

DESIGN AND PERFORMANCE EVALUATION OF A TRI-WAVE POWER GENERATION

A Project By

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In partial fulfillment of the requirement for award of the degree
Of
Bachelor of Science in Mechanical Engineering

January, 2026

Approval

This is to certify that the Project and Thesis work (ME-400) titled "Design and Performance Evaluation of a Tri-Wave power generation," submitted by Md. Ashikur Rahman (ID: ME2202027320), Sameul Alim (ID: ME2202027156), Md. Sohel Rana (ID: ME2202027147), Rakib Ullah (ID: ME2202027239), and Md. Hanif Sarder (ID: ME2202027298), has been duly approved by the examiners. This thesis fulfills a portion of the requirements for the award of the degree of Bachelor of Science in Mechanical Engineering at Sonargaon University, Green Road, Dhaka.

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DECLARATION

We, the undersigned, hereby solemnly declare that the work presented in this project has been exclusively carried out by us and has not been previously submitted to any university or organization for the award of any degree or certificate.

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Moreover, we undertake to indemnify the university against any loss or damage resulting from any breach of the aforementioned obligations.

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ABSTRACT

The increasing global demand for sustainable and uninterrupted energy has accelerated the development of hybrid renewable power generation systems. With ever-increasing global energy demand and finite reserves of fossil fuels, renewable forms of energy are becoming increasingly important to consider. Wave energy is a widely available source of renewable energy that is being investigated by dozens of wave energy projects using a variety of techniques. One common design for a wave energy converter (WEC) is the point absorber or buoy, which floats on or below the water surface and captures energy from the movement of the waves. This project presents the design and conceptual development of a tri-wave power generation system that integrates solar energy, sea water wave energy, and wind energy to achieve continuous power generation. The proposed mechanical system is specifically intended for marine (sea-based) installation, enabling effective utilization of abundant natural resources available in coastal and offshore environments. By combining three renewable sources, the system aims to overcome the intermittency limitations associated with single-source power generation and ensure all-time power availability regardless of season or time of day. The project emphasizes maximum utilization of natural energy sources with minimal environmental impact. Key challenges associated with marine deployment, such as cyclonic conditions, saltwater corrosion, and harsh sea environments, are analyzed, and design considerations are discussed to enhance system reliability and durability. The tri-wave power generation concept demonstrates significant potential as a sustainable solution for continuous renewable energy production, particularly in coastal regions. This project highlights the feasibility of hybrid renewable systems as an effective approach toward meeting future energy demands while reducing dependency on conventional fossil fuels.

TABLE OF CONTENTS

Approval.....	I
Declaration.....	II
Acknowledgement.....	III
Abstract.....	IV
Table of Contents.....	V
List of Tables.....	IX
List of Figures.....	X

CHAPTER 1

INTRODUCTION

1.1	Overview	1
1.2	Problem Statement	2
1.3	Aims	3
1.4	Objectives	4
1.5	Project Methodology	5
1.6	Quality Preservation	6
1.7	Optimization Techniques and Scale-Up Considerations	7

CHAPTER 2

LITERATURE REVIEW

2.1	Introduction	8
2.2	Context and Evolution of Hybrid Solar Energy Systems	9
2.3	Key Technological Components and Their Integration	10
2.3.1	Overall System Architecture	10
2.3.2	Solar Photovoltaic (PV) System	11
2.3.3	Wave Energy Converter (WEC)	11

2.3.4	Wind Energy System	11
2.3.5	Integration Strategy	12
2.4	Innovation Gap and Project Relevance	13

CHAPTER 3 MATERIALS AND METHOD

3.1	Methodology	15
3.1.1	Site and Resource Analysis	15
3.1.2	Conceptualization and Design	15
3.1.3	Material Selection	16
3.2	Experimental Setup and Equipment	16
3.3	Experimental Equipment	17
3.3.1	1”×1” angle bar	18
3.3.2	Stainless steel pipe	19
3.3.3	Plywood board	20
3.3.4	PVC Pipe	21
3.3.5	Battery	21
3.3.5.1	Key features of Battery	22
3.3.6	Solar panel	22
3.3.6.1	Key aspects of solar panels include	23
3.3.7	Buoy device	24
3.3.8	Generator	25
3.3.8.1	Key components	25
3.3.9	Turbine blade	26
3.3.10	Voltmeter	27
3.3.11	Combined display of voltage and ampere	29
3.3.12	Diode (1N4007)	30
3.3.13	DC Bulb	31
3.3.13.1	Key features	31
3.3.14	Bearing	32

5.5.5	System Components & Material Impacts	49
5.5.6	Mitigation Strategies	49

REFERENCES -----

LIST OF TABLES

Table 2.1	Integration Strategy	12
Table 2.1	Comparison of Traditional vs Tri Wave System	14
Table 3.1	Cost Analysis	39
Table 4.1	Experimental Setup Parameter	41
Table 4.2	Electrical Output Performance Data	42
Table 5.1	Environmental Impacts	47
Table 5.2	Social Impacts	47
Table 5.3	Quantitative Insights	48
Table 5.4	System Components & Material Impacts	49

LIST OF FIGURES

Figure 3.1	Experimental Setup and Equipment	16
Figure 3.2	Angle bar	19
Figure 3.3	Stainless steel pipe	20
Figure 3.4	Plywood board	20
Figure 3.5	PVC Pipe	21
Figure 3.6	Battery	22
Figure 3.7	Solar panel	23
Figure 3.8	Buoy device	24
Figure 3.9	Generator	25
Figure 3.10	Turbine blade	26
Figure 3.11	Volt meter	28
Figure 3.12	Volt and Current combined meter	30
Figure 3.13	Diode (1N4007)	30
Figure 3.14	DC bulb	32
Figure 3.15	Bearing	33
Figure 3.16	Buoy device part of our proposed system	36
Figure 3.17	Monitoring part of our proposed system	36
Figure 3.18	Solar and wind turbine part of our proposed system	36
Figure 3.19	Full overview of our proposed system	37
Figure 4.1	Electrical Output Performance Data Curve	42

INTRODUCTION

1.1 Overview

The rapid depletion of conventional energy resources and the growing demand for sustainable power have emphasized the need for efficient renewable energy systems. Marine environments offer vast and largely untapped potential for renewable energy due to the continuous availability of natural resources such as sunlight, wind, and ocean waves. This project focuses on the development of a Tri-Wave Power Generation System that integrates solar energy, wind energy, and sea water wave energy into a single hybrid mechanical system designed for offshore and coastal installation.

The primary objective of this project is to achieve continuous and reliable power generation at all times, irrespective of seasonal variations or time of day. Solar energy contributes power during daylight hours, wind energy supplements generation during windy conditions, and wave energy ensures power availability even during low solar and wind periods. The combined operation of these three renewable sources significantly reduces power intermittency and enhances system efficiency.[1]

The system is designed to maximize the utilization of natural energy while minimizing environmental impact. Special attention is given to mechanical design aspects suitable for harsh marine conditions, including resistance to saltwater corrosion, strong winds, high waves, and cyclonic disturbances. Protective structures, material selection, and robust mechanical components are considered to improve system durability and operational safety.

This tri-wave power generation project demonstrates the feasibility of hybrid renewable systems in marine environments and highlights their potential role in supporting sustainable energy solutions for coastal regions, offshore facilities, and isolated locations. [2] The project contributes toward the advancement of clean energy technologies and supports global efforts to reduce dependence on fossil fuels.

1.2 Problem Statement

The growing demand for electrical energy, coupled with the rapid depletion of fossil fuel resources and increasing environmental concerns, has created an urgent need for sustainable and reliable renewable energy solutions. While individual renewable energy sources such as solar, wind, and ocean wave power are widely used, each of these systems suffers from intermittency and reliability limitations due to their dependence on weather conditions, time of day, and seasonal variations. [3] As a result, single-source renewable power systems often fail to provide continuous and uninterrupted energy supply.

Marine and coastal regions possess abundant renewable energy potential; however, effective utilization of these resources remains a significant challenge due to harsh sea conditions, including cyclones, saltwater corrosion, strong winds, and mechanical stresses caused by waves. These environmental factors reduce system lifespan, increase maintenance costs, and limit the feasibility of conventional renewable energy installations in offshore environments.

Therefore, there exists a need for a robust, efficient, and continuous power generation system that can operate reliably in marine conditions while utilizing multiple renewable energy sources simultaneously. This project addresses the problem by proposing a Tri-Wave Power Generation System that integrates solar, wind, and sea wave energy to ensure all-time power generation regardless of season or time of day, while incorporating mechanical design considerations to withstand marine environmental challenges.

1.3 Aims

- To design and develop a tri-wave power generation system that integrates solar energy, wind energy, and sea water wave energy for continuous electricity production.
- To achieve uninterrupted power generation irrespective of seasonal variations, weather conditions, or time of day by utilizing multiple renewable energy sources.
- To utilize marine-based natural resources efficiently by installing the system in a sea environment where solar radiation, wind flow, and wave motion are abundantly available.
- To address the limitations of single-source renewable systems by reducing power intermittency through hybrid energy integration.
- To design a mechanically robust system capable of withstanding harsh marine conditions such as cyclones, saltwater corrosion, strong winds, and high wave forces.
- To promote sustainable and eco-friendly energy generation while minimizing environmental impact and dependence on fossil fuels.
- To demonstrate the feasibility of all-time renewable power generation for coastal regions, offshore applications, and remote locations.

1.4 Objectives

- To study and analyze the availability and behavior of solar, wind, and sea wave energy in a marine environment.
- To design a hybrid tri-wave power generation system that combines solar panels, wind turbines, and wave energy conversion mechanisms into a single integrated unit.
- To develop a mechanical structure suitable for offshore installation, ensuring stability, safety, and efficient energy capture.
- To select appropriate materials and protective measures to resist saltwater corrosion and harsh sea conditions.
- To reduce power generation intermittency by ensuring at least one energy source is active at any given time.
- To analyze mechanical and environmental challenges, including cyclones, high wind loads, wave forces, and structural fatigue.
- To evaluate the performance and efficiency of the tri-wave system under varying environmental conditions.
- To demonstrate the feasibility of continuous renewable power generation for coastal, offshore, and remote applications.
- To promote sustainable energy utilization and reduce dependency on conventional fossil-fuel-based power generation.

1.5 Project Methodology

The project begins with an extensive literature review on renewable energy systems, focusing on solar, wind, and sea wave power generation technologies, particularly those suitable for marine environments. Existing hybrid energy systems are studied to identify limitations and design challenges. Based on the study, a conceptual design of the tri-wave power generation system is developed. The system layout includes the integration of solar panels, wind turbines, and wave energy conversion mechanisms into a single mechanical structure designed for offshore installation. [4]

It's a combined project of Wind, Sun light, Sea wave for getting a regular power of any time of a day or any season of year. A set of solar panel is used for generating power from sunlight. Solar panel only can generate power at day time only. A set of wind turbine is used to generate power from wind, when enough wind is available. For the air velocity turbine blade rotate and for the rotation of blade generator shaft also rotate and generate electrical power. Also a set of buoy device used for generate power from wave of sea wave. Buoy devices moves vertically for the wave, for the vertical movement a shaft rotate which connected with gear. The shaft rotate generator for generate electrical power. The three system works individually but their production is combined.

The energy conversion mechanisms from each source are analyzed, and the generated power outputs are combined through appropriate coupling and power management arrangements to ensure continuous electricity generation.

1.6 Quality Preservation

To ensure the long-term integrity and performance of the developed system, a comprehensive quality preservation strategy was implemented, focusing on material selection, robust construction techniques, and advanced thermal management. The selection of corrosion-resistant materials and hermetic sealing for critical components prevents degradation from environmental exposure, thereby extending the operational lifespan of the system components. Specialized coatings were applied to reflective surfaces to resist oxidation and keep high specular reflectance over time, which is crucial for sustained energy concentration. Additionally, rigorous quality control protocols, including repetitive stress testing and accelerated ageing simulations, were employed to identify potential failure points and ensure the system's resilience under continuous operation, ultimately enhancing its reliability and cost-effectiveness over its projected lifespan. [5] This meticulous attention to detail in design and construction minimizes the need for frequent maintenance, further contributing to the system's economic attractiveness as a sustainable energy solution. This comprehensive approach ensures that the system not only performs optimally but also maintains its efficiency and structural integrity throughout its operational life, offering a reliable and durable energy supply. The integration of IoT capabilities further enhances quality preservation by enabling real-time diagnostics and predictive maintenance, allowing for proactive intervention before minor issues escalate into significant failures. This proactive approach significantly reduces downtime and operational costs, demonstrating the synergistic benefits of IoT integration for long-term system sustainability. This ensures the system's performance remains consistent over time, adapting to changing environmental conditions and operational demands. [6]

1.7 Optimization Techniques and Scale-Up Considerations

Optimization of the tri-wave power generation system focuses on maximizing energy output, improving efficiency, and ensuring reliable operation in a marine environment. The orientation and placement of solar panels are optimized to achieve maximum sunlight exposure while minimizing shading and salt deposition. Wind turbine blade design and height are optimized based on prevailing wind patterns to enhance aerodynamic efficiency. The wave energy conversion mechanism is optimized by matching its natural frequency with dominant sea wave frequencies to maximize energy extraction. [7]

Mechanical optimization includes reducing frictional losses through proper bearing selection, efficient transmission systems, and lightweight yet strong structural materials. Corrosion-resistant materials and protective coatings are optimized to extend component life and reduce maintenance requirements. Hybrid power management strategies are employed to balance energy input from solar, wind, and wave sources, ensuring stable and continuous power output.

For large-scale deployment, the system design must be modular, allowing multiple units to be connected in parallel to increase power capacity. Structural scaling requires enhanced load-bearing capacity to withstand higher wave forces, wind loads, and cyclonic conditions. Advanced anchoring and mooring systems are necessary to maintain stability in deeper waters.

Electrical integration and energy storage systems must be upgraded to handle higher power outputs and grid connectivity. [8] Maintenance accessibility, cost efficiency, and environmental impact are key considerations during scale-up. Proper feasibility analysis, site assessment, and compliance with marine safety standards are essential to ensure successful large-scale implementation of the tri-wave power generation system.

LITERATURE REVIEW

2.1 Introduction

This chapter provides a review of literature relevant to this thesis. The review begins with a background on wave energy conversion, followed by a discussion of fully submerged wave energy converters, which is a variety of converter that is of particular interest to this thesis. Subsequently, literature on the optimization of wave energy converters is presented, covering the areas of active control and geometric optimization. Finally, research on wave energy converter arrays is discussed, particularly the work on array optimization which is central to this thesis.

Wave power is the transport of energy by ocean surface waves and the capture of that energy to do useful work such as, electricity generation, water desalination, or water pumping. The machine with the function to exploit the wave power is known as a wave energy converter (WEC). The global scale of energy that could be generated by the waves is 8,000,000 TWh/year. The variations of the wave heights are a consequence of the energy flux between the wind and the ocean surface. The technological development of a device to generate electricity from waves needs a large amount of works. [9] The kinetic energy in the wind is a promising resource of renewable energy that has great potential in many places of the world, including in Malaysia. The energy that can be produced by wind turbine is dependent to local average wind speed. Near coasts, inland areas with open terrain or on the edge of bodies of water are the most attractive potential regions for wind energy applications. Solar energy is produced by changing of sunlight to power via the photovoltaic (PV) effect. The photovoltaic effect will produce an electrical current to flow through a solar cell when it is exposed to sunlight.

The increasing global demand for clean, sustainable, and secure energy is a key driver behind the ongoing shift toward renewable energy sources. With rising environmental concerns and depleting fossil fuel reserves, the need for decarbonized and decentralized electricity generation has become more urgent than ever (IEA, 2022). Among the most promising solutions are solar photovoltaic (PV) and wind energy, both of which are abundant, renewable, and have seen rapid technological improvements in recent years. Nevertheless, the major drawback of relying solely on either solar or wind energy is their inherent intermittency. Solar

energy production is restricted to daylight hours and is significantly affected by weather conditions. Wind energy, on the other hand, is highly variable depending on geographical location and wind patterns. This inconsistency can result in unstable power output that hinders the performance and reliability of renewable power systems (Kaldellis & Zafirakis, 2011).

2.2 Context and Evolution of Tri-wave Energy Systems

The growing global demand for clean and sustainable energy has driven continuous research into renewable power generation technologies. Traditional energy systems based on fossil fuels have led to environmental degradation, climate change, and resource depletion, creating a strong need for alternative energy solutions. Renewable energy sources such as solar, wind, and ocean wave energy have emerged as promising options due to their abundance and eco-friendly nature. [10]

Initially, renewable energy development focused on single-source systems, such as standalone solar photovoltaic plants or wind turbines. Although effective, these systems suffer from limitations related to intermittency, seasonal variations, and dependence on specific weather conditions. To overcome these challenges, researchers introduced hybrid energy systems, combining two or more renewable sources to improve reliability and power continuity.

The evolution of tri-wave energy systems represents an advanced stage of hybrid renewable technology, integrating solar energy, wind energy, and sea wave energy into a unified power generation framework. [11] Marine environments provide an ideal setting for tri-wave systems due to the simultaneous availability of sunlight, wind flow, and continuous wave motion. Advances in materials, offshore structural design, and energy conversion technologies have enabled the practical development of such systems.

Today, tri-wave energy systems are recognized as a promising solution for all-time renewable power generation, particularly for coastal regions, offshore installations, and remote areas. Their evolution reflects a shift toward reliable, sustainable, and resilient energy infrastructure capable of addressing future global energy demands.

Offshore Wind Energy: The most mature technology, with the first offshore wind farm installed in 1991 (Vindeby, Denmark). Rapid growth followed in the 2010s, driven by larger turbines and floating platforms for deeper waters. By 2024, global offshore wind capacity exceeded 70 GW, with projections reaching 380 GW by 2030.

Wave Energy Converters (WECs): Development began in the 1970s with early patents (e.g., Salter's Duck in 1974). Progress was slower due to harsh marine conditions, but key milestones include the Oscillating Water Column (OWC) systems in the 1980s and modern point absorbers in the 2000s.

Offshore Solar PV: More recent, with floating photovoltaic (FPV) systems gaining traction post-2010. Large-scale open-sea projects, like China's Shandong offshore solar farm (completed by 2024), demonstrate feasibility in marine environments. [12]

Evolution Toward Hybrid and Multi-Source Systems

Hybrid offshore renewables evolved from co-located farms (separate devices in the same area) to fully integrated platforms sharing structures, moorings, and grid connections.

- **Early Hybrids (2000s–2010s):** Primarily wind-wave combinations, such as the Poseidon P-37 (wind + OWC) and W2Power concepts, focusing on reduced costs and smoother power.
- **2010s Expansion:** Inclusion of solar, with prototypes like Sinn Power's floating platform (wave + wind + solar) and Float Inc.'s multi-source designs.
- **Recent Advances (2020s):** Full tri-hybrids emerge, e.g., NoviOcean's buoyancy-driven platform (wave primary, with wind and PV) and studies on North Sea multi-source parks integrating all three for 20–22% higher energy density and capacity factors up to 80%. Optimization tools like genetic algorithms and PSO have been applied for sizing and placement.
- Tri-wave systems represent the latest evolution, leveraging complementarity: waves for baseload, wind for boosts, and solar for daytime peaks—ideal for cyclone-prone regions with resilient designs.

2.3 Key Technological Components and Their Integration

2.3.1 Overall System Architecture

The Tri-Wave Power Generation System is a floating offshore hybrid platform that mechanically and electrically integrates three renewable energy sources: solar photovoltaic (PV), sea wave energy (via oscillating water column), and wind (via vertical-axis turbines). The design employs a semi-submersible floating structure for stability in deep-sea conditions,

allowing deployment in cyclone-prone marine environments. Shared infrastructure—such as the platform base, mooring lines, power conditioning units, and subsea cables—reduces costs and enhances synergy, enabling continuous power generation by exploiting resource complementarity.

2.3.2 Solar Photovoltaic (PV) System

High-efficiency flexible or rigid PV panels are mounted on the upper deck, oriented for optimal sunlight capture. Offshore advantages include cooler operating temperatures and reduced dust. Corrosion-resistant framing and floating-specific mounting resist saltwater exposure.

2.3.3 Wave Energy Converter (Oscillating Water Column - OWC)

Integrated into the platform's lower structure, the OWC uses chambers where incoming waves compress air, driving a bidirectional Wells turbine coupled to a generator. This mechanical conversion is robust for consistent baseload power from tidal and ocean swells.

2.3.4 Wind Energy System (Vertical-Axis Wind Turbines - VAWTs)

Compact VAWTs (e.g., Darrieus or Savonius hybrids) are mounted on the platform's masts. VAWTs are preferred offshore for omnidirectional wind capture, lower center of gravity, and easier maintenance (generators at base level). They excel in turbulent and high-wind conditions, including cyclones (with furling mechanisms).

2.3.5 Integration Strategy

The electrical outputs from solar, wind, and wave systems are integrated using a hybrid power management unit. This system regulates voltage, balances power input, and ensures smooth and uninterrupted energy supply. Energy storage systems may be incorporated to store excess power and stabilize output. [13]

The seamless integration of these components enhances system efficiency, minimizes power fluctuations, and enables all-time renewable energy generation in marine environments.

Component	Energy Type	Mechanical Priority	Survival Strategy
Wind Turbine	Kinetic (Air)	High-altitude placement	Blade Pitching / Mechanical Brake
Solar PV	Electromagnetic	Gimbal stabilization	Hydrophobic Coating
Wave Buoy	Kinetic (Fluid)	Buoyancy & Stroke Length	Ballast Locking / Submergence

Table 2.1: Integration strategy

2.4 Innovation Gap and Project Relevance

The Innovation Gap

Despite the growth of renewable energy, current marine energy systems suffer from three primary "gaps" that this project aims to close:

- **The Intermittency Gap:** Most existing offshore platforms are single-source (wind only or wave only). This creates "dead zones" in power production—for example, a wind turbine produces zero power on a calm day. By integrating three sources, this project minimizes downtime, filling the gaps where one source fails to produce energy.
- **The Structural Survival Gap:** Many wave energy prototypes have failed because they were designed for "average" waves but destroyed by "extreme" waves. There is a lack of mechanical designs that can intelligently switch between "Harvesting Mode" and "Survival Mode" for all three systems simultaneously during a cyclone.
- **The Space-Efficiency Gap:** Traditional offshore farms require massive sea-surface areas for separate wind and solar installations. There is a technological gap in designing a **shared-infrastructure platform** that reduces the physical footprint and the cost of subsea cabling. [14]

Project Relevance

The relevance of this "Tri-Wave" system is grounded in both economic and environmental necessity:

- **24/7 Power Reliability:** By leveraging the phase difference between wind, solar, and wave energy, this project moves offshore renewables closer to becoming a "Base Load" power provider. Solar peaks during the day, wind often peaks at night, and waves provide a lagging energy surge that continues even after the wind dies down.
- **Resilience to Climate Change (Cyclones):** As global sea temperatures rise, the frequency of cyclones increases. A mechanical project that specifically addresses survival mechanisms for saltwater environments and high-velocity winds is highly relevant to coastal nations (such as those in Southeast Asia or the Caribbean).
- **Corrosion Engineering:** This project addresses the "Salt-Water Problem" through

innovative material selection and protective mechanical housings, which is a major pain point for the offshore industry.

- **Sustainability Goals:** This research aligns with the United Nations Sustainable Development Goal (SDG) 7: Affordable and Clean Energy, by proposing a method to reduce the cost of offshore energy through multi-modal integration.

Comparison: Traditional vs. Tri-Wave System

Feature	Single-Source Offshore	Tri-Wave Hybrid (This Project)
Power Consistency	Highly Intermittent	Continuous (All-time)
Infrastructure Cost	High (separate platforms)	Optimized (shared platform)
Sea Space Usage	Large footprint	Compact, high-density footprint
Cyclone Strategy	Standard bracing	Integrated Multi-source Survival Mode

Table 2.2: Comparison of traditional vs Tri-wave system

MATERIALS AND METHODS

3.1 Methodology

This research outlines our approach to building a tri-wave hybrid energy system that combined solar, wind, and wave energy. We're using a setup that captures energy from the nature like solar power, wind power, and wave motion. We'll be evaluating how well the system performs in terms of energy efficiency, reliability, and whether it makes financial sense under different conditions. On top of that, we're exploring ways to enhance the system and make it easier to scale up, particularly for areas off the primary grid or in rural regions. Our approach combines real-world testing with computer modelling to gain a solid understanding of how the system works and how it could be used more broadly. This method really helps us dive deep into how the system can boost energy by three method. This is crucial for addressing the inconsistent nature of renewable energy sources and enhancing the overall system stability.

The methodology of the Tri-Wave Power Generation project is organized into systematic stages to ensure effective design, integration, and evaluation of the hybrid renewable energy system in a marine environment. [15]

3.1.1 Site and Resource Analysis

The project considers a sea-based location where solar radiation, wind flow, and wave motion are naturally available. Environmental factors such as wind speed, wave height, tidal behavior, and saltwater exposure are analyzed to guide system design and component selection.

3.1.2 Conceptualization and Design

A conceptual model of the tri-wave power generation system is developed, integrating solar panels, wind turbines, and wave energy conversion mechanisms into a single mechanical structure. The layout is designed to maximize energy capture while ensuring structural stability in offshore conditions.

3.1.3 Material Selection

Mechanical components such as supporting frames, shafts, bearings, and transmission mechanisms are designed with suitable safety factors. Corrosion-resistant materials and protective coatings are selected to withstand saltwater, high humidity, strong winds, and cyclonic loads. Materials were meticulously chosen to ensure optimal performance, durability, and cost-effectiveness.[16]

3.2 Experimental Setup and Equipment



Figure 3.1: Experimental Setup and Equipment

3.3 Experimental Equipment

The proposed Tri-Wave power generation is made of several components and they are:

- 1"×1" angle bar
- Stainless steel pipe
- Plywood board
- PVC Pipe
- Battery
- Solar Panel
- Buoy device
- Generator
- Turbine blade
- Voltmeter
- Combined meter of voltage and ampere
- Diode
- Indicator LED
- DC Bulb
- Resistor
- Bearing
- Plastic Pipe

3.3.5 1"×1" angle bar

In mechanical engineering and structural design, an angle bar (also known as an L-bracket or L-shaped cross-section) is one of the most common structural elements. For your offshore platform, a 1" × 1" angle bar would likely be used for the internal framing, solar panel mounts, or reinforcing the turbine mast.

- **Geometry and Dimensions**
 - ❖ **Equal Leg Lengths:** A 1" × 1" angle bar is an "equal angle," meaning both legs of the "L" shape are exactly 1 inch long.
 - ❖ **Thickness:** The "1x1" refers to the length of the legs, but the thickness (t) can vary (common sizes include $\frac{1}{8}$ " or $\frac{3}{16}$ "). This thickness determines the load-bearing capacity.
 - ❖ **90-Degree Bend:** The two legs are oriented at a precise 90-degree angle, providing high resistance to bending in two directions.
- **Structural Integrity**
 - ❖ **High Strength-to-Weight Ratio:** The L-shape provides excellent structural rigidity without the weight of a solid bar.
 - ❖ **Flexural Rigidity:** It is specifically designed to resist bending and "twisting" (torsional) forces, which is essential for a platform constantly moved by sea waves.
- **Material and Corrosion Resistance**
 - ❖ **Common Materials:** Usually available in Mild Steel, Aluminum, or Stainless Steel.
 - ❖ **Marine Grade (Essential for you):** For your sea-based project, you would specify **Grade 316 Stainless Steel** or **Galvanized Steel**. This prevents the salt water from causing "pitting corrosion" or structural weakening.
- **Joinery and Assembly**
 - ❖ **Welding vs. Bolting:** The flat surfaces of the 1" legs make it very easy to weld to other components or to drill holes for bolting.
 - ❖ **Standardization:** Because 1" x 1" is a standard size, it is easy to find pre-fabricated connectors and fittings for it.

- **Common Uses**
 - ❖ Brackets, frames, and supports
 - ❖ Trailers, gates, furniture, racks
 - ❖ Reinforcement in light structures
 - ❖ DIY projects, machinery guards, shelving
 - ❖ Often used in fabrication where small, strong corners are needed



Figure 3.2: Angle bar

3.3.5 Stainless steel pipe

- A stainless steel pipe is a hollow cylindrical metal section used for structural support and fluid transfer.
- Made from stainless steel alloys containing chromium, which provide excellent corrosion resistance.
- Highly resistant to rust, saltwater, and harsh environmental conditions.
- Offers high strength, durability, and long service life.
- Can withstand high pressure and temperature.
- Easy to weld, cut, and fabricate.
- Requires low maintenance compared to mild steel pipes.
- Widely used in marine structures, mechanical frameworks, pipelines, and offshore applications.



Figure 3.3: Stainless steel pipe

3.3.5 Plywood board

- A plywood board is an engineered wood product made by bonding thin layers of wood veneers together.
- The veneers are arranged with grains at right angles, providing high strength and stability.
- Offers good load-bearing capacity and resistance to cracking.
- Lightweight compared to solid wood of similar strength.
- Easy to cut, drill, and fasten using nails or screws.
- Available in different thicknesses and grades.
- Can be treated for water resistance for outdoor or marine use.
- Commonly used in platforms, panels, partitions, and structural support.

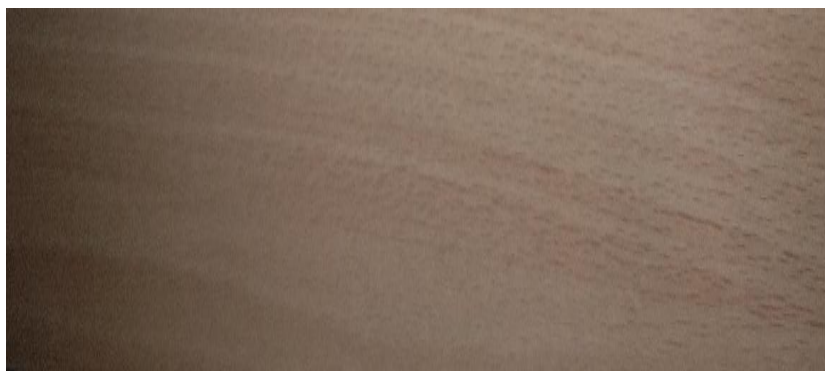


Figure 3.4: Plywood board

3.3.4 PVC Pipe

- A PVC electric pipe is a non-metallic conduit used to protect and route electrical wires.
- Made from polyvinyl chloride (PVC) material.
- Provides excellent electrical insulation and prevents electric shock.
- Resistant to moisture, corrosion, chemicals, and rust.
- Lightweight and easy to cut, bend, and install.
- Non-conductive and fire-retardant in nature.
- Offers good mechanical protection for electrical cables.
- Widely used in domestic, industrial, and outdoor electrical installations.



Figure 3.5: PVC Pipe

3.3.5 Battery

A 4V 3A rechargeable battery is a common power storage unit for backup and solar systems. Its durable plastic casing protects the internal components, which typically include lead plates in an electrolyte solution for lead-acid batteries. More advanced types use gel or fiberglass mats, making them spill-proof and resistant to vibration and temperature changes.

3.3.5.1 Key features of Battery:

- **Voltage** → 4 Volts (nominal output).
- **Capacity** → 3 Ampere-hours (Ah), supplies 3A for 1 hour or 1A for 3 hours.
- **Type** → Lead-acid (SLA/VRLA), Gel, AGM, or Lithium-ion.
- **Design** → Sealed, spill-proof casing; maintenance-free.
- **Durability** → Resistant to vibration, shocks, and temperature changes.
- **Applications** → Use for circuit power provide, small rechargeable lamp.



Figure 3.6: Battery

3.3.6 Solar Panel

A solar panel is a device designed to convert sunlight into electricity. It achieves this through the photovoltaic effect, utilizing numerous solar cells, typically made of silicon, to absorb solar energy and generate direct current electricity. This DC electricity is then transformed into alternating current by an inverter, making it suitable for powering homes, businesses, and various other electrical systems.

3.3.6.1 Key aspects of solar panels include:

- **Placement:** They are commonly installed on rooftops or in open areas to maximize exposure to sunlight.
- **Energy Source:** Solar panels provide a clean, renewable energy source, helping to reduce reliance on fossil fuels.
- **Economic Benefit:** Their use can lead to lower electricity bills.
- **Energy Storage:** In some systems, batteries are integrated to store excess energy, ensuring power availability during periods of low sunlight, such as at night or on cloudy days.



Figure 3.7: Solar panel

3.3.7 Buoy device

The device use to convert water wave to linear motion. Made with thermocol and geared pvc pipe.

- Light weight
- Available
- Low coast
- Easy movement
- Low loss when converting wave



Figure 3.8: Buoy device

3.3.8 Generator

An generator is an electrical machine that converts mechanical energy into alternating current (AC) electrical energy using electromagnetic induction.

- **Main output** Produces AC voltage (usually three-phase in power generation applications).
- **Basic working principle** A rotating magnetic field (created by the rotor) induces an alternating voltage in the stationary stator windings (Faraday's law).

3.3.8.1 Key components

- **Rotor** — Rotating part (electromagnet/permanent magnets) that creates magnetic field
- **Stator** — Stationary part with windings where AC is generated
- **Slip rings** — Allow current to flow to the rotating rotor (for excitation)
- **Brushes** — Make electrical contact with slip rings (in many designs)
- **Rectifier (diode bridge)** — Converts generated AC to DC (in automotive generators)
- **Common applications**
 - ❖ Vehicle charging systems (car generators)
 - ❖ Power plants (synchronous alternators / generators)
 - ❖ Wind turbines, wave energy converters (like in your Tri-Wave project!)
 - ❖ Backup diesel generators



Figure 3.9: Generator

3.3.9 Turbine blade

- A turbine blade is a rotating mechanical component used to extract energy from a moving fluid such as air, steam, water, or gas.
- Designed with an aerodynamic or hydrodynamic shape to efficiently convert fluid kinetic energy into mechanical energy.
- Commonly made from high-strength materials such as aluminum alloys, stainless steel, composites, or special alloys.
- Mounted on a rotor or hub to form the turbine assembly.

- Operates based on the principle of lift and drag forces.
- Designed to withstand high stresses, rotational speeds, and environmental conditions.
- Blade angle and shape directly affect efficiency and power output.
- Widely used in wind turbines, water turbines, gas turbines, and wave energy systems.

Blade design:

- Series NACA 0012 airfoil
- Max thickness 12% at 30% chord
- Max camber 0% at 0% chord



Figure 3.10: Turbine blade

3.3.10 Voltmeter

- **Purpose**

Measures direct current (DC) voltage in low to medium ranges (typically 0–30V, 0–100V, or 0–200V)

- **Size**

Very compact — usually 20–50 mm wide/tall/deep

- **Formats:**

Mini rectangular module (~23×15×10 mm)

- **Display Type**

Digital — 3-digit or 3.5-digit LED/LCD (most common today)

Bright red, blue, green, or white digits

Resolution usually 0.1V

- **Measuring Range**

Most popular models:

0–30V (perfect for 12V/24V batteries, solar projects)

0–100V (common for general use)

3–30V (with built-in protection, auto-scaling)

Some have extended range up to 200V or 500V

- **Power Supply**

Most digital ones need separate power: 3.5–30V DC (often taken from the same voltage being measured).

Some advanced models have isolated power input (4–28V separate).

Very low current consumption (~5–20 mA).

- **Accuracy**

Typical: $\pm 0.5\%$ to $\pm 1\%$ (very good for the price).

Resolution: 0.01V or 0.1V depending on model.

- **Connection**

Simple 2-wire or 3-wire:

Red wire: Positive (+) of measured voltage.

Black wire: Negative (–) / common ground.

- **Common Features**

Built-in trimmer potentiometer for calibration.

Waterproof versions available (with cover).

Very cheap in price and available.

- **Typical Applications**

Battery voltage monitoring (12V car, Li-ion packs).

Solar panel output checking.

DIY power supplies & bench testers.

Our Tri-Wave project — perfect for monitoring DC bus voltage from solar panels or rectified output from wave/wind generators.

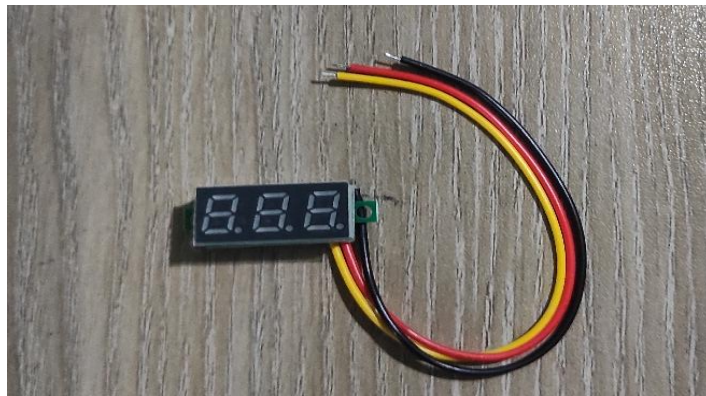


Figure 3.11: Volt meter

3.3.11 Combined display of voltage and ampere

- **Purpose**

Simultaneously measures and displays both DC voltage (Volts) and DC current (Amps) on one small device — perfect for monitoring batteries, solar panels, power supplies, chargers, or our Tri-Wave project DC bus.

- **Display Type**

Dual digital LED (most common):

Two separate readouts side-by-side or one above the other

Voltage (left/top) usually in red

Current (right/bottom) usually in blue or green

3-digit or 3.5-digit resolution (e.g., 12.3 V and 5.67 A)

Some models use LCD for lower power, but LED is brighter and more common.

- **Typical Measuring Ranges**

Voltage: 0–30V, 0–100V, or 4.5–100V (auto-ranging common)

Current: 0–10A (most popular), 0–50A, or 0–100A

Shunt resistor usually included (built-in for $\leq 10A$ models, external for higher current)

- **Power Supply**

Self-powered from the measured voltage (most models need at least 3.5–4.5V to operate)

Very low consumption ($\sim 10\text{--}30$ mA)

Some versions have separate power input for isolation (4–28V)

- **Accuracy & Resolution**

Typical: $\pm 1\% \pm 1$ digit (good enough for most hobby/project use)

Resolution: 0.1V and 0.01A (for 10A models)



Figure 3.12: Volt and Current combined meter

3.3.12 Diode (1N4007)

- 1N4007 is a general-purpose silicon rectifier diode.
- Used mainly for AC to DC conversion in rectifier circuits.
- Has a maximum reverse voltage rating of 1000 V.
- Rated for 1 A average forward current.
- Operates efficiently at low to medium frequencies
- Provides good reliability and low cost.
- Protects circuits from reverse polarity.
- Commonly used in power supplies, battery chargers, adapters, and renewable energy projects.



Figure 13: Diode (1N4007)

3.3.13 DC Bulb

Uses multiple high-brightness SMD LEDs mounted on a small circuit board

Designed specifically for 5V DC (direct current) — perfect for USB power, battery packs, or solar panels

- **Shape & Size**

Usually round or slightly domed (like a small puck or disc)

Diameter: 50–80 mm (most common ~70 mm, similar to your LED module)

Thickness: 10–20 mm (very flat and compact)

Often comes with a milky white plastic diffuser cover for soft, even light

LED Arrangement 6–18 LEDs

Arranged in a circular pattern on a white or aluminum PCB for heat dissipation

Color temperature: usually warm white (3000K), neutral white (4000K), or cool white (6000K)

- **Power & Brightness**

Voltage: strictly 5V DC (connect directly to USB, power bank, or 5V solar output)

Power consumption: 3–10 watts (depending on number of LEDs)

Current draw: 0.6–2A (e.g., 6 LEDs \approx 0.6A, 12 LEDs \approx 1–1.5A)

Brightness: 300–800 lumens (equivalent to 40–60W old incandescent bulb — very bright for its size!)

3.3.13.1 Key Features

Instant on, no warm-up time

Very low heat (runs cool even after hours)

Long life: 30,000–50,000 hours

Shockproof and vibration-resistant (no fragile filament)

Energy-efficient — uses 80–90% less power than traditional bulbs

Often waterproof or splash-proof (IP65 versions available)

- **Common Applications**

USB-powered desk lamps or night lights

Solar garden/fence lights

Camping lanterns and emergency lights

Car interior lighting (with USB adapter)

DIY projects, Arduino/Raspberry Pi mood lighting

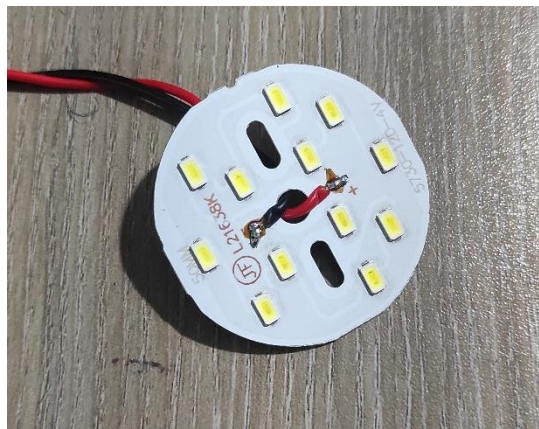


Figure 3.14: DC bulb

3.3.14 Bearing

- **Material & Construction**

Typically high-quality chrome steel (AISI 52100) rings and balls

Steel cage (pressed or machined)

Pre-lubricated with grease (lifetime lubrication in most cases)

3.3.15 Key Performance Specs

Handles both radial and moderate axial (thrust) loads

High rotational speed capability (due to deep groove design and single shield)

Low friction and quiet operation

Temperature range: usually -30°C to $+110^{\circ}\text{C}$ (grease-dependent)

Weight: $\approx 0.045\text{--}0.05$ kg (very lightweight)

- **Common Applications**

Electric motors, fans, pumps

Gearboxes, conveyors, agricultural equipment

Automotive (wheels, generators)

Power tools, skateboards, bicycles

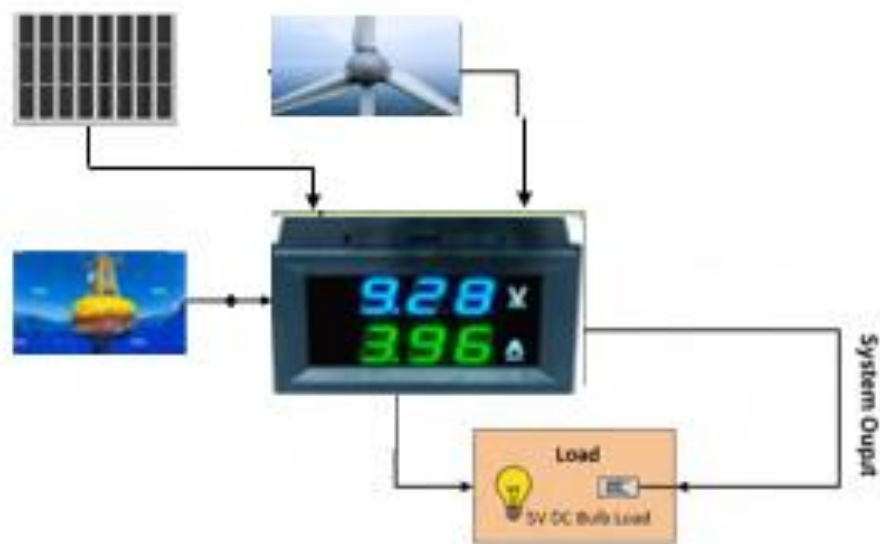
DIY projects, robotics, and light machinery



Figure 3.15: Bearing

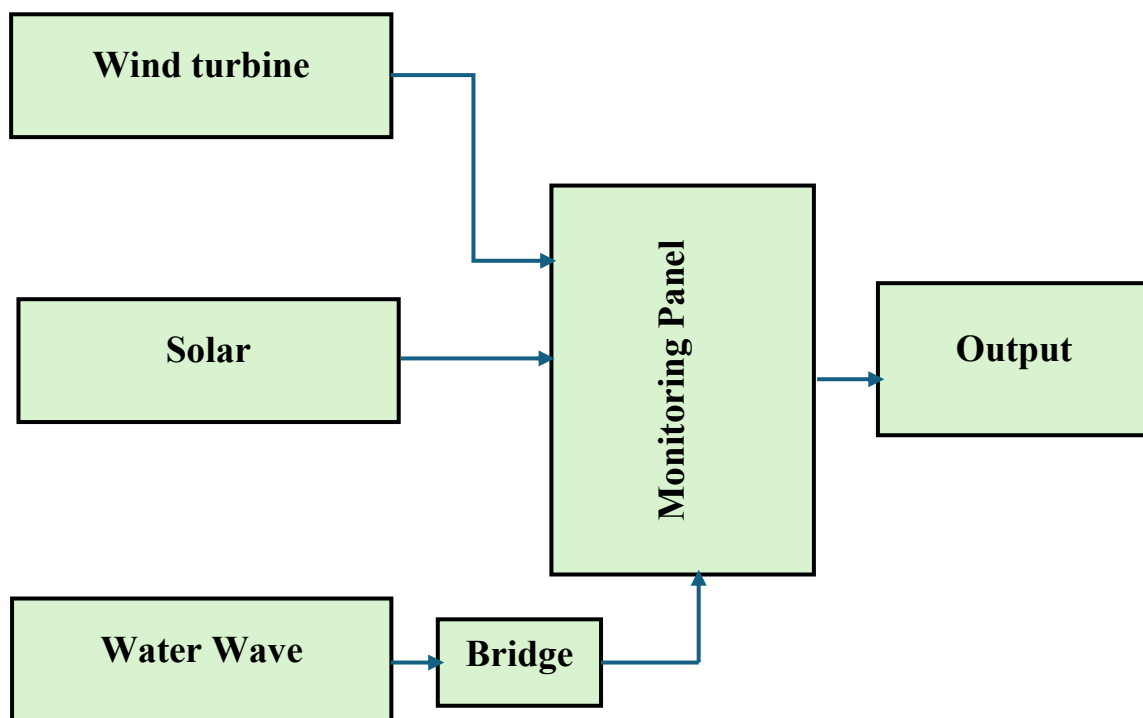
3.4 Circuit Diagram

Here we included the Circuit diagram of our proposed system. The system utilizes 2 solar panel to convert sunlight in to DC power. The generated voltage is directed to junction board, from where supplies to load. 2 wind turbine also generated power and directed to junction board. From wave, 2 generator generate AC power and converted into DC by rectifier bridge connection and also directed to junction board. All power combined in junction board and supplied to load. Digital display attached for real time monitoring the generated power.



3.5 Block Diagram

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3.6 Full overview

This is the Full overview of our Proposed system.



Figure 3.16: Buoy device part of our proposed system



Figure 3.17: Monitoring part of our proposed system



Figure 3.18: Solar and wind turbine part of our proposed system



Figure 3.19: Full overview of our proposed system

3.7 Applications

The key applications of this Project include:

- ✓ **Improved Efficiency:** This system generates electricity by using 3 common nature source solar, wind, wave. Leading to greater overall energy efficiency than single-source systems.
- ✓ **Reduced Fossil Fuel Reliance:** It offers a practical alternative to fossil fuels, encouraging the use of sustainable and environmentally friendly energy, thereby helping to combat climate change by lowering greenhouse gas emissions and decreasing dependence on limited fossil fuel reserves.
- ✓ **Continuous Power Supply:** Able to produce power all over the day and all over season. For combination of solar, wind and wave in every season power generation remains constant.
- ✓ **Coastal and Offshore Power Supply:** Provides continuous renewable electricity for coastal villages, offshore platforms, and island regions.[17]
- ✓ **Marine Navigation and Safety Systems:** Can be used to power lighthouses, buoys, navigation lights, and marine warning systems.
- ✓ **Remote and Isolated Areas:** Suitable for locations where grid power is unavailable or unreliable, ensuring all-time energy supply.
- ✓ **Emergency and Disaster Power Systems:** Can serve as a backup power source during natural disasters when conventional power systems fail.
- ✓ **Aquaculture and Marine Monitoring Systems:** Supplies power for sensors, monitoring equipment, and automation in fish farms and marine research stations.

3.8 Cost Analysis

Product Name	Quantity	Price	Total
Solar Panel	2	750	1500
Generator	4	125	500
Turbine Blade	2	70	140
Stainless steel pipe	1	350	350
Fiber shaft	1	500	500
Gear with belt	1	400	400
Bearing	2	50	100
Pulley with belt	2	50	100
Monitoring display	4	75	300
Switch	4	10	40
LED	3	5	15
DC bulb	1	50	50
Supporting wheel	1	100	100
Channel	1	100	100
PVC pipe	1	50	50
1"×1" Angle bar	3	600	1800
Plywood board	1	1500	1500
Thermocol	1	470	470
Battery	1	100	100
Diode	6	2	12
Resistor	3	2	6
Connecting wire	Required	450	450
Screw and Clamp	Required	200	200
Others cost	As needed	1500	1500
		Total=	10283/=

Table 3.1: Cost analysis

RESULTS & DISCUSSION

4.1 Data Sheet

The experimental evaluation of the tri wave power generation was carried out under typical daytime conditions to assess its performance of electrical output. The system demonstrated efficient integration of both solar and wind turbine, water wave manually created. The ambient temperature of our testing time period was 28 degree celsius to 35 degree celsius. Wind created by fan and velocity range was 2.7 m/s to 4.7 m/s.[18] Wind measured by digital Anomometer. Peak solar power voltage 6.82v. With load the peak voltage was 4.3V and 0.42A. By creating 4.2 m/s wind flow, voltage rating from wind turbine was 4.2V. With load the voltage was 3.5V and 0.04A. For every 5 cm wave fluctuation voltage gain from buoy device system was 1.2V. Combined power generation at peak time was 4.4V and 0.5A.

4.1.1 Experimental Setup Parameters

Parameter	Value/Description
Location	(Dhaka, Bangladesh)
Date & Time of Test	15-01-2026, Start–End Time (10:00 AM – 3:00 PM)
Solar Irradiance (Peak)	450–800 W/m ²
Ambient Temperature	28–35 °C
PV Panel Rating	5V / 3W
DC Bulb	5V / 3W
Turbine Type	Wind turbine (NACA 0012 series blade)
Wave power generator	12V DC generator
Monitoring system	Digital display monitor

Table 4.1: Experimental Setup Parameters

4.1.2 Electrical Output Performance

Time (HH:MM)	Solar Voltage (V)	Turbine Voltage (V)	Wave generator voltage (V)	Output Load Status
10:00	3.8	3.5	1.2	Medium
10:30	4.0	3.5	1.2	Medium
11:00	4.2	3.5	1.2	High
11:30	4.3	3.5	1.2	High
12:00	4.3	3.5	1.2	High
12:30	4.3	3.5	1.2	High
13:00	4.3	3.5	1.2	High
13:30	4.3	3.5	1.2	High
14:00	4.3	3.5	1.2	High
14:30	4.3	3.5	1.2	High
15:00	4.1	3.5	1.2	High
15:30	4.0	3.5	1.2	Medium
16:00	3.9	3.5	1.2	Medium

Table 4.2: Electrical Output Performance Data

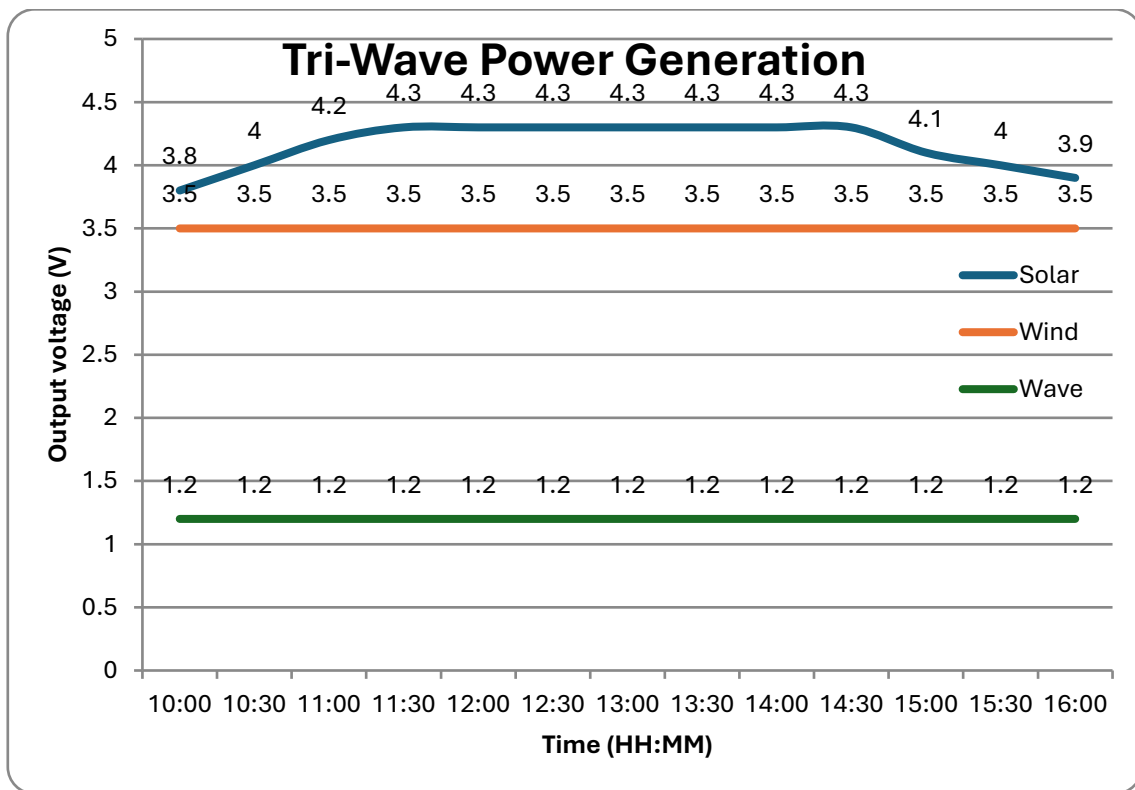


Figure 4.1: Electrical Output Performance Data Curve

4.2 Result

Here we will show the operational output of our proposed system.

4.2.1 Solar output:

$$\text{Average voltage} = (4.3+3.8)/2 = 4.05\text{V}$$

$$\text{Average Current} = (0.42+0.28) = 0.35\text{A}$$

$$\text{Average Power} = 4.05 \times 0.35 = 1.42\text{W}$$

4.2.2 Wind turbine output:

$$\text{Voltage} = 3.5\text{V}$$

$$\text{Current} = 0.04\text{A}$$

$$\text{Power} = 0.14\text{W}$$

4.2.3 Wave generator output:

$$\text{Voltage} = 1.2\text{V}$$

$$\text{Current} = 0.04\text{A}$$

$$\text{Power} = 0.048\text{W}$$

4.2.4 Combined output: -

$$\text{Solar+Wind+Wave} = (1.42+0.14+0.048) = 1.608\text{W}$$

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

The Tri-Wave Power Generation project successfully demonstrates the feasibility of generating continuous and reliable renewable energy by integrating solar, wind, and sea wave power into a single hybrid system. By utilizing multiple natural energy sources available in marine environments, the system effectively overcomes the limitations of single-source renewable power generation, such as intermittency and seasonal dependency.[19]

The project highlights the importance of hybrid energy integration for achieving all-time power generation regardless of weather conditions or time of day. Solar and wind energy contribute directly to power output, while wave energy, processed through a diode bridge rectifier, ensures consistent DC supply. The inclusion of voltage and current monitoring devices enables real-time performance evaluation, and the DC load demonstrates practical power utilization.

Design considerations addressing marine challenges such as saltwater corrosion, strong winds, and cyclonic conditions improve system reliability and durability. Overall, the tri-wave system proves to be a sustainable, eco-friendly, and efficient solution for coastal and offshore energy needs.

This project concludes that tri-wave hybrid power generation has strong potential for future development and large-scale implementation, contributing significantly to clean energy production and reduced dependence on fossil fuels.

5.2 Future Scope

✓ **Physical Prototype Development and Experimental Validation**

Conduct scaled model testing in a wave basin or wind tunnel facility to verify hydrodynamic performance, structural integrity under combined wind-wave loads, and power output complementarity.

✓ **Incorporation of Energy Storage and Advanced Power Management**

Integrate battery energy storage systems (BESS), supercapacitors, or emerging technologies like green hydrogen production to store excess energy during peak generation periods. An intelligent energy management system (EMS) using AI/ML algorithms could optimize power flow, predict resource variability, and further improve uptime beyond 95%, enabling seamless grid integration or island-mode operation.

✓ **Enhanced Resilience Features for Extreme Marine Conditions**

Develop advanced cyclone-resistant enhancements, such as adaptive damping systems, active mooring controls, or shape-morphing structures. Future iterations could incorporate materials with superior fatigue and corrosion resistance (e.g., advanced composites or self-healing coatings) and conduct long-term fatigue analysis under climate-change-amplified storm scenarios.

✓ **Multi-Use Platform Integration (Multi-Purpose Offshore Hubs)**

Explore co-location with other marine activities, such as offshore aquaculture (e.g., fish farms powered by Tri-Wave output), desalination units, or monitoring stations. Modular "floating energy islands" could combine Tri-Wave with additional sources (e.g., tidal currents or floating PV arrays) to maximize ocean space utilization and create hybrid marine hubs.

✓ **Economic and Environmental Impact Assessment**

Perform detailed levelized cost of energy (LCOE) analysis, life-cycle assessment (LCA), and environmental impact studies (e.g., marine ecosystem effects, biofouling mitigation). Techno-economic modeling for cyclone-prone regions (e.g., Bay of Bengal, South China Sea) would quantify viability for coastal/island microgrids and guide policy recommendations.[20]

✓ **Scaling and Commercial Deployment Pathways**

Investigate larger-scale arrays (e.g., 10–100 MW farms) with shared infrastructure for cost reduction. Collaborate with industry partners for pilot deployments in suitable sites, leveraging global trends toward floating hybrid renewables and multi-source parks. Future work could also explore grid-tie inverters, subsea cabling, and regulatory frameworks for offshore hybrid systems.

✓ **Technological Upgrades and Emerging Synergies**

Upgrade subsystems with next-generation components: higher-efficiency PV panels, optimized VAWT designs for turbulent marine winds, or bidirectional Wells turbines for improved wave-to-power conversion. Explore synergies with floating offshore wind trends, such as deeper-water semi-submersible platforms or AI-driven predictive maintenance.

5.3 Advantages:

The system offers these benefits:

- Continuous Power Generation
- Efficient Use of Natural Resources
- Reduced Power Intermittency
- Environment Friendly
- Suitable for Marine and Coastal Areas
- Low Operating Cost
- Energy Security for Remote Areas

5.4 Disadvantages

The system presents several drawbacks:

- High Initial Installation Cost
- Complex System Design
- Maintenance Challenges
- Exposure to Extreme Weather
- Power Output Variability
- Limited Small-Scale Capacity

5.5 Environmental and Social Impacts

5.5.1 Environmental Impacts

Category	Impact Type	Details
Air Quality	Positive	100% reduction in greenhouse gases during use.
Water Quality	Neutral/Minor	Potential for leaching if materials aren't properly coated.
Biodiversity	Mixed	Creates new habitats but may disrupt local seafloor balance.
Waste	Negative	Battery and electronic waste require specialized recycling.

Table 5.1: Environmental Impacts

5.5.2 Social Impacts

Category	Social Benefit	Target Group
Education	Night-time study through LED lighting	Students in remote areas
Safety	Reduced maritime accidents via beacons	Small-scale fishermen
Economy	Preservation of food/medicine via refrigeration	Local businesses & clinics
Communication	Constant power for mobile/radio stations	The general public

Table 5.2: Social Impacts

5.5.3 Positive Impacts (Overall Benefits)

- **Hybrid Efficiency:** Solar, Wind, Wave
- **Cost-Effectiveness:** Uses affordable, locally available materials (copper, mirrors, Arduino).
- **Scalability:** Modular design supports both household and community microgrid applications.
- **Resilience:** Provides reliable backup power in blackouts.
- **Climate Alignment:** Supports SDG 7 (Affordable & Clean Energy) and SDG 13 (Climate Action).

5.5.4 Quantitative Insights

Metric	Value
PV Panel Output	4.1 – 5.0 V (regulated)
Wave Generator Voltage	Upto 6.0 V
Turbine Voltage	Up to 6.0 V
CO ₂ Saved	500–800 kg/year (medium-scale unit, ~6h/day operation)

Table 5.3: Quantitative Insights

5.5.5 System Components & Material Impacts

Component	Material Impact	Risk/Challenge
PV Panels	Silicon, aluminum	High embodied energy in production.
Stainless steel	High recyclability	Mining impact.
Mirrors/Reflectors	Aluminum/Glass	Energy-intensive manufacturing.
Electronics (Diode, Resistor, Display)	Silicon, rare earth elements	E-waste generation if not recycled.
Battery	Lithium-ion or lead-acid	Toxic waste risk, limited lifespan.

Table 5.4: System Components & Material Impacts

5.5.6 Mitigation Strategies

1. Battery Management

- Shift to **LiFePO₄ batteries** (longer life, safer disposal).
- Establish recycling programs.

2. Water Management

- Closed-loop steam-condensate recovery.
- Smart pump algorithms to minimize waste.

3. Materials & E-Waste

- Modular, repairable design to extend lifespan.
- Encourage **local recycling chains** for PV and electronics.

4. Operational Sustainability

- Use AI/ML for predictive maintenance (reduce failures).
- Ensure training for safe handling of hot/pressurized components.

5. Scaling & Policy

- Subsidies/grants for rural deployment.
- Integration with microgrids for wider impact.

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