ANALYSIS AND ASSESSMENT OF A SMALL CAPACITY HORIZONTAL AXIS WIND TURBINE: COMOROS ISLAND CASE STUDY

BY

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A thesis submitted in fulfilment of the requirement for the degree of Master of Science (Mechanical Engineering)

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ABSTRACT

The use of renewable resources is growing since fossil fuels have already been exhausted and they will last only for a few years to come. Wind power is one form of renewable energy that can be harnessed using wind turbines. Many improvements in the design of wind turbines are continuously increasing, and still, a lot must be made. The primary objective of this project is to conduct a performance analysis (power coefficient, Reynolds number, turbulent level) with different airfoils for a small capacity horizontal axis wind turbine. Computational Fluid Dynamics (CFD) is adopted as a method of analysis. However, CFD procedures are hardware intensive and computationally expensive. Furthermore, freely available simple tools called QBlade is computationally inexpensive, and it can be used for performance and design analyses of horizontal and vertical axis wind turbines. In the present research, an effort has been made to use QBlade for performance analysis of a small capacity horizontal axis wind turbine using selected prospective airfoils. In this study, four airfoils (namely, NACA 4412, SG6043, SD7062 and S833) have been selected and investigated in QBlade at different Reynolds numbers, and different tip speed ratio. Overall, it has been found that the power coefficient values of NACA 4412 at different tip speed ratios are higher compared to the other three airfoils. However, in terms of lift and drag, SG6043 showing the highest lift coefficient compared to the other airfoils. The wind resource in Comoros altered through the year with a wind speed of 4 m/s to 5.5 m/s. Based on the performance analysis from QBlade, NACA4412 was selected to design a small capacity horizontal axis wind turbine. The range of power generated from our wind turbine is 0.5 kW at 3 m/s to 1.2 kW at 6 m/s. with this wind condition a small size of a wind turbine is suitable to satisfy the project of the design and analysis of low capacity horizontal axis wind turbine at any location. Moreover, the design of small capacity horizontal axis wind turbines will be helpful to maintain stable electricity which is still one of the problems facing Comoros Island.

خلاصة البحث

يتزايد استخدام الموارد المتجددة لأن الوقود الأحفوري قد استنفد بالفعل وسيستمر استخدامه لبضع سنوات مقبلة. طاقة الرياح هي أحد أشكال الطاقة المتجددة التي يمكن تسخيرها باستخدام توربينات الرياح. العديد من التحسينات في تصميم توربينات الرياح تتزايد باستمرار ، ومع ذلك ، يجب عمل الكثير. الهدف الأساسي من هذا المشروع هو إجراء تحليل للأداء (معامل القدرة ، رقم رينولدز ، المستوى المضطرب) مع جنيحات هواء مختلفة لتوربينات الرياح ذات المحور الأفقي ذات السعة الصغير و اعتماد علي ديناميات الموائع الحسابية كطريقة للتحليل. ومع ذلك ، فإن فإن إجراءات العقود مقابل الفروقات كثيفة الأجهزة ومكلفة حسابياً. علاوة على ذلك ، فإن الأدوات البسيطة المتوفرة مجانًا والتي تسمى Blade غير مكلفة من الناحية الحسابية ، ويمكن استخدامها لتحليل الأداء والتصميم لتوربينات الرياح المحور الأفقي والرأسي. في هذا البحث ، بُذل جهد لاستخدام QBlade لتحليل أداء توربينات الرياح الأفقية ذات السعة و القدرة الصغيرة باستخدام مجموعة من المحتملين. في هذه الدراسة ، تم اختيار أربعة جنيحات) وهي NACA 4412و SG6043 و SD7062 و (S833 وتم التحقيق فيها في QBlade بأرقام رينولدز مختلفة ، ونسبة سرعة طرف مختلفة. بشكل عام ، فقد وجد أن قيم معامل القدرة NACA 4412 بنسب مختلفة لسرعة الحافة أعلى مقارنة بالثلاثيات الأخرى. ومع ذلك ، من حيث الرفع والسحب ، تُظهر SG6043 أعلى معامل رفع مقارنةً بأنواع الهواء الأخرى. تغيرت موارد الرياح في جزر القمر خلال العام بسرعة رياح تتراوح بين 4 م / ث إلى 5.5 م / ث. بناءً على تحليل الأداء من QBlade ، تم اختيار NACA4412 لتصميم توربينات الرياح المحور الأفقي ذات السعة الصغيرة. يتراوح نطاق الطاقة المولدة من توربينات الرياح لدينا 0.5 كيلوواط عند 3 م / ث إلى 1.2 كيلوواط عند 6 م / ث. مع هذه الحالة من الرياح ، يكون حجم التوربينات الهوائية الصغيرة مناسبًا لإرضاء مشروع تصميم وتحليل التوربينات الهوائية ذات المحور الأفقي منخفضة السعة في أي مكان. علاوة على ذلك ، فإن تصميم توربينات الرياح ذات المحور الأفقي ذات السعة الصغيرة سيساعد في الحفاظ على الكهرباء المستقرة التي لا تزال واحدة من المشاكل التي تواجه جزيرة جزر القمر.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion; it conforms to acceptable standards of scholarly presentation and is entirely adequate, in scope and quality, as a thesis for the degree of Master of Science (Mechanical Engineering).

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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Signature .... Date ....

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Signature Date

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In the Name of Allah, the Most Compassionate, the Most Merciful

Allah - beginning with the name of - the Most Gracious, the Most Merciful Most Auspicious is he in whose control is the entire kingship; and he is able to do all things [67:1]. All Praise to Allah, the Lord of the creation, and countless blessings and peace upon our Master Mohammed, the leader of the Prophets.

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LIST OF SYMBOLS

λ	Tip Speed Ratio
V_∞	Free Steam Velocity
ρ_∞	Free Steam Density
ω	Angular Velocity
R	Rotor Radius
φ	Inflow Angle
σ	Rotor Solidity
a and a'	Axial induction factor and radial induction factors
α	Angle of Attach
R_e	Reynold's Number
C_P	Power Coefficient
C_L	coefficient of lift
C_D	Coefficient of drag
C_t	Torque Coefficient
C	Chord Line
B	Number of Blades
λ	Tip Speed Ratio
V_∞	Free Steam Velocity
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V_∞	Free Steam Velocity
ρ_∞	Free Steam Density
ω	Angular Velocity
R	Rotor Radius

LIST OF ABBREVIATIONS

HAWT	Horizontal Axis Wind Turbine
VAWT	Vertical Axis Wind Turbine
TSR	Tip Speed Ratio
BEM	Blade Element Momentum
GUI	Graphics User Interface
RPM	Revolution Per Minute
AOA	Angle of Attack
NACA	National Advisory Committee for Aeronautics

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

This chapter covers the introduction, research background, problem statement, and objectives of the current research. First, an introduction covering a brief overview of the topic is presented and followed by the research problem. At this point, the scope of the research is briefly clarified. With a specific end goal to answer the problem statement, objectives are laid down. Finally, the outline of the thesis is presented.

1.2 INTRODUCTION

Wind energy has been considered as one of the prominent renewable energy sources which can be exploited with lower emissions with energy production and has minimal impact on biodiversity (Bhuiyan et al., 2011). Also, it does not contribute to increased toxins in our environment (Islam et al., 2011). The main offenders obstructing the sustainable development of wind energy are the conventional fossil fuel and nuclear energy technologies that are accompanied by environmental degradation at regional, local and global levels, that threatens human well-being at present and as well as future (Islam et al., 2011). This degradation threatens human health and quality of life in the short term and affects ecological balance and biological diversity in the long term. On the other hand, wind energy utilized from the natural ecosystem is environmentally inexhaustible. Due to increasing efforts by the global communities to combat greenhouse gas emissions from conventional fossil fuel technologies, wind energy technologies will be playing a progressively more significant role in the coming years, and its different applications are expected to promote sustainable development (Zhu et al., 2016).

The present research aims to investigate the ways by which small wind turbines can be designed and built for Comoros Island. A wind turbine mechanism principle is simple. The wind energy turns two or three propeller-like blades around a rotor for harnessing energy. Usually, the rotor is connected to the main shaft, which rotates a generator to create electricity. Wind turbines are fixed on a tower to capture most of the wind energy. At 10 meters or more above the ground, they can take advantage of faster and less turbulent wind (David, 2011), which may be used in the production of electricity for a single home or building. They can also be connected to an electricity grid for more widespread electricity distribution.

Comoros Island is an archipelago situated in the tropical waters of the Indian Ocean between the eastern coast of Africa and Madagascar. The map of Comoros Island is shown in Figure 1.1. When the north-west monsoon prevails, the island has the weather of rainy and hot season from December to April and when the south-east trade winds blow, a relatively cool and dry season from May to November. The average daily temperature goes from around 27 °C in the warmest period (January to April), to about 23 °C in the coldest months from July to September. The average speed of the wind is 7 m/s from Northwest and 6 m/s in the East with a pressure of 1.016 bar and average humidity of 74% at 23°C dew point (Atlas wind data Comoros Island).

Figure 1.1 Map of Comoros Island

1.3 RESEARCH BACKGROUND

The use of energy resources has been taken as one of the keys to the development of human civilization. Nowadays one of the major challenges is to find out a reliable energy source. Conventional energy sources such as natural gas, coal, and fossil fuel have enhanced industrialization and modernization of different nations. However, the consternation around the world is that the emission of carbon dioxide into the atmosphere produced due to these traditional sources are the number which offender climate change. This modification has a massive impact on the environment such as inscribable pollution, flooding, dreadnought, the rise in sea levels, high temperature, etc.

Moreover, the rise in ocean temperature and the acidity levels cause significant changes to the natural system changes at violent be committing to finding out the solution of alternative energy resources besides the conventional sources. For this scenario, renewable and installable energy are getting attention in current years. However, one of the most significant difficulties in this century is to produce adequate and clean energy. The expansion in the world population and the persistent economic growth in many countries require more access to energy. Renewable and sustainable energy is gradually gaining interest in recent research due to the considerations on the depleting nature of non-renewable resources and the availability of renewable energy resources.

Similar to any nation, it is necessary for Comoros Island to pursue solutions in renewable energy resources with current technologies and low cost in maintenance and operation such as solar, wind, and biofuel, hydro which have shown to be a feasible alternative source of energy to other renewable sources of energy. Nowadays, Wind energy is one of the critical sources of electric power generation. Among all the renewable energy sources, wind energy, being easily accessible, environment-friendly, and being cost-effective, can be one of the favorite growing renewable energy sources of electricity generation. Wind power is considered as the most significant and never-ending potential resource. However, wind turbine technology can be utilized as the main key by such type of renewable energy source.

1.4 PROBLEM STATEMENT

Comoros Island is a small country situated on the coast of East Africa. It is currently battling with the generation of a stable supply of electricity. Petroleum remains the only alternative to the electrical power supply because as a country, it has neither oil nor gas production. Its neighboring countries like Tanzania, Mozambique and Reunion Island are significant exporters of oil and gas to Comoros Island. Apart from wind and solar sources, Comoros Island doesn’t have any other renewable energy. The need for wind turbines in Comoros Island is very high for different applications such as telecom towers, rural schools, clinics, industry and in the hospital. As a result, petroleum is very expensive and difficult to obtain. As such, a need to look for alternative forms of energy arises. Under this scenario, the present research aims to develop an alternate source of power generation from wind turbines to satisfy this great need of its inhabitants. Wind turbines work on a simple Principe which is converting the wind's kinetic energy into electrical energy. The use of wind turbines is now becoming an important source of renewable energy by making use of vertical and horizontal axis types. The performance of a horizontal axis wind turbine (HAWT) can be identified by using the QBlade software as a performance evaluation tool. Tangler and Wind, (2002) explained that the Blade Element Momentum (BEM) underestimates the overall performance of a turbine and overestimates the maximum power. Besides, with QBlade computational technique, it is possible to both reduce the amount of time and compare the activities of rotor designs to others (David Marten and Wendler, 2013).

1.5 RESEARCH OBJECTIVES

To evaluate the design and analysis of a small capacity horizontal axis wind turbines (HAWT), the objectives of this research are:

- To assess wind turbine performance for Comoros Island wind condition.
- To conduct a performance analysis (power coefficient, Reynolds number, and turbulent level) for different airfoils (NACA4412, S833, SD7062 and SG6043) for a small capacity HAWT using QBlade Software.
- To design a blade of HAWT with the best performance airfoil found in objective 2.

1.6 AIRFOIL SELECTION

Airfoil selection is an important part to determine the best performance due to the objective respectively. According to National Renewable Energy Laboratory (NREL), families' airfoil is used explicitly for the designer of HAWT (NACA0012, NACA4412, SG6040, SG6041, SG6043, SD7032, S833, etc.) since they exhibit a high lift coefficient C_L which is relative to the roughness effects, they address the need of stall regulator and variable pitch. There are a few airfoils that were used for the designing of a small wind turbine from 1991 until 2010 and the most used was SD6043 which developed by (Duquette and Visser, 2015). According to Duquette and Visser (2003), they have tested a 1 m of the radius of the rotor blade and varied the number of blades to investigate the effects of solidity on the power coefficient.

1.7 QBLADE SOFTWARE

QBlade software (Figure 1.2) is especially adequate to design and give performance simulation capabilities for HAWT and VAWT rotor design and show the fundamental relationship concepts and turbine performance easily and intuitively. It is also an open-source wind turbine software for calculation, distributed under the General Public License (GPL).

The one main advantage QBlade has over other software such as Fluent, Star ccm, etc. is the low computational cost required to run each simulation (rotor, blade, airfoil, etc.).

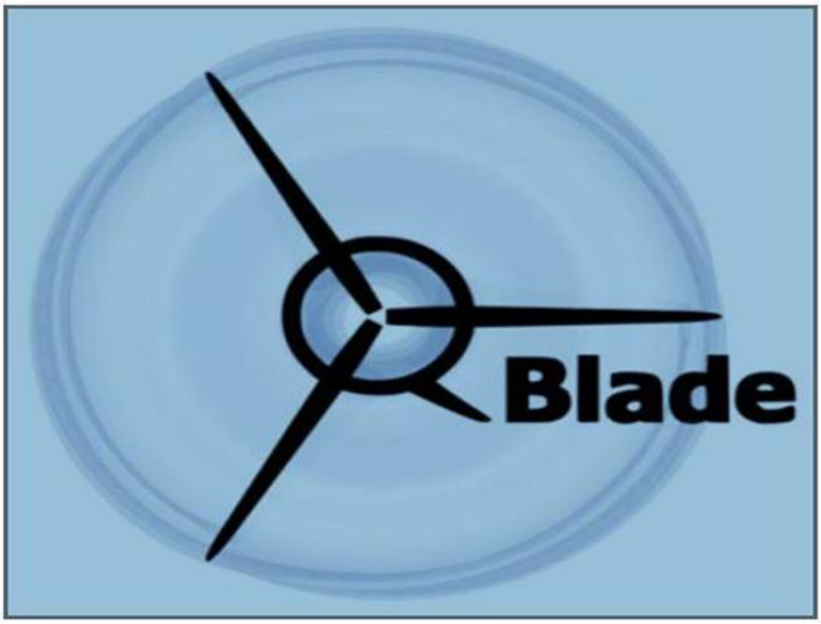

Figure 1.2 Interface of QBlade software.

1.8 THESIS OUTLINE

In this thesis, simulation and experimental investigations are performed to assess the design and the analysis of a small capacity horizontal axis wind turbine. The overall scopes of the study will be shown in Figure 1.3 and are mainly described below:

In Chapter 1, the general introduction about wind energy utilization with a unique accent on HAWT is discussed. Also, the objectives and scopes of the research are mentioned earlier. Chapter 2 aerodynamic analysis of a small capacity horizontal axis wind turbine HAWT has been explained. Different types of wind turbines and the choice of the airfoils suitable for HAWT. The use of new computational tools for HAWT which is called QBlade. Also, the current electricity market in Comoros Island is described. Chapter 3 presents the main point of this research which is the performance analysis of a small capacity horizontal axis wind turbine using QBlade. After the performance, the design of the wind turbine will be performed in this section. Chapter 4 describes the analysis of different results from the QBlade and comparison will be shown with the experimental result from (Anderson, Milborrow, and JN, 1982). Chapter 5 contains the outcomes of this project with significant contributions and short shortcomings it is provided some recommendations for the future work in Comoros Island and Elsewhere.

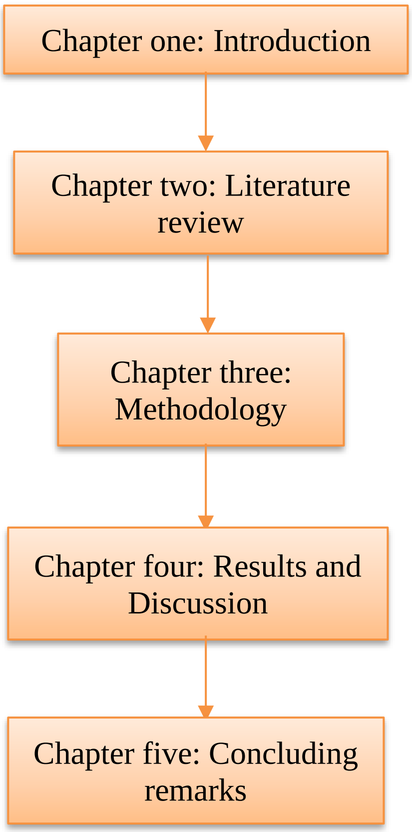

Figure 1.3 Thesis organization flow chart

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter highlights a brief background about the wind turbine, CFD and their importance, followed by a look at the different applications of the CFD. The next two sections present a review of the application of the HAWT and VAWT. After that, a review of the Comoros Islands and weather conditions. Finally, the last section explores a critical literature review and observations.

Wind energy acts a significant role in the domain of electricity production. The use of wind turbines to supply electricity has overgrown in the last decade (Gitano-Briggs, 2012). Wind is becoming more often the power technology of choice as utilities, energy planners and national governments seek to diversify their energy mix, reduce CO2 emissions and air pollution, protect their economies from macroeconomic shocks associated with volatile fossil fuel prices, and to build new industries with the investment and employment opportunities that come as part of the package (Gitano-Briggs, 2012). Recently, many studies on small capacity Horizontal Axis Wind Turbine (HAWT) are concentrated on the developments in the fields of aerodynamics and mechanical/electrical engineering. The optimal Horizontal Axis Wind Turbine (HAWT) blade design and the performance analysis is characterized as a part of aerodynamics in that they are intensively analyzed by using the blade element momentum.

The wind turbine system is defined in two fundamental purposes which are to convert the kinetic energy of the moving air into mechanical energy and the electrical energy with the application of an electrical generator. Wind turbines come in many