VERTICAL AXIS CURRENT TURBINE USING ARM AND SELF-ADJUSTING BLADE ANGLE FOR LOW SPEED CURRENT

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Dedicated to prophet Mohammad (S.A.W.)

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ABSTRACT

Utilization of electrical energy is important for economic growth and improvement of people's living, especially for rural and remote areas which have access to the water but lack of electricity supply. It is known that global energy, especially in developing countries such as Malaysia, is still heavily dependent on fossil fuels, which are costly, cause environmental pollution and rapidly depleting. Hydrokinetic energy, which is one of green and environmentally friendly energy resources, is promising to replace fossil fuels for electricity generation. The objectives of this research are firstly to investigate the effect of arm on torque coefficient of turbine in low speed current, and secondly to determine the effect of self-adjusting blades on power coefficient. Numerical and experimental research methodologies have been applied to achieve the objectives. RANS equations have been applied in CFD simulations using ANSYS-CFX commercial code. For validation of the simulation results, towing tank experiments using fixed blades condition to obtain suitable arm length have been carried out at the Marine Technology Centre (MTC)-Universiti Teknologi Malaysia (UTM). Based on the results obtained by fixed blades condition, a series of test using self-adjusting blades have been done in three conditions of load at different current speeds to determine the performance of turbine. The results show that the arm length and blades angle have a strong effect on the performance of turbine, where there is 23% increase in terms of performance of self-adjusting blades turbine compared to fixed blades turbine. This is because the returning blade angle is in closed position which decreases the hydrodynamic resistance. In addition, the advancing blade angle is in open condition to have the maximum force acting. The combined effects result in the increase of torque by the turbine. The maximum efficiency of the modified self-adjusting system was 16% at tip speed ratio, λ=0.45. The developed turbine can be applied as a useful tool for electricity generation in low speed currents. It could also be integrated with a wide range of generators with different loads.

ABSTRAK

Penggunaan tenaga elektrik adalah penting untuk perkembangan ekonomi dan pembangunan taraf hidup, terutamanya di kawasan pedalaman dan terpencil yang menerima bekalan air namun kekurangan saluran bekalan elektrik. Kita sedia maklum bahawa tenaga global, khususnya di negara-negara membangun seperti Malaysia, masih bergantung pada bahan api fosil, yang mana adalah mahal, penyebab pencemaran alam sekitar dan semakin kehabisan. Tenaga hidrokinetik, yang mana merupakan salah satu sumber tenaga hijau dan mesra alam, berpotensi menggantikan bahan api fosil untuk penjanaan tenaga elektrik. Objektif kajian ini adalah pertama, untuk mengkaji pengaruh lengan pada pekali tork turbin dalam arus halaju rendah, dan kedua adalah untuk mengenalpasti kesan penggunaan bilah bolehubah pada pekali kuasa. Kaedah berangka dan eksperiment telah gunakan untuk mencapai objektif kajian. Persamaan RANS telah digunakan dalam simulasi CFD menggunakan kod komersil ANSYS-CFX. Untuk pengesahan hasil keputusan simulasi, eksperimen tangki tunda menggunakan situasi bilah tetap untuk mendapatkan panjang lengan yang sesuai telah dijalankan di Pusat Teknologi Marin (MTC)- Universiti Teknologi Malaysia. Berdasarkan keputusan daripada situasi bilah tetap, satu siri ujian menggunakan bilah boleh laras-sendiri telah dijalankan dalam tiga situasi bebanan pada halaju arus berlainan untuk mengenalpasti prestasi turbin. Keputusan menunjukkan bahawa panjang lengan dan sudut bilah mempunyai pengaruh yang besar pada prestasi turbin, di mana prestasi bilah bolehubah mempunyai peningkatan sebanyak 23% berbanding bilah tetap turbin. Ini berikutan sudut bilah kembali adalah dalam posisi tertutup, dan mengurangkan rintangan hidrodinamik. Tambahan pula, sudut bilah maju adalah dalam posisi terbuka untuk tindakan tekanan maksimum. Gabungan kesan-kesan ini telah meningkatkan tork turbin. Keberkesanan maksimum oleh sistem bolehubah yang telah dimodifikasi ini adalah 16% pada nisbah halaju hujung, λ=0.45. Turbin ini boleh diaplikasikan sebagai alat yang berguna untuk penjanaan tenaga elektrik pada arus halaju rendah. Ia juga boleh diintegrasikan dengan pelbagai jenis janakuasa dengan beban yang berbeza.

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LIST OF ABBREVIATIONS

BEM	-	Boundary Element Method
BDA	-	Bidirectional diffuser augmented
B.C	-	Boundary conditions
CFD	-	Computational Fluids Dynamic
CICT	-	Centre for Information and Communication Technology
FDM	-	Finite Difference Method
FEM	-	Finite Element Method
FTT	-	Folding tidal turbine
FVM	-	Finite Volume Method
GHG	-	greenhouse gases
GW h		Giga watt per hour
IEA	-	International Energy Agency
MFR	-	Multiple Frame of Reference
Mph	-	Miles per hour
MRF	-	Moving Reference Frame
MTC	-	Marine Technology Centre
PVC	-	Polyvinyl Chloride pipe
RNG	-	Re-Normalisation Group
RPM	-	Revolutions Per Minute
RANS	-	Reynolds Averaged Navier Stokes
SIMPLE	-	Semi-implicit method for pressure-linked equations
SREP	-	Small Renewable Energy Power Program
SMM	-	Sliding Mesh Motion
SST	-	Shear Stress Transport
TSR	-	Tip speed ratio
UTM	-	Universiti Teknologi Malaysia
VACT	-	Vertical axis Current Turbine

LIST OF SYMBOLS

A_s	-	Swept area, (m^2)
A_B	-	Bucket area, (m^2)
C_P	-	power coefficient
C_T	-	Torque coefficient
C_{Ts}	-	Static torque coefficient
D	-	Turbine diameter, (m)
d	-	Bucket diameter, (m)
F	-	Force, (N)
F_L	-	Load cell force, (N)
F_n	-	Froude number
g	-	Gravity Acceleration, (m/s^2)
H	-	Height of turbine, (m)
L_p	-	Prototype length, (m)
L_m	-	Model length, (m)
P	-	Power output, (Watt)
P_{max}	-	The total power available in the free stream flow, (Watt)
R	-	Radius of turbine, (m)
r	-	Arm length, (m)
r_b	-	Radius of bucket
r_1	-	Radius of pulley, (m)
r_{wire}	-	Radius of wire, (m)
S	-	Spring balance reading, (kg)
T	-	Torque (N.m)
V_0	-	Current velocity, (m/s)
Y^+	-	wall distance
(x, y, z)	-	Cartesian coordinate system with its origin at the centre of turbine

LIST OF GREEK SYMBOLS

ω	-	Rotational speed
η	-	Efficiency
η_t	-	Total efficiency
η_g	-	Drive train efficiency
β	-	Overlap ratio
ρ	-	Density of water,(kg/m^3)
λ	-	Tip speed ratio
ε	-	Dissipation energy
τ_w	-	Shear stress
μ	-	Dynamic viscosity of water
γ	-	Scale factor

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CHAPTER 1

INTRODUCTION

1.1 Background

The variety of energy in such country reflects the strength of the economic, social, environmental and security development issues. It can be used as an sign for income level, poverty, jobs and, access to social services, population growth, industrial and agricultural production. On the other hand, the shortage of electrical energy causes the economic crisis in many countries. Many people all over the world, especially in the rural and poor areas have no access to electricity. According to one-third of the world's population does not have access to electricity, but does have access to flowing water (Bertsch, 2012).

Electricity is the fastest-growing final form of energy that International Energy Agency (IEA) estimated a 53% increase in global energy consumption is foreseen by 2030 (International Energy Agency (IEA), 2014,). It is noteworthy that world energy, especially in developing countries such as Malaysia (Chong and Lam, 2013) is still heavily dependent on fossil fuels, which are costly, environmental pollutant and rapidly being depleted. At current production rates, global proven reserves of crude oil and natural gas are estimated to last for 41.8 and 60.3 years, respectively (Altan *et al.*, 2008 and Kaltschmitt *et al.*, 2007), so that the role of renewable energy as green and clean energy to generate electricity, reduce the greenhouse gas emissions and decrease the fuel prices (Bernad *et al*. 2008) is significant.

Malaysia is considering renewable energy to alleviate the high dependency on fossil fuel. It is in the process of utilizing its available resources and discovering its potential. It is considerable Malaysia has a significant amount of hydropower resources as renewable energy, due to the geographical location of Malaysia, with the surrounding South China Sea, equatorial climate, high rainfall rate of around 250 cm per year, long coastlines such as the Straits of Malacca, many rivers and irrigation channels (Chong and Lam, 2013). In addition, some remote areas in Malaysia beside the ocean but without access to electricity are poised to exploit the great potential of ocean energy as hydrokinetic energy to generate electricity, such as Sabah and Sarawak using hydrokinetic devices.

Also, hydropower among the other renewables energy is the prime choice to contribute to the world's energy generation because it is continuously available, high density, powerful, predictable and independent of random weather conditions, as opposed to solar and wind options, and has less impact on environmental and human activity (William and Jain, 2011; Junior, 2011; Paish, 2002; Frankel, 2002 and Yuen *et al*. 2009).

There are different types of hydrokinetic turbine horizontal axis (axial-flow) and vertical axis turbine where the turbine blades would turn the generator by capture the energy of the water flow to produce electricity (Sornes, 2010; Frankel, 2004 and Gorlov, 2004). There is no consensus yet on whether horizontal axis or vertical axis will be the best option for using water current energy; however, the vertical axis turbine appears to have advantages over the horizontal axis turbine in several aspects (Eriksson *et al.*, 2008).

Conventional current turbines which include Darrieus, Gorlov (helical), Davis, Cyloidal and Kobold turbines are very much depending on current speed and water depth. However, the average ocean current velocity in many locations in Malaysia is 1 m/s (Royal Malaysia navy, 2010 and Hassan *et al.*, 2012), while the optimum current speed for ideal turbine operation is at least 2 m/s (4 knots) (Hassan *et al.*, 2012). Hence, the use of conventional current turbines is no longer a feasible solution to employ them for generating electricity in low current speed. As a result, modifications of turbine system are needed to harness maximum power, especially for remote areas alongside the ocean.

Despite attempts to develop renewable energy, up to now it has not been used to its maximum potential in Malaysia because of restrictions on the head and current speeds (Yogi, 2010 and Kamarulzaman, 2012) and it will be such a waste if these natural sources of energy leave without any usage. It is essential for Malaysia to strike a balance in terms of policies, and in the meantime continue the improvement and development of kinetic energy devices towards a greater contribution of hydrokinetic energy as renewable energy to ensure a secure and sustainable future.

Vertical axis current turbine to control energy of low speed currents is at the early stage of development but have significant effect to generate electricity for future supply of clean energy.

This research presents a new design of Vertical Axis Current Turbine (VACT) applicable in low speed current which increase torque and decrease resistant of water leading high output power and hence generate more electricity while is being increasingly used to harness kinetic energy of water and convert it into other useful forms of energy as a clean and renewable energy.

1.2 Problem statement

Nowadays, population growth, electrical demands, rising fuel prices, depleting fossil resources, their environmentally harmful effects and economic problems, are serious subjects to replace fossil resources with renewable energy to generate electricity especially in developing countries.

Malaysia is a country that is surrounded by rivers, ocean and irrigation or rainy channels have rich energy resources, but some of rural and remote areas where they are located alongside ocean are very poor, with low living conditions and limited access to media and information which grid extension way for electrification of them is uneconomical hence hydrokinetic technology can generate a significant amount of electric power. Another challenge is the characteristics of Malaysian currents. The Malaysian ocean current velocity, averagely, is 1 m/s which are approximately half of the speed for ideal turbine operation. These characteristics of the Malaysian current impose some limitations on the energy that can be extracted, that some modifications must be undertaken to allow hydrokinetic turbines to overcome this velocity limitation so as to extract maximum power from the current and permit electrification of rural and remote areas with access to running water but little electricity. There are very few and limited studies that considered the problems associated with the low current speed in Malaysia.

Consider extracting energy of current using vertical axis current turbines, it is necessary to solve challenges associated with turbine configuration, enhancing the efficiency and achieve high output power using the best design of turbines that can be employed in low speed current.

According to above challenges, the research will develop a new vertical axis current turbine using arm and self-adjusting blades which can decrease the resistance force, produce high torque and output power, consequently generate more electricity as a clean source that detail of it will be elucidated in the next chapters.

1.3 Research Objectives

The aim of this study is to develop new knowledge and find solution for challenges about increasing performance of vertical axis current turbine and find the suitable design that can operate in low current speed. The objectives of present research are as follows:

i) To develop a vertical axis current turbine suitable for low speed currents.

ii) To evaluate the effect of arm and different (arm length (r)/blade diameter (d)) on torque and performance characteristics of vertical axis current turbine.

iii) To study the resistance reduction and performance characteristics of vertical axis current turbine due to the self-adjusting blades and different blades angle.

1.4 Research Scope

The aim of the project is to evaluate the performance of new vertical axis turbine using arm and self-adjusting blades in low speed current. This project has been done using numerical and experimental method to achieve the aim of research which each one has several steps. The research scope is explained as follows:

i) The literature review was carried out about necessity of renewable energy, Hydropower energy extraction technique, operation principle of turbines, turbine performance, development and progress of turbines. This step made a good guideline for present research work.

ii) The Computational Fluid Dynamics (CFD) method has been used for numerical simulation and parametric study for investigation the torque and power output, optimum angle and resistance reduction of blades, pressure and velocity distribution on blade surface for different rotational blades angle, different arm length for generate the torque.

iii) Experimental work has been conducted to validate the numerical simulation. Characteristics of turbine performance - torque and power output - for fixed and self-adjusting blades conditions have been measured to compare the results with CFD simulation. The series of tests has been performed in Universiti Teknologi Malaysia (UTM) - Marine Technology Centre (MTC).

1.5 Organization of thesis

This research composed of 7 chapters. The first chapter includes the background, statement problem, research objectives, and research scope. The other chapters (2-7) explain the literature review, research methodology, experimental works, numerical simulation validation, parametric study, results and discussion. Also, it will be mentioned in the conclusion and future work chapters that all of them are to be used for paper publication in journals and presentation in conferences. A brief of each chapter is mentioned in following:

Chapter 1 presents an introduction to the research study consist of the background, statement problem, research objectives, and research scope.

Chapter 2 explains a comprehensive literature review of available scientific information related to topic of this research. This chapter, the necessity for renewable energy in the world and Malaysia, hydropower capacity, hydrokinetic technology, and development and progress of turbines are reviewed.

In chapter 3, research methodology which composed of numerical and experimental methods is described. Computational methodology includes the general information about Computational Fluid Dynamics (CFD), turbulence models, solver, model geometry and meshing, computational domains and boundary conditions. The experimental methodology gives the background about towing tank of Marine Technology Centre (MTC), Univerciti Teknologi Malaysia (UTM). Also, some explanation about turbine model fabrication, experimental setup, torque measurement and performance characteristic of turbine calculation are presented.

The numerical simulation of fixed blades turbine, and self-adjusting blades turbine to show their characteristics in dynamic or static conditions are investigated in chapter 4. The numerical works have been done using high performance computer in centre for information and communication technology (CICT) - Universiti Teknologi Malaysia (UTM).

In chapter 5, the experimental performance characteristics of fixed blades turbine, Experimental performance characteristics of self-adjusting blades turbine in static and dynamic conditions, experimental hydrodynamic characteristic of one blade and CFD validation are investigated. The results of experimental test for fixed blades turbine, self-adjusting blades turbine and one blade of self-adjusting blades turbine in different condition are analyzed and compared with numerical simulation results. The experimental results are validated the CFD simulations with good agreement.

Chapter 6 presents the parametric study using numerical simulation. This chapter shows the performance characteristics of self-adjusting blades turbine affected by different arm to blade diameter ratio (r/d) in fixed R, different blades angle and different current velocity.

Finally, the important and valuable conclusions are described in chapter 7 included with results and discussion from present research. Moreover, some future works for next research are recommended in this chapter.

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