CFD MODELLING OF HORIZONTAL-AXIS WIND TURBINE AND SOLAR CHIMNEY PERFORMANCES FOR POWER GENERATION

By

Amr Ahmed Abd-Elhamid Mohamed

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

MECHANICAL POWER ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

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FACULTY OF ENGINEERING, CAIRO UNIVERSITY

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Title of Thesis:

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Key Words: CFD, FLUENT, CFX, Aerodynamics, blade design, blade element momentum (BEM), horizontal wind turbine (HWT), solar energy, collector, chimney, solar chimney.

Summary: The thesis objective was to discuss and simulate an alternative solution for power generation, two sustainable energy sources have been selected to be simulated and investigated, therefore this thesis will be discussing utilizing of different kind of renewable energy system, they are the wind power energy which the simulation of Horizontal axis wind turbine (HAWT) has been done, and the solar energy which the solar chimney system has been modeled as well. Both system are very valuable and suitable to Egypt weather where the sources of wind and solar are available over the year.

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I wish to express my deepest gratitude to all of my supervisors Prof. Dr. Essam E. Khalil, Dr. Amr Yehia Abdo and Dr. Omar Huzayyin for their guidance, advice, criticism, encouragements and insight throughout the research.

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NOMENCLATURE & ABBREVIATIONS

2-D, 3-D	Two-dimensional, Three-dimensional
A	Axial interference factor
A	Constants for polynomial approximation
BEM	Blade Element Momentum
C_P	Power coefficient
C	Specific heat of air (J/(kg· K))
CFD	Computational Fluid Dynamics
D, *R*	Rotor diameter, rotor radius (m)
F	Viscous damping factor
g	Acceleration due to gravity (m/s^2)
HAWT	Horizontal Axis Wind Turbine
k	Thermal conductivity of air ($W \cdot m^{-1} \cdot K^{-1}$)
L	Length of enclosure in meter (m)
MRF	Moving Reference Frame
M	Shaft mechanical moment (N. m)
Nu	Nussult number of air
Pr	Prandtl number of air
P	Shaft mechanical power (Watt)
QUICK	Quadratic Upwind Interpolation for Convective Kinetics
q	Heat flux (W/m^2)
Ra	Rayleigh number of air
RANS	Reynolds Averaged Navier-Stokes
S-A	Spalart-Allmaras (Turbulence model)
SIMPLE	Semi-Implicit Method for Pressure Lined Equations
SST	Shear Stress Transport
T	*Temperature in Kelvin (K)*
t	Time (sec)
u_i	Velocity components (m/s)

u	Velocity in x-axis (m/s)
v	Velocity in y-axis (m/s)
x,y	Coordinates along x-axis and y-axis

Greek symbols

α	Thermal diffusivity (m^2/s)
ß	Thermal coefficient of expansion
γ	Kinematic viscosity of air (m^2/s)
ρ	Density of air (kg/m^3)
µ	Dynamic viscosity of air (kg/m. s)
t	Shear stress at the wall
η	Slip coefficient
λ	Mean free path
s	Momentum accommodation coefficient

Subscripts

m	Mean
h	Hot
c	Cold
s	Slip.

Abstract

This thesis has been conducted to discuss the power generation from renewable resources, hence the energy is very important; and the demand of the energy around the world is increasing specially in our country that's why we are facing a shortage in power. Therefore this thesis has been submitted as a proposal to overcome the shortage of power that could be very useful for our country.

There are many renewable energy sources; such as wind, ocean waves, solar flux, and biomass, which offer emissions-free production of electricity and heat. This thesis has been discussed two different kind of renewable energy system, these are the wind power energy which the simulation of horizontal axis wind turbine (HAWT) has been performed, and the second is the solar energy which the solar chimney system has been modeled as well. Both system are very valuable and suitable to Egypt weather where the sources of wind and solar are available over the year.

First is about utilization of wind energy, which the aerodynamics of HAWT are investigated using CFD simulation package that has been used to solve 3-D turbulent-steady incompressible flow, using the k-ω SST turbulence models, The aim of this work is to get a better understanding of HAWT aerodynamic mechanisms governing the energy conversion process. Modeling of such system has presented many difficulties due to complex of geometry and huge size of the domain that has been used in order to simulate this kind of turbine. However many aspects have been investigated and power curve has been obtained, blade element method (BEM) used to validate the model, the two results found are highly matched together.

Second is about utilization of the solar energy; which is concerned about the overview of the main characteristics of the solar chimney power plant. It is a technology of electric power generation using solar energy by employing the principle that when air is heated it rises. The created updraft can be used to rotate a turbine placed at an appropriate position within a tall chimney to generate electricity. Discussion has been conducted of these principles and characteristics of the solar chimney, and its requirements.

The solar chimney power plant is considered as an artificial device for wind generation, it is a natural draft device which provides an upward momentum to the in-flowing air; first by converting solar energy into thermal energy in the solar collector. Second the generated thermal energy is converted into kinetic energy in the chimney and ultimately into electric energy using a combination of a wind turbine and a generator.

The technologies for the SCPP (solar chimney power plant) are very simple and reliable, therefore this technology is accessible for the less developed countries, which have limited raw material resources. Furthermore, using large scale of the solar chimney power plant will lead to higher conversion efficiency and is leading to reduction in the energy cost. The objective of this thesis is to analyses the effect of some parameters such as solar radiation, chimney height, and collector radius on the power output of solar chimney power plants. CFD model has been developed for the solar chimney power plant, the simulation package has been used to investigate the selected model.