PERFORMANCE OF IMPROVED SAVONIUS VERTICAL AXIS MARINE CURRENT TURBINE ROTOR DESIGN

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I humbly dedicate this pearl of my effort to…

my beloved parents,

Ramli bin Sihes & Badariah binti Abdul Hamid

and my family

who have supported me in many ways.

ALLAH bless all of us

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ABSTRACT

Renewable energy resources are being explored as a respond to the diminishing fuel and fossil energy. One form of renewable energy is ocean current which requires horizontal and vertical axis turbines for its energy extraction. Savonius turbine is a vertical axis marine current turbine that has been found to suit the application in shallow water and low current speed of Malaysian seas. This turbine however has a very low mechanical efficiency. The purpose of this research is to improve the performance of the turbine. This research starts with a comparison of initial simulation data with previous work so that further simulation steps are reliable. The analysis was carried out using Computational Fluid Dynamic (CFD) ANSYS software. With its dimension limited to Malaysia sea characteristics and other consideration, a 1.67m height turbine was used for simulation and model construction for experiment. Parametric studies were carried out during the simulation steps focussing on the outer structure optimization of a plate or guide vane. The conventional shape of two stage Savonius rotor with overlap ratio of 0.21 and 90° phase angle difference was used. The effect of water speed to the incoming turbine was investigated. The used of a duct shows an improvement on the water speed, but it has very small effect to the rotor efficiency. However, the used of a plate at certain angle and distance from the turbine increase the rotor performance. It was also shown two plates are better than one, leading to a 25.6 percent increase of efficiency. For validation purpose, a 1:2.4 scale model was constructed from composite material and tested in Universiti Teknologi Malaysia Marine Technology Centre. This experimental work is to validate the simulation results of the two deflectors. The pattern of improvement is similar between numerical and experimental, although the quantitative differences of Coefficient of Performance range from 4 to 30%. This is sufficient to validate that the results of this project are acceptable, hence the Savonius rotor have been significantly improved.

ABSTRAK

Sumber tenaga boleh diperbaharui dikaji berpunca dari bahan api dan tenaga fosil yang semakin berkurang. Salah satu bentuk tenaga boleh diperbaharui adalah arus lautan yang memerlukan turbin paksi mendatar dan menegak untuk mengekstrak tenaganya. Turbin Savonius adalah turbin paksi menegak marin yang didapati sesuai dipasang pada kelajuan air yang rendah dan perairan Malaysia yang cetek. Turbin ini bagaimanapun mempunyai kecekapan mekanikal yang sangat rendah. Tujuan kajian adalah untuk meningkatkan prestasi turbin. Kajian bermula dengan perbandingan data awal simulasi dengan kerja sebelumnya supaya simulasi selanjutnya boleh dikira tepat. Analisis dijalankan menggunakan perisian Computational Fluid Dynamic (CFD) ANSYS. Dengan dimensinya terhad pada ciri-ciri laut Malaysia dan pertimbangan lain, turbin setinggi 1.67m digunakan untuk simulasi dan pembinaan model untuk ujikaji. Kajian parametrik dibuat dalam simulasi dengan tumpuan diberi kepada penambahbaikan struktur luar plat. Bentuk konvensional dua peringkat Savonius dengan nisbah pertindihan 0.21 dan 90 ° sudut fasa perbezaan bagi setiap peringkat digunakan. Kesan kelajuan air pada kemasukan turbin dikaji. Penggunaan 'Duct' menunjukkan peningkatan pada kelajuan air, tetapi kesan yang sangat kecil pada kecekapan. Bagaimanapun, plat pada sudut dan jarak tertentu dari turbin, meningkatkan prestasi pemutar. Dua plat adalah lebih baik daripada satu, membawa pada peningkatan 25.6 peratus daripada kecekapan. Untuk kerja-kerja pengesahan 1:2.4 skala model telah dibina daripada bahan komposit gentian kaca dan diuji di Pusat Teknologi Marin, Universiti Teknologi Malaysia. Kerja-kerja ujikaji adalah untuk mengesahkan keputusan simulasi bagi dua plat. Corak peningkatan adalah sama antara berangka dan simulasi walaupun dari sudut perbezaan kuantitatif pekali prestasi adalah antara 4 hingga 30%. Ini adalah memadai untuk mengesahkan bahawa hasil projek boleh diterima, dengan menyimpulkan yang turbin Savonius telah meningkat kecekapannya.

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LIST OF SYMBOLS

A_s	-	Swept area
C_p	-	Coefficient of Performance
C_t	-	Coefficient of Torque
d	-	Diameter of bucket or paddle
D	-	Diameter of rotor
D_{cyl}	-	Cylinder diameter
D_m	-	Model diameter of rotor
D_{noz}	-	Nozzle diameter
D_p	-	Prototype diameter of rotor
e	-	Overlap between the paddle
e'	-	Gap ratio
F	-	Force
F_n	-	Froude number
g	-	Gravity
H	-	Height of rotor
H_m	-	Model height of rotor
H_p	-	Prototype height of rotor
L_{cyl}	-	Cylinder length
L_m	-	Model length
L_p	-	Prototype length
L_{noz}	-	Nozzle length
m	-	Model
N	-	Newton
P	-	Output power
p	-	Prototype
R	-	Radius of the rotor
t	-	time

T	-	Torque
U	-	Water current speed
V	-	Current velocity
V_m	-	Model current velocity
V_p	-	Prototype current velocity
W	-	Relative velocity
X	-	Deflector length from Y axis
Y	-	Deflector length from X axis
Z	-	Second deflector length
α	-	Aspect ratio
β	-	Overlap ratio
ϕ	-	Shield angle
γ	-	Scale factor
φ	-	Blade twist angle
λ	-	Tip Speed Ratio
θ	-	Phase difference
θ_1	-	Angle of deflector one
θ_2	-	Angle of deflector two
ρ	-	Water density
ω	-	Angular velocity

LIST OF ABBREVIATIONS

2D	-	Two dimensional
3D	-	Three dimensional
CAD	-	Computational Aided Design
CFD	-	Computational Fluid Dynamic
HAMCT	-	Horizontal Axis Marine Current Turbine
MTC	-	Marine Technology Centre
NACA	-	National Advisory Committee for Aeronautics
RANS	-	Reynolds-Averaged Navier-Stokes
RPM	-	Revolution per minute
SG	-	Specific gravity
SIMPLE	-	Semi-Implicit Method for Pressure-Linked Equations
TSR	-	Tip Speed Ratio
UTM	-	Universiti Teknologi Malaysia
VAMCT	-	Vertical Axis Marine Current Turbine

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CHAPTER 1

INTRODUCTION

1.1 Background

Conventional energy such as coal, oil and natural gas is proven very efficient and productive. This energy however gives a bad effect and damaging the environment and human health (Herzog *et al*., 2001). Furthermore, the energy may run out after another years of exploration. As an option, renewable energy sources such as solar energy, wind energy, biomass, geothermal and water energy recently developed over these years. Renewable energy is a new field of exploration that seems promising as the energy will continuously been produced. As matter of fact it is very environment friendly which helps to conserve the eco system of a population. Renewable energy is easy to find and utilized. The only problem lies in the technology of the energy extraction itself. Most of the renewable energy extraction technology is in development level. The applications were also built in small scale production.

Despite on technology development, another form of renewable energy which is still new is ocean energy. Since the world is formed by 2/3 of water or ocean, there is a lot of possible exploitable area. Ocean energy produces several types of energy such as wave energy, tidal energy, ocean thermal energy and salinity gradient energy. These energies that came from ocean are beneficial to organization if effectively utilized. Wave energy is captured by devices that are stationary or move up and down with the frequency of waves. For ocean thermal it depends on the differences occurred between ocean temperatures. While the salinity difference located at the meeting place between ocean and fresh water. Lastly, tidal energy generally came from the gravitational pull of the moon and sun. Tidal current moves in two directions and reverses four times per day. Figure 1.1 shows the potential area location of tidal ocean energy extraction globally. From figure, Asian region specifically Malaysia seas suffer from a low tidal energy generation. At some period of time, tidal current in Malaysia is at its highest with average differences between low and high tide is between 2.5 to 3.0 meters (Yaakob *et al*., 2006). Both peninsular and east Malaysia is surrounded by ocean and it will be such a waste if this natural source of energy is left untapped without any usage. Since this source is predictable and high intense, it has a great potential to be explored on a large scale (Akwensivie, 2004). These advantages have given it the priority to be selected and developed in Malaysia as a new energy source.

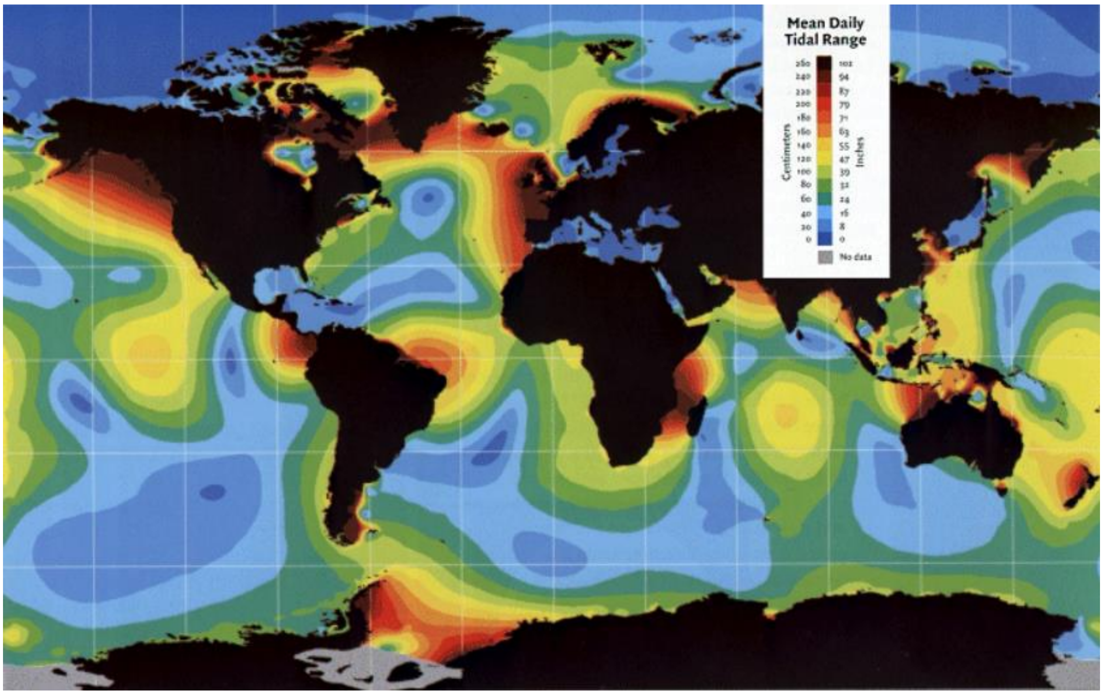

Figure 1.1 Global distribution of mean tidal range courtesy (NREL, 2009)

Marine current turbine is a device used to extract this tidal energy. As mentioned before, this is a new area of interest. Most of the turbines built and developed were used in wind turbine application. Later, these turbines are implemented in water or ocean. Since the density of water is 816 times bigger than air density, power produce by water is bigger. The size for turbine under water also can be reduced because of the large density differences. Fluid current turbines can be classified according to the orientation of the rotating axis. A horizontal axis turbine is an axial flow rotor which is favoured generally for wind turbines application. The cross flow rotor or vertical axis turbines are either of drag or lift designs. Another alternative, the reciprocating device has also been developed. In marine application, horizontal axis turbine is called horizontal axis marine current turbine (HAMCT) while vertical axis turbine is VAMCT. Figure 1.2 shows the performance of existing horizontal and vertical axis turbines for wind application (Akwa *et al*., 2012). Since the performance coefficient Cp is dimensionless, the value can be taken for further analyses and comparison purposes.

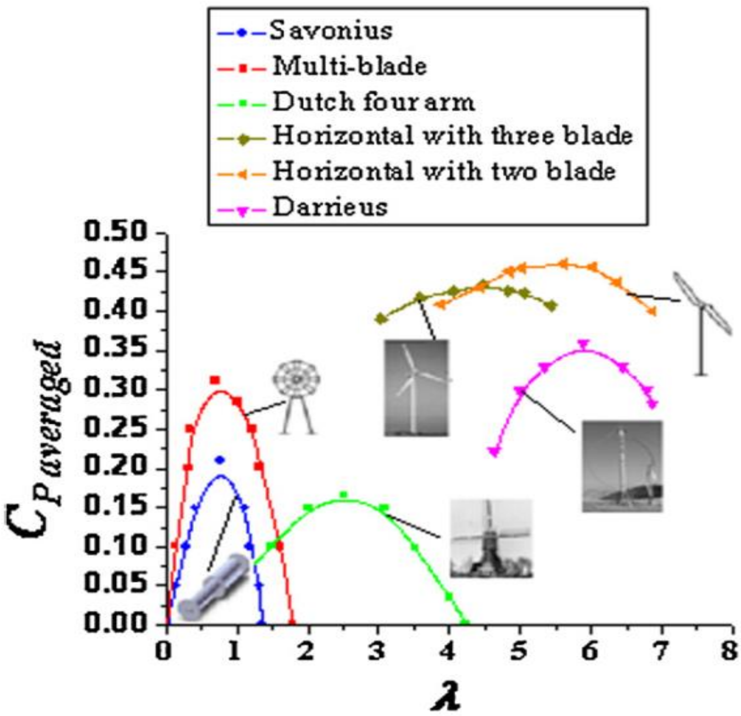

Figure 1.2 Characteristic curves of Cp averaged as a function of tip speed ratio (TSR), λ for various wind turbines (Akwa *et al*., 2012)

Figure 1.2 shows several Cp of horizontal and vertical types of turbine that existed in wind turbine application. From figure, horizontal axis turbines indicate the highest performance forming a range of 0.3 to 0.45 Cp. There are only two vertical turbines presented in the figure, Savonius and Darrieus with both having 0.18 and 0.35 of highest efficiencies respectively. Darrieus turbine utilized high tip speed ratio, λ for maintaining its maximum performance while Savonius at lower TSR value of 0.7. From water turbine application point of view, the efficiency of vertical axis turbine depends on its current speed and water depth. For the turbine to work the ideal current speed is at least 2 m/s (4 knots) obtained from prototypes that have been developed and tested by other researchers in other countries. The average current in Malaysia is 1 m/s (2.0 knots), which is exactly half of the speeds of turbine that has been developed. Malaysia water depth is in the range of 15-30 m (Suprayogi, 2010). Vertical axis turbine is more suitable to be used in this shallow water depth. The generator and energy monitoring system can be placed above the water. Thus, there are significant costs savings in design, build and maintenance. It also reduces other losses directly if vertical turbine is used.

1.2 Problems Statement

Savonius rotor is a rotor that has a high starting capability which is suitable for a low speed flow. For a low speed experienced by Malaysia seas, Savonius rotor is the best selection of vertical type turbine than others. In previous work (Yaakob *et al*., 2013), the simplicity of operation VAMCT Savonius can offer greater cost effectiveness in power generation. The problem however shows that the efficiency of power produced was very low. The use of Savonius rotor in marine current flow in Malaysian water ways specifically needed to be improved. The power produced is low because of the low water speed entering the turbine.

Savonius vertical marine current turbine will be improved by developing ways to improve the efficiency and increase the RPM of the present turbine. The RPM can be increased by using flaps, guide vanes, duct or any other outer added structure as the accelerator. Therefore, some modification must be made on the current speed or the turbine itself, or both to enable the turbine to work efficiently in low current speed. Hence, this project mainly focuses on developing an efficient rotor of Savonius vertical axis marine current turbine (VAMCT) to match the Malaysian ocean characteristics.

1.3 Objectives

The goal of this project is to improve the efficiency of Savonius turbine in low current speed application. Specifically the objectives of this project are as follows:

1. To determine optimum parameters in improving the incoming water characteristics of Savonius rotor Vertical Axis Marine Current Turbine at low velocity using Computational Fluid Dynamics (CFD) analysis.
2. To improve Savonius rotor Vertical Axis Marine Current Turbine coefficient of performance (Cp) with combination to external or additional structure by using CFD simulation and experimental validation.

1.4 Scope of Project

The scope of the project consists of the following:

1. Performing literature review on marine current energy resources, prototypes of VAMCT that have been developed by other researchers and study of venturi effect to a flow.
2. Determination of a suitable shape, size and number of deflector to place upon the rotor, developing deflector using Computational Aided Design (CAD) software and analysing the designs using Computational Fluid Dynamic (CFD) software.
3. Analysing developed Savonius rotors using CFD software in two different conditions; ‘without deflector’ condition, and ‘with deflector’ condition and calculating their performance.
4. Analysing developed Savonius rotors using CFD software in others condition include duct or guide vane.

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