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Numerical Analysis of Innovative Wind Booster Configurations for Vertical Axis Wind Turbines

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Abstract: ***Vertical Axis Wind Turbines has been looked upon by researchers as a potential avenue for power generation at domestic level. The Coefficient of Power of Vertical Axis wind Turbine has its limitations mentioned by Betz theory. In this paper three configurations viz one stage, two stage and three stage Wind booster has been designed, modelled and numerically analyzed. A Multistage concept of flaps has been used in wind booster so that wind velocity may increase during each stage. The performance of turbine is assessed by wind booster for Flow velocity, Pressure. For Numerical analysis SST K-epsilon turbulence model has been used. From the analysis it is found that, the two stage wind booster velocity and pressure magnitude range is superior as compared to other two configurations.***

Keywords **:** ***Multistage, Performance, Wind Booster, VAWT.***

I. INTRODUCTION

Vertical Axis Wind Turbine is looked upon by many researchers as a potential avenue for Domestic power generation. Vertical axis wind turbine has the capability to operate at low height in spite of wind turbulence. The performance of Vertical axis wind turbine has been improved by using omni directional guide vane Hadi et.al. [1] Daegyom and Gharib [2] had developed straight bladed vertical axis by using upstream deflector. The deflector is normal to the free stream velocity, the local wind speed outside the local wind speed outside the near-wake region of the plate is larger than the free- stream velocity. Chong et.al [3] had developed a novel Omni directional guide vane fixed to H rotor wind turbine. They estimated the performance of vertical axis wind turbine with and without Omni directional guide vanes. Greenblatt et.al used a dielectric barrier discharge plasma actuators on the blade edges. This was done to control the dynamic flow of fluid over the turbine blade. Daegyoum and Gharib used upstream deflector to improve the efficiency of straight bladed vertical axis wind turbine. Kirke and Lazaukas [4] had used a variable pitch system in which blade pitch amplitude is governed by a combination of aerodynamic forces on the blade and internal forces on stabilizing mechanism. Pope et.al [5] had developed a Zyphyer vertical axis wind turbine which has an external stator and internal rotor. Their work provided an empirical correlations that characterize the operating performance of a Zephyr VAWT. Many researchers had put their endeavors in developing innovative vertical axis wind turbines which are capable in confronting the problems encountered by the existing wind turbines. They have developed turbines which are site specific reduction in noise and weight. Newman and Ngabo [6] used sails for their wind turbine. Two types of sail a double sail and jib sail was tested. The performance of sail type wind turbine is almost 50 % of the turbine with solid blades. This could be overlooked by the ease in manufacturing the turbine. Pope et al [7] had performed energy analysis on four different wind power systems, including both horizontal and vertical axis wind turbines. They took two aerofoil (NACA 63(2)-215 and FX 63-137) commonly used in HAWTs and VAWTs (Savonius and Zephyr). Biswas et al [8] developed a new aerodynamic model for obtaining the performance characteristics of a vertical axis wind turbine to estimate aerodynamic loading, which was subsequently used for dynamic analysis of VAWTs. The model incorporates gyroscopic generation through an induction or synchronous type generator. Kumbernuss et al [9] introduced a novel magnetic levitated bearing suitable for VAWTs. The bearing system generates a magnetic force, which can support the weight of the wind turbine rotor. They had done simulation of the bearing by using finite element method which reveals that how low the torque of this bearing is. Small scale model of novel magnetic levitated bearing system has been fabricated and tested. Chong et.al [10] developed a novel power-augmentation-guide-vane (PAGV) to improve the wind rotor performance. Greenblatt et.al [11] deployed inboard and outboard plasma actuations on the blade to counter the positive and negative angle of attack that produces dynamic stall.

In this paper an attempt has been made to develop an innovative multistage wind booster. Different configurations of the wind booster has been developed and tested numerically. The wind extraction rate has been numerically analyzed for each configuration. It further provides insight about the wind flow field in the wind booster and around the wind turbine.

II. WIND BOOSTER

The innovative wind booster is made after studying the aerodynamics around the turbine. The booster consists of two semi hemispherical troughs as its endplates.

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Figure 1a, 1b and 1c shows Single stage wind booster, two stage wind booster and three stage wind booster. Deflectors are used which are at different radial distance. The combination of deflectors and endplates will act like a venturi. It has convergent and divergent section at the upstream side and downstream side of turbine. Due to negative pressure on the downstream side of the booster, the wind flowing through upstream side will be pulled into the turbine with enhanced wind speed. Two and three stages of deflectors are used so as to increase the flow velocity while passing through each deflectors. While designing the booster due care is taken to incorporate combine effect of venture and set of deflectors. The inner diameter of booster is bigger than outer diameter of turbine, so that turbine can be comfortably fitted inside the booster. The height of the booster is governed by height of the turbine. Turbine will be fitted inside the wind booster. The number of deflectors in one stage, two stage and three stage are 8, 16 and 24.

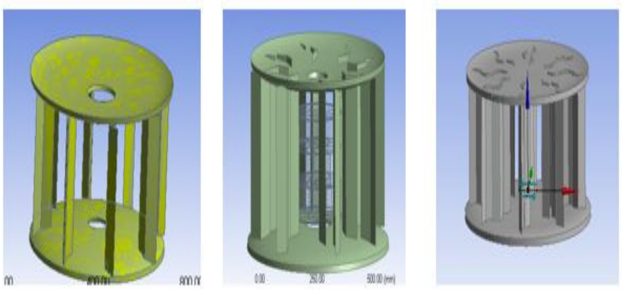

Fig 1. a) Single Stage Wind Booster b) Two Stage Wind Booster c) Three Stage Wind Booster

III. NUMERICAL ANALYSIS OF MULTISTAGE WIND BOOSTER

Due to advancement in computational facilities, it has been very much possible to simulate different configurations and do optimization. Here in this analysis, ANSYS Fluent has been used. The governing equations used is presented in differential form.

The continuity equation

$$\frac{\partial \rho}{\partial t} + \nabla = (\rho \vec{v}) = 0$$

The momentum equation

$$\nabla(\rho . \vec{v}\vec{v}) = -\nabla p + \nabla(\bar{\bar{\tau}}) + F$$

Energy Equation

$$\frac{\partial(\rho E)}{\partial t} + \nabla . \left(\vec{v}(\rho E + p) = \nabla \left[K_{eff} \nabla T - \sum_i h_i j_i + (\bar{\bar{\tau}}_{eff} . v_e \right) \right] + S$$

The turbulence model used for this simulation is Shear Stress Transportation (SST) K - ϵ model. This model can reasonably predict the airflows around turbine. Moving Reference Frame (MRF) has been used for simulating rotating turbine as its one of alternative for dynamic meshing. The fluid domain encloses the turbine, MRF and wind booster. The boundary conditions are velocity inlet, Pressure outlet, turbine rotation. The outlet pressure is considered as absolute pressure. The turbine angular rotation speed is taken from previous experimental data. Tetrahedron mesh is used for entire analysis. The mesh used is unstructured tetrahedron. The results are checked for mesh independence.

IV. RESULTS AND DISCUSSION

Numerical analysis of innovative wind booster is done in ANSYS Fluent. The entire analysis id done in two phases. In first phase detailed study of pressure and velocity variation inside the wind booster has been simulated. In second phase vertical Axis wind turbine has been placed inside the wind booster and its performance analysis is been done.

IV.I Pressure and Velocity analysis of one stage blade Wind booster:

The wind booster is simulated for wind velocity range 5-12 m/s. The wind booster has been placed in fluid domain which is about three times diameter on upstream and downstream side. The total number of nodes for the meshing are 232000. Wind booster with single blade configuration is simulated for velocity range. It has observed that, the velocity values at the inlet is 10 m/s whereas the velocity values at center of wind booster is 10.2m/s. The pressure value ranges from maximum of 0.5 Pa to -0.25 Pa.

IV.II Pressure and Velocity analysis of two stage blade Wind booster:

Wind booster is simulated for pressure and velocity parameters. Figure 2a represents the pressure plot of wind booster having two stage blades. From figure 2a it is interpreted that pressure at the middle portion of wind booster reduces considerably as compared to the pressure at inlet. The pressure value at the upstream side of wind booster is 39 Pa, where in the pressure at the mid portion is about -1490 Pa. The maximum pressure is 39 Pa and min pressure is -6081 Pa. Fluent computes and displays all pressure as relative pressure from an operating pressure. Negative values of pressure is obtained due to its value lower than operating pressure. As the pressure inside the wind booster is reduced than upstream pressure this corroborates that wind velocity inside the wind booster is improved.

Fig. 2a. Pressure plot of two stage Wind Booster

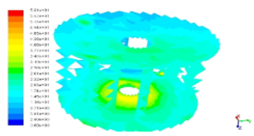

Fig. 2b. Velocity plot of two stage

Fig 2b. Shows velocity plot of innovative wind booster. The wind booster has been simulated for different wind velocities ranging from 5-10 m/s. Fig 2b shows that, wind velocity at the upstream side of wind booster is 10 m/s, whereas the velocity magnitude at the middle of the wind booster is 37 m/s. The maximum velocity magnitude estimated in the wind booster is 40 m/s. The enhancement of velocity is due to combine effect of venturi and two stage deflectors. The pressure drop inside the wind booster causes increase in velocity.

IV.III Pressure and Velocity analysis of three stage blade Wind booster:

Figure 3a and 3b shows Pressure and Velocity plots for three stage wind booster. Three stage blades wind booster is simulated for pressure and velocity parameters. Pressure in three stage wind booster ranges from 60Pa to -58 Pa, wherein the velocity ranges from to 12 m/s. It is observed that in three stage wind booster.

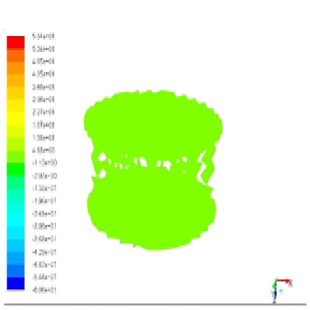

Figure 4 a. Pressure Plot

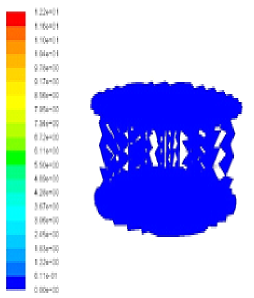

Figure 4 b. Velocity Plot

V. CONCLUSION

An innovative multistage Wind booster has been designed to increase the wind velocity. The Wind booster performance analysis has been done in ANSYS Fluent. Three different configurations of wind booster has been modelled viz, single stage, two stage and three stage wind booster.

The performance analysis of wind booster has been done for pressure and velocity parameters. From the CFD analysis it is observed that velocity range in two stage wind booster is 10 - 40 m/s, wherein one stage the velocity range 10-10.2 m/s. In three stage the velocity range is 10- 12m/s.

The pressure magnitude range for single stage wind booster is 0.5 Pa to -0.25 Pa, for two stage wind booster it is 39 to -6081 Pa and for three stage the pressure magnitude range is 60Pa to -58 Pa.

From the analysis two stage wind booster is having superior performance as compared to one stage and three stage wind booster.

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Abhijeet Malge (PhD) has completed his B. E. Mechanical from Shivaji University, Masters in Design Engineering from Pune University and PhD (Mechanical Engg) from Solapur University. His Research areas are Renewable Energy, Design Thinking, and Intelligent Systems. He has published six International Scopus listed research papers, Book Chapters. He is member of SAE and IMECHIE, UK.

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