Numerical Investigation of Partially Cascaded Horizontal Axis Wind Turbines

By

Deyaa EL-Haq Nabil Hasan EL-Shebiny

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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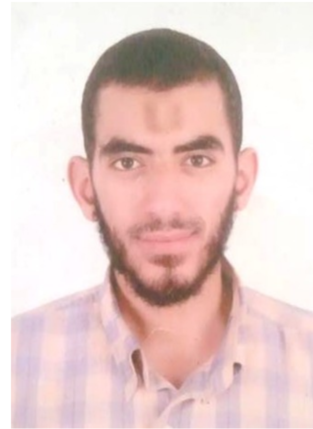

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Title of Thesis: Numerical Investigation of Partially Cascaded Horizontal Axis Wind Turbines

Key Words: - Wind Turbine, Cascaded Tip, Wind Speed, Output Power.

Summary:

The thesis objective is to evaluate numerically the performance of partial cascades at the blade tip of horizontal axis wind turbines. The numerical investigations of the flow fields around the wind turbine are done using the ANSYS FLUENT commercial package. A parametric study is performed taking in to consideration the effect of the cascade spacing, cascade length and cascade configuration on the turbine performance. The Blade Element Theory model is used to design a suitable wind turbine. The turbine is then simulated numerically and the results are compared with those obtained by the blade element method. The results show good agreement. The turbine geometry is modified by adding the partial cascades at the blade tip. A simple two dimensional cascading airfoils analysis is achieved by changing the axial and tangential spacing and the results are applied to the three dimensional HAWT project. The new configuration has a large impact on turbine power over a wide range of operating conditions.

الرَّحْمَٰنُ {1} عَلَّمَ الْقُرْآنَ {2}

خَلَقَ الْإِنْسَانَ {3} عَلَّمَهُ الْبَيَانَ {4}

الرَّحْمَٰنُ

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Finally a Cairo University Project "Design of Small Wind Turbine System for Remote sites" will be designed to produce power of 7KW that may be used for irrigation and electric generation in farms at remote sites, we ask ALLAH for helping us to continue this project.

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NOMENCLATURE

Symbols	Description	Units
a	Axial induction factor,	(-)
A	Rotor disk area,	(m^2)
AOA	Angle of attack,	(°)
$\acute{a}$	Tangential induction factor	(-)
AR	Blade aspect ratio = L_b/ c	(-)
B	Number of blades,	(-)
C	Airfoil chord length,	(m)
C_d	Drag coefficient,	(-)
C_l	Lift coefficient,	(-)
C_n	Normal force coefficient (⊥ chord),	(-)
C_t	Tangential force coefficient (// chord),	(-)
C_P	Wind rotor power coefficient,	(-)
C_T	Wind rotor thrust coefficient,	(-)
C_Q	Wind rotor torque coefficient,	(-)
D	Drag force parallel to the relative velocity vector,	(N)
h	Cascaded blade height,	(m)
L	Lift force perpendicular to the relative velocity	(N)
L_b	Wind rotor blades span length,	(m)
l/d, c_l/c_d	Lift to drag ratio,	(-)

$\dot{m}$	Mass flow rate	(Kg/s)
N	Rotational speed,	(rpm)
P_o	Atmospheric pressure	(Pa)
P	Rotor overall power,	(W)
Q	Rotor overall torque,	($N.m$)
r	The local blade radius,	(m)
R_t	The rotor tip radius,	(m)
r_H	Rotor hub radius,	(m)
Re	Airfoil chord-based Reynolds number,	(-)
$\frac{S_x}{c}$	Axial cascade space to chord ratio	( )
$\frac{S_\theta}{c}$	Tangential cascade *space to chord ratio*	( )
T	Rotor overall thrust force,	(N)
V_o	Free stream wind velocity,	(m/s)
u	Wind speed at the rotor disk location,	(m/s)
u_1	Far wake wind velocity,	(m/s)
w	Wind relative speed,	(m/s)

Greek Symbols

λ	The tip speed ratio,	(-)
ω	Rotor Rotational speed,	(-)
ρ	Air density,	(kg/m^3)
σ	Rotor solidity,	(-)

Acronyms and Abbreviations

2D	Two Dimensional.
3D	Three Dimensional.
AoA	Angle of Attack.
BEM	Blade Element Momentum Theory.
CFD	Computational Fluid Dynamics.
HAWT	Horizontal Axis Wind Turbine.
NACA	National Advisory Committee for Aeronautics.
NASA	National Aeronautics and Space Administration.
NREL	American National Renewable Energy Laboratory.
NWTC	American National Wind Technology Centre.
RPM	Revolution Per Minute.
SA	Spalart-Allmaras Turbulence model.
$TAoA_{ap}$	Approximate Blade Tip Angle of Attack.
TSR	Tip Speed Ratio.
UAE	Unsteady Aerodynamic Experiment.
VAWT	Vertical Axis Wind Turbine.
WEC	Wind energy converter.
WL	Winglet.
WPU	Wind power unit.
WT	Wind turbine.

ABSTRACT

In order to reduce wind energy cost, the output power of wind turbines should be augmented. A new concept to enhance the performance of horizontal axis wind turbine is suggested in the current study by adding partial cascades at the blade tip. The effect of fitting partial cascading tip arrangement on the performance of horizontal axis wind rotors is investigated numerically using finite volume CFD ANSYS FLUENT code. The numerical study demonstrates the resulting flow pattern of this new configuration and its effect on the turbine performance. Subsequently, several design parameters are studied -over a wide range of angle of attack- to select the optimum design of the new turbine configuration. These parameters include the axial and tangential space to chord ratios and the length of the partial cascaded tip to blade tip radius.

A simple two dimensional study on the cascaded airfoils is performed and the results of this study are applied to three dimensional horizontal axis wind turbines. Two HAWT cases are considered before and after fitting the partial cascading tip arrangement. These cases are NREL phase II wind turbine which is designed with an untapered untwisted blade and a highly tapered and highly twisted 7kW Cairo University HAWT project.

The two dimensional results indicate that the tangential force is increased as a result of the separation delay. Thus the cascade compound can be used at high angles of attack. The optimum cascade spacing for angles of attack below 17^o is different from the optimum spacing for angles of attack above 17^o because the suction side of turbine blade is affected by the pressure side of the front cascade while the pressure side of the blade is affected by the suction side of the back cascade.

The cascades are added to the horizontal axis wind turbine of NREL phase II. The results indicate that adding a cascade on the front side of the blade increases the power by 26.5%, and adding a cascade on the back side of the blade increases the power by 26.8%. Using both cascades, the power can be increased by 75% at wind speed of 13 m/s.