DYNAMIC ANALYSIS OF A 10M DIAMETER WIND TURBINE ROTOR UNDER MAXIMUM WIND LOAD OF MALAYSIA

SOFIAN BIN MOHD

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Universiti Teknologi Malaysia

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To my beloved family,
The lover in you who brings my dreams comes true.

To my wife, Ruhiana Idayu Abd Hamid and daughter, Nurkhaleeda
who have brought a new level of love, patience
and understanding into our lives.

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"In the name of Allah that the most Gracious, the most Merciful"

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ABSTRACT

This project describes the application of finite element analysis (FEA) in studying the strength of the design of the wind turbine rotor under the wind speed of 36 m/s. The forces and pressure produced by the mentioned speed was initially estimated using Computational Fluid Dynamic (CFD). With the forces and pressure set as a boundary loads, the stress analysis was performed using Finite Element Method (FEM). The important criteria such as the displacement and factor of safety were considered in order to produce the optimized model of the wind turbine rotor. The optimized model was defined as the model with low maximum displacement and the minimum factor of safety of 1.5. As an option for cost effective design, the studies were also performed on the wind turbine model under the 15 m/s wind speed load. The model with the thinner AE2 blade (3mm thick) was found to be sufficient for the average wind speed of 15 m/s.

ABSTRAK

Projek ini membincangkan tentang aplikasi kaedah analisa unsur terhingga untuk menganalisa kekuatan dan keteguhan rekabentuk bagi struktur kincir angin yang dikenakan beban angin dengan kelajuan 36 m/s. Daya-daya dan tekanan yang terhasil dari kelajuan angin 36 m/s ini terlebih dahulu dianggarkan dengan menggunakan kaedah dinamik bendalir berkomputer. Daya dan tekanan yang diperolehi ditetapkan sebagai beban sempadan untuk analisa tegasan yang dilakukan dengan menggunakan kaedah unsur terhingga. Daripada keputusan analisa tegasan, anjakan dan faktor keselamatan adalah kriteria penting yang perlu diambilkira dalam menghasilkan model kincir angin yang optimum. Model optimum adalah merujuk kepada model yang berupaya menghasilkan anjakan maksima yang rendah dan faktor keselamatan sekurang-kurangnya 1.5. Sebagai alternatif untuk menghasilkan rekabentuk yang berkos efektif, analisa juga dijalankan ke atas model yang dikenakan beban oleh angin yang berkelajuan lebih rendah iaitu 15 m/s. Berdasarkan keputusan analisis, model dengan bilah AE2 yang lebih nipis (3mm tebal) berupaya menampung beban angin selaju 15 meter sesaat.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

v	-	Wind speed (m/s)
λ	-	Tip speed ratio
P_m	-	Mechanical shaft power (kW)
C_p	-	Power coefficient
a	-	Angle of attack (^{o})
b	-	Setting angle (^{o})
w	-	Resultant velocity (m/s)
E	-	Kinetic energy per unit volume (J/m^3)
ρ	-	Air density (kg/m^3)
P	-	Power in wind (kW)
A	-	Rotor frontal area (m^2)
v_{ave}	-	Average wind speed (m/s)
$\sigma_{1,2,3}$	-	Principal stresses (N/m^2)
σ_y	-	Yield stress (N/m^2)
Re	-	Reynolds number
l	-	Characteristic length (m)
l_{cr}	-	Critical characteristic length (m)
μ	-	Air viscosity (kg/ms)
v_{max}	-	Maximum wind speed (m/s)
r	-	Radius of the blade (m)
u	-	Rotating speed (rpm)

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

The wind energy conversion systems (WECS) have increasingly been developed over the last 10 years. The main reason of having wind as the source of energy is due to its capability of offering the energy without negative environmental impact. Wind energy has long been recognized as a potential source of free, clean and inexhaustible energy.

In order to realize the use of wind energy as the main energy source, there are still a lot of problems that need to be solved such as the wind turbine design, site and wind resources. The major issue recognized as the main barrier to the use of wind energy was the high cost to develop the whole system of wind energy conversion. The cost reduction need to be done in order to make the wind power cost-competitive with the other power source especially for the area which experiences low wind speed.

In Malaysia the wind energy is still new and not yet being applied for any practical use. In 1988 the research group from Universiti Teknologi Malaysia has made first move to investigate the Malaysian wind resource. From the wind data provided by the Malaysian Meteorological Department, it was found that there is a potential to use wind energy for electrical power generation especially in the East Coast of Peninsular Malaysia.

In this project, the static and flow analysis (under maximum wind load of Malaysia) will be conducted on two types of blades which form a complete set of wind turbine rotor (3 pieces each). The focus of this analysis is on both hub and rotor blade sections since they are the major components of the wind rotating system. And the positioning of the wind rotor is only set as perpendicular to the wind load. The main blade is named as AE2 blade which is manufactured through the bending of the flat aluminium plate into 8 bending lines to form its thin aerofoil section. The blade has wider area at its root as compared to its tip. The blade is then twisted lengthwise through a twist angle of 5 degrees. The above mentioned features enable the blade to absorb more energy from low speed wind thus giving the better efficiency to Low Wind Speed Wind Turbine. The smaller blade is called as Starter blade that acts as a starter to initiate the rotation of the whole rotor blade system. The starter blade is fabricated by bending the flat aluminium plate into 2 bending lines. The diameters of the main and starter blades are 10m and 6m respectively which have been scaled up from the previous prototype in order to increase the power produced by the wind turbine system.

The stress analysis is performed on both blades under static and dynamic loads. Static and dynamic loads are obtained from the Computational Fluid Dynamics (CFD) simulation. The wind turbine rotor model will be optimized in order to ensure that it will satisfy the stress analysis. The optimization will be covering certain aspects such as the blade thickness, the addition of stiffener and the extra supports. This particular project also will be considering the analysis at different wind speed as a comparison study in order to permit an option for cost reduction and easy fabrication.

1.1 Objective

The objective of this project is to analyze the strength of the wind turbine rotor under the wind speed of 36 m/s. In this study, it is important to come out with the optimized design of the wind turbine rotor that could be operated safely under the specified wind load.

1.2 Scopes

The project scopes are as follow:

- Study on the wind turbine rotor including the analysis required
- Design the hub for the wind turbine system
- Perform the solid modelling of the wing turbine rotor using SolidWork 2005
- Perform the flow analysis on the wind turbine rotor using FLUENT
- Perform the stress analysis on the wind turbine rotor using COSMOSWork
- Modification and improvement of the model to produce an optimized model

CHAPTER 2

LITERATURE REVIEW

An extensive literature search in the related area was conducted. It has been done to get some idea for the project. The main sources for the literature search are books and technical papers. One of the papers that closely related to this project is written by N.M. El Chazly.

As engineering investigation revealed that many of the structural failures of wind turbines occur in the blade root section, several possible solutions have been introduced in order to deal with this type of failure. One of the most promising solutions is to do a 3D analytical modeling to compute critical parameters of the rotor blades such as the deflection, stresses, and eigenvalues. As proposed by N.M El Chazly [1], this analytical modeling can be done using a bending triangular plate finite element.

In particular, lift and drag forces are set in a steady wind conditions and they are analyzed as normal and tangential forces on the blade sections at certain angle of attack. According to his work, these forces are applied as boundary loads to the computer program in order to perform both static and dynamic analysis of the rotor blades for a symmetrical aerofoil NACA 0015 series.