the drag effect and enhance the efficiency of rotor. While performing they found that three and four blade is less efficient than the two blades. Performance of double stage is better than the single stage rotor. Frederikus Wenehenubun et al [5] they conducted an experiment and investigated for performance of savonius rotor by varying number of blades. In this 2, 3, and 4 bladed wind turbines were compared, to check the tip speed ratio, power coefficient and torque related to wind speed. The results of study showed that. Savonius model with three blades has the best performance at high tip speed ratio. It shows that the wind speed of 7 m/s and the highest tip speed ratio is 0.555. K.K. Sharma et al [9] they conducted an experiment on two stage and two bladed savonius wind turbine in subsonic wind tunnel. They studied about overlap, tip speed ratio, power coefficient (Cp) and torque coefficient (Ct). So the result shows that maximum Cp of 0.517 was obtained when overlap ratio is 9.37%. Fluctuation of power and torque coefficients between 9.37% to 19.87%.Mohammed Hadi Ali et al [10] It is observed that two bladed rotor is more efficient than three bladed rotor

3.5 SHAPE OF ROTOR

Various shapes of conventional savonius VAWT which affects the performance of turbine, Modified shape of savonius turbine was compared with conventional savonius turbine show some good results. Pinku Debnath[1] They compared the three bladed conventional savonius wind turbine to helical three bladed wind turbine for improving the efficiency using 90° twist in blade on conventional savonius wind turbine .using cfd FLUENT from the simulation high performance obtained at rotor angle 60° static pressure nearly 436pascal along with maximum velocity was 25.7m/s. The rotor angle 150° maximum static pressure distribution near the chord ends obtain 3.97*10^2pascal it means maximum positive torque obtained. U.K. Saha et al [6] they conduct an Experiment and shows that potential of the twisted blade rotor provides smooth running capability, increment in efficiency and self-starting ability as compared to the conventional savonius rotor. They stated that optimize the twist angle 15° for 6.5m/s and power coefficient is Cp=13.99 and efficiency is 23.6. Yan-Fei Wang et al [7] they compare and seen that the performance of the wind rotor of semi-circular blades is comparable to that of the semi-cylindrical wind rotor, and is slightly less than that of the helically twisted wind rotor. However, the semi-circular rotor runs more smoothly.

3.6 Interference of Shaft

According to some studies show that the savonius wind turbine with shaft has poor performance than without shaft savonius wind turbine. Because passing of shaft block the wind flow this effect is called as blockage effect. M.A. Kamoji [14] the performance of helical rotor with shaft and without shaft were compared and it is found that helical rotor with shaft has lower power coefficient than helical rotor without shaft. Helical savonius rotor with shaft has lowest power coefficient 0.09 and tip speed ratio 0.9. Rajat Gupta et al [11] they investigated for helical savonius rotor with shaft at 45° twist angle using cfd software FLUENT . Standard k-ε turbulence model with second order upwind discretization scheme and they found that the power coefficient (Cp) increases with the increase in tip speed ratio up to 1.636 then decrease. Also they found that power coefficient positive in all direction of rotor.

3.7 Influence of Stator

According to several studies introducing stator means static part which deflates wind flow and concentrate on concave portion of rotor. Reduce the wind flow on convex portion of rotor which causes reverse torque. M.H.Mohamed et al [8] using cfd analysis power coefficient increased by making obstacle for returning blade and checked the static torque and found to be positive at any angle, it is high enough for self-starting conditions. J.V. Akwa et al [18] author found in his study they used various configuration of savonius turbine like as free savonius rotor, cylindrical with three opening, cylindrical with two opening, wall shaped like a wings, one deflector, four deflector blade, one deflector has higher power coefficient than free savonius rotor at high Tip speed ratio. The use of four deflector blades at TSR=1 provides improvement in performance up to 12% compared to savonius rotor without stator, because better air direction on concave side of the advancing blade. This device can be used successfully at air is coming from several direction.

3.8 Influence of Reynolds Number

When Reynolds number increases coefficient of power also increases. Khandakar Niaz Morshed et al [12] they found that at higher Reynolds number the turbine without overlap ratio gives better aerodynamic coefficient, and at lower Reynolds number the model with overlap ratio gives better result. M.A. Kamoji et al. [14] helical savonius rotor without shaft with null overlap ratio shows higher power coefficient of 0.174 at Reynolds number of 150000

4 CONCLUSION AND DISCUSSION

Numerous configurations were adapted for enhancing the performance of savonius wind turbine. Each configuration of savonius rotor gives good performance characteristic. In previous studies show that performance of savonius wind turbine was affected by some parameters like aspect ratio, overlap ratio, number of blades, rotor shapes, Reynolds number, turbulence intensity, shaft interface, influence of stator, direction of wind flow. For predicting performance accuracy experimental and Cfd simulation method was used by many of researchers. These two methods provide good results comparing to each others. Experimental method is costly and time consuming and other hand Cfd simulation method less costly and time consuming. The functional relationship between coefficient of power and geometric parameter and wind flow parameter,

Cp = f (tip speed ratio, geometric parameter, flow parameter)

Numerical method is very effective for testing the flow and turbine performance. The three bladed savonius wind turbine has best performance at high tip speed ratio & four bladed savonius turbine has good performance at lower tip speed ratio. When wind is coming from several & constant direction then four deflector blades gives good performance over conventional savonius turbine. Effective rotor angle 45° & 90° gives improved performance of savonius rotor. Without shaft interface provides better results than with shaft interface. Aspect ratio increases coefficient of performance also increases. Rotor with overlap ratio gives poor performance than without overlap ratio. Design and optimization can be done by using Computational Fluid Dynamic analysis. Two stage rotor has best performance than single stage savonius rotor.

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