FLUID STRUCTURE INTERACTION OF SMALL WIND TURBINE BLADE

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ABSTRACT

This work present a FSI (Fluid Structure Interaction) study for small HAWT (Horizontal Axis Wind Turbine) blade. The conventional HAWT included in the study has rated power of turbine is 50 watt. The study has included the effect of winglets on the wind turbine performance. The study also has included material structure analysis and selection. The design of blade has conducted using BEM (Blade Element momentum) theory. The aerodynamic loads have calculated using a computational fluid dynamics (CFD) model implemented in ANSYS FLUENT. The blade structural responses have determined using a FEA (finite element analysis) model implemented in ANSYS Static Structural module. The manufacturing of turbine has been included for the optimal selection between variety of wind turbine materials in Egypt.

Keywords: wind turbine blade, Aeroelasticity, FSI (fluid structure interaction) ,CFD (computational fluid dynamics).

1-INTRODUCTION

Practical horizontal axis wind turbine design uses airfoils to transform the kinetic energy in the wind into useful energy. The sectional blade consists of the two dimensional 2D airfoils. The airfoil is responsible for producing the lift and drag forces by asset of pressure differences between its pressure and suction surfaces. The BEM has been widely used to outline a procedure for the aerodynamic design of a HAWT blade. The optimum distributions of the chord length and the pitch angle in each section can be acquired according to the design parameters. These parameters include the rated wind speed, number of blades, design tip speed ratio and design angle of attack [1,2]. During the operation of wind turbine, the aerodynamic loads on the blade may cause blade deflection. This deflection can in turn lead to additional variation in the flow field, resulting in further load variation. The interaction of fluid and structure may lead to aero-elastic instability problems depending on material of the blade. These include edgewise instability and flutter, which can have a disturbing effect on the blade itself and the wind turbine as a system [3]. For that reasons, it is important to select a material that can withstand the loads. These material include wood, metals, glass fiber reinforced polymer, carbon fiber reinforced polymers, natural fiber reinforced polymer, and Nano-composites are the various materials available in the market for small wind turbine blade [4]. On the other hand to enhance the performance of wind turbine, the total drag from blades should

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be reduced and this can be achieved be adding winglets to blades. The winglet is a good load carrier that reduces the span wise flow. It also works on diffusing the tip vortex far away from the rotor plane reducing the downwash and thereby the induced drag on the blade [5]. FSI model required both aerodynamics load and structure components to investigate the blade performance. The CFD is a good investigator for the aerodynamic performance of blade [6]. The structure analysis depends on FEA which capable of examining the detailed stress distributions within each layer of composite blade structure [7].
This paper introduce FSI model for wind turbine blade with a winglet and studies its aerodynamic performance which calculated by using CFD and its structure analysis which calculated by FEA and ANSYS static structure, the analysis will be applied on three different materials, Epoxy E-glass, Epoxy carbon fiber and Aluminum alloy (6061-T6).

2-Methods

2-1 wind system model.

The design parameters for the HAWT blade are presented in Table1. The design of wind turbine model conducted using the blade element momentum (BEM) theory. The rotor blade airfoil considered during the current study is NREL's S809. The Reynolds number is $5*10^5$. The configuration of the rotor blade element is shown in figure 1. The figure shows the applied aerodynamic forces, relative wind angle (φ) and angle of attack (α) acting on the airfoil. Where T_N and T_Q are the normal (thrust) and tangential (torque) forces respectively.
BEM theory applied for estimation the power produced as following:

Chord distribution for each element,

$$C_{schmitz(i)} = \frac{1}{Z} * \frac{16\pi r_i}{CL} * \left(\frac{\sin\phi 1}{3}\right)^2 \quad (1)$$

Where C_L is the lift coefficient and r is local radius of blade and subscript (i) is the number of element along the blade and

$$\phi_1 = \text{Tan}^{-1}\left(\frac{R}{\lambda r_i}\right) \quad (2)$$

Relative wind angle (φ_i) for each element

$$\varphi_i = \frac{2}{3} * \phi_1 \quad (3)$$

Twist angle,

$$(\beta_i) = \varphi_i - \alpha \quad (4)$$

The solidity ratio,

$$(\sigma_i) = Z * \frac{C_i}{2\pi r_i} \quad (5)$$

Prandtl tip loss,

$$(f_i) = \frac{2}{\pi} * cos^{-1}\left(e\left(-\frac{z}{2} * \frac{1-\frac{r_i}{R}}{\frac{r_i}{R} * sin\varphi_i}\right)\right) \quad (6)$$

Axial induction factor,

$$(a_i) = \frac{1}{1+\frac{4f_i * sin^2\varphi_i}{\sigma_i * c_l * \cos(\varphi_i)}} \quad (7)$$

Elemental torque,

$$(dT_{Qi}) = \left(\sigma_i \pi \rho \frac{V^2(1-a_i)^2}{sin^2\varphi_i} * C_L \sin\varphi_i - C_d \cos\varphi_i\right) * r_i * dr \quad (8)$$

Where (ρ) density of air, (C_d) drag coefficient, (dr) radial length of element.

Power,

$$(P) = (\Sigma dT_{Qi} * \Omega) \quad (9)$$

Power coefficient,

$$C_p = \frac{P}{0.5\rho\ \pi\ R^2 * V^3} \quad (10)$$

Table.1 HAWT blade design parameters

Name	symbol	Value	Unit
Rated power	P_{rat}	50	watt
Rated wind speed	V_{rat}	8	m/s
Design tip speed ratio	λ	4	
Radius of blade	R	35	cm
Number of blades	Z	3	
Design angle of attack	α	7	°
Rated rotor speed	Ω	91.43	rad/s

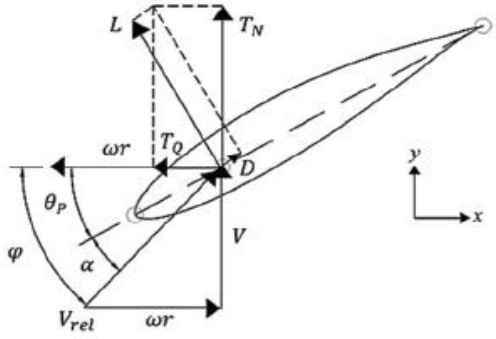


Fig .1. An infinitesimal element of the rotor blade

By solving these equations to find the blade geometry as shown in figure 2 with hub diameter(D_h) = 40mm, and power output =44.453 watt and power coefficient (C_p)=0.368.

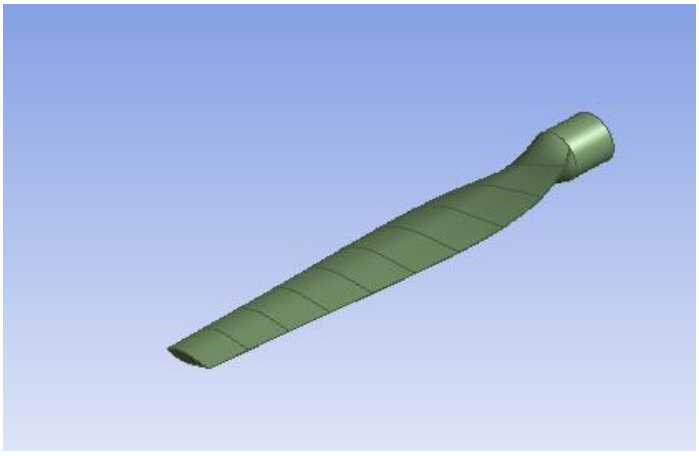


Fig.2. Blade Geometry

2-2 VALIDATION OF ANSYS CODE.

Validation is done by taking the model of NREL [8] (the National Renewable Energy Laboratory) it is an experimental test for of a Tapered and Twisted Blade of airfoil S809. Validation is taken at velocity =6.3 m/s at which power output =4470 watt for three blades case the results as shown in figure 3.

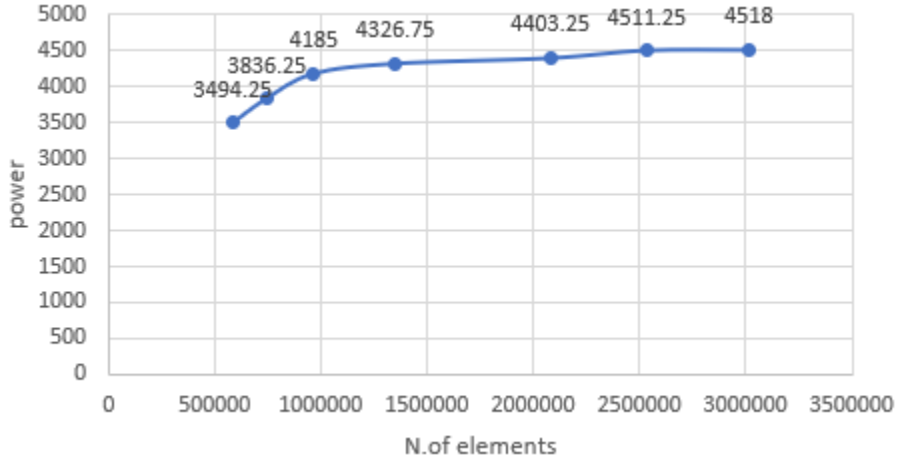


Fig.3 grid sensitivity analysis

The results show that at number of elements=1,3 million the power output=4326.75 W, and the percentage of error is 3.08%, So we choose this number of elements to perform our study.

2.3 CFD MODELLING.

A CFD model of wind turbine blades is established using ANSYS FLUENT ,the flow is obtained by solving the steady state governing equations of continuity and momentum conservation combined with one viscous turbulence models K-ω.SST (shear-stress transport)[9],itis a two equation eddy-viscosity model .

3-Results and Discussion

The analysis is done at velocity =8m/s and angular velocity =91.43 rad/s and the power output is 45.77watt and C_P=0.37. Table 2 shows the comparison between the BEM results and CFD results.

Table 2 comparison between the BEM results and CFD results

	BEM	CFD
Power (watt)	44.453	45.77
C_p	0.368	0.37

The pressure contour is shown in Figure 4 shows that the maximum pressure is 715.1 pa. The coupling method of the FSI modelling is based on the one- way coupling. The fluid field is solved using CFD until the convergence criteria are reached. The aerodynamic pressures on the blade obtained from CFD modelling are then mapped to the FEA model as load boundary conditions. The FEA model is use to calculated the structural responses of the blade (such as deformation and stress distributions) subjected to aerodynamic loads.

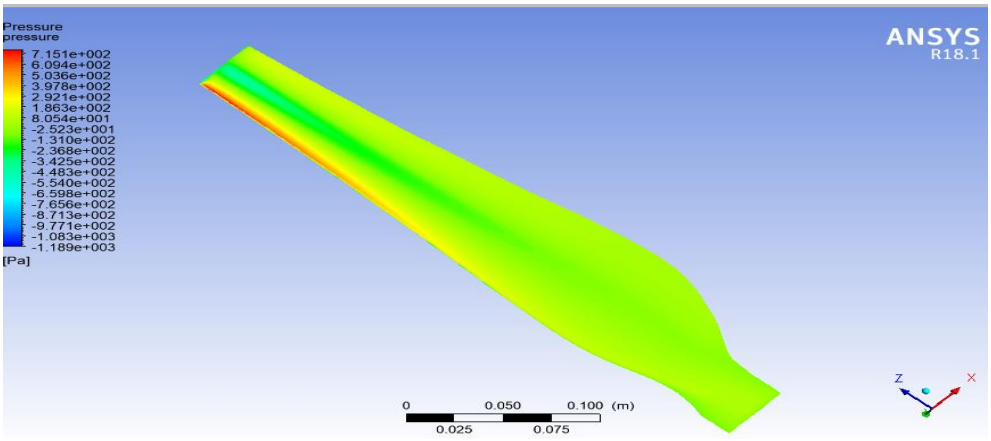


Fig.4 pressure contour

The displacement of the tip of the blade at the nominal wind speed (8 m/s) is obtained (0.12mm) as shown in figure 5 when the loads applied on one of three materials (Epoxy E-glass).

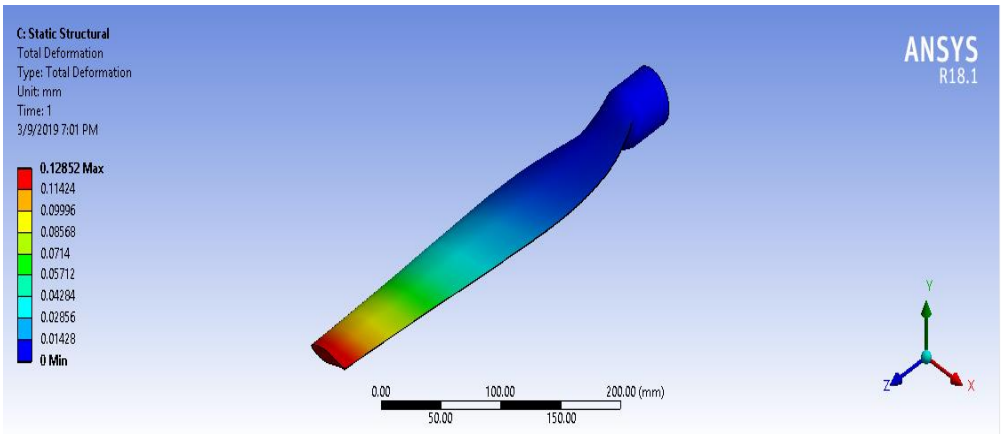


Fig.5 The displacement in (mm)

Figure 6 shows the performance of the turbine and maximum power produced at different velocities and different angular velocities.

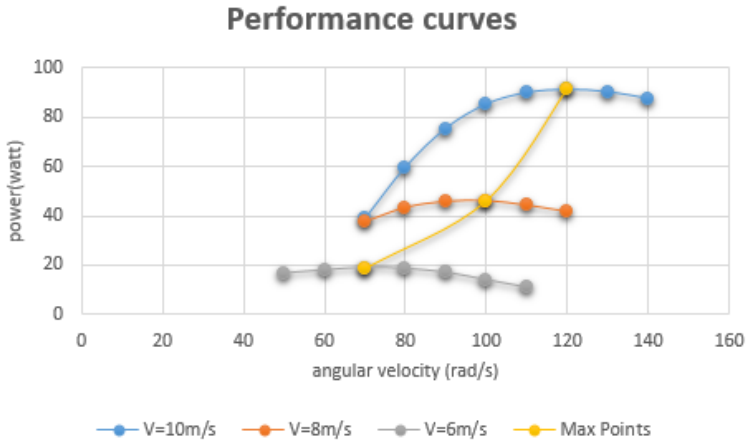


Fig.6 wind turbine performance

4-CONCLUSIONS

In this study, a FSI (fluid structure interaction) model for horizontal-axis wind turbine blade has been established by coupling CFD (computational fluid dynamics) and FEA (finite element analysis).and analysis will be done in three different materials. The study has been subdivided into two parts. Part one will study the aerodynamics and structural analysis of wind turbine without winglets. Part two will study the aerodynamics and structural analysis of wind turbine with winglets and analyses how the power produced will be effected by winglets.

5-Referances.

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