

**HYBRID BACKWARD BENT DUCT BUOY AND  
POINT ABSORBER WAVE ENERGY  
CONVERTER FOR LOW WAVE HEIGHT**

**MUHAMAD AIMAN BIN JALANI**

**DOCTOR OF PHILOSOPHY  
(MECHANICAL ENGINEERING)**

**UNIVERSITI PERTAHANAN NASIONAL  
MALAYSIA**

**2024**

**HYBRID BACKWARD BENT DUCT BUOY AND POINT ABSORBER  
WAVE ENERGY CONVERTER FOR LOW WAVE HEIGHT**

**MUHAMAD AIMAN BIN JALANI**

Thesis submitted to the Centre for Graduate Studies, Universiti Pertahanan Nasional  
Malaysia, in fulfilment of the requirements for the Degree of Doctor of Philosophy  
(Mechanical Engineering)

**2024**

## ABSTRACT

Recently, most Wave Energy Converter (WEC) was designed to harvest energy from high wave height conditions, which had less efficiency for low wave height conditions. This weakness causes difficulties for countries with a high potential to utilise ocean energy, such as Malaysia. Furthermore, research on suitable designs to harness highly efficient energy from low wave heights is lacking. Therefore, this study aims to determine the optimum condition parameters for a WEC to provide the best performance in low wave height. Its main objective is to investigate the hydrodynamic characteristics of a hybrid WEC by applying a new form of hybrid Backward Bent Duct Buoy (BBDB) and Point Absorber (PA) at low wave height. To overcome the weakness of BBDB and PA as well as to solve precision methods for investigating the performance of the results, the effects of single BBDB, PA, and a new hybrid form of BBDB-PA on heave Response Amplitude Operator (RAO) and power absorption were examined within various ranges of wave periods under regular wave conditions using ANSYS Advanced Quantitative Wave Analysis (AQWA) is examined. The results revealed that the new hybrid form significantly influenced the hydrodynamic characteristics like excitation force, radiation damping coefficient, and added mass of the BBDB and PA. This form also has a peak of heave RAOs and power absorption occurring in  $T = 1.2$  s, with a value around 1.5 - 3 and 6 kW -16 kW, respectively. Besides, this research also optimises the position of PA, gap length between BBDB and PA, and diameter of PA of hybrid WEC and performs an empirical model at low wave height. The optimisation process was applied based on the data collected over one year about sea characteristics for a nearshore region of Mantanani Island. Note that this research presents a methodology for optimising the

hybrid BBDB-PA based on statistical analysis and hydrodynamics of the system in frequency and performing empirical model. The optimum parameter was selected for front position PA with a 5 m diameter and 7 m gap length with BBDB for the Mantanani Island wave characteristics. To validate the empirical model of response amplitude operator for hybrid WEC at low wave height using an experiment, it was verified with an experimental scale model of 1:30 in a 2D wave flume with a wave height of 0.5 m and a wave period of 1 s -1.5 s. The hybrid BBDB and PA yielded higher performance at  $T = 1.25$  s, with a value of 4 and 8, respectively, compared to the single BBDB and PA. Despite the condition parameter, it was discovered that the WEC position and arrangement were responsible for the highest power value regardless of the PA position used in the experiment. The results offer recommendations for optimising the design of hybrid WECs and imply the possibility of synergy between BBDB and PA to fully utilise ocean space for energy.

## ABSTRAK

Sedasawarsa ini, kebanyakan WEC telah direka untuk menuai tenaga daripada keadaan ketinggian ombak tinggi, yang mempunyai kecekapan yang kurang untuk keadaan ketinggian ombak rendah. Kelemahan ini menyebabkan kesukaran kepada negara yang berpotensi tinggi dalam memanfaatkan tenaga lautan seperti Malaysia. Tambahan pula, terdapat kekurangan penyelidikan mengenai reka bentuk yang sesuai untuk memanfaatkan tenaga yang sangat cekap dari ketinggian ombak rendah. Oleh itu, kajian ini bertujuan untuk menentukan parameter optimum untuk penukar tenaga ombak bagi memberikan prestasi terbaik dalam ketinggian ombak rendah. Objektif utamanya adalah untuk menyiasat ciri-ciri hidrodinamik penukar tenaga ombak hibrid dengan menggunakan bentuk baharu *Backward Bent Duct Buoy (BBDB)* dan *Point Absorber (PA)* hibrid pada ketinggian ombak rendah. Bagi mengatasi kelemahan BBDB dan PA serta untuk menyelesaikan kaedah yang tepat untuk menyiasat prestasi keputusan, kesan BBDB tunggal, PA dan bentuk hibrid baharu BBDB-PA pada *Heave Response Amplitude Operator (RAO)* dan penyerapan kuasa telah diperiksa dalam pelbagai julat tempoh ombak di bawah keadaan ombak biasa menggunakan ANSYS-AQWA. Hasilnya menunjukkan bahawa ciri-ciri hidrodinamik seperti *excitation force*, *radiation damping coefficient*, dan *added mass* bagi BBDB dan PA dipengaruhi dengan ketara oleh bentuk hibrid baharu. Bentuk ini juga mempunyai kemuncak *heave* RAOs dan penyerapan kuasa yang berlaku dalam  $T = 1.2$  s, dengan nilai sekitar 1.5 - 3 dan 6 kW - 16 kW, masing-masing. Selain itu, kajian ini juga mengoptimumkan kedudukan PA, panjang jarak antara BBDB dan PA, dan diameter PA WEC hibrid dan melakukan model empirikal pada ketinggian ombak rendah. Proses pengoptimuman telah digunakan berdasarkan data yang dikumpul selama satu

tahun tentang ciri-ciri laut untuk kawasan berhampiran pantai Pulau Mantanani. Penyelidikan ini membentangkan metodologi untuk mengoptimumkan BBDB-PA hibrid berdasarkan analisis statistik dan hidrodinamik sistem dalam kekerapan dan melaksanakan model empirikal. Parameter optimum dipilih untuk PA kedudukan hadapan dengan diameter 5 m dan panjang jarak 7 m dengan BBDB bagi ciri ombak Pulau Mantanani. Untuk mengesahkan model empirikal RAO untuk WEC hibrid pada ketinggian ombak rendah menggunakan eksperimen, model empirikal telah disahkan dengan model skala eksperimen 1:30 dalam tanki ombak 2D dengan ketinggian ombak 0.5 m dan tempoh ombak 1s -1.5s. BBDB hibrid dan PA menghasilkan prestasi yang lebih tinggi pada  $T = 1.25$  s, dengan nilai 4 dan 8, masing-masing; berbanding dengan BBDB dan PA tunggal. Selain keadaan parameter, didapati bahawa kedudukan dan susunan WEC juga memberi kesan untuk nilai kuasa tertinggi tanpa mengira kedudukan PA yang digunakan dalam eksperimen. Hasilnya menawarkan cadangan untuk mengoptimumkan reka bentuk WEC hibrid dan membayangkan kemungkinan sinergi antara BBDB dan PA untuk menggunakan sepenuhnya ruang lautan untuk tenaga.

## ACKNOWLEDGEMENTS

In the Name of Allah, the Most Merciful and the Most Compassionate. All praise to Allah, the Lord of the world, and peace be upon Muhammad, His servant and messenger. I managed to complete this project successfully. Firstly, I would like to express my sincere gratitude to my supervisor, Assoc. Prof. Ir. Dr. Mohd Rosdzimin bin Abdul Rahman, for his invaluable advice, guidance, and encouragement throughout the preparation of this thesis. His profound knowledge and professional insight are of great value to me. His instructions not only on the research methodology but also on the truth in life mentor to the people I am now.

I would also like to thank Assoc. Prof. Ir. Ts. Dr. Mohd Rashdan bin Saad for his suggestions, discussions, and encouragement going through the completion of this thesis. Thank you very much for always helping and guiding me in this project.

Special thanks are also given to my parents, especially my beloved father and mother, Jalani Abdullah and Suzana Zakaria, for their love and support throughout my life. I want to express my love and thanks to my wife, Nurul Kauthar Ahlaamie Binti Pakrudin. Also, my brothers and sisters, for all their support and motivation from the beginning until the end of this project. Their continuous love, care, encouragement, and patience are of utmost importance to me.

Furthermore, the work that I have completed during the completion of my program would not have been possible without the support of. Last but not least, I would like to thank everybody important to this thesis, and I want to thank all of the individuals who have always provided their encouragement throughout my graduate career and who have contributed massively to the success of my project and academic Doctor of Philosophy in Universiti Pertahanan Nasional Malaysia (UPNM).

I would like to acknowledge the Ministry of Higher Education, Malaysia, and Universiti Pertahanan Nasional Malaysia, Malaysia, for their financial support under FRGS/1/2020/TK0/UPNM/02/3. This study was also performed under the m Akaun Amanah Industri Bekalan Elektrik (AAIBE) under Grant No.- UPNM/2018/AAIBE-KETTHA/TK/1/P4.

Thank all of you so much.

## APPROVAL

The Examination Committee has met on **27<sup>th</sup> September 2023** to conduct the final examination of **Muhamad Aiman bin Jalani** on his degree thesis entitled **'Hybrid Backward Bent Duct Buoy and Point Absorber Wave Energy Converter for Low Wave Height'**.

The committee recommends that the student be awarded the **Doctor of Philosophy (Mechanical Engineering)**.

Members of the Examination Committee were as follows.

**Prof. Madya Dr. Raja Nor Izawati Raja Othman**

Faculty of Engineering

Universiti Pertahanan Nasional Malaysia

(Chairman)

**Prof. Madya Dr. Khisbullah Hudha**

Faculty of Engineering

Universiti Pertahanan Nasional Malaysia

(Internal Examiner)

**Prof. Ir. Ts. Dr. Mohammad Shahril Osman**

Faculty of Engineering

Universiti Teknologi Sarawak

(External Examiner)

**Prof. Madya Ir. Ts. Dr. Mohd Azli Salim**

Faculty of Engineering

Universiti Teknikal Malaysia Melaka

(External Examiner)

## **APPROVAL**

This thesis was submitted to the Senate of Universiti Pertahanan Nasional Malaysia and has been accepted as fulfilment of the requirements for the degree of **Doctor of Philosophy (Mechanical Engineering)**. The members of the Supervisory Committee were as follows.

**Assoc. Prof. Ir. Dr. Mohd Rosdzimin bin Abdul Rahman**

Faculty of Engineering

Universiti Pertahanan Nasional Malaysia

(Main Supervisor)

**Assoc. Prof. Ir. Ts. Dr. Mohd Rashdan bin Saad**

Faculty of Engineering

Universiti Pertahanan Nasional Malaysia

(Co-Supervisor)

# UNIVERSITI PERTAHANAN NASIONAL MALAYSIA

## DECLARATION OF THESIS

Student's full name : Muhamad Aiman Bin Jalani  
Date of birth : 19<sup>th</sup> August 1995  
Title : Hybrid Backward Bent Duct Buoy and Point Absorber  
Wave Energy Converter for Low Wave Height  
Academic session : 2021/2022

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

I further declare that this thesis is classified as:

- CONFIDENTIAL** (Contains confidential information under the official Secret Act 1972)\*
- RESTRICTED** (Contains restricted information as specified by the organisation where research was done)\*
- OPEN ACCESS** I agree that my thesis to be published as online open access (full text)

I acknowledge that Universiti Pertahanan Nasional Malaysia reserves the right as follows.

1. The thesis is the property of Universiti Pertahanan Nasional Malaysia.
2. The library of Universiti Pertahanan Nasional Malaysia has the right to make copies for the purpose of research only.
3. The library has the right to make copies of the thesis for academic exchange.

\_\_\_\_\_  
Signature

\_\_\_\_\_  
\*\*Signature of Supervisor/Dean of CGS

\_\_\_\_\_  
IC/Passport No.

\_\_\_\_\_  
\*\*Name of Supervisor/Dean of CGS

Date:

Date:

Note: \*If the thesis is CONFIDENTIAL OR RESTRICTED, please attach the letter from the organisation stating the period and reasons for confidentiality and restriction.

\*\* Witness

## TABLE OF CONTENTS

	<b>Page</b>
<b>ABSTRACT</b>	ii
<b>ABSTRAK</b>	iv
<b>ACKNOWLEDGEMENTS</b>	vi
<b>APPROVAL</b>	viii
<b>DECLARATION</b>	x
<b>TABLE OF CONTENTS</b>	xi
<b>LIST OF TABLES</b>	xiv
<b>LIST OF FIGURES</b>	xv
<b>LIST OF ABBREVIATIONS</b>	xviii
<b>CHAPTER</b>	
<b>1</b>	
<b>INTRODUCTION</b>	1
1.1 Background Research	1
1.1.1 Wave Energy Potential in Malaysia	2
1.1.2 Wave Energy Converter	3
1.2 Problem Statement	4
1.3 Objectives	7
1.4 Research Scope and Limitations	8
1.5 Significance of Study	9
1.6 Thesis Outline	11
<b>2</b>	
<b>LITERATURE REVIEW</b>	14
2.1 Introduction to Energy Challenges	14
2.2 Exploring Alternative Energy Sources	15
2.3 Ocean Energy Selection	17
2.3.1 Type of Ocean Energy	18
2.4 Rational for Wave Energy Focus	20
2.4.1 Wave Energy in Malaysia	20
2.4.2 Mantanani Island	24
2.5 Wave Energy Converter	29
2.6 Backward Bent Duct Buoy	38
2.7 Hybridisation with Point Absorber	42
2.8 WEC Performance Enhancement	48
2.9 ANSYS Advanced Quantitative Wave Analysis (AQWA)	51
2.10 Fundamentals of Wave Force Theory	54
2.10.1 Response Amplitude Operators (RAO)	59
2.10.2 Incident Wave Theories	59
2.10.3 Linear regular wave (Airy wave)	60
2.11 Power Take-off Mechanism	61
2.11.1 Power Take-off (PTO) for PA	61
2.11.2 Power Take-off (PTO) for BBDB	62
2.12 Summary and Research Gap	63

<b>3</b>	<b>METHODOLOGY</b>	<b>65</b>
	3.1 Introduction	65
	3.2 Numerical Work	68
	3.2.1 Numerical Modelling	69
	3.2.2 Verification & Validation Work	70
	3.2.3 Hybrid Vs. Non-Hybrid Setup	72
	3.3 Factors Parameter Setup for Optimisation	74
	3.3.1 Range Diameter of PA (D)	77
	3.3.2 Range length of the gap between BBDB and PA (L)	78
	3.4 Design of Experimental Setup	79
	3.4.1 Number of Work Process for Condition Parameter Optimisation	80
	3.5 Experimental Phase	82
	3.5.1 2D Wave Flume	83
	3.5.1.1 Wave Tank Operation Limitation	84
	3.5.2 Froude Scaling Similarity Analysis	85
	3.5.3 Calibration	88
	3.5.3.1 Ultrasonic Level Sensor	88
	3.5.3.2 Incident Wave	91
	3.5.4 Model Fabrication	94
	3.6 Experiment Setup	97
	3.7 Experiment Test Condition	100
	3.8 Experiment Data Analysis	101
	3.9 Chapter Summary	104
<b>4</b>	<b>RESULTS AND DISCUSSION</b>	<b>105</b>
	4.1 Introduction	105
	4.2 Validation of Simulation Results	106
	4.2.1 Validation of the BBDB and PA for experimental and numerical	107
	4.2.2 Validation for the interaction between two bodies	109
	4.3 Numerical Results	111
	4.3.1 Hybrid and Non-Hybrid Comparison	111
	4.3.1.1 Excitation Force	111
	4.3.1.2 Radiation Damping Coefficient	114
	4.3.1.3 Added Mass	116
	4.3.1.4 Actual Velocity Response and Wave Surface Elevation around WEC	118
	4.3.1.5 Heave Response Amplitude Operator and Power Performance	120
	4.3.2 Condition Parameter (Factors) Optimisation	125
	4.3.2.1 PA Position Comparison	126
	4.3.2.2 Diameter PA and Gap Length Interactions	127
	4.3.2.3 Optimum Diameter and Gap Length	129
	4.3.2.4 Empirical Equations for Response Parameter	132
	4.4 Experimental Results	133

4.4.1	Validation and Verification with Numerical Model	134
4.4.2	Optimisation of Experiment Parameter	136
4.4.3	Experiment Comparison for Hybrid and Non-Hybrid	138
4.5	Summary and Discussion	140
<b>5</b>	<b>CONCLUSION AND FUTURE WORK</b>	<b>143</b>
5.1	Introduction	143
5.2	Summary and Conclusion	144
5.2.1	Hydrodynamics Characteristic for Hybrid BBDB-PA	144
5.2.2	Condition Parameter for Hybrid BBDB-PA	146
5.2.3	Empirical RAO Validation for Hybrid BBDB-PA	147
5.3	Recommendations for the Future Work	148
	<b>REFERENCES</b>	<b>150</b>

## LIST OF TABLES

<b>TABLE NO.</b>	<b>TITLE</b>	<b>PAGE</b>
2.1	Global potential of ocean power sources	18
2.2	Experimental studies on BBDB conversion efficiency	38
3.1	Point Mass and Inertia Properties of Model Structure	74
3.2	Minimum and Maximum values for the Hybrid BBDB-PA Condition Parameter	81
3.3	Central Composite Value for Diameter (D) and Gap Length (L)	82
3.4	Design Experiment of Central Composite Design	82
3.5	Froude Scaling Ratio	87
3.6	Selected run for motion experiment	100
4.1	Experiments Designed for Front Position	124
4.2	Experiments Designed for Back Position	125

## LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Location Map of Mantanani Island in the Northern Part of Sabah	25
2.2	The ADCP deployment northeast of Mantanani Besar Island	26
2.3	Bathymetry Survey at Mantanani Island	27
2.4	Joint Distribution Percentage of Mantanani Island	27
2.5	Monthly Average Wave Power Mantanani Island	29
2.6	The axisymmetric WEC, oscillating in six DoF	30
2.7	Example of Attenuators Method	31
2.8	Example of Point Absorber Method	32
2.9	Example of Oscillating Wave Surge Method	33
2.10	Example of Submerge Pressure Differential Method	34
2.11	Example of Bulge Wave Method	35
2.12	Example of Rotating Mass Method	35
2.13	Example of Overtopping Method	36
2.14	Example of OWC Method	37
2.15	Illustration of the floating OWC, known as BBDB	39
2.16	Illustration of the floating rigid motion	55
2.17	Illustration of Force Acting on Body	55
3.1	Overall research framework	66
3.2	The BBDB model with dimension	70
3.3	The Conical Point Absorber with dimensions	70
3.4	BBDB experiment in 3D wave basin at NAHRIM	71
3.5	Model structure of BBDB Model	73
3.6	Model structure of Conical PA Model	73
3.7	Side view(left) and Top view(right) of Hybrid BBDB-PA numerical setup	74
3.8	Generic View of Hybrid BBDB-PA System	75
3.9	The Optimisation Process of the Hybrid BBDB-PA	76
3.10	2D wave flume at UPNM	84
3.11	Graph of the ability of the UPNM Flume wave maker	85
3.12	Froude scaling for Experiment Parameter	87

3.13	Ultrasonic Level Sensor	89
3.14	Ultrasonic Liquid Level Sensor calibration	90
3.15	Ultrasonic Sensor calibration result	90
3.16	Location for Wave Data Calibration	92
3.17	Ultrasonic sensor mounted on Aluminum Frame	92
3.18	Incident wave calibration data by the different location	93
3.19	Detailed drawing of BBDB Model	95
3.20	Prototype Picture of BBDB Model	95
3.21	Polystyrene Picture of PA Model	96
3.22	Prototype Picture of PA Model	96
3.23	PVC Pipe with variation length	97
3.24	Prototype Picture of Full Hybrid Model	97
3.25	High Pixel Camera used for Tracking Motion	98
3.26	Picture captured by High Pixel Camera	98
3.27	Full mooring system of experiment model	99
3.28	Tracker software user interface	102
3.29	Tracker software calibration tool	102
3.30	Tracker software collected data	103
4.1	The comparison of simulation and experimental results of wave elevation inside BBDB.	108
4.2	Time series of the experimental and simulation of wave elevation inside BBDB	108
4.3	The comparison of simulation and experimental results of Heave Motion for Cone PA	109
4.4	The comparison of experimental, CFD, and Aqwa results of Heave RAO for two closing bodies	110
4.5	Force Excitation vs. Wave Period for BBDB Model	113
4.6	Force Excitation vs. Wave Period for PA model	113
4.7	Radiation Damping Coefficient vs. Wave period for BBDB model	114
4.8	Radiation Damping Coefficient vs. Wave period for PA model	115
4.9	Added Mass vs. Wave Period for BBDB Model	117
4.10	Added Mass vs. Wave Period for PA Model	117
4.11	Velocity response for Hybrid BBDB-PA under regular wave conditions	118
4.12	Wave Surface elevation around Hybrid BBDB-PA	119

4.13	Time series of wave surface elevation for three different measured locations	120
4.14	Heave motion RAO vs. Wave Period for Hybrid and Non-Hybrid for BBDB	121
4.15	Heave motion RAO vs. Wave Period for Hybrid and Non-Hybrid for PA	122
4.16	Power absorption vs. Wave Period for Hybrid and Non-Hybrid for BBDB	123
4.17	Power absorption vs. Wave Period for Hybrid and Non-Hybrid for PA	123
4.18	Maximum Power absorption versus Diameter PA for Front and Back PA Positions	127
4.19	Contour Plot of the Condition Parameters (Length and Diameter) for PA Front Position (Left) and Back Position (Right)	129
4.20	Main Effect Diagram for Force Excitation	130
4.21	Main Effect Diagram for Heave RAO	131
4.22	Main Effect Diagram for Maximum Power Absorption	131
4.23	Surface Plot Corresponding to: RAO (left) and Maximum Power Absorption (Right) versus PA Diameter and Gap Length	132
4.24	Correlation Experiment and Simulation	135
4.25	Time series of the experimental of heave RAO for hybrid BBDB-PA	135
4.26	Normal probability plot for RAO against residuals	136
4.27	Response surface plots (contour (L) and 3D (R)) for RAO showing the effect of Gap and Period	137
4.28	Main Effects plots (Period (L) and Gap (R)) for Mean of RAO	138
4.29	Heave motion RAO vs. Wave Period for Hybrid and Non-Hybrid BBDB.	139
4.30	Heave motion RAO vs. Wave Period Experiment and Empirical for Hybrid PA	140

## LIST OF ABBREVIATIONS

BBDB	Backward Bent Duct Buoy
PA	Point Absorber
RAO	Response Amplitude Operator
WEC	Wave Energy Converter
RE	Renewable Energy
OWC	Oscillating Water Column
PTO	Power Take-Off
PV	Solar Photovoltaic
MW	Mega Watt
CFD	Computational Fluids Dynamic
PFT	Potential Flow Theory
CO <sub>2</sub>	Carbon Dioxide
IEA	International Energy Agency
OES TCP	Ocean Energy System Technology Collaboration Program
TWh	Tera Watt hour
OTEC	Ocean Thermal Energy Conversion
MWh	Mega Watt hour
DTN	<i>Dasar Tenaga Nasional</i>
GW	Giga Watt
USA	United States America
DoF	Degrees of Freedom
EMEC	European Marine Energy Centre
AWS	Archimedes Wave Swing
OWCOB	Oscillating Water Column Oscillating Buoy
OWT	Offshore Wind Turbine
FABWEC	Floating Array Buoys Wave Energy Conversion
AQWA	Advanced Quantitative Wave Analysis
BEM	Boundary Element Method
DOE	Design Of Experiment
kW	Kilo Watt

$\lambda$	Length Of Wave
k	Wave Number
$\omega$	Angular Velocity
$d$	Water Depth
T	Wave Period
$M$	Mass
$z$	Vertical Displacement
$F_e$	Force Excitation
$F_r$	Force Radiation
$F_h$	Force Hydrostatic
$F_{drag}$	Force Drag
$F_{ext}$	Force External
$F_{pto}$	Force PTO
$F_{FK}$	Force Froude-Krylov
$F_d$	Force Diffraction
$C$	Radiation Damping
$F_d$	Morrison Drag Force
$C_d$	Drag Coefficient
$\mu$	Flow Velocity
$H$	Wave Height
$\rho$	Water Density
$g$	Gravity
$K$	Hydrostatic Stiffness
$B_{PTO}$	PTO damping coefficient
$q_{iws}$	Airflow driven by the Internal Water Surface
$P_{reg}$	Power in Regular Wave
WG	Wave Gauge
CAD	Computer-Aided Design
2D	Two Dimension
3D	Three Dimension
KeTSA	<i>Kementerian Tenaga dan Sumber Asli</i>
RSM	Response Surface Method
GPS	Global Positioning System
L	Length of gap between BBDB and PA

m	Metre
D	Diameter of PA
s	Second
ADCP	Acoustic Doppler Current Profiler
IMU	Inertial Measurement Unit
UPNM	Universiti Pertahanan Nasional Malaysia

# CHAPTER 1

## INTRODUCTION

### 1.1 Background Research

Nowadays, in the era of the industrial revolution in the eighteenth century, humans began to explore further and develop towards more sophisticated technological advances. Development in science and technology is increasing rapidly. Hence, society's demand for energy has increased in terms of energy consumption, especially fossil fuels. Fossil fuel combustion emits large amounts of toxic gases and produces a greenhouse effect, leading to global anomalous climate and extreme weather changes [1].

Climate change has caused energy shortages and the greenhouse effect in recent years, alarming many countries to opt for a full range of alternative energy solutions [2]. Some countries conducted studies and developed a variety of alternative energy that can reduce carbon and cost to reduce fossil fuel energy. Renewable Energy (RE) is the most promising alternative energy, including solar, wind, geothermal, biomass, and ocean energy. However, widely used RE sources such as wind and solar have low energy density and poor stability due to their dependence on a seasonal basis [3]. Therefore, due to the advantages of wave energy and its status

as one of the most dense, predictable, and persistent energy sources, this wave energy is the main focus of this study [4].

### **1.1.1 Wave Energy Potential in Malaysia**

Malaysia is among the countries with high potential in utilising ocean energy for electricity as it has a vast coastline along the South China Sea and the Straits of Malacca, with a length of 4,675 km [5]. Malaysia also has strong seasonal monsoon blows, causing it to always have turbulent waves in its surrounding sea and some areas [6]. Hence, properly using the geographical advantage of Malaysia, which is surrounded by the sea, development, and research on ocean utilisation, will contribute greatly and solve the problems of difficult energy consumption in Malaysia.

Malaysia's government has established many energy policies, as well as monetary support for RE research and development, particularly in local institutions, to reduce the country's reliance on fossil fuels [7]. Since the Malaysian government's encouragement of RE in the 11th Malaysian Plan [8], only 8% of Malaysia's energy is currently generated from RE, despite the country's pledge to increase that percentage to 20% by 2025 [9]. Therefore, Malaysia's government has been exploring high-potential, nascent new energy sources such as geothermal, wind, solar thermal, and ocean, as stated in National Energy Policies 2022-2040 [10]. Nevertheless, the major challenge faced by the RE industry in Malaysia is the intermittency problem in energy production, particularly solar energy. Malaysia only receives an average of 6 hours of direct sunlight for electricity generation during the day, provided that it is not raining and many sun rays are not reflected. The average monthly solar radiation

is approximately 400 MJ/m<sup>2</sup> [11]. Wind energy is also restricted by low wind velocity (less than 2 m/s), blows irregularly, and is not only weather dependent [12] but also has a weak ecosystem and low biodiversity [13].

Wave energy has a substantially higher intensity than other RE sources like wind and solar [14]. Nonetheless, there are limitless waves along the coastline, whether during the day or night. In addition, Kai et al. researched the current status of marine RE in Malaysia and its challenges [5]. The authors concluded that this energy is the best alternative to electricity and can also contribute to the energy-balancing market in Malaysia. Note that the coastal regions in Malaysia are accessible to low wave power with an optimum annual power of 8.5 kW/m yearly, except for the east coast of Peninsular Malaysia during the monsoon season [15]. However, the ideal wave power density for WEC to generate enough power and be commercially viable should be more than 50 kW/m [5]. This energy will become important when variable RE becomes a larger part of the energy mix. Due to its continuous supply, Malaysia has a great opportunity to convert wave energy into electrical energy. Aside from that, it can be regarded as a low-cost, environmentally friendly RE source capable of reducing reliance on fossil fuels for electricity generation.

### **1.1.2 Wave Energy Converter**

Wave Energy Converter (WEC) devices can be divided into three types, namely, Oscillating Water Column (OWC), wave-activated bodies, and overtopping bodies [16]. OWC WECs are among the most promising types [17] compared to the other two types in terms of their mechanical and structural simplicity, accessibility, and

reliability [18]. Other than that, OWC devices are relatively simple in design and have no underwater moving parts. This simplicity can lead to higher reliability and lower maintenance requirements compared to more complex and moving parts like oscillating bodies and overtopping devices.

One of the most successful OWC types [19], called a Backward Bent Duct Buoy (BBDB), is a simple floating structure WEC concept [20], [21] and is cost-efficient compared to other WECs [22]. Note that the BBDB is a floating OWC proposed by Masuda and Yamazaki [23]. For wave-activated bodies type of WECs, the Point Absorber (PA) is a WEC that takes advantage of the ocean waves' oscillatory up and down heave movement [24]. PAs are also one of the most common devices that typically have a floater moving in an oscillating, heaving, and pitching motion turned into electricity by a Power Take-Off (PTO) system [25]. This non-directional device absorbs energy from all directions by moving at or near the water's surface. Owing to their simplicity, PAs are more durable than other wave energy devices in harsh wave conditions [26].

## **1.2 Problem Statement**

Although the ocean surrounds Malaysia, taking advantage of its energy is challenging due to the wave conditions. Compared to other countries, Malaysia has a relatively low energy wave characteristic. Malaysian seas have a low climate, with significant wave heights ranging between 0.5 and 1.5 m and peak periods ranging between 5 s and 7 s. Due to Sumatera's protection, the west coast of peninsular Malaysia, Malacca