Experimental and Numerical Investigation of the Effect of Vertical Axis Wind Turbine Blade Cascading on the Dynamic Stall Phenomenon

By

Amr Ahmed Ahmed El-Feky

A Thesis Submitted to the

Faculty of Engineering at Cairo University

In Partial Fulfillment of the

Requirements for the Degree of

DOCTOR OF PHILOSOPHY

IN

AEROSPACE ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2019

Experimental and Numerical Investigation of the Effect of Vertical Axis Wind Turbine Blade Cascading on the Dynamic Stall Phenomenon

By

Amr Ahmed Ahmed El-Feky

A Thesis Submitted to the

Faculty of Engineering at Cairo University

In Partial Fulfillment of the

Requirements for the Degree of

DOCTOR OF PHILOSOPHY

IN

AEROSPACE ENGINEERING

Under the Supervision

Of

Prof. Dr. Ibrahim Mohamed Ali Shabaka
Professor, Aerospace Department

Faculty of Engineering-Cairo University

Prof. Dr. Mahdy Taha El Sayed Badawy
Professor, Mechanical Department

National Research Center, Dokki, Giza, Egypt

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2019

Experimental and Numerical Investigation of the Effect of Vertical Axis Wind Turbine Blade Cascading on the Dynamic Stall Phenomenon

By

Amr Ahmed Ahmed El-Feky

A Thesis submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
In
Aerospace Engineering

Approved by the Examining Committee:

Prof. Dr. Ibrahim Mohamed Ali Shabaka **(Thesis Main Advisor)**

Professor- Aerospace Department- Faculty of Engineering- Cairo University

Prof. Dr. Mahdy Taha Badawy **(Advisor)**

Professor- Mechanical Engineering Department- National Research Centre- Egypt

Prof. Dr. Ali Abd El Fattah Hashim **(Internal Examiner)**

Professor- Aerospace Department- Faculty of Engineering- Cairo University

Prof. Dr. Ossama EzzatAbd El-Elatif **(External Examiner)**

Mechanical Engineering Department- Faculty of Engineering- Benha University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2019

Engineer's Name: Amr Ahmed Ahmed El-Feky
Date of Birth: 25/11/1986
Nationality: Egyptian
E-mail: amr.elfeky@gmail.com
Phone: +2 01066805995
Address: NRC, El-Buhouth St., Dokki, Giza

Registration Date: 1/3/2015
Awarding Date: 2019
Degree: Doctor of Philosophy
Department: Aerospace Engineering
Supervisors:
Prof. Dr. Ibrahim Mohamed Ali shabaka
Prof. Dr. Mahdy Taha El-Sayed Badawy
(Mechanical Engineering Dept., National Research Centre)
Examiners:
Prof. Dr. Ossama Ezzat Abd El-Latif (External Examiner)
(Mechanical Engineering Dept – Faculty of Engineering- Benha University)
Prof. Dr. Ali Abd El-Fattah Hashim (Internal Examiner)
Prof. Dr. Ibrahim Mohamed Ali shabaka (Thesis Main Advisor)
Prof. Dr. Mahdy Taha El-Sayed Badawy (Advisor)
(Mechanical Engineering Dept., National Research Centre)
Title of Thesis: "Experimental and Numerical Investigation of the Effect of Vertical Axis Wind Turbine Blade Cascading on the Dynamic Stall Phenomenon"
Key Words: Lift and Drag Coefficients, Oscillating airfoil, VAWT, Dynamic Stall, NACA Airfoils.
Summary:
The study is began with a wide numerical investigation on the deep dynamic stall phenomenon of unsteady flow around oscillating NACA 0012 airfoil at low Reynolds number. The numerical work uses two experimental cases for validating the predicted hysteresis loops and flow structure. The investigation is performed by solving the Navier-Stokes equations with three turbulence models Spalart-Allmaras, kε-Realizable and kω-SST. The results show that the kω-SST is a good model for predicting the dynamic stall stages especially the detecting of leading edge vortex (LEV) and post stall shedding comparing to the experimental data. Comparison between static and dynamic situation is performed. Effects of reduced frequency and oscillation amplitude, effects of airfoil thickness and effects of wing end plates on the dynamic stall phenomenon are studied. Fifteen cascading configuration are studied under the same operating conditions including upper cascading, upper forward cascading, and lower forward cascading during oscillation motion. Comparison between the overall generated torque with azimuthal angle resulting from the CFD and DMST of VAWT models in Darrieus motion is performed including forward and backward auxiliary airfoils with specific offset distances effects. Three cases of vertical axis wind turbine are tested experimentally in static situation. The first configuration is the conventional VAWT with three straight blades. The second configuration is the same turbine in the first configuration but adding auxiliary blade parallel to the main blade at each arm with offset radial distance 0.27c with no forward or backward shifting distance. The last configuration is adding auxiliary blade parallel to the main blade at each arm with offset radial distance 0.27c and 0.5c backward offset distance. The results show that the last configuration enhances the self-starting capability by increasing the static torque four times more than the conventional configuration. In dynamic situation, the tangential force increases by increasing the inlet wind speed. The increasing in applied load cause the decreasing in the tangential faces produced by each blade. In case of the back ward cascading, significant value of the positive pitching moment is produced over the main blade and increases with increases the turbine rotation. It causes a negative load cells reading however the turbine rotate in clockwise.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

Name: Amr Ahmed Ahmed El-Feky Date: 15/4/2019

Signature: 

Dedication

To my Father’s soul, **Dr. Ahmed Ahmed El-Feky**, The greatest father and the best friend.

Acknowledgement

I would like to thank all my family, my **Father**, **Mother** and my **Brother** for their encouragement and help during this thesis. I wish for them all the best in their life.

I have greatly appreciated to my supervisor **Prof. Dr. Ibrahim Mohamed Shabaka** for his technical advices, continuous support and redirecting me in the right way during my research.

I would also like to give special thanks to my supervisor **Prof. Dr. Mahdey Taha Badawy** for his help, support and deep revise that added a lot to the value of the work in this thesis.

I would like to express my sincere gratitude to **Dr. Hany El Said Fawaz**, National Research Center; "from whom I learned how to work hard," for his support, and great help in facilitating a lot of difficulties; which faced me throughout this work.

I also would like to express my deepest appreciation to **Prof. Dr. Mohamed Ibrahim El Anwar**, National Research Center; for his valuable guidance, and advices during the course of this work.

I am also owe a heavy debt of gratitude **Prof. Dr. Mohamed Khalil** for his special help and timely support to complete this work.

I cannot express enough thanks to my committee for their continued support and encouragement: **Prof**. **Dr. Ossama Ezzat Abd Ellatif** and **Prof**. **Dr. Ali Abd El Fattah Hashim**. I offer my sincere appreciation for the learning opportunities provided by my committee.

The help and encouragement of my friend **Eng. Dyaa El Hak Nabil** is deeply appreciated.

Finally, I wish to acknowledge and express my deep gratitude to all those who helped me in presenting this work.

Table of Contents

List of Tables

List of Figures