UNSTEADY HYDRODYNAMIC EFFECTS ON THE DYNAMIC PERFORMANCE OF LOW SPEED VERTICAL AXIS CURRENT TURBINE

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DEDICATION

Bism Allah Alrrahman Alrrahim

This thesis is dedicated to my beloved parents, Brothers and Sisters, whose prayers always afforded me the power to accomplish. It is also dedicated to my caring and beloved wife and my children, for their motivational support and patience. It is also dedicated to all my friends and companions, to those who helped me, thanks for everything. To all, I dedicated this work with great respect and love.

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ABSTRACT

Malaysia's rivers and ocean energy can be the best resource for green marine renewable energy. The generation of electricity by the burning of fossil fuels are expensive and produce undesirable greenhouse gases. Malaysia's sea has average speed of 1 m/s, which is twice less than the minimum speed that can operate the conventional turbines. Low-Speed Vertical Axis Turbine (LS-VACT) as a drag device represents a promising technology to exploit marine currents. It can be applied to harness current energy in rivers, coastal area and ocean due to their relative simplicity with reduced installation and maintenance costs. The purpose of this research is to investigate performance of the turbine and the influence of added mass, damping and arm-length to its performance at low current velocities. To achieve that, numerical simulation was conducted using MATLAB program by utilizing the hydrodynamic coefficients and derivatives of the hydrodynamic forces and moments acting on the turbine buckets. The simulation program was validated through the experiments of the LS-VACT. This developed simulation program can be used as a fast and useful tool to achieve design improvements for this turbine at several speeds and various loads. This computer programming can match and integrate the full-scale turbine to a suitable generator with different powers and loads efficiently. The simulation results showed that the performance of LS-VACT agreed within 10% with the experiment results and having the same trend at various flow speeds. A parametric study was performed to analyse the effects of added mass and arm-length at several current speeds. LS-VACT has the highest power coefficient of 0.196 at 0.32 m/s. Also, the peak power (8.6W) and the maximum torque (19.4N.m) values were recorded at a flow velocity of 0.64 m/s. At low water flow speed of 0.17 m/s and 0.32 m/s, the added mass has a significant influence on the LS-VACT performance. At this condition, the inertia forces were dominant at low Keulegan-Carpenter number (K-C) of 3 to 9. The torque and the power magnitudes of the turbine decreased about 18 % and 52.7% respectively. At K-C number above 10, the boundary layer separated with formation of vortex shedding occur. The drag forces were found to be dominant in this situation. At the current speed of 0.32 m/s and arm-length of 0.27 m, the maximum torque of 10.11 N.m and corresponding power of 1.75 W was achieved. However, further increase of the arm-length results in decreasing torque and power. The dynamic performance of LS-VACT was carried out and it can facilitate improvements in its design at low current speed.

ABSTRAK

Air sungai dan tenaga lautan di Malaysia boleh menjadi sumber yang terbaik untuk tenaga hijau diperbaharui. Penjanaan elektrik dengan pembakaran bahan api fosil adalah mahal dan menghasilkan gas rumah hijau yang tidak diingini. Laut Malaysia mempunyai kelajuan arus purata kira-kira 1 m/s, iaitu dua kali ganda kurang daripada kelajuan minimum yang boleh mengendalikan turbin konvensional. Turbin Paksi Vertikal Kelajuan Rendah (LS-VACT) sebagai peranti daya seret merupakan teknologi yang mampu untuk mengeksploitasi arus laut. Ia boleh digunakan untuk menjana tenaga arus di sungai, kawasan pantai dan lautan kerana kesederhanaan kompleksiti mereka dapat mengurangkan kos pemasangan dan penyelenggaraan. Tujuan penyelidikan ini adalah untuk mengkaji prestasi turbin dan pengaruh jisim tambahan, redaman dan panjang lengan kepada prestasinya ketika halaju arus yang rendah. Untuk mencapai itu, simulasi kaedah berangka telah dijalankan dengan menggunakan program MATLAB berdasarkan pekali hidrodinamik dan terbitan daya hidrodinamik dan momen yang bertindak pada baldi turbin. Program simulasi telah disahkan dengan ujikaji LS-VACT. Program simulasi ini boleh digunakan sebagai alat yang cepat dan berguna untuk mencapai penambahbaikan reka bentuk turbin pada beberapa kelajuan dan beban. Pengaturcaraan komputer ini boleh menyamai keberkesanan turbin berskala penuh kepada penjana elektrik yang sesuai dengan kuasa dan beban yang berlainan. Hasil simulasi menunjukkan bahawa prestasi LS-VACT adalah dalam julat perbezaan sebanyak 10% dengan keputusan ujikaji dan mempunyai corak yang sama pada pelbagai kelajuan aliran. Kajian parametrik telah dijalankan untuk menganalisis kesan jisim tambahan dan panjang lengan pada beberapa kelajuan arus. LS-VACT mempunyai pekali kuasa tertinggi sebanyak 0.196 pada 0.32 m/s. Kuasa puncak (8.6 W) dan nilai kilas maksimum (19.4 N.m) dicatatkan pada halaju aliran 0.64 m/s. Pada kelajuan arus air rendah 0.17 m/s dan 0.32 m/s, jisim tambahan mempunyai kesan yang penting terhadap prestasi LS-VACT. Dalam keadaan ini, daya inersia adalah dominan pada nombor Keulegan-Carpenter (K-C) yang rendah iaitu dari 3 hingga 9. kilas dan kuasa turbin turun sebanyak 18% dan 52.7% masing-masing. Pada nombor K-C di atas 10, lapisan sempadan memisahkan pembentukan vorteks. Daya seretan didapati dominan dalam keadaan ini. Pada halaju arus 0.32 m / s dan panjang lengan 0.27 m, kilas maksimum 10.11 N.m dan kuasa sepadan 1.75 W dapat dicapai. Namun, peningkatan panjang lengan yang akan mengurangkan kilas dan kuasa. Prestasi dinamik LS-VACT telah dijalankan dan ia boleh memudahkan penambahbaikan dalam reka bentuk pada kelajuan arus rendah.

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LIST OF ABBREVIATIONS

2 D	-	Two Dimension
3 D	-	Three Dimension
CFD	-	Computational Fluid Dynamic
CFT	-	Cross Flow Turbine
CFX	-	Computational Fluid Dynamic
DAAS	-	Data acquisition and analysis system
DAQ	-	Data acquisition
DOF	-	Degree of Freedom
FKM	-	Fakulti Kejuruteraan Mekanikal
GDW	-	General Dynamic Wake
GUI	-	Graphical User Interface
HECS	-	Hydrokinetic Energy Conversion System
HTS	-	Hydraulic Transmission System
IMO	-	International Maritime Organization
ITTC	-	International Towing Tank Conference
LS-VACT	-	Low-Speed Vertical Axis Current Turbine
MCT	-	Marine Current Turbine
MRF	-	Moving Reference Frame
MTC	-	Marine Teknologi Centre
MW	-	Megawatts
ODD	-	Ordinary Differential Derivatives
ODE	-	Ordinary Differential Equation
ODE'	-	Ordinary Differential Equation Solver
OREG	-	Organization Renewable Energy Generation
PMM	-	Planar Motion Mechanism
RANS	-	Reynolds Averaged Navier Stokes
RPM	-	Rotation Per Min
SLM	-	Sliding Mesh
SR-VACT	-	Self- Rotating Vertical Axis Current Turbine
SST	-	Shear Stress Transport Turbulence Model

THAT/s	-	Transverse Horizontal-Axis Turbine/s
TSR	-	Tip Speed Ratio
UK	-	United Kingdom
USA	-	United States of America
UTM	-	Universiti Teknologi Malaysia
VACT	-	Vertical Axis Current Turbine
VAMCT	-	Vertical Axis Marine Current Turbine

LIST OF SYMBOLS

A_S	-	Swept turbine area/Swept rotor area (m^2)
C_P	-	Power coefficient /Performance coefficient
C_t	-	Torque coefficient
D	-	Diameter of rotor/turbine, (m)
d	-	Paddles/Buckets diameter, (m)
D_m	-	Diameter of model rotor/turbine, (m)
d_m	-	Diameter of model paddles/buckets, (m)
D_P	-	Rotor/Turbine diameter, (m)
d_P	-	Diameter of prototype paddles/buckets, (m)
e	-	Gap between two paddles: main overlap, (m)
e′	-	Gap between two paddles: second overlap, (m)
F	-	Force of model/turbine, (N)
Fx, Fy, Fz	-	Force acting in x, y and z direction respectively
Fn	-	Froude number
Gxyz	-	Body co-ordinate system about centre of gravity
g	-	Gravity=9.81m/s^2
H	-	Rotor/Bucket Height, (m)
I_x, I_y, I_z	-	Principal mass moments of inertia about the X, Y and Z axes respectively
J_{ZZ}	-	Add moment of inertia around Z-axis
K	-	Gear factor
m	-	Mass of body (Kg)
N	-	Moment with respect to the z- axis
n	-	Rotation rate (RPM - Revolutions per minute)
N'_v, N'_{vvv}	-	Partial derivative of N with respect to v
N'_r, N'_{rrr}	-	Yaw moment due to yaw motion
N'_{vvr}, N'_{vrr}	-	Partial derivative of N with respect to v and yawing
Q	-	Flow rate (m3/s)
P	-	Power, (Watt)

P	-	Pressure, (Pa)
P_P	-	Peak Power, (Watt)
r	-	Angular velocity along the respective z axes
r'	-	Non-dimensionless turning rate
r_m	-	Arm length, (m)
r_{lever}	-	Lever length, (m)
T	-	Torque, (Nm)
T_{depth}	-	Total depth to the seabed from surface (m)
U_∞	-	Current velocity / flow stream velocity (m/s)
u	-	Velocity in x- direction (surge)
$\dot{u}$	-	Acceleration in x-direction (surge)
V	-	Blade/Bucket velocity, (m/s)
v	-	Velocity in y-direction (sway)
$\dot{v}$	-	Acceleration in y-direction (sway)
x, y, z	-	Ship-fixed coordinate system
x_0, y_0, z_0	-	Space-fixed coordinate system
X	-	Force in x-direction acting on the blade and turbine (m)
X_0, Y_0	-	Forces in the x_0- or y_0- direction (N)
x_G	-	Centre of gravity (m)
x_S	-	Transducer distant from centre gravity of turbine (m)
X'_{uu}	-	Non-dimensional ship resistance
X'_{vr}	-	Partial derivative of X with respect to v and yawing
Y	-	Force in y-direction, acting on the blade and turbine
Y_B	-	Front transducer X-component
Y_S	-	Back transducer Y-component
Y'_v, Y'_{vvv}	-	Partial derivative of Y with respect to v
Y'_r, Y'_{rrr}	-	Sway force due to yaw motion
Y'_{vvr}, Y'_{vrr}	-	Partial derivative of Y with respect to v and r (yawing)
ω	-	Angular velocity, (rad/s)
ω_e	-	Encounter frequency (Hz)
ω_n	-	Natural frequency (Hz)
ψ	-	Euler angles (yaw)

λ	-	Tip speed ratio – TSR
α	-	Aspect ratio
α'	-	Angular Interference Factor
β	-	Overlap ratio
θ	-	Angle direction of Savonius turbine
γ	-	Conversion factor
η	-	Efficiency
ε	-	Phase angle (rad)
μ	-	Dynamic Viscosity
ρ	-	Density of Water
a_{jj}	-	Hydrodynamic reaction in phase with acceleration (Added mass) in the j^{th} - direction (j = 1, 2,…, 6)
b_{jj}	-	Hydrodynamic reaction in phase with velocity (Damping) in the j^{th} - direction (j = 1, 2,…, 6)
c_{jj}	-	Hydrostatic stiffness of body in the j^{th} - direction (j = 1, 2,…,6)
m_j	-	Mass or mass moment of inertia of body in the j^{th} - direction (j = 1,2,…,6)

LIST OF APPENDICES

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CHAPTER 1

INTRODUCTION

1.1 Research Background and Research Rationale

Malaysia's total carbon dioxide emissions from fossil fuels increased from approximately 115 million metric tonnes in 2000 to approximately 195 million metric tonnes in 2010 and 2011 (The Energy Information Administration, 2012). Burning fossil fuels - such as coal, oil, and natural gas - to generate electricity produces greenhouse gases (Kang et al., 2012) harmful to the ozone and environment, as the Energy Information Administration at US Department of Energy (2011) reports. Moreover, fossil fuels are expensive (Yee et al., 2009) and their reserves limited (Hook, 2013) and quickly disappearing (Bhutta et al., 2012) - and, as if these threats to traditional energy were not enough, no perfect technique exists to estimate how many fossil fuels remain (Ng et al., 2013). Accordingly, using fossil fuels alone to generate conventional electricity is considered unsustainable and, not unrelatedly, insufficient for the demand of the world's seven billion people (Khan et al., 2009), and especially for the demand of those in remote communities. While global energy demand forecasts indicate that energy needs will nearly triple by 2050, renewable power sources only presently provide somewhere between 15% – 20% of total worldwide energy needs and demand. In response to the emerging deficit in renewable energy, researchers and developers are exploring and investigating potential renewable energy resources and trying to extract these resources by developing novel devices and innovative technologies that enable them to generate electricity (Ng et al., 2013).

The recent trend toward a Renewable Energy solution, as stated by Ashnani et al. (2014), emerged in part to reduce carbon dioxide emissions. For our purposes, it is important to note that Malaysia has recently been home to rapid economic development and, with it, increased energy demand (Oh et al., 2010; Chandran et al., 2010). To be sure, effective alternative power sources are necessary meet this demand.

Accordingly, Malaysia formulated the National Green Technology policy in 2009 (Hassan et al., 2012) to encourage the use of green technology alongside its economic development, as Chua and Oh (2010) state. On the other hand, Global Carbon Reduction Commitments are pushing to use reliable sources of power. Such initiatives must grapple with the double-digit annual growth experts anticipate for the energy sector by 2020.

In November 2008, Marine Current Turbines (MCT), a company focused on green renewable energy, successfully implemented Sea-Gen, a commercial-scale project in Northern Ireland (Garman, 1998) involving two horizontal turbines of a total power of 1.2 megawatts, able to provide electricity to approximately 1500 households. To date, Sea-Gen has provided over 3 gigawatt hours of power in the mean grid system, and the power system generates the most electricity of any such systems based on tidal current. Similar projects remain in the planning stage, such as Anglesey Skerries' 10 MW project in Wales and Kyle Rhea's 8 MW project in Scotland.

As is well known, marine - and especially ocean - energy can be categorised according to current, tide, thermal gradient, wave and salinity (OES-IA, 2006; Bedard et al., 2010). Among these elements, marine flow streams represent a relatively new and practically unexploited source, with potentially highly productive sites present worldwide. Because water is 800–835 times denser than air (Yaakob et al., 2008a; Chua and Oh, 2010; Maniaci and Ye, 2011), a current turbine can produce approximately 800 times more power (per unit area of the turbine) than a wind rotor. The power produced can be then transferred through a marine electric cable to the coastline or shore, and then connected to the grid. But the important thing to hold onto here is that water current turbines can harness hydrokinetic energy from flowing water such as ocean currents, run-of-river and tidal streams.

Khan et al. (2009) state that two kinds of hydro-turbines - vertical axis and horizontal axis - can be used as power generation devices for marine flow energy. Much work has been done on the feasibility of power generation devices, systems and plants as well as on their advantages, including on vertical axis and horizontal axis turbines. Horizontal axis turbines are a complex system and are appropriate only for large power plants since such plants can balance the high expenses of the turbines' installation and maintenance by producing a great deal of energy. On the other hand, vertical axis turbines are relatively simple and represent a promising technology for exploiting marine currents - unlike horizontal axis turbines, vertical axis turbines can be used by small power plants (Khan et al., 2007) and in remote areas (Das and Balakrishnan, 2012; Rae and Bradley, 2012) due to their relatively low costs of installation, repair and maintenance (Khan et al., 2007).

Malaysia's rivers and ocean serve as great resources for green marine renewable energy. Hassan et al. (2012) suggest that the success of marine current turbines in Malaysia depends on the current velocity and water depth of their installation sites. More specifically, the researchers suggest that 4 knots (2 m/s) is the minimum ideal marine current velocity for a turbine's operation. Meanwhile, the Malaysian Sea has an average current speed of only 2.0 knots (1 m/s), as the Royal Malaysian Navy reports (2010). Hassan et al. (2012) situate 2 knots as half the flow velocity required by conventional turbines, which are primarily designed and developed outside Malaysia. Moreover, the researchers also report that due to the low current velocity, a big device or turbine system is required to harness the energy of Malaysia's sea currents, which presents a problem in that blade size is limited by water depth.

Addressing this context, Yaakob et al. (2008) proposed a Savonius vertical axis turbine to harness energy from Malaysia's sea despite its slow current and shallow depth. Research was accordingly conducted to develop an optimal turbine drag type for Malaysian waters, which have a typical annual average current speed of 0.5 m/s and depth of approximately 15–30 meters (Yaakob et al., 2008; RMN-Royal Malaysian Navy, 2005). Notably, this vertical axis turbine has two main drawbacks: low torque and a low tip speed ratio (TSR, λ), which make it difficult to integrate with a generator. Nevertheless, this low-speed vertical axis current turbine (LS-VACT) - which makes novel modifications to the Savonius rotor (a rotor that extracts energy from low current speed, as Khan et al. (2009) and Yaakob et al. (2010) report) - appears to be a suitable technology for harnessing marine energy from low-speed currents.

Notably, this innovative marine turbine has four blades with arms of a reduced size as well as higher torque, elements that ensure the efficient rotation of the loaded turbine.

To be sure, LS-VACT design and analysis require the accurate modelling of fluid dynamics, and especially of the mass and structural dynamic forces that impact the rotor blades. The deeper point is that the more accurately these forces can be modelled, the more efficiently these turbines can be designed. In this respect, the development of a new technique for determining a dynamic performance using a dynamic simulation program for assessing the dynamic characteristics of LS-VACT and its performance is of prime importance.

Simulation and simulation-based optimisation techniques are frequently used for many applications in the research of different systems such as airspace and automotive systems, to name but a couple. In the maritime field, simulation models have been used for different types of current turbines. Most existing simulations emphasize the study of static simulation using CFD and pay very little attention to dynamic simulation for dynamic performance assessment using hydrodynamic derivatives.

This research study accounts for the dynamics and performance of the LS-VACT with the aid of computer modelling simulation and validation testing. Ultimately, this research aims to obtain the dynamic characteristics of the turbine, including the added mass effect and the performance of the turbine, to inform the development of a sufficient system for harnessing marine energy. Techniques for dynamic study were gleaned by producing new experimental procedures for conducting model tests using PMM to obtain the hydrodynamic coefficients set to be incorporated into the dynamic simulation program to assess the efficiency of LS-VACT and, subsequently, to investigate the impact of added mass, which may significantly influence performance due to the blades' oscillations at very low current speeds.

1.2 Background of the Problem

In Malaysia and some other countries, sea, rivers and ocean energy may be the best resource of green marine renewable energy. The VACT offers opportunities for supplying power to islands, coast and remote and rural areas. However, in Malaysia, research on ocean-based power sources remain in the development stage - only limited research on this topic exists, and most publications are assessment studies. Responding to this gap in the archive, this study sought to develop a new technique for predicting power output and power and torque coefficients using hydrodynamic derivatives. Notably, the research also sought to determine the added mass effect to improve performance at low flow velocity. To account for the reduced height necessary in Malaysian waters while maintaining efficiency, the LS-VACT was matched with a suitable generator using a dynamic simulation MATLAB program. By incorporating the hydrodynamic coefficients obtained from PMM experiments into the simulation program, an optimal turbine system was developed for the slow current and shallow depth of Malaysian waters. To account for the low flow velocities of Malaysian waters, which are between 0.5 to 2.0 m/s or less, all validated simulations were performed and conducted with a constant flow stream velocity of 1 m/s (i.e. the design speed) and a current speed of 0.5 m/s.

As noted above, LS-VACT is based on a conventional Savonius turbine design. While the Savonius turbine was originally developed for wind energy, it seems essentially suitable for the low flow stream of the Malaysian Sea because this rotor has the ability to run and operate at very low current velocity (Yaakob et al., 2010). So the modified LS-VACT appears a suitable technology for harnessing marine energy from a low-speed current. A potential solution to this innovative marine turbine lies in increasing torque by having four suitable blades with arms of a reduced size to rotate the turbine efficiently. Due to the nature of the LS-VACT, the blades operate in an unsteady condition and experience dynamic loads and interactions during their rotation. This interaction is further complicated by the addition of unsteady velocity in either the fluid or the buckets. The relative speed and angle of the azimuth of the blade oscillate continuously with the rotational frequency of the turbine. The blades on the downstream pass interact with the wake generated on the upstream pass; therefore, the level of unsteady forces is higher on the downstream pass. All these factors significantly influence turbine performance. The non-uniformity of the incoming flow changes the relative velocity pattern of the blades in the upstream pass at a frequency higher than the rotational frequency of the blades. The unsteady incoming flow condition of the upstream pass directly affects the quality of the output power of the turbine, as the majority of the net torque is created in this pass.

Meanwhile, the principal weakness of the stream-tube, cascade and vortex simulations is that they require lookup tables of static lift and drag data to calculate the forces on a turbine, even when dynamic effect corrections are implemented. Static experimental test data are often obtained under ideal, uniform and rectilinear flow conditions. The VACT, on the other hand, operates with the blades in a circular rotation, with a constantly varying angle of attack or azimuth, and the downstream blades are affected by the wake from the upstream blades. Furthermore, up-to-date, experimentally verified tabular data for a particular dynamic situation may not be available. Therefore, it is beneficial to develop dynamic turbine performance simulations that organically generate torque and drag characteristics within the model with the ability to assess the added mass effect.

Computational Fluid Dynamics (CFD) simulations offer an advantage over simpler potential flow models in that they do not require lift and drag data to resolve the flow field and the current structure around the turbine. Furthermore, CFD can, in principle, provide a more accurate representation of ancillary turbine structures, including support shafts and struts (Dai et al., 2011). The main drawback with using CFD simulations to resolve flow structure is that they involve long computation periods and high-power computing, even in 2D models. Whereas dynamic simulation turbine performance models and double, multiple stream-tube models take only seconds to present a solution, the traditional vortex model requires a few minutes and CFD a full day (or more) to solve and run a single turbine operating point (Dai et al., 2011) - the correlational and computation power of CFD simulations must be improved.

Therefore, it is necessary to develop an effective procedure for investigating the performance characteristics and influence of the hydrodynamic forces and added mass on a turbine by utilizing hydrodynamic coefficients. This can be achieved by developing a dynamic simulation computer program capable of assessing the dynamic performance of the LS-VACT by incorporating the derivatives obtained using developed PMM model tests into simulations. This method is useful in accounting for the effect of dynamic characteristics on turbine performance to enhance design in its initial stages. Accordingly, the primary goal of this study was to develop a computational dynamic simulation tool with which to run experimental tests to deepen knowledge of the dynamics, influence of added mass, arm effect and flow stream velocities that impact LS-VACT operation and performance. Meanwhile, the secondary goal of this study was to conduct experimental tests to yield data to calibrate and validate the results of the dynamic performance simulation program. This dynamic computer simulation was developed using Simulink-MATLAB software and is based on the hydrodynamic derivatives and coefficients incorporated into the dynamic simulation code.

1.3 Problem Statement

Several counties like Malaysia have a sea with low-speed current and shallow water depth which are not suitable conditions to extract the current energy. Malaysia's sea has an average speed about 1 m/s (low current speed) (Royal Malaysian Navy, 2010; Hassan et al., 2012), which is twice less than the minimum speed (2 m/s) that can operate the conventional turbines (Hassan et al., 2012). Savonius as VACT drag type essentially might harvest the energy from current speed as stated by Yaakob et al. (2010); however, the VACT is very much depending on current speed and water depth (Hassan et al., 2012). The low-speed VACT drag type can also extract the power from the current energy like a Savonius rotor. However, this low-speed VACT will not be able to rotate at a constant speed at low current speed. The blades oscillate; added mass influence will be of significant effect to the turbine performance.

To be sure, understanding the dynamic behaviour of a system is a necessary condition for applying it. Until now, the field has largely negated the impacts of added mass and damping on the performance of a turbine at a low speed. Assessing the dynamic characteristics using a technique based on the hydrodynamic coefficients and derivatives is a better approach to studying the added mass effect to yield insights on optimal turbine design for low current speeds. The goal of this research was thus to develop a technique or procedure for dynamic-model performance. Accordingly, this study's primary research question was:

"How can the hydrodynamic performance and added mass effect of low-speed vertical axis current turbine be quantified or assessed in terms of its dynamics? "

1.4 Research Questions

The research questions as follows:

(a) How to best assess the dynamic performance characteristics of the LS-VACT?

(b) What is the influence of added mass and damping have on the performance of LS-VACT?

1.5 Research Objectives

Understanding the dynamic performance and behaviour of a system is a necessary condition for applying it. The goal of this research is to develop a new method to determine the dynamics of LSVACT, in order to gain better insight on the dynamic behaviour of the turbine and explore the influence of the main design parameters. In addressing the above issues, this research work will be carried out with the following objectives:

(a) To develop a computer simulation program for dynamic performance simulations. This program accounts for the effect of added mass and damping on the performance of LS-VACT. This program incorporates a generator to present a complete turbine-electric system for the performance assessment of LS- VACT.

(b) To assess hydrodynamic coefficients, derivatives and dynamic characteristics to investigate the performance of LS-VACT by using the model experimentation technique developed and the PMM. One blade was attached to the mechanism of the carriage and towed along the towing tank to simulate current flow velocity.

(c) To determine the performance of the LS-VACT turbine experimentally to validate the simulation results using the straight-line experimental model tests. The simulation program was validated to conduct the parametric study to obtain the influence of arm's length and added mass at different arm lengths and different speeds.

(d) To predict the power take-off of the Low-Speed Vertical Axis Current Turbine by matching it to a suitable generator using the MATLAB software.

1.6 Research Scopes

Dynamic performance is meaningful for evaluations of the performance coefficient. Accordingly, this research sought to develop a method (i.e. a new procedure of model experimentation) and a tool for predicting efficiency (i.e. power and torque coefficients), torque and power output to present recommendations for improving LS-VACT performance. The tool should be fast and able to quantify the effects of different design parameters, such as arm length and the height of the bucket, added mass and damping effects and free stream velocity, on the performance of the turbine.

More specifically, this study focused on a vertical axis drag type turbine made up of four buckets connected to arms. These arms attach the buckets to the main shaft to increase torque by increasing leverage, thereby increasing the amount of power generated. The simulation program for the dynamic performance of the LS-VACT, developed using MATLAB software, uses the hydrodynamic forces, moments and the derivatives of one bucket on the turbine. This program thus simulates the rotations of the buckets and the turbine based on a bucket's equation of motion with three degrees of freedom (3DOF). The hydrodynamic coefficients and derivatives of the bucket were derived using PMM at current speeds of 0.17, 0.32 and 0.64 m/s. This simulation program has been used for numerical simulation and parametric study about torque and mechanical power output, added mass and damping impact, arm length effect and power take-off. Load mass method tests at the constant current speeds mentioned were used to validate this simulation program. The performance characteristics of the LS-VACT (i.e. torque and mechanical power output) were also measured to compare the results with the MATLAB simulation results. The tests were performed in a towing tank operated by the Marine Technology Centre (MTC) at the Universiti Teknologi Malaysia (UTM) with no surface or wave interaction and with constant carriage speeds of 0.17, 0.32 and 0.64 m/s to simulate incoming water flow (the water current was assumed to exhibit a uniform flow stream). The tank had a total length of 120 metres, a width of 4 metres, and a depth of 2.5 metres. Notably, this study was limited to obtaining the hydrodynamic derivatives, current forces and drag forces and coefficients from a single bucket experiment. The added mass coefficients are based on PMM tests, while the model follows a different trajectory from the rotational one. Therefore, the study operates on the assumption that these two types of motion will result in the same added mass. In addition, the interaction of the nearby buckets is neglected: the method assumes that each one is independent and thus that the results are based on single bucket PMM tests. This means that the effects from the interaction between the parts are neglected.

1.7 Significance of Findings

This research proposes the development of a framework for establishing a procedure/technique for dynamic performance using oblique and PMM model tests, dynamic simulations and performance analysis of the LS-VACT which leads to a better understanding of the hydrodynamic forces, moments and inertia forces (added mass) acting on the turbine. The benefit of the extended framework is visible in providing guidelines on the interpretation of data for conditions other than those under which they were obtained. The dynamic simulation program will be incorporated into the performance simulation program for predicting the power take-off of the turbine. The outcome of the proposed research; a validated methodology for assessing added mass effect, powering and dynamic performance of the turbine by considering the hydrodynamic derivatives, forces, added mass and Inertia and simulating them. In addition, this research will demonstrate the benefits of the simulation programs developed in terms of reliability and times, saving when using them for determining the optimum size to match it with the generator by simulating the different dimension of the turbine and variable current speeds.

1.8 Thesis Outline

The research thesis outline has been constructed in the most suitable flow process to assess the operation and the performance of the LS-VACT and the effect of the arm's length added mass and damping on its power. The thesis starts with the introduction and background of the problem and rationale. Then it's followed by chapter 2, which is the ' Literature Review and Theory ' and it deals an overview of the present research and theory existing for LS-VACT, specifically focusing on the dynamic load, performance and operation of Low-Speed Vertical Axis Current Turbine. After that becomes chapter-3, 'Methodology', and describes the methodology and theory adopted and used in this research. Besides, presents the framework to carry out this research. Then followed by, Chapter 4,' Dynamic Modeling and Simulation ', and it deals with the software development and describes the mathematical model, dynamic simulation programs and model settings, used in this thesis. Besides this chapter 5, provides the dynamic analysis and simulation results in detail, discusses the results obtained from the simulation programs. Next, Chapter-5, ' Experiments, Experimental Process and Experiment Results ', it is describing model tests set up and conducting the static and dynamic experiments and experiments for validation and experiment results in detail. Chapter 6, ' Parametric Study ', describes the results obtained from conducting the parametric study using the validated numerical simulation program to evaluate the power of the turbine and the influence of the parameters on it. Chapter 7 ' discussion ' discusses the simulation and experiment results. Chapter 8 provides a summary of the research and highlights some of the important conclusions and recommendations for future work.

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