AIN SHAMS UNIVERSITY

Faculty of Engineering

Mechatronics Engineering Department

Development of Wind Turbine Pitch Angle Controller

A thesis submitted in partial fulfillment of the requirements for the degree of

Master Of Science In Mechanical Engineering

(Mechatronics Engineering)

By

AbdelRahman Marzouk Ahmed Elkattan

Bachelor of Science in Mechatronics Engineering

High Institute of Engineering – 6th October City, 2008

Supervisors:

Prof. Dr. Farid A. Tolba **Prof. Dr. Zakaria Ghoneim**

Prof. Dr. Magdy M. Abdel Hameed **Dr. Aya Diab**

Cairo, Egypt - 2015

AIN SHAMS UNIVERSITY

Faculty of Engineering

Mechatronics Engineering Department

Development of Wind Turbine Pitch Angle Controller

By

AbdelRahman Marzouk Ahmed Elkattan

Bachelor of Science in Mechatronics Engineering

High Institute of Engineering – 6th October City, 2008

Examination Committee

Name and Affiliation	Signature
Prof. Dr. Farid A. Tolba Design and Production Engineering Dept. Faculty of Engineering – Ain Shams University	
Prof. Dr. Taher Abou-Elyazied Design and Production Engineering Dept. Faculty of Engineering – Ain Shams University	
Prof. Dr. Osama Ezzat Abellatif Mechanical Power Engineering Dept. Faculty of Engineering – Shoubra, Benha University	

Date: 26 December 2015

STATEMENT

This thesis is submitted in partial fulfilment of Master of Science degree in Mechanical Engineering, Faculty of Engineering, Ain Shams University.

The author carried out the work included in this thesis, and no part of this thesis has been submitted for a degree or qualification at any other university.

Signature

AbdelRahman M. Elkattan

Date: 26 December 2015

RESEARCHER PROFILE

Name:	AbdelRahman Marzouk Ahmed Elkattan
Date of birth	9 January 1987
Place of birth	Saudi Arabia
Last academic degree:	BS.c. in Mechatronics Engineering
Field of specialization	Mechatronics Engineering
University issued the degree:	High Institute of Engineering – 6th October City
Date of issued the degree:	30 July 2008
Current job:	Teaching Assistant – High Institute of Engineering

Name : AbdelRahman M. Elkattan

Signature :

THESIS SUMMARY

The world's need for energy that does not end, but is growing day after day. The renewable sources of energy come in the first priority of the world. Especially, wind energy is the best developing energy technology between the other renewable energies. Additionally, it has more benefits such as pollution free and clean. These factors made the wind energy production in continuously increasing.

So it became very important to generate more power from wind turbines while significantly reduce more loads. Thus, the control strategies are playing an important role to deal with the challenging characteristics of the wind turbines, these control models must be designed as robust as possible to do its role in different operating conditions and over a long period of time.

The main aim of our thesis is to design and simulate a pitch controller for reducing loads and maximizing the output power using FAST code developed by NREL, and Matlab/Simulink. But naturally, we should initially introduce aerodynamics and loads calculations of the horizontal axis wind turbine (HAWT).

Thesis presents two WT control models for two different machines (NREL 5 MW HAWT and NREL 1.5 MW HAWT). The control model of NREL 5 MW HAWT uses FAST to control and simulate the results of the two wind turbines operation regions (Region 2 for wind velocities below rated velocity and Region 3 for wind speeds above rated velocity). On the other side, the interfacing between FAST and MATLAB/Simulink is used to control of NREL 1.5 MW HAWT to control and simulate the results of the two wind turbine operation regions.

However, we can deduce from the simulation results of the two control models that in Region 2, which wind velocities are less than the rated value, blade pitch is kept at a certain value and generator torque control is applied to change the velocity of the turbine to sustain tip speed ratio (*TSR*) at certain value consistent to best power coefficient (C_p), therefore maximizing energy extracted. In Region 3 which wind velocities are greater than the rated value, generator torque is kept at rated torque, and blade pitch control is applied to control aerodynamic power to keep constant turbine velocity, in addition to decrease the moments on the wind turbine blades.

Keywords: Wind turbine, Control, Aerodynamics, Loads, Simulation, Power, Moments, Wind speed.

ACKNOWLEDGEMENT

I am very grateful to **ALLAH** Subhanahu Wa Ta'ala who gave me an excellent family to live with and provided me the environment where I could finish my M.Sc., without whose will it would have been impossible to complete my degree.

I would like to express my deepest thanks to **Prof. Farid A. Tolba** for his supervision and providing me with the resources I needed for work.

I would like to express my warmest gratitude to **Prof. Magdy Abdelhameed** for his continuous encouragement.

I would also like to thank **Prof. Zakaria Ghoneim** for his valuable help.

Similarly, I thank **Dr. Aya Diab** for her active contribution to refining my research work and in filling the gaps. At times, when things looked difficult, she was the one who gave me hope. She was there to listen to my concerns, review the material, provide feedback and show direction.

Thanks to my **great parents** for what they have contributed towards my different levels of education. Great advice with enthusiastic soul always make me supported. Their prayers over the years are something that I cannot thank them enough.

I am deeply indebted to great people. My wife **Nehal** for her care and daily support. My brothers **Ahmed, Amr, Mohamed**, and **Mostafa** for their encouragements. And I dedicate this thesis to my dear daughter **Pissan.**

Finally, I owe special thanks to all my colleagues **Eng. Abdelhaleim Elkhawas** and **Eng. Abeer Sabry,** and my teacher and my big brother **Dr. Sameh Farid** for many helps and encouragements.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

BEM	Blade Element Momentum Method
BldPitch1	Blade-1 Pitch Angle
CART	Controls Advanced Research Turbine
CBP SS	Collective Blade Pitch State Space
CPC	Collective Pitch Control
DFIG	Doubly Fed Induction Generator
DOF	Degree of Freedom
EMA	Exponential Moving Average
FAST	Fatigue, Aerodynamics, Structures And Turbulence
FLC	Fuzzy Logic Control
GenSpeed	Generator Speed
GenPwr	Generator Power
GenTq	Generator Torque
GH	Garrad Hassan
GL	Germanischer Lloyd
GSPI	Gain Scheduled Proportional-Integral Controller
GWEC	Global Wind Energy Council
HAWT	Horizontal Axis Wind Turbine
HorWindV	Horizontal Wind Speed
HSS	High Speed Shaft
HSShftPwr	High Speed Shaft Power
IBP	Individual Blade Pitch
IPC	Individual Pitch Control

LQG	Linear Quadratic Gaussian
LSS	Low Speed Shaft
MBC	Multi-Blade Coordinate
MIMO	Multi Input Multi Output
NREA	National Renewable Energy Authority in Egypt
NREL	National Renewable Energy Laboratory in USA
PC	Pitch Control
PI	Proportional-Integral
PID	Proportional-Integral-Derivative
PIP	Proportional-Integral-Plus
PMSG	Permanent Magnet Synchronous Generator
RootMEdg1	Blade-1 Root Edgewise Moment
RootMFlp1	Blade-1 Root Flapwise Moment
RotSpeed	Rotor Speed
RotPwr	Rotor Power
SISO	Single Input Single Output
SS	State Space
TS	Tower Shadow Effect
TSR	Tip Speed Ratio
WAMIT	Wave-Body Interaction Program
WECSs	Wind Energy Conversion Systems
WS	Wind Shear Effect
WT	Wind Turbine

LIST OF GREEK SYMBOLS

$\boldsymbol{\alpha}$	Angle of Attack [deg]
$\boldsymbol{\beta}$	Blade Pitch Angle [deg]
$\Delta\boldsymbol{\beta}$	Small Perturbation of the Blade-Pitch Angles about their Operating Point [deg]
$\boldsymbol{\beta_{opt}}$	Optimal Pitch Angle [deg]
$\boldsymbol{\zeta_{\varphi n}}$	Damping Ratio
$\boldsymbol{\lambda}$	Tip Speed Ratio (TSR)
$\boldsymbol{\lambda_{opt}}$	Optimal Tip Speed Ratio
$\boldsymbol{\mu}$	Non-Dimensional Radial Position, r/R
$\boldsymbol{\rho}$	Air Density [kg/m^3]
$\boldsymbol{\sigma}$	Rotor Solidity
$\boldsymbol{\phi}$	Flow Angle [deg]
$\boldsymbol{\psi}$	Azimuth Angle [rad]
$\boldsymbol{\omega}$	Angular Speed [rad/s]
$\boldsymbol{\omega_g}$	Generator Rotational Speed [rad/s]
$\boldsymbol{\omega_r}$	Rotor Rotational Speed [rad/s]
$\boldsymbol{\omega_{\varphi n}}$	Natural Frequency [rad/s]
$\boldsymbol{\Omega}$	Rotor Speed [rad/s]
$\boldsymbol{\Omega_2}$	Rotor Speed at Rated Torque [rad/s]
$\boldsymbol{\Omega_0}$	Rated Low-Speed Shaft Rotational Speed [rad/s]
$\boldsymbol{\Delta\Omega}$	Small Perturbation of Low-Speed Shaft Rotational Speed about the Rated Speed [rad/s]
$\boldsymbol{\Delta\dot{\Omega}}$	Low-Speed Shaft Rotational Acceleration [rad/s^2]
$\boldsymbol{\gamma}$	Cone Angle of the Rotor [rad]
$\boldsymbol{\tau}$	Tilt Angle of the Rotor [rad]

LIST OF ALPHABETIC SYMBOLS

a	Axial Flow Induction Factor
a'	Tangential Flow Induction Factor
A, A_d	Rotor Swept Area [m^2]
A_∞, A_W	Upstream and Downstream Stream-Tube Cross-Sectional Areas [m^2]
AC	The Distance from Leading Edge A to Pressure Center C [m]
b	Surface Roughness Length
B_{ls}	Low Speed Shaft Stiffness [N.m/rad]
c	Blade Chord [m]
C	Decay Constant
C_d	Sectional Drag Coefficient
C_l	Sectional Lift Coefficient
C_M	Pitching Moment Coefficient
C_n	Normal Force Coefficient
C_p	Power Coefficient
C_q	Torque Coefficient
C_T	Thrust Coefficient
C_t	Tangential Force Coefficient
F	Prandtl Loss Factor
F	Force [N]
F_x	Edgewise Force [N]
F_y	Flapwise Force [N]
$J_{Drivetrain}$	Drivetrain Inertia Cast to the Low-Speed Shaft [$kg.m^2$]