ANALYSIS AND PERFORMANCE STUDY OF POINT-ABSORBER WAVE ENERGY CONVERTERS USING FLOW-3D

TAN WAN CHING

UNIVERSITI SAINS MALAYSIA

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by

TAN WAN CHING

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TABLE OF CONTENTS

CHAPTER TWO – LITERATURE REVIEW

CHAPTER THREE – METHODOLOGY

CHAPTER FOUR – RESULTS AND DISCUSSIONS

CHAPTER FIVE – CONCLUSION AND FUTURE WORKS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
AF	Area Fractions
AWS	Archimedes Wave Swing
CFD	Computational Fluid Dynamics
DOF	Degree-Of-Freedom
FAVOR^{TM}	Fractional Area Volume Obstacle Representation
GMO	General Moving Object
GMRES	Generalized Minimum Residual
OPT	Ocean Power Technology
OTEC	Ocean Thermal Energy Conversion
OWC	Oscillating Water Column
PRO	Pressure Retarded Osmosis
PTO	Power-Take Off
RANS	Reynolds-Average Navier-Stokes
RE	Renewable Energy
RED	Reversed Electro Dialysis
RNG	Renormalized Group
SPH	Smoothed Particle Hydrodynamics
STL	Sterolithography
TAPCHAN	Tapered Channel System
VF	Volume Fractions
VOF	Volume-Of-Fluid

WRASPA	Wave-Driven, Resonant, Arcuate-Action, Surging Point-Absorber
WEC	Wave Energy Converter

LIST OF SYMBOLS

A_{wet}	Area of water plane
b	Damping coefficient
c	Spring coefficient
c_z	Restoring spring coeeficient
f	Frequency
f_z	Natural frequency
F	Total force
F_c	Net control force
F_g	Gravitational force
F_h	Hydraulic force
F_{ij}	Linear reaction force
g	Gravitational acceleration
h	Height of buoy
H	Wave height
k	Wave number
m	Mass of the device
m_a	Added mass
m_b	Mass of buoy
M	Virtual mass
r	Diameter of buoy
T	Wave period
T_c	Control torque about the mass centre
T_g	Gravitational torque
T_h	Hydraulic torque
T_G	Total torque about G
v	Wave speed
V_b	Volume of buoy
V_G	Mass centre of gravity
ω	Angular wave frequency
ρ	Density of seawater
ρ_w	Density of water

ε	Dimensionless wave amplitude
$[J]$	Moment of inertia tensor in body system
ψ	Stream function
λ	Wavelength

ANALISIS DAN KAJIAN TERHADAP PENUKAR TENAGA OMBAK "POINT-ABSORBER" DENGAN MENGGUNAKAN FLOW-3D

ABSTRAK

Tenaga ombak telah menjadi salah satu sumber tenaga yang paling berpotensi dan dengan itu ia telah menarik perhatian pihak kerajaan dan syarikat-syarikat tenaga. Dalam usaha untuk memenuhi permintaan tenaga global yang semakin meningkat, penciptaan alat mengekstrak tenaga bagi generasi akan datang perlu lebih cekap dari segi kos operasi yang lebih rendah dan kelasakan juga perlu diambil kira bagi alat penukar tenaga di luar laut. Oleh itu, reka bentuk awal alat penukar tenaga adalah sangat penting bagi ramalan sifat hidrodinamik. Dalam kajian ini, interaksi struktur ombak dengan alat mengekstrak tenaga dikaji dengan menggunakan Flow-3D. Analisis pengiraan dinamik bendalir (CFD) berdasarkan persamaan Reynolds Purata Navier Stokes (RANS) digunakan untuk mengkaji interaksi antara ombak dan struktur, dan kesan lokasi antara alat. Kaedah berangka dengan kos pengiraan yang munasabah boleh menjadi satu alternatif kepada ujian eksperimen fizikal dalam bidang kejuruteraan luar laut. Latar belakang kajian ini diperkenalkan, termasuk kaedah yang digunakan dalam kajian ini, diikuti oleh kajian kes untuk menunjukkan kesesuaian model berangka. Ini termasuk pegesahan penjanaan ombak dan ramalan prestasi "point-absorber". Ia telah menunjukkan bahawa model berangka mampu perambatan gelombang pemodelan dan interaksi dengan struktur termasuk kesan tidak linear dengan tahap ketepatan yang munasabah. Penukar tenaga "point-absorber" telah dipilih sebagai objek dalam kajian ini. Pendekatan RANS dalam domain masa meningkatkan ketepatan apabila berbanding dengan potensi berasakan kaedah teori. Pengaruh penukar “point-absorber” terhadap prestasi mereka kemudiannya disiasat di bawah keadaan ombak yang tidak sekata dalam usaha untuk meningkatkan prestasi keseluruhan. Kajian ini menghasilkan pemahaman yang lebih baik terhadap masalah struktur ombak dan telah melanjutkan pelbagai model RANS digunakan dalam penyelidikan tenaga ombak. Keputusan menunjukkan bahawa keadaan fasa optimum boya boleh diperolehi dengan melaraskan ketumpatan dan diameter “point-absorber”. Kajian mendapati bahawa boya “point-absorber” dengan ketumpatan 100kg/m^3 dan 0.2m diameter adalah saiz optima bagi keadaan yang ditentukan dalam kajian ini dengan menghasilkan kuasa sebanyak 126.49N.

ANALYSIS AND PERFORMANCE STUDY OF POINT-ABSORBER WAVE ENERGY CONVERTERS USING FLOW-3D

ABSTRACT

Wave energy has become one of the most promising energy resources and hence has attracted more attention from the governments and energy companies. In order to meet the growing demands on global energy, the next generation of energy extracting devices need to be more efficient with less operation cost, and as an offshore structure, the survivability also needs to be taken into consideration. Therefore, it is vital that the hydrodynamic behaviour of the energy device can be predicted accurately at the initial design stage. In this research, the wave structure interaction with application to wave energy device is studied numerically using Flow-3D. The computational fluid dynamic (CFD) analysis based on the Reynolds Average Navier Stokes (RANS) equations is used to investigate the interaction between wave and structure, and array effects among devices. The numerical method with a reasonable computational cost can be an alternative to physical experimental test in offshore engineering. The background to this research is firstly introduced, including methodologies adopted in this study, followed by a series of case study to demonstrate the applicability of the numerical model. These include wave generation validation and the predication of the performance of wave point absorber. It has been shown that the numerical model is capable of modelling wave propagation and interaction with structure including nonlinear effect with a reasonable degree of accuracy. The wave point absorber energy device has been chosen as the object to study. The RANS approach in time domain improves the accuracy when compared with the potential theory based method. The influence of wave point absorber devices array on their performance is then investigated under the irregular wave conditions in order to improve the overall performance. The study yields an improved understanding of wave-structure problem and has extended the range of RANS model used in wave energy research. Results show that optimum phase condition of buoys can be obtained by adjusting the mass density and diameter. Studies found that cylinder buoy of mass density of 100kg/m^3 with 0.2m diameter is the optimal size for the condition set in this research with the produced maximum force of 136.49N.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Global primary energy consumption kept increasing every year with a total of 13276.3 million tonnes oil equivalent by the end of year 2016. Half of the energy consumption is mainly by China and United States. The primary energy consists of renewables, oil, hydroelectricity, natural gas, nuclear energy and coal. The demand for oil is the highest compare to other primary energy. Oil holds one third of global energy consumption with a total of 4418.2 million tonnes oil (British Petroleum, 2017). Figure 1.1 below shows the present world energy supply in 2016.

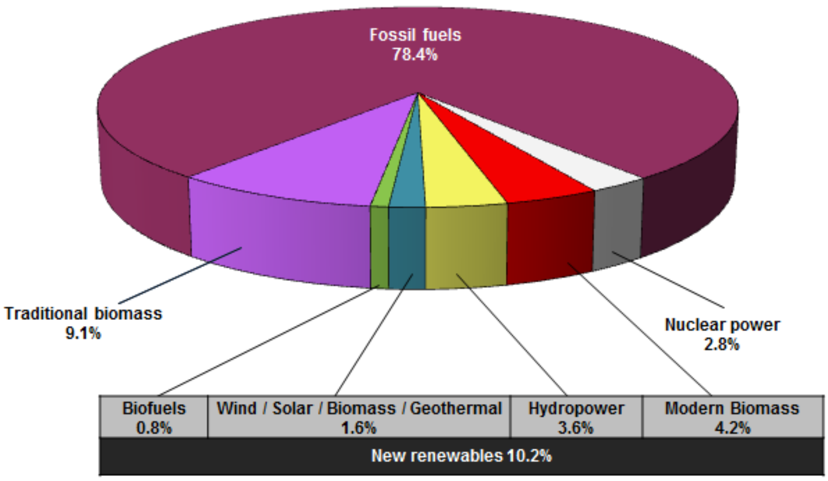

Figure 1.1: World total primary energy supply 2016

From the chart above, 80% of the world energy supply is by fossil fuels. The lifespan of oil, natural gas and coal are predicted to last for 41, 64 and 155 years respectively with continuous production. Other than the issue of depletion, the usage of fossil fuels cause serious environmental issue especially global warming (REN21, 2017). The concern towards the security of fossil fuel for future use increases with the increment of demand of fossil fuel around the world. Hence, renewable energy (RE) are being researched and studied widely to replace the need for fossil fuel in near future. The vast availability of renewables assured energy security towards future will reduce the dependence on fossil fuels. Besides that, RE are less polluting and labour intensive (Goldemberg, 2007).

In Malaysia, the country is facing the growing threat of climate change and pollution. The government have invested in promoting the green technology in order to overcome this problem. Hence, RE has been a wide field to venture on which will provide a huge possibility for it to replace the needs of fossil fuel in the future (Oh, Pang & Chua, 2010). The following section will be discussing the research background, problem statement, research objectives and research scope. A short summary of the whole thesis will be presented in thesis outline.

1.2 Research Background

By the end of year 2016, renewables comprised an envisioned 30% of the world's power production. From 24.5% of the total global electricity, 16.6% of electricity is produced by hydropower (REN21, 2017). The wind and sun energy collection are growing over the years and are viable to produce over 20% of the total energy demand. There are countries taking the advantage of using these two energies for commercial and industrial usage instead of heavily depending on coal, oil and natural gas. The focus on the less advanced sustainable energy with huge potential is essential to increase the percentage of RE resources (Arent, Wise & Gelman, 2011).

The ocean wave is among the most promising RE available. Galarraga stated that the ocean wave is feasible to generate up to 10TW energy with the highest density around (Galarraga, González-Eguino & Markandya, 2011). The power density of wave energy is way better compared to wind and solar energy. Wave energy converters (WEC) can produce as much as 90% of the time in a day while solar and wind power systems can produce power around 30% of the time in a day.

In 1799, Girard and his son gotten the first wave power patent (Lawrence et al., 2013). Due to the fact then, the attention on wave energy continues to increase and many ideas were proposed and evolved. Figure 1.2 below shows a map of mean wave power density (in kW/m) from January 2000 to December 2014.

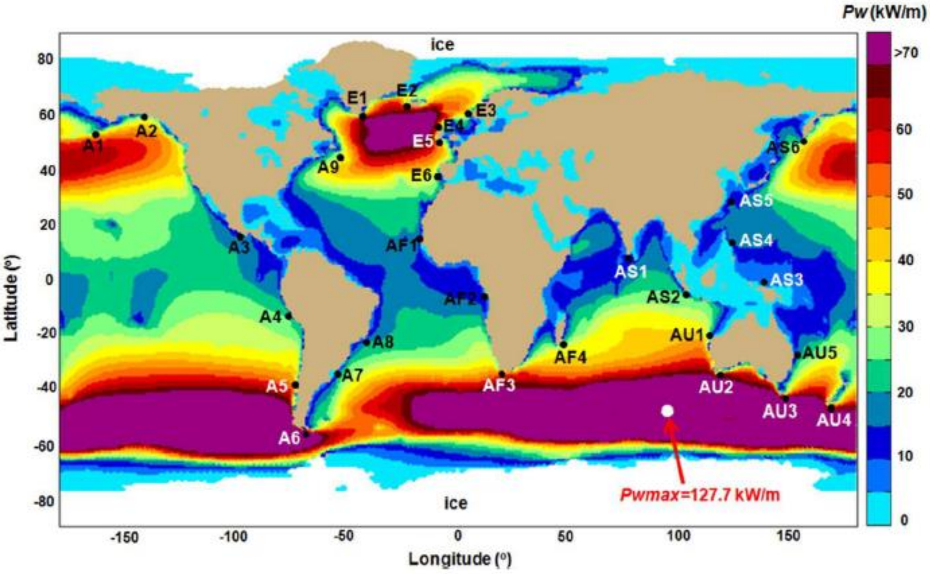

Figure 1.2: Map of the mean wave power density (in kW/m) corresponding to the 15-year interval from January 2000 to December 2014 (Rusu & Onea, 2017)

Figure 1.2 illustrates the positions of 30 reference points, distributed along the coastal environments of America (A1–A9), Europe (E1–E6), Africa (AF1–AF4), Asia (AS1–AS6) and Australia (AU1–AU5), are also indicated (Rusu & Onea, 2017). The 40° and 60° range latitude lines (north and south) at Indian Ocean regions provides most stable and highest wave power of 127.7kW. Countries with the potential range of 70-80 kW/m wave power from southern part of Australia and some regions in Europe are demonstrating extensive attention on wave energy harvesting. The first commercial wave energy plant is in Europe which is the Mutriku plant that successfully produce 296kW of power (REN21, 2017).

Although the potential of developing wave power is promising, there is only a few full scale model remains at sea. The idea of commercializing wave farm is still in consideration due to the high operating cost compared to other RE sources. Besides the high operating cost, it is difficult to operate at the unpredictable large force and oscillating motions of the wave which is used to drive the generator with a sufficient quality output for utilization (Drew, Plummer & Sahinkaya, 2009). In the long run, the performance of wave energy devices in saltwater will deteriorate and higher cost is needed for the maintenance (Czech & Bauer, 2012).

Among the RE resources, wave energy has been overlooked to the extent of no commercial scale power plants. There are a few challenges that are needed to be considered before commercialising the wave energy harvesting to the global market. Effective wave energy collection device in a compact space is essential to maximize the output at any location at the sea. Efficiency of the devices can be improved if optimization had done according to location and wave condition (Drew et al., 2009).

1.3 Problem Statement

A commercial Computational Fluid Dynamic (CFD) code Flow-3D can be used for numerical modelling and the potential for the code to simulate free surface linear waves and wave structure interaction will be evaluated. In this work, CFD analysis based on Reynolds-Average Navier-Stokes (RANS) solver has been developed to study the WEC structures. Whilst compared to the current existing approach, the CFD technique improves the accuracy of the wave-structure simulation in order to obtain a better