ANALYSIS OF A LOCALLY MANUFACTURED VENTIS 20-100WT HAWT

By

Mahmoud Mohamed Shawky

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE
In
AEROSPACE ENGINEERING

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Title of Thesis: ANALYSIS OF A LOCALLY MANUFACTURED VENTIS 20-100WT HAWT

Key Words: Renewable energy, Wind turbine, Blade design, Composite material, unsteady loading

Summary:

The Ventis 20-100WT turbine is operated in wind farms in Hurghada. The blades were locally manufactured because of the multiple failures and lack of spare parts at the AOI. Here in this thesis, the re-designed blades are aerodynamically and structurally examined. First, the steady and unsteady aerodynamic loads are computed using BEM theory. The structural properties of the 10m composite blade are then obtained from NREL dedicated HAWT software PreComp. The steady loads are computed using NREL software and compared to a FEM, and agree reasonably well. The dynamic loads are then analyzed to determine the fatigue life and that the blades operating at frequencies other than the resonant modes. The fatigue analysis suggests that the re-designed blades have a short life about (70 month at operating RPM). Furthermore, results from an environmental study suggest that the blades life will be shorter about (52 month). In future plan we will test experimentally the manufactured blade locally to meet the design constraints requirements and try to optimize it and find a solution for isolating the material used from the environmental effect.

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Finally, I would like to present this work to my father. Also, I would like to present this thesis to my daughter Norseen.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

A	rotor area, scaling factor
a'	tangential induction factor
B	number of blades
C	damping matrix
C_p	power coefficient
C_T	thrust coefficient
C_l	lift coefficient
C_d	drag coefficient
C_m	moment coefficient
C_n	normal load coefficient
C_t	tangential load coefficient
C	chord
D	rotor diameter, drag
dA	normal vector to area
E	modulus of elasticity
EI	moment of stiffness inertia
ES	moment of stiffness
F	force (vector)
F	force, Prandtl's tip loss correction
GI	torsional stiffness
H	tower height, form factor
h	height above ground level
h_W	Weibull distribution
I	moment of inertia, turbulence intensity
K	stiffness matrix
K_t	terrain factor
L	lift, distance between two points in space
M	mass matrix
M	aerodynamic moment
M_{flap}	flapwise bending moment
M_a	Mach number
$\dot{m}$	mass flow
m	mass per length
n	rotational speed of shaft
P	momentum (vector)
P	power
PSD	power spectral density function
p	pressure, load

P_N	load normal to rotor plane
P_T	load tangential to rotor plane
P_c	centrifugal load
R_e	Reynolds number
R	rotor radius, resistance
r	radius (vector)
r	radius
T	thrust, total time
t	time
u	x-component of velocity vector, axial velocity at rotor plane, deflection
u^{1f}	flapwise eigenmode deflection first
u^{1e}	edgewise eigenmode deflection first
u^{2f}	flapwise eigenmode deflection second
V	velocity (vector)
V_o	wind speed
V_∞	velocity at infinity
V_{rel}	relative velocity to aerofoil
V_θ	tangential velocity component
V_{10min}	time averaged wind speed over a period of 10 minutes
v	angle between chord line and first principal axis
α	angle of attack
β	twist angle
θ	local pitch
θ_p	Pitch angle
μ	dynamic viscosity
υ	kinematic viscosity, wind shear component
ρ	density
σ	solidity factor, stress, standard deviation
σ_r	stress range
σ_m	mean stress
φ	flow angle
ω	angular velocity of rotor, Eigen frequency
ω_n	natural frequency

ABBREVIATIONS

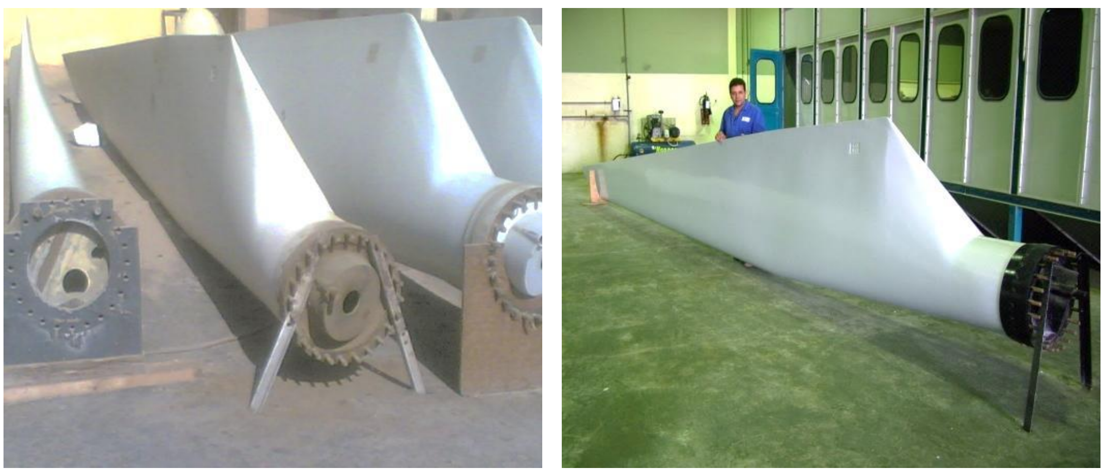
BEM	Blade Element Momentum
BModes	Blade Mode Shape Calculator
PreComp	Blade Property Extraction tool
CFD	Computational Fluid Dynamics
DP	material Division Point
FAST	Fatigue, Aerodynamics, Structures and Turbulence
FE	Finite Element
FEA	Finite Element Analysis
GUI	Graphical User Interface
HAWT	Horizontal Axis Wind Turbine
LCS	Lift Curve Slope
MCR	Matlab Compiler Runtime library
NREL	National Renewable Energy Laboratory
NuMAD	NUmerical Manufacturing and Design tool
NWTC	National Wind Technology Center
SNL	Sandia National Laboratories

ABSTRACT

The Ventis 20-100WT turbine is operated in wind farms in Hurghada. The blades were locally manufactured because of the multiple failures and lack of spare parts at the AOI. Here in this thesis, the re-designed blades are aerodynamically and structurally examined. First, the steady and unsteady aerodynamic loads are computed using BEM theory. The structural properties of the 10m composite blade are then obtained from NREL dedicated HAWT software PreComp. The steady loads are computed using NREL software and compared to a FEM, and agree reasonably well. The dynamic loads are then analyzed to determine the fatigue life and that the blades operating at frequencies other than the resonant modes. The fatigue analysis suggests that the re-designed blades have a short life about (70 months at operating RPM). Furthermore, results from an environmental study suggest that the blades life will be shorter about (52 months).In future plan we will test experimentally the locally manufactured blade to meet the design constraints requirements and try to optimize it and find a solution for isolating the material used from the environmental effect.

1 Introduction

The Ventis 20-100WT is a 100 kW wind turbine system used in wind farms in Hurghada. The system consists of a rotor drive train assembly, yaw system, tower, foundation and electrical system. Multiple failures and lack of spare blades initiated a multidisciplinary project led by the AOI to study the cause for the failure and manufacture blades locally. To this end in this thesis, a study is performed to examine the cause of failure and suggest improvements for future blades. Figure (1-1) shows the original and manufactured blade locally.



(a) ***(b)***

Figure 1-1 (a) The original blade (Ventis) and (b) The manufactured blade locally

The locally manufactured blade had some problems. First, in the analysis, the unsteady dynamic analysis was ignored for both aerodynamic and structure loads. Second, the service lifetime estimation, which is an important factor in any dynamic system, was not accounted for. Third, in the manufacturing process, the materials used were not as recommended by the design team.

Here in this thesis, the shortcomings in the analysis are examined, an estimate for the service lifetime is computed and environmental effect on the composite material are taken into account, in order to make a safe wind turbine blade designed with an accurate service life.

1.1 Statement of Purpose

The main objective of the thesis is to answer several questions that will help manufacture serviceable wind turbine blades. The three questions are:

- What is the main root cause failure of the original blades?
- Can we estimate the service lifetime of the manufactured blades?
- What is the effect of the environmental conditions on the manufactured blades?

In order to answer the first question we analyze the original blade, which is made from composite orthotropic materials, with an irregular and asymmetrical shape and extract the geometrical properties. We then determine the aerodynamic steady loads for this blade. Software tools such as Abaqus, Q-Blade, and AeroDyn are used to obtain the aerodynamic and structural loads.

In order to answer the second question we will need to make an unsteady dynamic simulation for the blade to meet the requirements of IEC 61400-1 standards[1] by using tools available such as Q-Blade, Fast, AeroDyn, SNL wind simulators, B-modes, PreComp and M-life. The dynamic loading for a turbulent wind profile is computed to determine the fatigue loading applied on the blade.

By using available data at the AOI for the environmental effect on the composite materials subjected to weather conditions, we will investigate weathering effects on our blade to know what will happen after a long period of operation for the blade. The data