ANSYS-based Force Analysis on a New Horizontal Axis Wind Turbine Shield

ANSYS-based Force Analysis on a New Horizontal Axis Wind Turbine Shield

Daniyar Seitenov[1], N.Mir-Nasiri [2*], and Md. Hazrat Ali[2]

[1] Ph.D. Student, Nazarbayev University, 010000 Astana, Kazakhstan
[2] School of Engineering, Nazarbayev University, 010000 Astana, Kazakhstan
[*] **nazim.mir-nasiri@nu.edu.kz**

Abstract. The importance of renewable energy sources cannot be denied in the era of increase of greenhouse gas emission and depletion of fossil fuels. The wind energy and design of new yet effective windmills become a necessity nowadays. This paper introduces a new configuration of wind turbine with a horizontal axis and ANSYS-based dynamic analysis of its high-speed protection shield that protects the turbine from overspending at extreme wind conditions. In comparison to traditional horizontal wind turbine structure, HAWT blades have a flat shape, and they are exposed to wind stream in such a way that the wind forces are strictly perpendicular to the blade surfaces. This structure extracts more wind energy and minimizes the useless forces affecting shaft joints in traditional wind turbines. The ANSYS-based force analysis presented in this paper proves the advantage of using of protection shield in such windmill structure.

Keywords: Protection Shield, Wind Turbine, Force Simulation, HAWT.

1 Introduction

One of the primary goals of the energy sector is to develop cheap alternative energy sources and reduce greenhouse gas emissions. Solar and wind power are the main sources of renewable energy in the energy sector. However, wind power contributes more than solar PV sources into the energy sector. The main focus of this paper is on the development of new wind power turbine system. Traditional wind turbines are classified depending on the axis of rotation, either horizontal or vertical as well as on location, either onshore or offshore [1]. Horizontal-axis wind turbines (HAWT), in fact, have higher efficiency than vertical-axis turbines (VAWT). One drawback of HAWT is that it requires aerodynamic modelling to identify the optimum height of the tower, control systems, and blade and rotor size [2]. Based on rotor location HAWTs are classified into upwind and downwind types. In case of upwind rotor type, it is faced to the wind, whereas for downwind type the wind passes tower and nacelle first only then reaches rotor for downwind. Cianetti et al. [3] include additional components such as yaw motor, gearbox, and foundation. The operation (mechanical rotation) of HAWT is based on aerodynamic lift force when wind reaches the rotor and blades. The rotor is connected with the low-speed shaft, which is, in turn, connected to the gearbox and creates a high-speed motion. The high-speed shaft has a rigid connection with the generator. The design of blades is a major concern for such turbines. Mouhsine et al. [4] have analysed the effect of the blade on the performance of the wind turbine. It was concluded that blades should have a low angle of attack for HAWTs in order to reach a higher aerodynamic lift and thus higher efficiency for the turbine. Additionally, the design of HAWTs considers the protection system to eliminate possible damage to the rotor at high wind speeds [5]. Sorenson et al. [6] have identified the two major operational speed terms. The first is “cut-in speed” at which wind turbine starts to generate power and the second is “cut-off speed” at which wind turbine must stop to avoid possible damage of rotor and entire turbine. One of the methods to avoid this problem is based on keeping turbine rotation at a preferable operation region [7]. The operation is based on torque control, i.e. on the calculated reference torque as a function of rotational speed. Vertical-axis wind (VAWT) turbines, as opposed to HAWT, are widely used in an urban area because of its ineffectiveness in chaotic, less predictable and turbulence region [8]. The operation principles of VAWT are based on the difference of aerodynamic drag on each concave and convex blade [9]. One advantage of VAWTs is due to its ability to operate regardless of height and wind speed [10]. Additionally, it has a low cut-in speed, less structural support and does not require a yawing mechanism. Nevertheless, the major drawbacks of the turbine are because of its low efficiency and the absence of reliable performance prediction. The approximate point force analysis (when the result of wind forces are applied at the centre of the blade area) and preliminary proof of work efficiency of HAWT has been described in details in the paper [11]. This paper is focused on the shield design by using ANSYS simulation tools.

2 Design of a Horizontal Axis Wind Turbine (HAWT)

Fig. 1 shows the overall view of a new horizontal axis wind turbine. Platform 1 supports the turbine generator high enough to catch the streams of wind. The generator shaft 2 has horizontal orientation and is fitted with four flat blades 3 with slightly bent edges. The shaft has two sets of four blades symmetrically located along the shaft. The orientation of blades in two sets is selected to be offset in order to make the rotation of the shaft smooth and less jerky. For ANSYS simulation, only one set of blades have been used in this paper. Fig. 1 shows that only two blades are exposed to the wind at any time. Other two blades below the axis of the shaft are hidden by the sloped platform 1. Platform 1and vertical post 4 is connected by means of thrust bearings. It allows the platform to rotate about a vertical axis and select the best orientation for the blades with respect to changing wind direction. The orientation and rotation of the platform are controlled by the vertically oriented tail fin 5 that always keeps its plane parallel to the wind stream. The fin ensures that perpendicular forces of the wind stream always attack the blades. The distinctive and important feature of the designed system is the oscillating shield 6 that is connected to the main frame by means of horizontal hinge 7 and able to rotate about its axis. The angle of rotation is defined by the stiffness of the set of springs 8 that links shield 6 to platform 1. The stronger is wind, the larger is a deflection of springs and thus larger is the angle of the shield rotation.

IOP Conf. Series: Materials Science and Engineering **653** (2019) 012048 doi:10.1088/1757-899X/653/1/012048

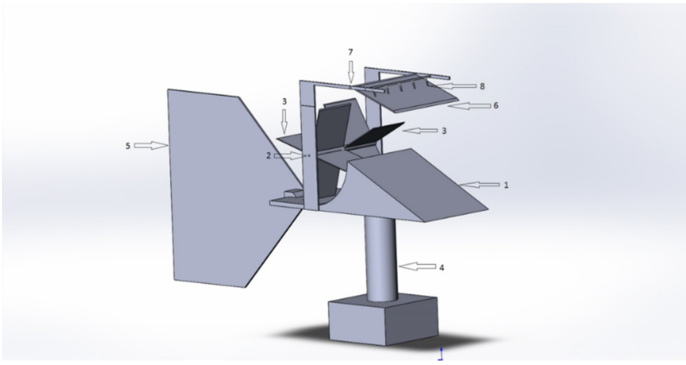

Fig. 1. Schematic view of the designed turbine system

3 Simulation and Force Analysis of the Shield

The simulation is conducted for the large scale wind turbine rotor that implies using a big size of turbine blades to generate sufficient power. For example, for the generator of 6 kW power, the selected one set of blades have 2 m width and 4 m height. For these dimensions of the blades, the shield width is determined to be W_S = 4 m wide to cover both visible to wind blade sets. The maximum wind speed that may cause full stretch of the shield is selected to be v_{max} = 25 m/sec. For the height of the selected blades H_b = 4m, the height of the shield is defined to be H_S =6 m.

3.1 Forces analysis of the shield under varying wind speed and selection of springs

This analysis first step is to analyse the deflection of the shield under various wind conditions and select the proper springs that will hold it from deflection for speeds less than 10 m/sec and start deflecting when speed exceeds 10 m/sec as well as able to hold the fully defected shield when speed reaches maximum assumed speed of 25 m/sec. This methodology can be used successfully for other possible boundary values of wind speeds, if necessary. The model of the shield was constructed using Solidworks and parameters given in paper [**100**,"Conceptual Design and Simulation of Horizontal Semi-exposed Wind Turbine (HSWT) Structure]. Computational domain has a size of 22.5x16x16 m, i.e., large enough to include the rotor blades later into the simulations (Fig. 2).

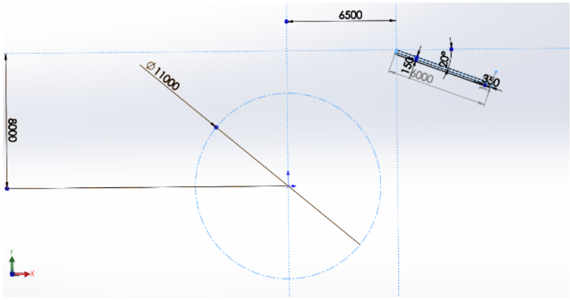

Fig. 2. Shield dimensions and location.

Patch Conforming method using tetrahedrons was chosen to save up time for simulations. The total number of elements is approximately 310 000. The set-up domain for an inlet wind speed of 10 m/sec and the selected initial shield angle of 20 degrees is shown in Fig. 3.

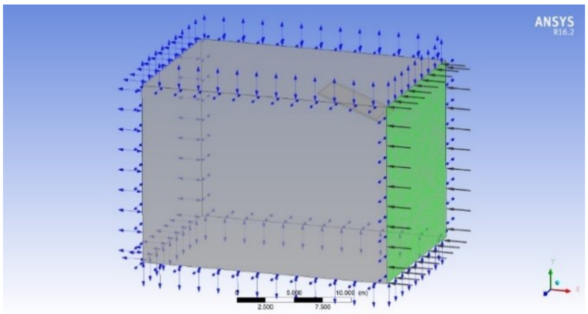

Fig. 3. Set-up of a domain with an inlet wind velocity of 10 m/s.

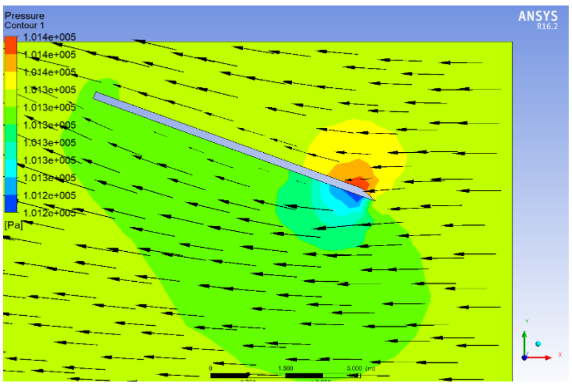

Fig. 4. Pressure distribution

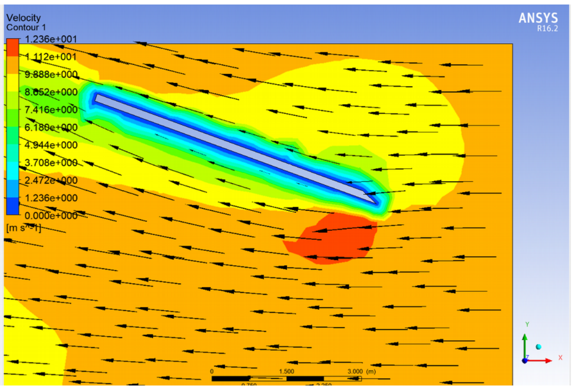

Fig. 5. Velocity distribution

Figures 4 and 5 show the pressure distribution due to wind flow and velocity contours at the center plane of the shield. In order to calculate torque on the axis of a shield, a new coordinate frame was specified to predict its value using a function calculator accurately. As a result, the torque acting on a shield around z-axis revealed to be -3401.4 N*m, which is apparently in a clockwise direction. Springs selection is based on the following methodology. The distance which is left open due to windshield position is dependent on the wind speed attacking the shield surface and selected spring parameters.

4 Conclusion

The developed HASWT system is able to fully utilize the wind energy due to the perpendicular orientation of the blades towards the wind flow. The wind forces applied on the blades generates only radially rotating forces on the shaft, and no or very minimum components of the force are generated in the axial direction of the shaft. Also, the vertically oriented tail of the platform enables the system to keep the rotor axis strictly perpendicular to the wind direction, similar to a rudder of the aeroplane. Its structure increases the efficiency of wind power absorption. The paper is focused on a small part of the project, i.e. pressure distribution on the protective shield of the wind. This distribution, as well as wind stream distribution, are generated by ANSYS software (Fig. 4 and Fig. 5) based on the given parameters and geometry of the shield in Fig. 1 and Fig. 2.

References

1. W. Tong, "Wind Power Generation and Wind Turbine Design," *WIT PRess*, 2010.
2. S. Thyagarajan, A. Bhalla, I. T. Masmanidis, C. N. Nayeri, T. P. Philippidis, and C. O. Paschereit, "HAWT for Power Generation," *International Journal of Engineering and Management Research*, vol. 3, no. 4, pp. 43–47, 2014.
3. F. Cianetti, A. Cetrini, M. Becchetti, F. Castellani, and C. Braccesi, "Dynamic modeling of wind turbines. Experimental tuning of a multibody model," *Procedia Structural Integrity*, vol. 8, pp. 56–66, 2018.

4. S. Mouhsine, K. Oukassou, M. Inchenical, B. Kharbouch, and A. Hajraoui, "Aerodynamics and structural analysis of wind turbine blade," *Procedia Manufacturing*, pp. 747–756, 2017.
5. S. Thyagarajan, A. Bhalla, I. T. Masmanidis, C. N. Nayeri, T. P. Philippidis, and C. O. Paschereit, "HAWT for Power Generation," *International Journal of Engineering and Management Research*, vol. 3, no. 4, pp. 43–47, 2014.
6. S. Sorensen, K. Brodbaek, M. Moller, A. Augustesen, and L. Ibsen, "Evaluation of the Load-Displacement Relationships for Large-Diameter Piles in Sand," *Proceedings of the Twelfth International Conference on Civil, Structural and Environmental Engineering Computing*, 2009.
7. M. Rossander, A. Goude, and S. Eriksson, "Critical Speed Control for a Fixed Blade Variable Speed Wind Turbine," *Energies*, vol. 10, no. 11, 2017.
8. P. Gulve and S. Barve, "Design and construction of vertical axis wind turbine," *International Journal of Mechanical Engineering and Technology (IJMET)*, vol. 5, no. 10, pp. 148–155, Oct. 2014.
9. K. Pope, G. F. Naterer, and E. Tsang, "Canadian Society for Mechanical Engineers 2008 forum," in *Canadian Society for Mechanical Engineers* , 2008.
10. S. Shah, R. Kumar, K. Raahemifar, and A. Fung , "Design, modeling and economic performance of a vertical axis wind turbine," *Energy Reports*, pp. 619–623, 2018.
11. N. Mir-Nasiri, D. Seitenov, "Conceptual Design and Center-point Force Dynamic Simulation of a New Horizontal Axis Semi-exposed Wind Turbine", *International Journal of Renewable Energy Research*, Vol. 6, no. 1, pp. 1-9, 2016 .