ANALYSIS OF AN INDUSTRIAL WIND TURBINE TO HARNESS WASTE ENERGY FROM AIR-CONDITIONING CHILLERS

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Dedicated to My Beloved Parents

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ABSTRACT

In recent decades depletion of energy resources along with global warming concern has made a need to study green renewable energy resources, one of which is to reuse waste energy in industrial applications, exhaust wind from cooling towers of large scale air-conditioner is addressed in this study to be harnessed by a small Darrieus vertical axis wind turbine (VAWT). This study in particular is analyzing the performance of the turbine under the influence of some design parameters including tip speed ratio (TSR), rotor diameter, solidity that includes number of blades and effect of laminar boundary layer separation. ANSYS FLUENT 14 has been used to simulate a 2-D VAWT with NACA0018 airfoils along with ICEM as pre-processor software to create mesh, Shear Stress Transport (SST) k-ω model has been used to model the turbulent flow around the airfoils. Grid independency has been studied for cell size of 65,000 and 140,000 by the comparison of graphs for horizontal force components as a function of angle of rotation. This simulation has been validated by comparing the result with experimental work of Claessens (Claessens, 2006). Maximum power coefficient of 0.34 was obtained for 3 bladed VAWT at TSR=4 while for 6 bladed VAWT maximum amount was achieved 0.32 at lower TSR of λ=3. Power coefficient remains constant for different rotor diameter when chord length and rotor diameter ratio is constant. Performance has been observed low for laminar flow. In order to boost the efficiency in this type of flow different airfoil geometries can be investigated in further studies. Bigger number of blades causes larger effect of blockage and consequently larger torque but maximum C_p is achieved at comparatively lower value of λ as compared to 3 bladed VAWT and a great deal of torque is needed to generate the same power coefficient.

ABSTRAK

Sejak kebelakangan ini, isu pengurangan sumber tenaga dan pemanasan global memberi kebimbangan yang memerlukan kajian dalam sumber-sumber tenaga hijau yang boleh diperbaharui , antaranya adalah untuk menggunakan semula sisa tenaga ekzos angin dari penyejukan menara berskala besar penghawa dingin di mana tumpuan dalam kajian ini untuk memanfaatkan turbin angin paksi mengak kecil Darrieus (VAWT).Kajian khususnya adalah untuk menganalisa prestasi turbin di bawah pengaruh beberapa parameter reka bentuk termasuk nisbah kelajuan tip (TSR), garis pusat pemutar , kekukuhan yang melibatkan bilangan bilah dan kesan lamina lapisan sempadan pemisahan. ANSYS FLUENT 14 telah digunakan untuk simulasi 2-D VAWT dengan NACA0018 kerajang udara bersama-sama dengan ICEM sebagai perisian pra- pemprosesan untuk mewujudkan jaringan.Model Pengangkutan Tekanan Ricih k- ω (SST) telah digunakan untuk memodelkan aliran bergelorasekitar aerofoil .Pengaruh grid telah dikaji untuk saiz sel dari 65,000 dan 140,000 berdasarkan graf perbandingan untuk komponen daya mendatar sebagai fungsi sudut putaran .Simulasi ini telah disahkan dengan membandingkan hasil dengan kerja eksperimen Claessens (Claessens , 2006). Pekali kuasa maksimum 0.34 telah diperolehi bagi 3 bilah VAWT di TSR = 4 manakala bagi 6 berbilah Jumlah maksimum VAWT dicapai 0.32 di TSR lebih rendah λ = 3.Pekali kuasa kekal malar untuk garis pusat pemutaradalah berbeza apabila panjang kord dan pemutar nisbah diameter adalah ditetapkan. Prestasi yang rendah untuk aliran lamina telah diperhatikan . Dalam usaha untuk meningkatkan kecekapan dalam aliran jenis ini geometri aerofoil yang berbeza juga disiasat dalam kajian ini. Tambahan bilangan bilah menberi kesan yang lebih besar pada sumbat dan mengakibatakan tork yang lebih besar tetapi Cp maksimum dicapai pada nilai yang lebih rendah daripada λ berbanding dengan 3 bilah VAWT dan tork tinggi diperlukan untuk menjana pekali kuasa yang sama.

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LIST OF SYMBOLS

λ	Tip speed ratio
C_p	Power coefficient
U_a	Free stream wind velocity
V_{rel}	Relative speed of oncoming winds for blades
α	Angle of attack
θ_i	Initiation angle for pulsed actuation
σ	Solidity
N_b	Number of blades
c	Chord length
F_p	Pressure force on the air per unit mass
ρ	Density
$\partial P/\partial n$	Pressure gradient
F_c	Friction force on the air per unit mass
f	Coirilis parameter
ω	Angular velocity
A	Swept area
P	present power in the air
$\bar{U}$	Annual average wind speed
K_e	air energy pattern factor
$\bar{P}$	Win power density
σ_U	Wind speed average
$\bar{E}$	Wind energy density
$\bar{P}_w$	Average wind power machine
R	Rotor radius
L	Blade span
θ	Azimuthal angle
x	Position along the airfoil chord
y	Half thickness at particular position on chord line
t	Maximum thickness of airfoil

ε	Turbulence dissipation rate
k	Kinetic energy
μ	Dynamic viscosity [N-s/m^2]
T	Torque [N-m]
t	Time [sec]
Re	Reynolds number

LIST OF ABBREVIATIONS

VAWT	Vertical Axis Wind Turbine
TSR	Tip Speed Ratio
CFD	Computational Fluid Dynamics
RANS	Reynolds Average Navier Stokes
S k-ε	Standard k-ε
SST K-ω	Shear Stress Transport K-ω
CO_2	Carbon Dioxide
HAWT	Horizontal Axis Wind Turbine
NACA	National Advisory Committee for Aeronautics
SB-VAWT	Straight Bladed Vertical Axis Wind Turbine
URANS	Unsteady Reynolds Average Navier Stokes
LES	Large Eddy Simulation
PIV	Particle Image Velocimetry
RNG K-ω	Re-Normalisation Group K-ω
VATT	Vertical Axis Tidal Turbine
ZNMF	Zero Net Mass Flux
DBD	Dielectric Barrier Discharge
AC	Alternating Current
DC	Direct Current

CHAPTER 1

INTRODUCTION

1.1 Introduction

A sustainable future with limited atmospheric CO_2emissions and growing energy needs forces us to consider alternative energy sources to oil, gas and coal. The situation is more than worrying as the impact on the earth climate will be incurable without a swift move to clean energy. In 2007, the electrical power generation accounted for 29% of the atmospheric CO_2 emissions. Reducing this source will not solve the problem but can significantly contribute to its solution. None of the CO_2 free technologies that are technically mature today, or in the near future can on its own, tackle the problem. A global solution must also provide capacity to match the fluctuating demand. Therefore storage and transmission networks are also key factors. Wind power is a strong candidate towards a sustainable future: wind power with hydro power, are among the most cost effective renewable energies. For many countries, with its relatively fast development potential, wind power represents a good starting point for developing renewable energy sources, although, due to its variability, it cannot aim to be the sole electricity source for a single country.

Wind power has been commercially successful in Europe for more than a decade. European countries have more than 70 GW installed capacity with 5 top leading countries: Germany with 25,777 MW, Spain 18,320 MW, Italy 4,850 MW, France 4,492 MW and UK 4,070 MW (Deglaire, 2010). Although Europe has been the number one region when it comes to new yearly installed capacity for more than a decade, US and China are now moving ahead. In Europe offshore wind power opens a new arena for wind developments, especially in the North Sea. The world's leading manufacturers were originally situated in countries where local incentives have accelerated the installation of turbines namely Germany, Denmark and Spain. Now fast emerging markets like US, China and India have pushed strong local suppliers. The market leaders are today Vestas (Denmark) 12.5%, GE Energy (US) 12.4%, Sinovel (China) 9.2%; Enercon (Germany) 8.5%, Goldwind (China) 7.2% and Gamesa (Spain) 6.7% (Deglaire, 2010). The total market in 2009 represents around 30 GW for wind turbine manufacturers leading to a total turnover of 30 billions Euros. In terms of technology, the market is dominated by three bladed upwind horizontal axis wind turbines (HAWTs) with gearbox and asynchronous generators.

The current thesis will concern a less well known but emerging technology, the vertical axis wind turbines (VAWTs). this type of turbine is close to the surface of the ground, hence it is easy to maintenance, on the other hand the rotor blades are designed in a robust form. furthermore the need of yaw mechanism that exists in HAWTs is obviated in VAWTs, VAWTs comprise of Darrieus type and Savonius type the former operated based on lift force while the latter operates based on drag force, it is proven that the power coefficient of Darrieus type is higher than Savonius type, Darrieus turbines were introduced in 1931 by G. J. M. Darrieus and it created an interesting field for other scholars. Depending on the tip speed ration, there are two options for turbine blades, at high TSR straight bladed VAWTs are deployed to handle the problem of self-starting while turbines with helical blades are appropriate to operate at relatively smaller amount of tip speed ratio.

1.2 Background of The Problem

Today the wind turbine industry is dominated by horizontal axis wind turbines (HAWTs). The vertical axis wind turbines (VAWTs) seem to be virtually non-existent. In fact the only VAWT, which has ever been manufactured commercially at any volume, is the Darrieus machine but its manufacturer, Flo Wind, United States went bankrupt in 1997(D'Ambrosio & Medaglia, 2010). There were other small manufacturers of cylcoturbine, another variant of VAWT but these too did not perform well in the commercial wind turbine market. A lot of research work had been carried out on VAWTs, mainly Darrieus types, in the late 1970s, 1980s and early 1990s in the U.K., United States, Canada and Australia. But in terms of efficiency, the results were not very promising and inferior to HAWTs. VAWTs were, therefore, abandoned.

The last decade of the twentieth century witnessed a phenomenal growth of HAWTs both in terms of number and size throughout the world. The continuous research and design efforts led to the development of HAWTs in the MW range - 1MW, 1.3 MW, 1.5 MW, 2 MW and now 3 MW machines are appearing. Undoubtedly the HAWTs have proved a big commercial success. Their future appears to be bright with increasing worldwide emphasis on development of renewable energies.

Despite their wide use, a major disadvantage associated with the HAWTs is that these must be shut down when the wind speed exceeds a particular value known as cut-off speed. The shutting down is required from the point of view of safety of the wind turbine structures, mainly blades. For most of the HAWTs currently available on the market, the cut-off speed ranges from 20 to 25 m/s. These machines are designed to survive in wind speeds up to 60 m/s but only under shut down conditions. This limitation of the HAWTs makes them unsuitable for cyclone and storm prone areas. One is amazed by the energy contained in wind gusts. The efforts required to push the doors or windows in home against the wind thrust under stormy conditions makes one speculate if a machine could be devised to convert the energy contained in these wind gusts into useful energy. Obviously the answer does not lie in HAWTs which look for shelter for themselves to escape the wrath of the wind gusts just like human beings. This has led to the renewal of interest of researchers in VAWTs, which may bridge the gap created by HAWTs.

Efforts to improve industrial energy efficiency focus on reducing the energy consumed by the equipment used in manufacturing (e.g., boilers, furnaces, dryers, reactors, separators, motors, and pumps) or changing the processes or techniques to manufacture products. A valuable alternative approach to improving overall energy efficiency is to capture and reuse the lost or "waste wind energy" that is intrinsic to all industrial air conditioners, During these manufacturing processes, a lot of the energy consumed is ultimately lost via waste wind produced in cooling towers. Captured and reused waste wind energy is an emission-free substitute for costly purchased fuels or electricity. This study investigates industrial waste wind energy recovery practices, opportunities needed to enable further recovery of industrial waste wind energy losses. Three essential components are required for waste wind energy recovery: 1) an accessible source of waste wind, 2) a recovery technology, and 3) a use for the recovered energy. This study specifically investigates a recovery technology.

1.3 Objectives of Study

After compiling the data from literature review five goal were chosen to achieve in this study:

i) The analysis of aerodynamic performance of a Darrieus VAWT having airfoil NACA0018 by the use of 2D CFD simulation, at unsteady flow with Reynolds number of 10^6.

ii) This study seeks the maximum power coefficient for blades with NACA0018 airfoil by investigating optimum tip speed ratio TSR in which this maximum power is achieved through simulating the case in different tip speed ratios.

iii) To find out the effect of rotor diameter on the power coefficient of Darrieus VAWT.

iv) To investigate the influence of separation of laminar boundary layer on the aerodynamic performance of a VAWT by comparing the findings of turbulence model and laminar viscous model.

v) To study the influence of solidity on the aerodynamic performance of Darrieus VAWT by comparing the results for turbine with three bladed VAWT and six bladed VAWT.

1.4 Scope of the Study

This work presents a numerical analysis with the idea of obtain the suitable design that permits to have the blades in their best performance in order to obtain the largest work done for the incoming wind. The principal idea is to have the blades in a perpendicular position with the incoming wind direction. The case of study is considered oncoming wind exhausted from a large scale industrial air conditioner cooling tower, Characteristics of the wind produced by these cooling towers are taken into account so as to design the suitable Darrieus VAWT Thus, the largest work obtained by the turbine was the result of integrating the Moment of the turbine for each tip speed ration (TSR). By using computational fluid dynamic tools, this numerical analysis was made for different TSR values, plotting the Moment that can be generated.

As it has been said this study focus on the Darrieus type of VAWTs and this aim is achieved by the means of literature review and CFD study of aerodynamic performance and power coefficient. In literature review an investigation has been carried out to find out the different advantages and disadvantages of different types of Darrieus turbine such as Straight-bladed VAWT (SB-VAWT) and helix Darrieus VAWT to harness the wind energy, Figure 1.1 and Figure 1.2 show SB-VAWT and helix VAWT respectively. As it can be seen from the figures, straight bladed VAWT includes simple blades that are made without curvature. In this type of blades all extent of the leading edge of each blades experiences an identical angle of attack while in helix configuration blades have an inclination angle and are not straight. The latter type of turbines requires more complex fabrication process due to helix blades.

Figure 1.1 Straight-Bladed VAWT (Travis Justin Carrigan, 2010)

Figure 1.2 Helix VAWT (Rodriguez, 2010)

The effect of utilization of different actuator systems on the improvement of performance of these turbines and possibility of removing the effects of dynamic stall have been studied, in the last parts of literature review general characteristics of wind resources, wind data analysis and resource estimation and wind measurement and instrumentation are respectively addressed. ICEM software is used for mesh generation and pre-processing and subsequently ANSYS FLUENT 14 has been used as solver software for post processing.

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