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THESIS

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Speciality: - renewable energy in electrical engineering

- Industrial electrical engineering

Presented by

- YAHI NADIA
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Subject title

Design of a Wave Energy Converter for Maritime Markers

Supported in 09 July 2024 in front of the jury:

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His passion for the subject and commitment to excellence inspired us to push our boundaries and strive for the best

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The summary:

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List of abbreviations and symbols

OWC: oscillating wave columns

DOP: department of energy

PTO: power take off

OAF: oscillating arm floating

WEC: wave energy converter

IALA: international association of maritime aids to navigation and lighthouse authorities

LED: light emitting diode

IOT: internet of things

EMF: electromotive force

ESP 32: espressif systems

CPU: central processing unit

IMU: inertial measurement unit

IDE: integrated development environment

Abstract:

This project focuses on harnessing wave energy to power maritime markers for signalization in marine environments. A wave energy converter (WEC) prototype is developed, utilizing electromagnetic induction to convert the kinetic energy of ocean waves into electrical power. The WEC consists of a buoyant PVC tube housing magnets and a coil wrapped around its exterior. As the tube moves with the waves, the magnets induce an electric current in the coil through electromagnetic induction. The generated electricity is used to power maritime markers, enhancing safety and navigation aid at sea. To enable remote operation and monitoring, an ESP32 microcontroller is integrated with a Lora WAN communication protocol. This setup allows for efficient command and data transmission between shore-based stations and the maritime markers deployed at sea. Additionally, a gyroscope sensor is employed to track the orientation and movement of the markers, providing essential operational data.

This project combines renewable energy generation with advanced IoT technology, demonstrating a sustainable approach to maritime signalization and navigation in coastal and offshore environments

Key words:

WEC – maritime markers- electromagnetic induction- renewable energy- IOT

Résumé :

Ce projet se concentre sur l’exploitation de l’énergie des vagues pour alimenter des marqueurs maritimes pour la signalisation dans les environnements marins. Un prototype de convertisseur d'énergie houlomotrice (WEC) est développé, utilisant l'induction électromagnétique pour convertir l'énergie cinétique des vagues océaniques en énergie électrique. Le WEC se compose d'un tube flottant en PVC abritant des aimants et d'une bobine enroulée autour de son extérieur. Lorsque le tube se déplace avec les ondes, les aimants induisent un courant électrique dans la bobine par induction électromagnétique. L'électricité produite est utilisée pour alimenter les balises maritimes, améliorant ainsi la sécurité et l'aide à la navigation en mer.

Pour permettre le fonctionnement ET la surveillance à distance, un microcontrôleur ESP32 est intégré à un protocole de communication LoRaWAN. Cette configuration permet une transmission efficace des commandes ET des données entre les stations terrestres et les marqueurs maritimes déployés en mer. De plus, un capteur gyroscope est utilisé pour suivre l’orientation et le mouvement des marqueurs, fournissant ainsi des données opérationnelles essentielles.

Ce projet combine la production d'énergie renouvelable avec une technologie IoT avancée, démontrant une approche durable de la signalisation maritime et de la navigation dans les environnements côtiers et offshore.

<u>Mots clés :</u>

Énergie renouvelable- technologie IOT- signalisation maritime- induction électromagnétique- ESP32

الملخص:

يركز هذا المشروع على استغلال الطاقة الغامضة لتغذية العلامات البحرية للإشارات في البيئات البحرية. تم تطوير نموذج أولي لمحول الطاقة الحركية(WEC) ، باستخدام الحث الكهرومغناطيسي لتحويل الطاقة السينمائية من المحيطات الغامضة إلى طاقة كهربائية. يتكون WEC من أنبوب عائم من مادة PVC مقطوعة للأهداف وكرة يتم لفها على السطح الخارجي. عندما يتحرك الأنبوب بين الأضواء، يحث الهدف تيارًا كهربائيًا في البكرة بواسطة الحث الكهرومغناطيسي. يتم استخدام الكهرباء المنتجة لتغذية الغواصات البحرية وتحسين الأمن والمساعدة في الملاحة في البحر.

للسماح بالوظيفة والمراقبة عن بعد، تم دمج وحدة التحكم الدقيقة ESP32 مع بروتوكول اتصال LoRaWAN. يتيح هذا التكوين إرسالًا فعالاً للأوامر والبيانات بين المحطات الأرضية والعلامات البحرية المنتشرة على البحر. بالإضافة إلى ذلك، يتم استخدام ملتقط جيروسكوب لمتابعة الاتجاه وحركة العلامات، بالإضافة إلى البيانات التشغيلية الأساسية.

يجمع هذا المشروع بين إنتاج الطاقة المتجددة وتقنية إنترنت الأشياء المتقدمة، ويخلق نهجًا مستدامًا للإشارات البحرية والملاحة في البيئات الساحلية والبحرية.

الكلمات المفتاحية:

الطاقة المتجددة-تكنولوجيا IOT-الإشارة البحرية-الحث الكهرومغناطيسي-ESP32

General Introduction

General introduction

Wave energy is a promising energy production resource that harnesses the natural power of the oceans in an environmentally friendly way. Its importance lies in its ability to diversify the energy mix, reduce greenhouse gas emissions and stimulate the local economy. This renewable source also offers opportunities for sustainable development and job creation while contributing to the fight against climate change. Wave energy conversion is the process of harnessing the energy generated by ocean waves and converting it into a usable form of energy, such as electricity. This renewable energy source harnesses the vast and powerful movement of water in the Earth's oceans to provide a sustainable alternative to fossil fuels. The principle of wave energy conversion is to capture the kinetic and potential energy existing in waves through various technologies and mechanisms.

The principle of maritime buoyage is crucial to safe navigation at sea. Standardized markings are used to guide ships and mark hazards. The system has evolved over centuries and includes buoys, lights and beacons that convey important information to sailors. International standards such as the IALA offshore buoy system ensure consistency and safety in a variety of offshore environments. Maritime Focus plays a key role in improving the efficiency and reliability of the global maritime network. Its development reflects an ongoing commitment to maritime safety and navigational excellence.

Integrating energy conversion technologies into sea buoys not only solves many existing problems, but also contributes to the creation of sustainable and environmentally friendly navigation systems. This innovation will enable the buoy to generate energy from ocean waves, reducing dependence on traditional energy sources and reducing operating costs. It will also increase the power and efficiency of transportation vehicles, improve the functioning of seawater and contribute to changing the world in search of energy.

We will divide our works into five chapters:

In chapter one we will see the state of art on wave energy its characteristics, its revolution and advantages and disadvantages.

In the second one: we will discuss the principles of wave energy conversion and we will see the types of converters

In the third one: we will have a look on the maritime markers, its importance, the different types …

For the fourth one: here we will see the design of our wave converter using the electromagnetic induction

For the last chapter we will discuss the results of the test of our converter

At the end, we will end this dissertation with a general conclusion and Perspective

Chapter one
State of art on wave energy

I.1. Introduction:

Wave energy is a promising energy production resource that harnesses the natural power of the oceans in an environmentally friendly way. Its importance lies in its ability to diversify the energy mix, reduce greenhouse gas emissions and stimulate the local economy. This renewable source also offers opportunities for sustainable development and job creation while contributing to the fight against climate change. In this chapter, we will see a general information about the wave's energy and it importance.

I.2. Renewables energies:

Renewable energy refers to energy that is obtain from naturally renewable sources such as sunlight, wind and water. Its importance lies in its sustainability, providing cleaner alternatives to fossil fuels, reducing greenhouse gas emissions and combating climate change. Renewable energy is abundant, available and used locally, promoting energy independence and security. The use of renewable energy can promote innovation, create jobs and stimulate economic growth while mitigating environmental impacts. As an important part of the transition to a more sustainable future, renewable energy plays a crucial role in shaping a greener and more resilient energy landscape.

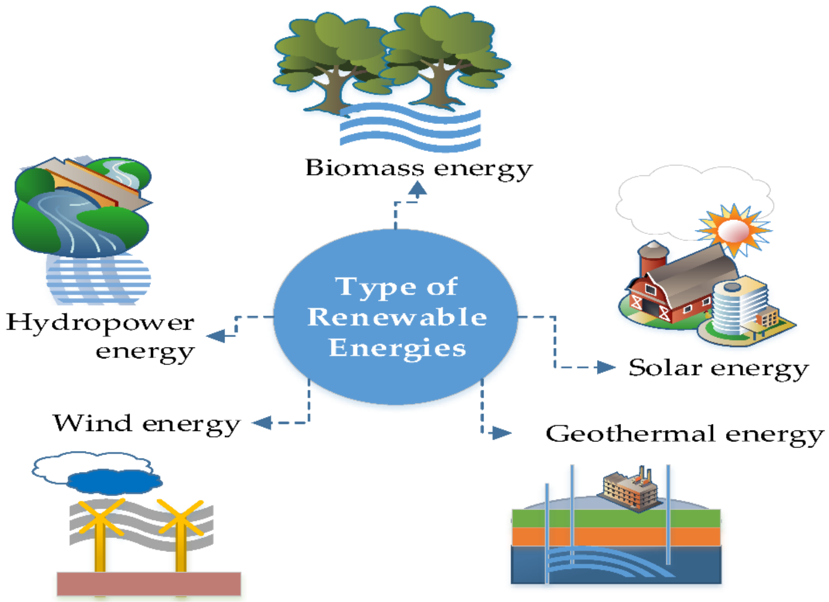


Figure I.1: types of Renewable energies

I.3.Evolution of global production of renewable energies:

The world production of marketed energy was in 2020, according to BP (British Petroleum Company) (see Figure I.1), 556.6 exa joules, and an increase of 10.1% since 2010. It was divided into 31.2 % oil, 27.2% coal, 24.7% natural gas, 4.3% nuclear and 12.6% renewable energy (hydroelectricity 6.9%, wind 2.5%, solar 1.00%, 4%, biomass and geothermal energy 1.1%, agro- fuels 0.7%) [1]

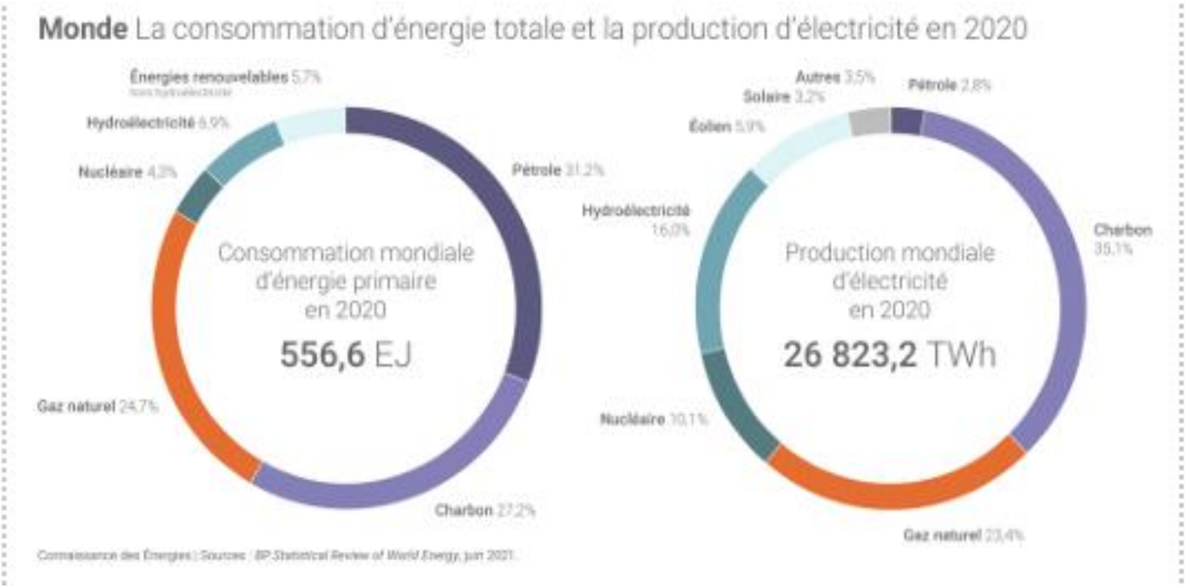


Figure .I. 2: Evolution of global production of renewable energies

I.4Waves energy

Wave energy is a special form of solar energy. The sun heats the different atmospheric layers, creating winds that, through friction, create movements and animate the sea surface (currents, waves). The waves that the wind creates on the surface of the sea transport energy. When they encounter an obstacle, they release some of this energy, which can be converted into electrical current.

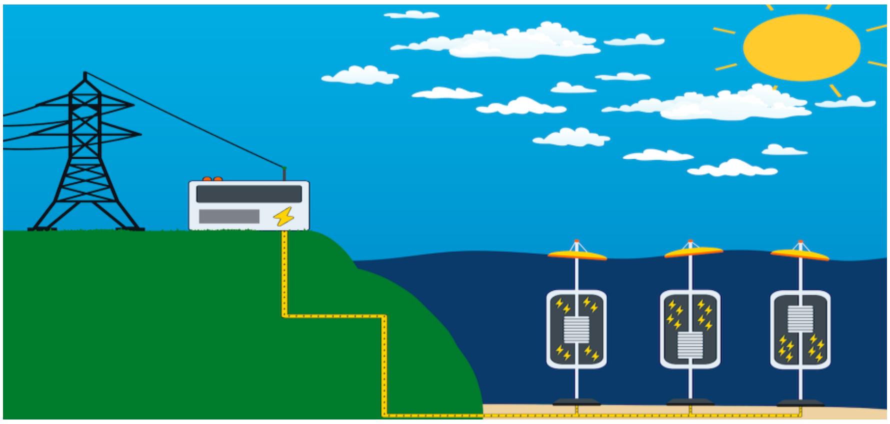


Figure I.3: Wave’s energy system

I.5 Wave’s energy history:

The first system for recovering wave energy appeared in the 18th century. This was the subject of a fifteen-year patent for invention on July 12, 1799 by Mr. GIRARD father and son entitled “For various means of using sea waves as motors”. In 1885, Don Jose Barrufet, a Spanish inventor, patented a device called "Marmotor", a series of buoys floating in the ocean whose undulatory up-and-down movement generated by the driving force of the waves is transformed through mechanical structures and from a generator into electricity. In 1965, Yoshio Masuda, a Japanese naval officer, invented the first “oscillating water column” (QWC) converter intended for powering buoys or offshore installations. With studies carried out since the 1940s, he is considered the father of modern wave energy harvesting technologies. The principle of its converter, based on an air turbine, has been used for the installation of more than a thousand navigation buoys throughout the world. In response to the oil crisis, research in the field of wave energy extraction began in earnest in the 1970s in several countries. In Japan, after the success of the Masuda air turbine buoys, the JAMSTEC (Japan Marine Science and Technology Center) created in 1971, built in 1976 the first floating prototype of a large-scale converter to be deployed offshore.

The KAIMEI is a large barge measuring 80 by 12 meters used in 1978 and 1979 as a test platform with up to nine OWCs on board equipped with different air turbines. From 1975 to 1982, the British government authorized a major research and development program into wave energy, led by Clive Grove-Palmer. The Department of Energy (DOE) financially supports several projects during this period: - The “Duck” by Stephen Salter; - The “NEL OWC”, a water column system developed by the National Engineering Laboratory (NEL) in East Kilbride in Scotland; - The “wave-contourig raft” commonly called “Cockerell raft”, an articulated float (or raft) developed by Sir Christopher Cockerell, British engineer. This first generation of systems was overwhelmingly shoreline, the major drawbacks being their visual impact and the obligation to adapt to the coastal topology. [2]

I.6 Wave energy characteristics:

Wave energy refers to the energy carried by ocean waves as they move across the surface of the water. The characteristics of wave energy can vary depending on several factors, including the following:

1.6.1. Wave Height:

The height of a wave, measured from the trough to the crest of the wave, is a defining characteristic of wave energy. Larger waves generally carry more energy than smaller ones.

1.6.2. Wave Period:

The period of a wave is the time it takes to complete a wave cycle. Waves with longer periods typically carry more energy than those with shorter periods.

1.6.3 Wave Speed:

The speed at which a wave moves through water. Wave speed is determined by factors such as wind speed, water depth and wave wavelength.

1.6.4 Wave frequency:

The number of wave crests that pass a fixed point per unit of time. Higher frequency waves generally carry more energy.

1.6.5 Wavelength:

The distance between two crests (or troughs) of consecutive waves. Longer wavelengths usually indicate waves with more energy.

1.6.6 Wave Power:

The speed at which waves transmit energy. It depends on the height, period and speed of the wave.

1.6.7 Direction:

The direction from which waves approach a particular point. Wave energy devices often need to be designed to efficiently capture the energy of waves coming from different directions.

1.6.8 Seasonal and Geographical Variability:

Wave energy characteristics may vary depending on the season, geographic location and prevailing weather conditions.

1.6.9 Wave spectrum:

Distribution of wave energy at different frequencies and wavelengths. Waves can be divided into different spectral components based on their properties.

1.6.10 Interference and Interaction:

Waves can interfere with each other, resulting in complex patterns of energy distribution and interaction. This interference can affect the overall wave energy properties in a given area.

I.7 wave energy potential:

Wave energy represents enormous potential in the global energy mix. In fact, 71% of the Earth's surface is covered by the sea or ocean! The World Energy Council estimates that 10% of the world's annual electricity needs could be met by wave energy. However, not all countries have the same potential: certain regions such as the North Atlantic are particularly well suited for the recovery of wave energy. In mainland France, the potential is estimated at 40 TWh/year, mainly on the Atlantic coast (10 to 15 GW).

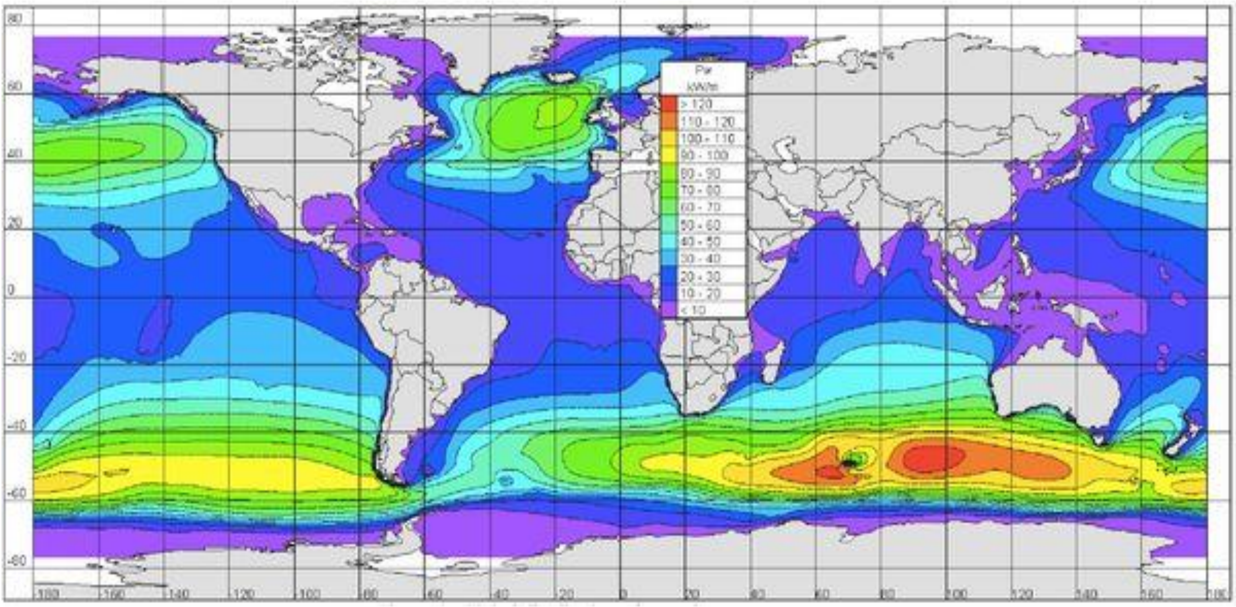


Figure I. 4: Global distribution of the wave energy resource

I.8 Advantages and disadvantages:

I.8.1Advantages of wave energy [3]

1. Zero emissions

- Inherently, wave energy does not emit greenhouse gasses when generated, as fossil fuels do.
- Turbines generate electricity through the power of waves, making them a completely pollution-free, renewable energy source.
- If we can get the technology right, tidal power can be a huge part of the green energy mix, complementing solar power, wind turbines, geothermal, and hydropower.

2. Renewable

- Like all alternative energy sources, wave power is renewable.
- Waves are created by wind, and wind is caused by uneven heat on the planet's surface driven mostly by the sun warming different locations at different rates.

- Wind moves heat energy from one part of the planet to another, which causes waves to form. Because wind will always exist, waves will always be available at the surface of the water to generate electricity, making this a renewable source.

3. Enormous energy potential

- For example, an average 4-foot, 10-second wave can put out 35,000 horsepower per mile of coast. The ocean provides a lot of potential for energy production because it is constantly moving and generating energy.
- There is also a lot of potential because many countries have access to an ocean that can help power their electric grids.

4. Reliable energy source

- Waves are hardly interrupted and usually in motion. This makes electricity generation from wave energy a more reliable energy source compared to wind power, since wind is not constantly blowing.
- It should be noted that the amount of energy that is being transported through waves does vary every year, and from season to season. Generally, waves are more active in the winter because of the increased wind, which is due to colder temperatures.

I.8.2 Disadvantages of wave energy:

1. Environmental effects

- Because wave energy is still in its infancy, mostly in research, there is no measure of the environmental effects of large-scale power stations on the shore.
- Building plants or electrical wires directly on the beach might prove challenging because they would be unsightly and can cause damage to marine life and the surrounding ecosystems.
- Local fishing zones could be affected or the plants could lead to more coastal corrosion. However, more research is needed to determine the true environmental impacts that wave energy plants could cause.

2. High costs

- Wave power is an emerging energy technology in the early stages of development, making speculating on costs difficult.
- Wave energy systems have the potential to be as cheap as $07.5 cents per kWh to build, but will depend on location and maintenance costs. However, now, the costs of wave power are generally very high because they are in the research phase of development and generally paid for by government grants or research grants. There are no energy companies utilizing wave energy at scale - something that would bring the cost down.
- Maintenance for these plants is projected to be very expensive because they will be submerged in constantly moving saltwater. Because constant movement can lead to more breaking, wave energy plants will most likely need regular (and costly) maintenance.

3. Hard to scale

- Perhaps the biggest con now is that no utility has the ability to install wave farms because they are not yet large enough to provide a significant amount of electricity.
- While some wave energy systems have been tested in Scotland, Hawaii, and most recently, Australia, their power generation capacity is only about 2.5MW at their peak. The industry is expected to grow, but it remains challenging to implement wave energy generators at a usable scale.

I.9.The future of wave energy [3]

- For many ocean-bordering countries, wave energy could be a great addition to the renewable energy mix.
- Waves would provide 24/7 energy that could be harnessed for clean electricity generation. Because wave energy is still in its early stages, it remains expensive to install and the potential environmental disadvantages are not yet known.
- The bottom line is that wave power has enormous global potential. However, the industry needs more funding and research to finalize the technology involved so that countries and utilities can begin adding wave energy to their renewable energy arsenal.

I.10: Conclusion:

In the conclusion, wave energy represents an important solution to our search for clean and sustainable energy sources. The benefits are many: it provides a constant and renewable energy supply, reduces carbon emissions and provides economic opportunities to local communities. Additionally, wave energy is geographically diverse, complements other renewable energies, and minimizes environmental impact. Harnessing wave energy not only fuels our transition to a low-carbon future, but also promotes innovation, economic growth and energy independence.

Chapter Two:

Principles of wave energy conversion

II.1. Introduction:

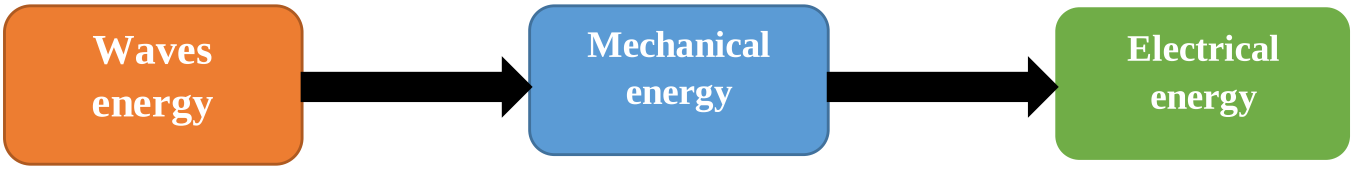
Wave energy conversion is the process of harnessing the energy generated by ocean waves and converting it into a usable form of energy, such as electricity. This renewable energy source harnesses the vast and powerful movement of water in the Earth's oceans to provide a sustainable alternative to fossil fuels. The principle of wave energy conversion is to capture the kinetic and potential energy existing in waves through various technologies and mechanisms.

II.2. The recovery of wave's energy:

Wave energy recovery represents a promising milestone in the field of renewable energy, providing a clean and abundant energy source with the potential to contribute significantly to global energy needs. Continuous research and development is essential to overcome current challenges and realize the full potential of wave energy as an important contributor to sustainable energy portfolios around the world.

II.3. General Structure of a wave energy conversion system:

The energy contained in wave motion is captured by many wave energy capture devices, such as mechanical energy on the surface (ripples) or underwater (translations or orbital movements), capturing variations in pressure when waves pass (variations in water height) or even the physical capture of a mass of water (via a reservoir). The energy of water movement transform into mechanical energy of rotation. Then, the torque present on the shaft powers an electric generator, which is then responsible for providing electrical energy via its stator winding. [4]



FigureII.1: Global distribution of the wave energy resource

II.4. waves energy conversion categories:[5]

Wave energy conversion is the process of converting the kinetic and potential energy present in ocean waves into usable forms of energy, such as electricity. This renewable energy source harness through various technologies, each with its own mechanism for capturing wave energy. Wave energy conversion methods can classify according to the principle of operation or location of the technology.

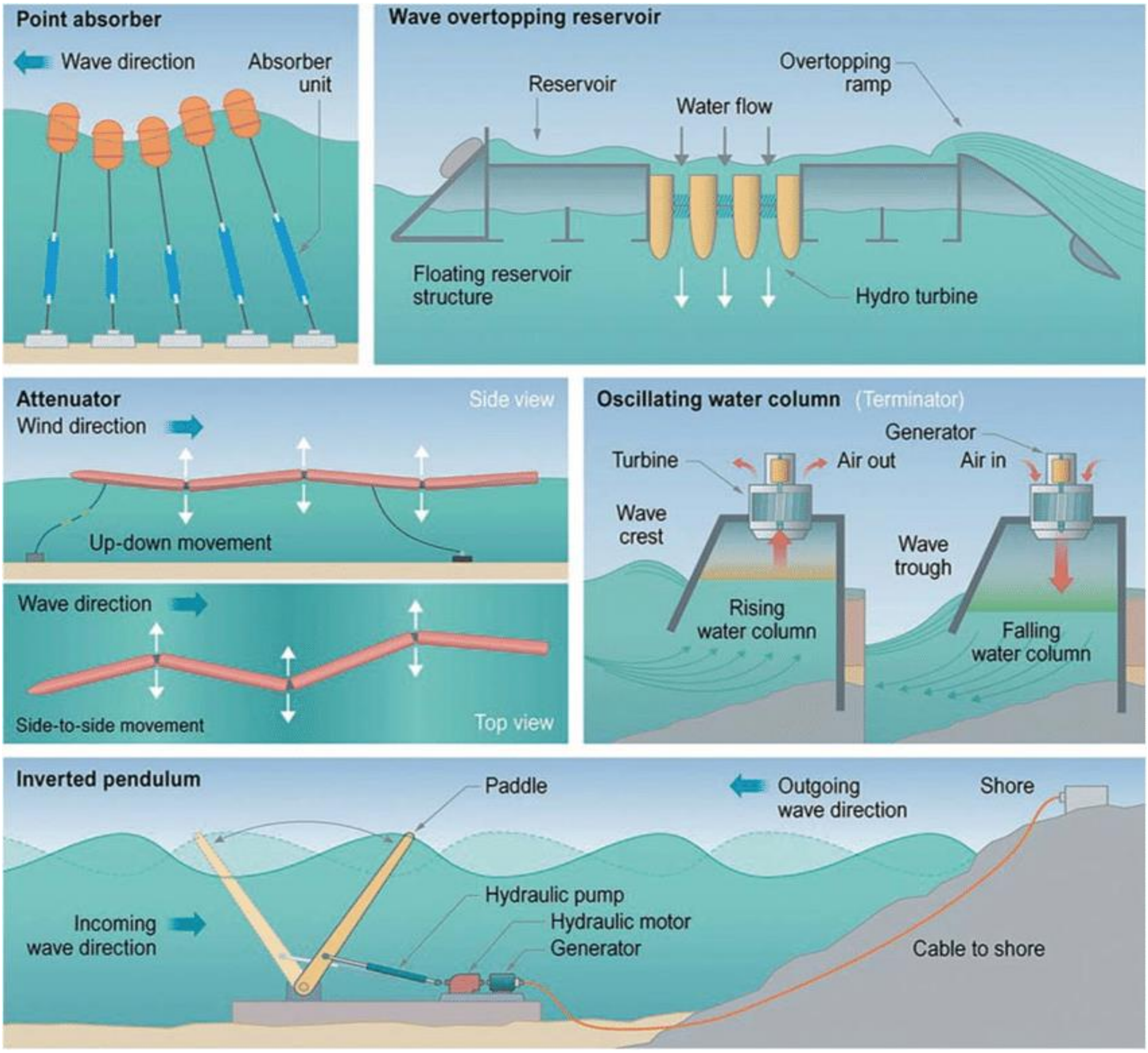


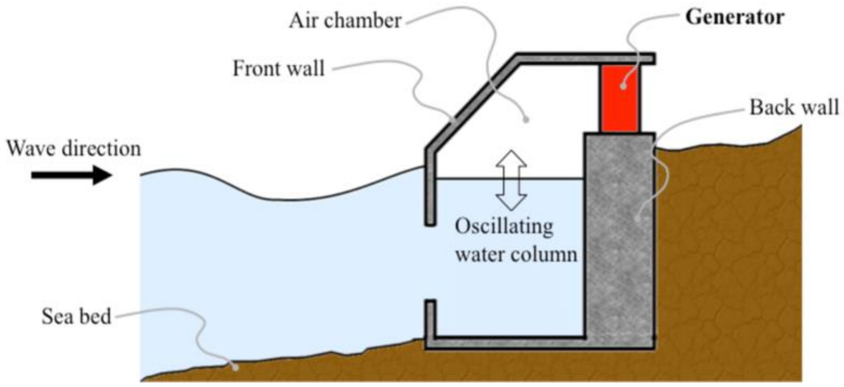
Figure II.2: Types of wave energy converters

Below is an overview of the main categories:

II.4.1 Hydraulic technologies:

II.4.1.1 Oscillating Water Columns (OWC)

An oscillating water column system refers to a method of harnessing wave energy through the oscillating movement of water within a chamber. As the waves enter the chamber, they compress and decompress the air inside, creating vibrations that can use to drive turbines and generate electricity.



FigureII.3:Oscillating Water Column Systems (OWC)

II.4.2. Mechanical technologies

II.4.2.1 Point absorbers

- **Principle:**

Point absorbers are buoy-like structures that float on the surface of the sea and absorb energy from all directions through their movements. The relative movement between the buoy and a fixed reference point use to drive hydraulic pumps or electrical generators.

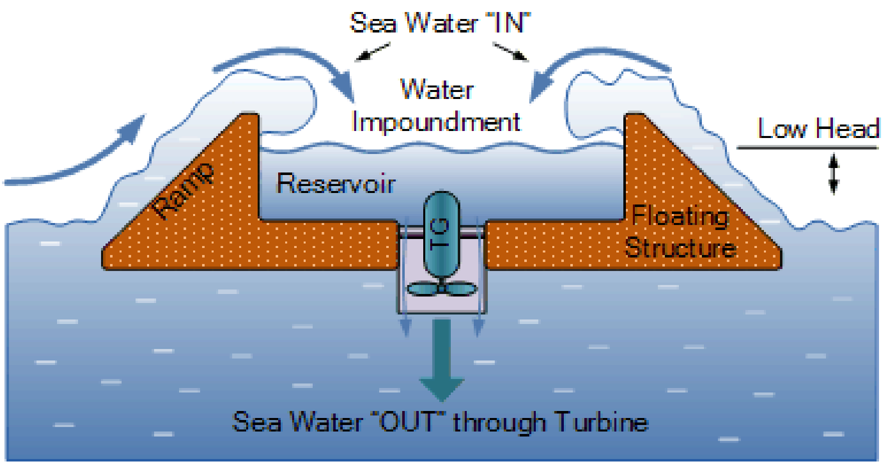
- **Location:**

Typically used offshore, these devices can anchor individually or in groups to maximize energy production.

FigureII.4: Point absorbers system

II.4.2.2 floating rotation systems:

Floating rotation systems are devices for capturing wave energy with floating structures equipped with rotating mechanisms. These systems use the kinetic energy of wave motion to drive turbines or other mechanisms, converting it into usable electrical energy.



FigureII.5: Floating rotation systems

II.4.3 Pneumatic technologies

II.4.3.1 Attenuators

- **Principle :**

Attenuators are long, multi-segment floating structures that align parallel to the direction of the wave. They bend at the joints as waves pass by, and this movement use to generate electricity.

- **Site :**

The offshore attenuators design to work with the prevailing wave direction and adapt to varying wave conditions

FigureII.6: Attenuators

II.4.3.2 Submerged Pressure Difference Principle:

This category includes devices that generate electricity from pressure differences created beneath the surface of the water by passing waves. A common type is the submerged plate or corrugated mat, which moves with shaft pressure fluctuations and drives a PTO system.

- **Location :**

These systems install beneath the surface of the water, often near the coast or on the seabed.

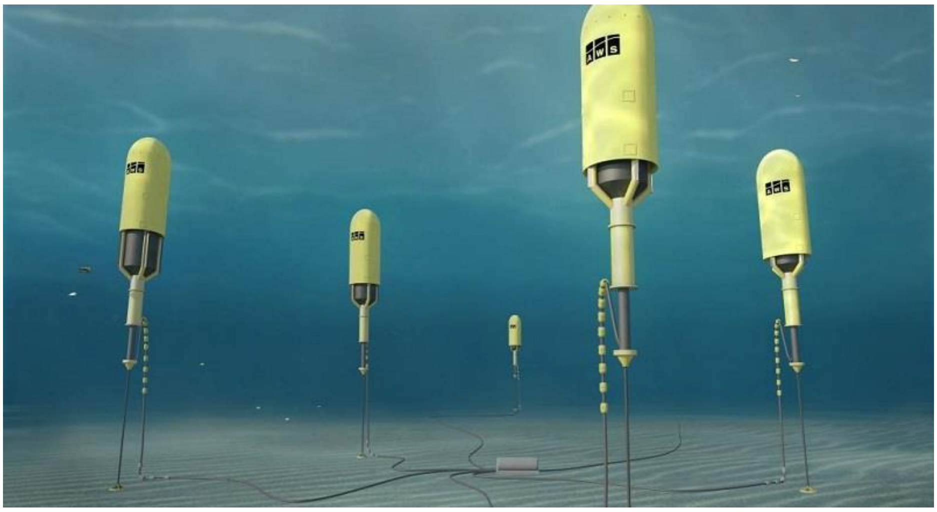
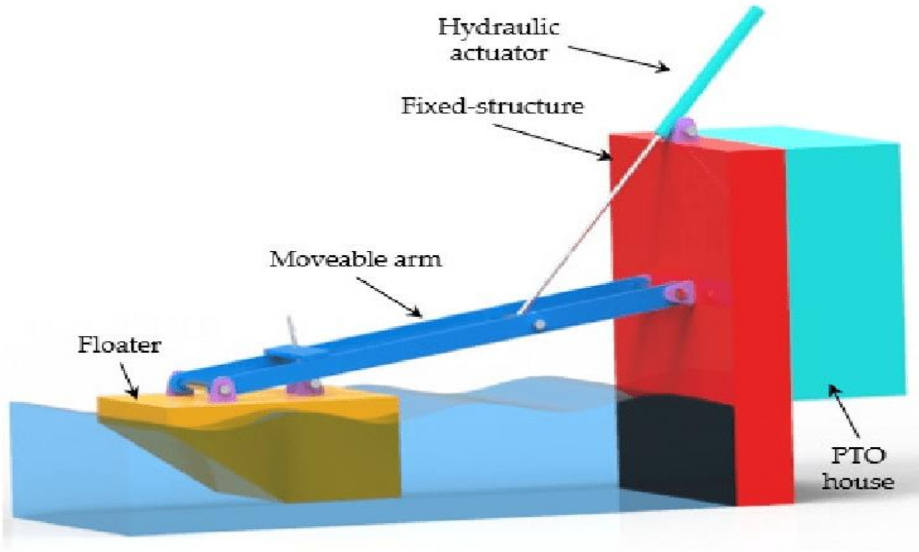


Figure II.7. Submerged Pressure Difference system

II.5 The floating arm system:

The oscillating arm-floating wave energy converter (OAF-WEC) is a wave energy conversion device that uses a floating oscillating arm to capture mechanical wave energy and convert it into electrical energy.

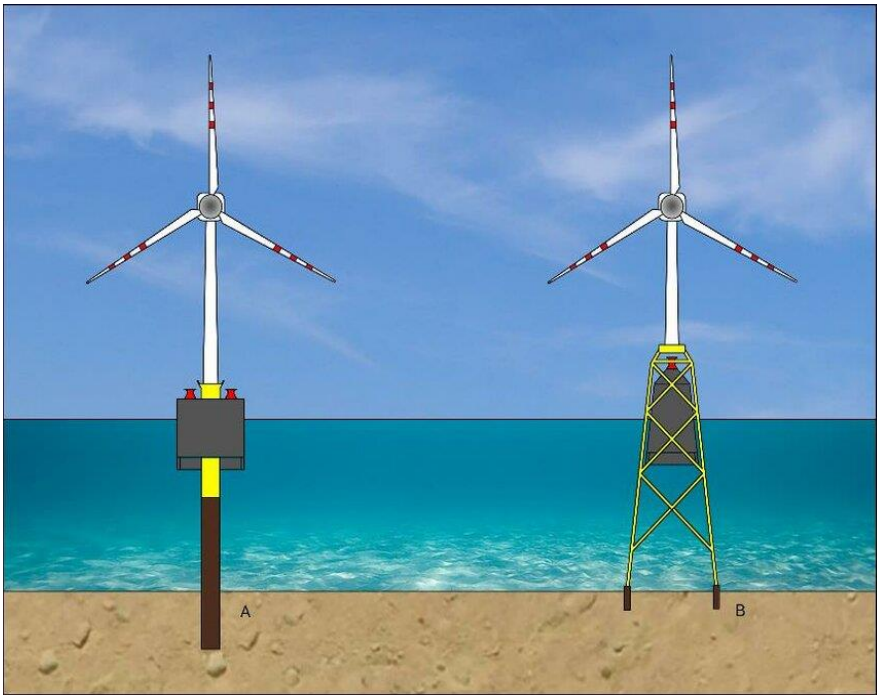
It is based on the oscillatory movement of the swimming arms in response to waves. As the waves pass by, the arms move up and down or back and forth, activating a conversion mechanism that converts this movement into mechanical energy.



FigureII.8: Example about the floating arm system

II.6. Wave energy converters combined with offshore wind

The main advantage of integrated wind power generation is shared infrastructure costs, especially foundations and grid connections. Hybrid power generation architectures that integrate WEC with offshore wind turbine generators or energy storage systems can be a promising solution for power quality improvement and sustainable electric power production. However, with the existing WEC techniques, the costs per kWh produced are still higher with a combined wind-wave application than with wind energy alone. Synergy benefits can also be sought through improved stability of the structure, for example in the case of an OWC wave energy converter integrated into an offshore wind turbine mono pile. Stability improvement can be a major benefit for designs in which the interaction between the wind and wave sub-structures is strong, as in the case of a WEC combined with a floating wind turbine. Wave energy converters can also reduce wave heights inside a wind farm, increasing in this way the weather windows to access the wind turbines. [5]



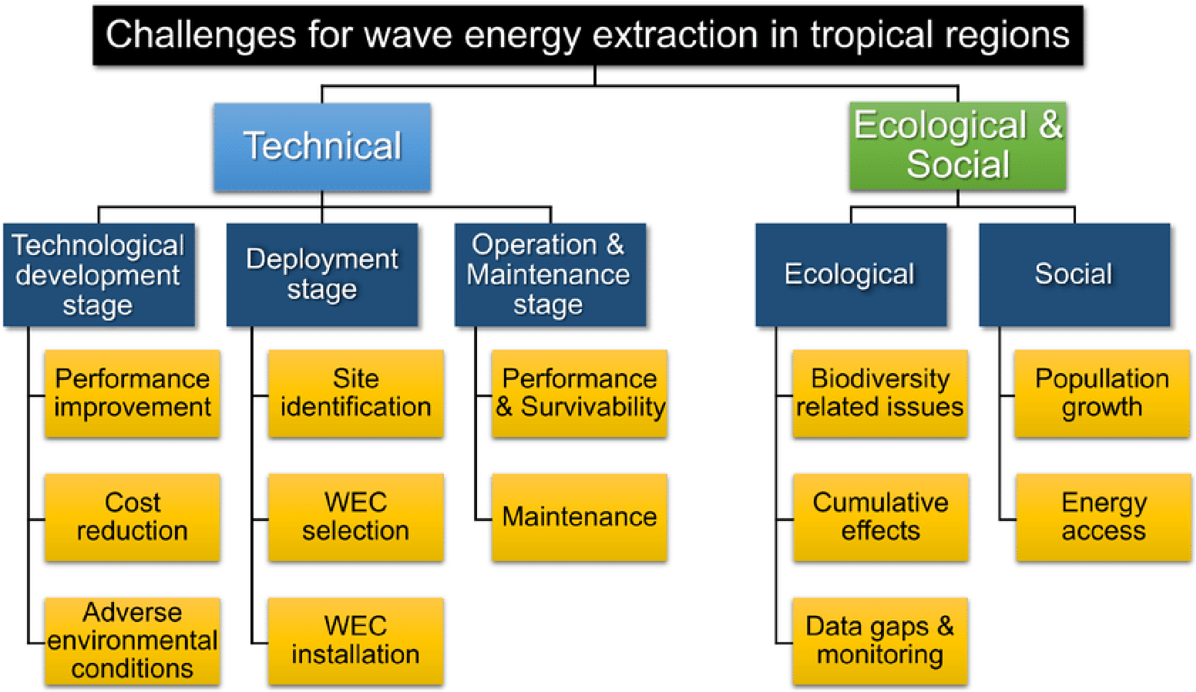
FigureII.9:Wave energy converters combined with offshore wind

II.7. Environmental influences of wave energy converters technologies:

The installation of WEC in coastal areas can have both positive and negative impacts on the environment. It can positively reduce greenhouse gas emissions and fossil fuel use by providing a clean, renewable energy source and improving biodiversity and marine habitats through the creation of coral reefs and artificial protected areas. Additionally, it can reduce coastal erosion and flooding by dissipating wave energy and protecting coastlines. However, it can also alter wave structure and currents by absorbing or reflecting wave energy, which can disrupt or harm marine life by producing noise, electromagnetic fields, or physical collisions. In addition, it can interfere with other marine uses and activities by taking up space, creating hazards or restricting access.

II.8. WAVE ENERGY AND ASSOCIATED CHALLENGES:

Wave energy, a renewable resource derived from ocean waves, faces several challenges. These include the variability of wave resources due to unpredictable weather conditions, the complexity of developing efficient wave energy conversion technologies, and the high capital costs associated with the design, implementation, and maintenance of wave energy devices. Waves. Environmental impacts such as disruption to marine ecosystems and the need for grid integration solutions due to intermittent power generation also pose challenges. Furthermore, the lack of standardized technologies and suitable deployment areas limits the widespread adoption of wave energy as a clean energy solution.



FigureII.10:challenges for wave energy

II.9. wave energy storage:

Wave energy storage systems are technologies for capturing, storing and using the energy generated by ocean waves. These systems are important because they help convert the kinetic energy of waves into a more stable and usable form of energy, contributing to the production of renewable and sustainable energy. These are some of the technologies and methods used in wave energy storage systems:

II.9.1 Wave Dams:

These systems use structures similar to hydroelectric power plants to capture wave energy. When waves reach the dam, they push water through turbines that generate electricity. The energy generated in this way can be stored in batteries or used directly in the power grid.

FigureII.11:wave dams

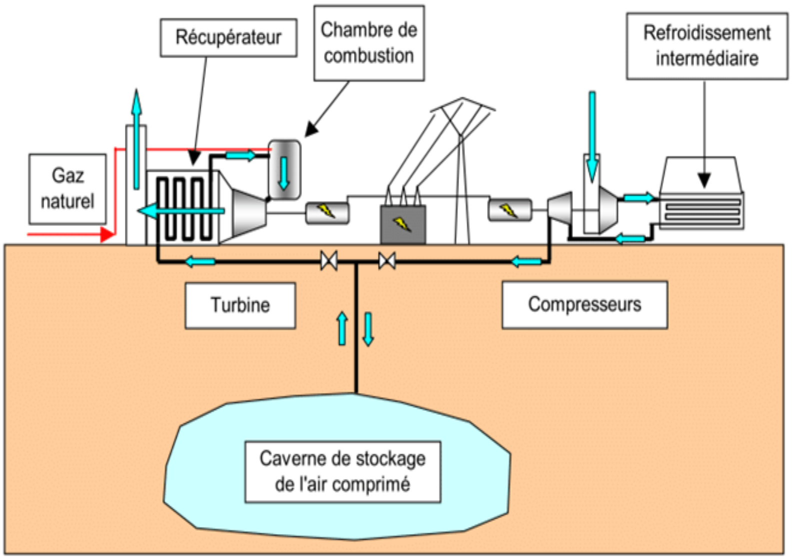
II.9.2 Seawater pumps:

This system uses wave energy to pump seawater to higher reservoirs. When electricity is needed, water is released through turbines to produce energy. This process stores the water's potential energy and keeps it high until it is needed.

FigureII.12:seawater pump

II.9.3 Compressed Air Storage Systems:

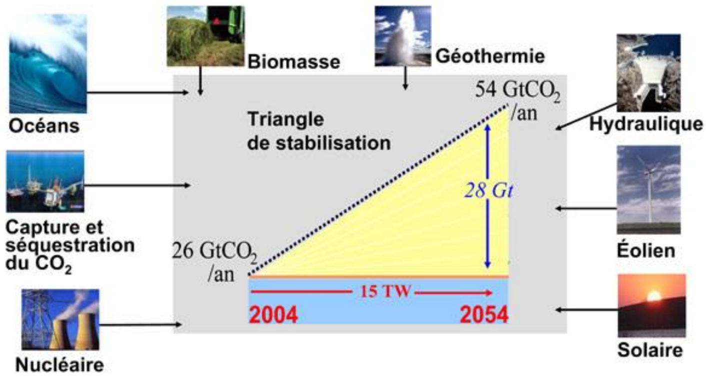
This type of system uses wave energy to compress air into underwater tanks. When electricity need, compressed air is released and spins turbines to produce energy. This method provides an efficient and scalable energy storage solution.



FigureII.13:Compressed Air Storage Systems

II.9.4.Electrochemical Storage Technologies:

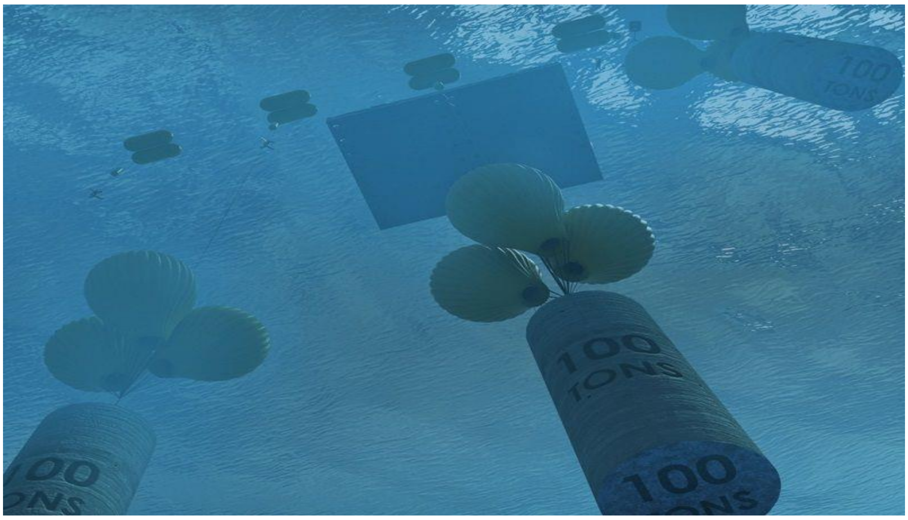
These technologies use batteries or super_ capacitor-based energy storage systems to capture and store electricity generated by waves. Advances in this area aim to improve the efficiency, durability and storage capacity of these devices.



FigureII.14: Electrochemical Storage Technologies

II.9.5 Gravity Storage Systems:

These systems use wave energy to lift heavy weights or counterweights to store potential energy. When this energy is needed, the weights are released to spin generators and produce electricity. These various wave energy storage methods are being developed and optimized to make a significant contribution to the transition to cleaner and more sustainable energy sources. Each system has its technical advantages and challenges, and continued research in this area is essential to improve the efficiency and cost-effectiveness of these technologies.



FigureII.15: Gravity Storage Systems

II.10: Conclusion:

In the conclusion, the principles of wave energy conversion hold great promise for renewable energy production. By harnessing the power of ocean waves, we can reduce dependence on fossil fuels and mitigate climate change. Despite challenges such as resource variability, technological complexity, and environmental impacts, on-going research and development efforts continue to improve wave energy conversion technologies. With advances in technology, grid integration solutions and supporting policies, wave energy has the potential to become a major player in the global transition to a more sustainable energy future.

Chapter 03: The principles of maritime buoyage

III.1 Introduction:

The principle of maritime buoyage is crucial to safe navigation at sea. Standardized markings are used to guide ships and mark hazards. The system has evolved over centuries and includes buoys, lights and beacons that convey important information to sailors. International standards such as the IALA offshore buoy system ensure consistency and safety in a variety of offshore environments. Maritime Focus plays a key role in improving the efficiency and reliability of the global maritime network. Its development reflects an ongoing commitment to maritime safety and navigational excellence.

III.2. Historical Background and Evolution of Maritime buoyage:

The marine navigation system required for navigation has evolved over the centuries from a simple floating indicator to a high-quality international tool. Ancient Romans designed stone-marked pipes that evolved into wood and later steel in the late 19th century. The 1977 International Illumination Administrators Agreement (IALA) established a global purchasing system that resolved conflicting issues for the two regions. Modern buoys with GPS, solar power and advanced equipment increase reliability and ease of maintenance. This development demonstrates the progress from primitive navigation equipment to advanced technological systems that ensure water safety. [5]

III.3 Role and importance of maritime buoyage: [6]

Providing suitable navigation buoys is no easy task. The structures need to be reliable even in the harshest environments and internationally recognisable.

All navigational buoys and lights around the world come under the jurisdiction of the International Association of Lighthouse Authorities (IALA). IALA is responsible for ensuring navigation aids are recognised globally and reliable in all conditions.

A good understanding of buoyage is essential when heading out to sea to ensure mariners can navigate channels to safe water. Until 1980, there were a staggering 30 systems of buoyage in use around the world. Nowadays, there are just two systems in place — although some would argue that even that is one system too many.

In the British Isles, we use IALA System A, whereby port show by the colour red and starboard indicate by green. This system also covers Europe, Africa, Asia, the Middle East, Australia and New Zealand.

IALA System B then works the opposite way, with port shown by the colour green and starboard by red. This system covers North, Central and South America as well as Japan, Korea and the Philippines.

Even if you're a seasoned mariner, it can be easy to forget how each system works and what all the marks mean — particularly if you're used to using System A but then venture into a region using System B.

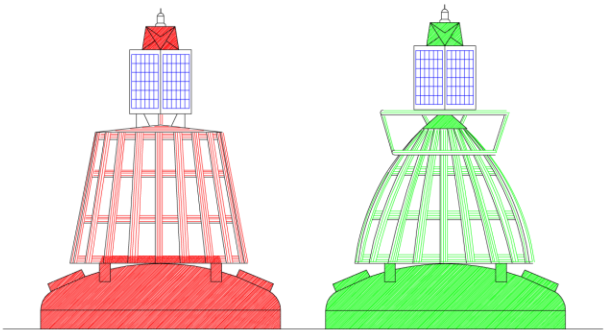
As such, it is well worth brushing up on the IALA Maritime Buoyage System guidelines, which provide a detailed overview of aids to navigation and the different types of navigation marks. These include lateral marks, safe watermarks, isolated danger marks, new danger marks, special marks and cardinal marks.

III.4 General Principles of maritime buoyage system: [7]

The responsibility for safe navigation resides with the mariner, through the appropriate use of aids to navigation in conjunction with official nautical documents and prudent seamanship, including voyage planning as defined in IMO Resolutions. This booklet provides guidance on the Maritime Buoyage System and other aids to navigation for all users. The IALA Aids to Navigation system has two components: The Maritime Buoyage System and other aids to navigation comprised of fixed and floating devices. This is primarily a physical system; however, all of the marks may complement by electronic means. Within the Maritime Buoyage System, there are six types of marks, which may use alone or in combination. The mariner can distinguish between these marks by identifiable characteristics. Lateral marks differ between Buoyage Regions A and B, as described below, whereas the other five types of marks are common to both regions. These marks describe below:

III.4.1 Lateral marks:

Lateral Marks used generally to mark the sides of well-defined, navigable channels. They positioned in accordance with a Conventional Direction of Buoyage

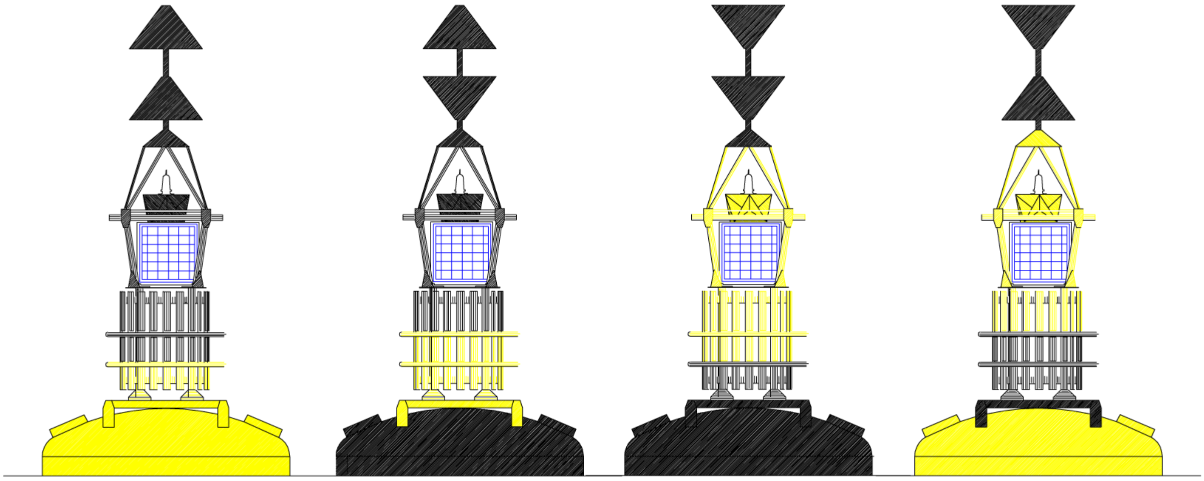


FigureIII.1: Lateral mark

Lateral marks indicate the port and starboard hand sides of the route to follow. They are coloured red (port hand marks) and green (starboard hand marks).

III.4.2 Cardinal marks:

Cardinal Marks use in conjunction with the compass to indicate the direction from the mark in which the deepest navigable water lies, to draw attention to a bend, junction or fork in a channel, or to mark the end of a shoal



FigureIII.2: cardinal marks

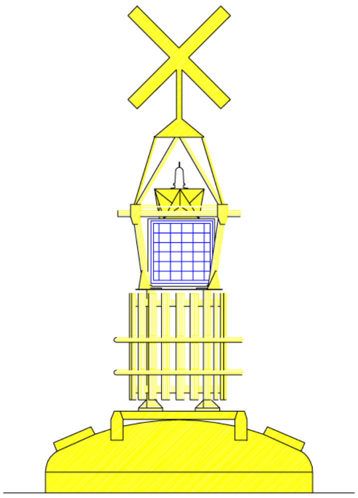
Mariners will be safe if they pass north of a north mark, south of a south mark, east of an east mark and west of a west mark. Cardinal Marks use for permanent wreck marking whereby North, East, South and West Cardinal buoys place around the wreck. In the case of a new wreck, any one of the cardinal buoys may duplicate and fixed with a Radar Beacon

At night, the lights of Cardinal Marks are programmed with distinct identifying characters; as an aide memoire they can be considered to flash in accordance with positions on a clock face whereby an East Cardinal flashes three times, a South Cardinal six times (but with an added long flash to make it more distinctive) and a West Cardinal nine times. The North Cardinal does not quite fit the pattern – having a continuous quick or very quick flash.

The buoy illustration shows Type 2 configurations of buoys. These are approximately three metres in diameter and weigh approximately six tonnes excluding moorings. Buoys need to recognise both in daylight and at night and use top marks to assist in identification. A top mark on a Cardinal Buoy is triangular and coloured black. Top marks and buoy colours themselves arrange in order to represent the points on a compass.

III.4.3.Special marks

Special Marks are not primarily intended to assist navigation but are used to indicate a special area or feature, the nature of which is apparent by referring to a chart or Notice to Mariners



FigureIII.3: special marks

Special Marks uses in the marking of cables and pipelines, including outfall pipes and recreation zones. Data Buoys classed as Special Marks. They are coloured yellow.

III.4.4 Isolated danger marks

Isolated Danger Marks are used to mark small, isolated dangers with navigable water around the buoy

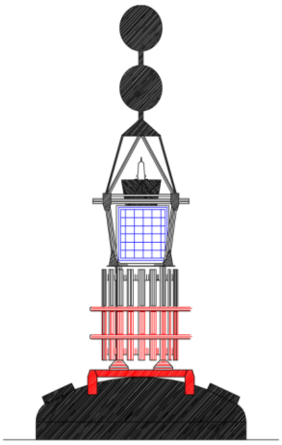


Figure III.4 isolated danger marks

III.4.5 Safe water marks:

Safe Water Marks may be used mid-channel, as a centreline or at the point where land is reached. These buoys indicate the presence of safe, navigable water all around the buoy

The safe water buoy may also indicate the best point of passage under a fixed bridge. These buoys are coloured red and white.

The buoy illustration shows a Type 2 configuration of buoy. These are approximately three metres in diameter and weigh approximately six tonnes excluding moorings.

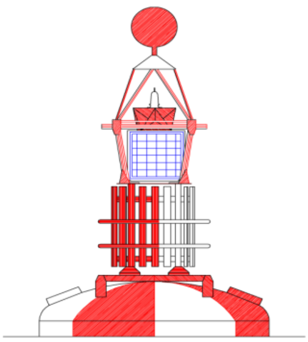


Figure III.5: safe watermarks

III.4.6 Emergency Wreck Marking buoys:

On Saturday, 14 December 2002, the car carrier Tricolor and the container vessel Kariba collided. The collision occurred when both vessels were about to enter the north-south shipping route through the English Channel. The Kariba struck the Tricolor on the port side. The car carrier quickly took on water, capsized and sank.

Two days later the German cargo vessel Nicola struck the wreck of the Tricolor. Tugs pulled the cargo ship from the wreck on the same day.

On Wednesday, 1 January 2003, the Tricolor was struck for a third time. On this occasion, the Turkish tanker Vicky, carrying 77,000 tons of gas oil, hit the wreck.

These wrecks in the Dover Strait brought into sharp focus the effective responses required to adequately and quickly mark such new dangers and prevent collisions. Responsible authorities needed to assess their areas of responsibility and rapid response capability as part of their contingency planning.

The Emergency Wreck Marking Buoy is maintained in position until:

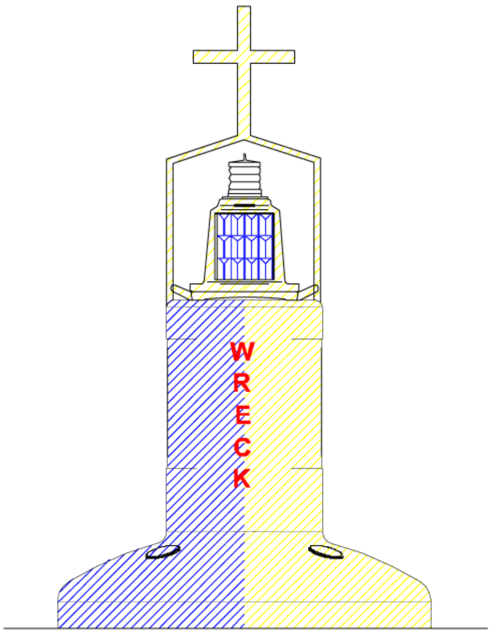
- the wreck is well known and has been promulgated in nautical publications;
- the wreck has been fully surveyed and exact details such as position and least depth above the wreck are known;
- A permanent form of marking of the wreck has been carried out.

The characteristics of Emergency Wreck Marking buoys:

The buoy has the following characteristics:

- A pillar or spar buoy, with size dependent on location.
- Coloured in equal number and dimensions of blue and yellow vertical stripes (minimum of 4 stripes and maximum of 8 stripes).
- Fitted with an alternating blue* and yellow flashing light with a nominal range of 4 nautical miles where the blue and yellow 1 second flashes are alternated with an interval of 0.5 seconds.
- If multiple buoys are deployed then the lights should be synchronised.
- Consideration should be given to the use of a racon Morse code “D” and/or AIS transponder.
- The top mark, if fitted, is to be a standing/upright yellow cross.

- The light characteristic was chosen to eliminate confusion with blue lights to identify law enforcement, security and emergency services.



FigureIII.6: Emergency Wreck Marking buoys

III.5. Technologies and Equipment Used in Maritime buoyage:

Maritime buoyage require a variety of techniques and equipment to navigate the world's waters. Shopping, lighting and illumination during the cruise feature channels, effects and interesting benefits using strong materials such as polyethylene to withstand the marine environment. Modern technologies such as LED lighting provide better night and bad weather conditions. While the radar system features radar beams, buoys and beacons, AIS (Automatic Identification System) transponders combine this traditional buoy with modern systems to transmit location and status information to nearby ships. In addition, sound signals such as bells and horns also play an important role in dark conditions where hand signals do not work well. Together, these technologies form a complete network that will significantly increase water security and efficiency.

III.6. Maintenance and Management of Maritime buoyage: [7]

Timely, professional maintenance of aids to navigation is essential for safety at sea. Our service includes periodic cleaning, examination and maintenance using our specialised fleet of vessels.

At each location, we carry out an annual inspection and planned, preventative maintenance that includes checking location, moorings and exhibited character, lifting and cleaning, repair or replacement of parts and an annual condition report including advice and recommendations.

Trinity House maintain and manage buoys as part of our statutory work as the General Lighthouse Authority. We utilise the same knowledge and expertise to provide services to customers through our buoy life cycle programme. Periodic maintenance on-site is part of that programme.

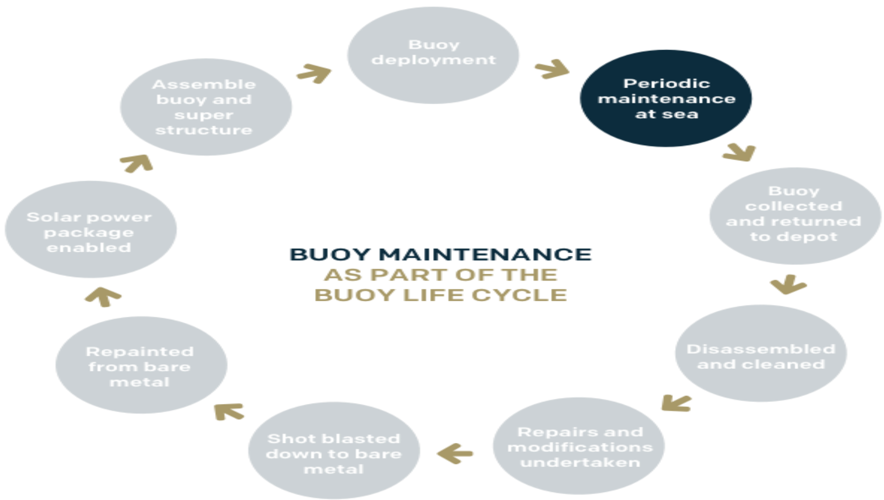


Figure III.7: buoyage maintenance

Figure III.8: Cleaning a buoy aboard THV Patricia

III.7 Environmental Impacts and Protection Measures in Maritime buoyage: [8]

Marine signage plays an important role in maritime safety but can also have an impact on the environment, requiring careful management. Materials used in navigation equipment such as buoys and beacons, usually plastic and metal, can contribute to ocean pollution and harm the environment if not used properly. Preventive measures need to solve these problems. These include the use of environmentally friendly materials, regular maintenance to prevent contamination of the buildings, proper disposal protocols, and the use of energy-efficient technologies such as solar energy. Additionally, implementation of environmental monitoring programs, community participation and regulatory compliance are important measures to reduce environmental impacts and promote sustainable maritime activities. Thanks to these measures, the sector can reduce environmental pollution and contribute positively to the protection of ecosystems.

III.8. Future evolution of maritime buoyage: [9]

The future development of maritime signals is about to change as the latest technologies are integrated to increase safety, efficiency and environmental protection at sea. One of the most important trends is the adoption of buoy systems that use IoT (Internet of Things) technology for real-time monitoring and decision-making. The autonomous navigation system equipped with artificial intelligence algorithms will help improve the performance of the navigation system, increasing the efficiency and pay out of the Reality navigation (AR) navigation will provide sailors with information about available objects, which will increase awareness. Environmentally friendly transportation will contribute to the protection of the oceans, while renewable energy and modern communication systems will lead to sustainable development and information exchange. Hydrodynamic design and data analysis will further improve performance and reduce maintenance. The Technology Alliance promises a future where marine marking systems are not just symbols but part of a safe, green and efficient industry.

III.9 Conclusion:

Maritime navigation is essential to the safety and efficiency of maritime operations. It provides clear, regular signals to guide ships through safe channels, around hazards and through key locations such as ports. Buoy systems help prevent accidents, falls and collisions by marking hazardous areas, waterways and clear water. They also facilitate international maritime trade by providing seafarers around the world with a consistent means of navigation, increasing the overall safety and security of maritime operations.

Chapter 04:

The design of the

Wave energy converter

IV.1 Introduction:

Integrating energy conversion technologies into sea buoys not only solves many existing problems, but also contributes to the creation of sustainable and environmentally friendly navigation systems. This innovation will enable the buoy to generate energy from ocean waves, reducing dependence on traditional energy sources and reducing operating costs. It will also increase the power and efficiency of transportation vehicles, improve the functioning of seawater and contribute to changing the world in search of energy.

IV.2 The design of wave energy converter:

IV.2.1 The power part:

IV.2.1.2 Electromagnetic induction [10]

Michael Faraday discovered electromagnetic induction, a fundamental principle of physics, in the 1830s. This describes how a change in magnetic field within a closed coil causes a conductor to transmit an electromotive force, often called voltage. The operation of many electrical devices, including transformers, induction motors and generators, depends on this phenomenon. Michael Faraday discovered electromagnetic induction, a fundamental principle of physics, in the 1830s. It explains how changes in the magnetic field occur within a closed coil. A conductor transmits electrical energy, also called voltage. Many electrical devices, including transformers, induction motors and generators, depend on this element for their operation.

IV.2.1.3 Principle of electromagnetic induction: [10]

Principle of Electromagnetic Induction states that the (emf) induced in a loop due by a changing magnetic flux is equal to the rate of change of the magnetic flux threading the l Faraday's Law is the equation that mathematically describes electromagnetic induction. It states that voltage (EMF) will be induced when there is a change in the magnetic environment of a coiled wire. Many ways were discovered by Faraday for this to happen.

Changing the magnetic field strength by moving a magnet over a coil of wire or by moving a coil of wire through a magnetic field, etc.

The voltage (EMF) generated can be explained by the help of the following equation:

$$\text{EMF} = -N \frac{d\emptyset}{dt} \qquad \textbf{[IV.1]}$$

Where:

N: is the number of turns in the wire.

d(∅): is the difference in magnetic flux.

Dt: is the difference in time.

Faraday's methods found the change in flux and can be expressed with the help of this equation. However, because of Lenz's Law, this equation is negative, as it requires the change in magnetic flux to be reproduced in equal strength and the opposite direction by the wire.
For many electromagnetic applications around the world, including cars, Faraday's Law is important. For example, in a car the ignition system, the internal combustion engine takes only 12 volts from the battery and ramps it up to 40000 volts.

Faraday's Law of electromagnetic induction states the use of magnetic flux through a wire.

The magnetic flux is defined as:

$$\phi B = \int B.dA \qquad \text{[IV.2]}$$

Here: ΦB: is the magnetic flux

dA: is the surface of the element

B: is the magnetic field.

According to Faraday's Law of induction, when there is a change in the flux through the surface, the wire coil obtains the electromagnetic force. The rate of variation in magnetic flux, which is surrounded by the circuit, is equal to the induced electromotive force in a closed circuit as per the Law.

$$\epsilon = -d\phi B/dt \qquad \text{......................................} \quad [IV.3]$$

here:

- ϵ is EMF
- ϕB Is the magnetic flux and t is the time.

With the help of Lenz's Law, the direction of the electromotive force is given. It states that when an electric current is induced by changing the magnetic field of a source, it will always create a counterforce opposing the force induced in it.

The Law explains such phenomena as diamagnetism and the electrical properties of inductors.

$$\epsilon = -N\frac{d\emptyset B}{dt} \qquad \text{..} \quad [IV.4]$$

With the help of variation in magnetic flux through the surface of a wire loop, an EMF can be generated.

- The magnetic field B variations.
- The wire loop is misshapen, and the surface Σ changes.
- The alignment of the surface dA changes

IV.2.1.4: Battery choice:

The battery chosen is battery of type lithium. This type of batteries provide stable and stable output power, improving the performance and reliability of electronic devices.

The characteristics:

- Voltage : 3.7V
- Rated capacity: 3000 mAh

Figure IV.1: the batteries

IV.2.1.5 Choice of Buck converter STEP DOWN [11]

A Buck converter is used to step down the input voltage to obtain the required output voltage.

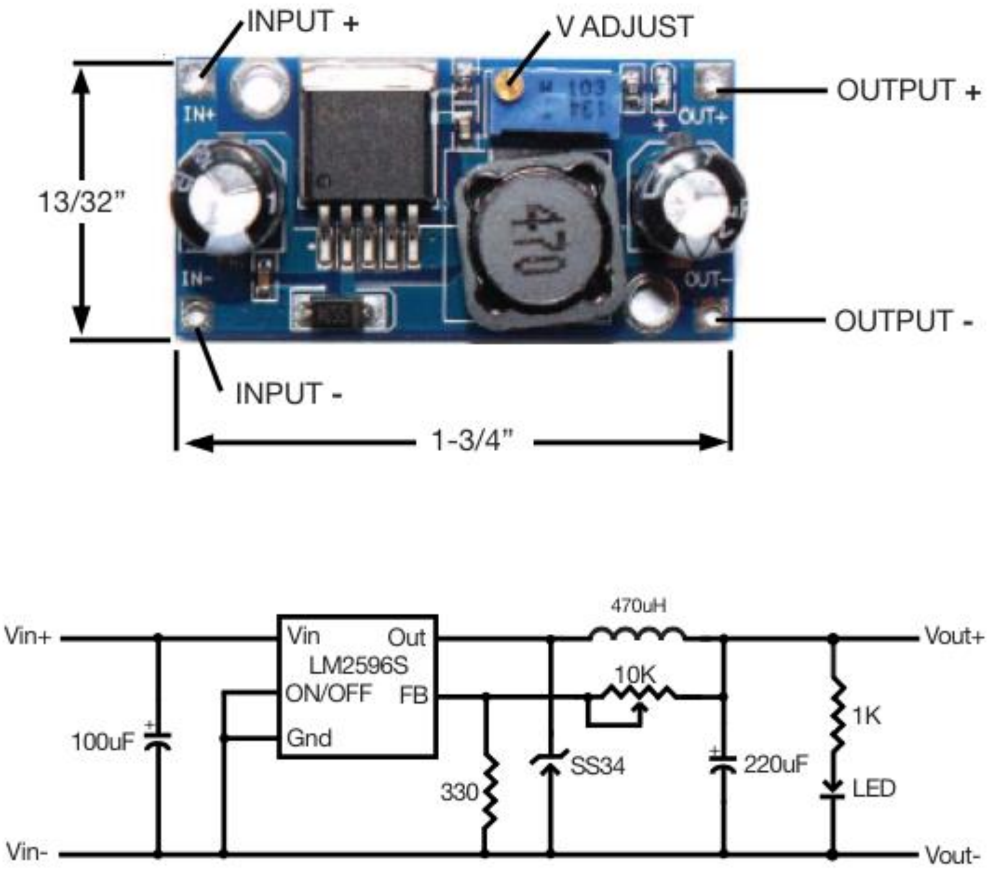
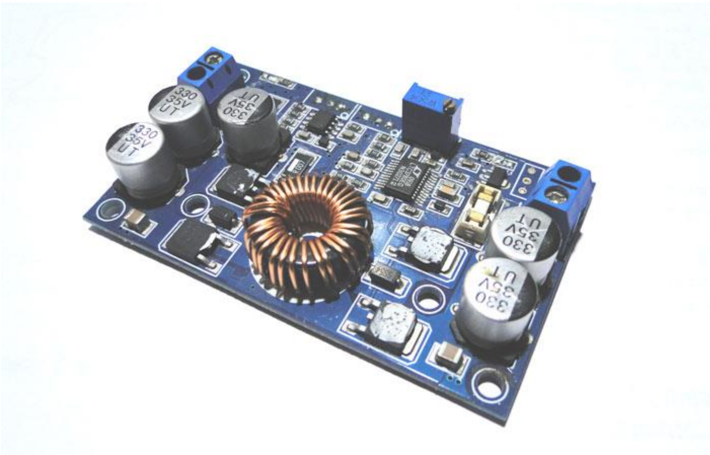


Figure IV.2: buck converter LM2596 HW-411

IV.2.1.6 Choice of Buck converter Step up: [12]

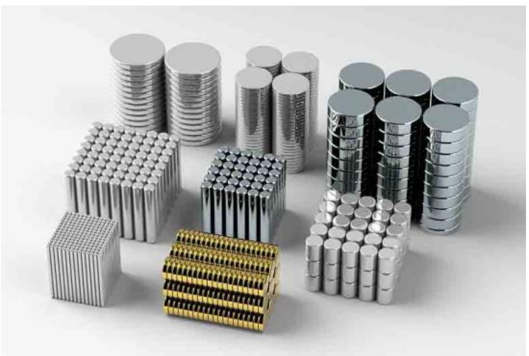
A DC-DC step converter or boost converter is an electronic device that takes low voltage from a power source and steps it up to high voltage to power a load. Temporarily storing energy in an inductor and then releasing that energy at a higher voltage at the output achieve this. This process is continuous and provides continuous energy production. Boost switching is especially useful when you need more voltage than is available at the source, such as in battery-powered devices.



FigureIV.3: The step up converter

IV.2.1.7: POWERFUL Neodymium MAGNETS:

They have high magnetic power and can produce even large amounts of magnetic force.



FigureIV.4. Neodymium magnets

IV 2.2. Command Part:

IV.2.2.1 ESP 32: [13]

ESP32-WROOM-38 is a powerful and generic Wi-Fi + BT + BLE MCU module that targets a wide variety of applications, ranging from low-power sensor networks to the most demanding tasks, such as voice encoding , music streaming and MP3 decoding. At the heart of this module is the ESP32-D0WDQ6* chip. The integrated chip is designed to be scalable and adaptive. There are two processor cores that can be controlled individually and the processor clock frequency is adjustable from 80 MHz to 240 MHz. The chip also has a low-power coprocessor that can be used in place of the CPU to save power while performing tasks that don't require a lot of computing power, such as monitoring devices. ESP32 integrates a rich set of peripherals, ranging from capacitive touch sensors, Hall sensors, SD card interface, Ethernet, high-speed SPI, UART, I2S and I2C.

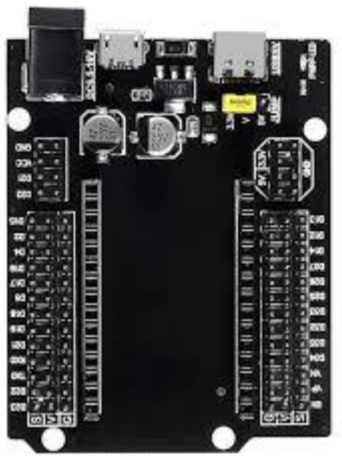
The integration of Bluetooth®, Bluetooth LE and Wi-Fi makes it possible to target a wide range of applications, and that the module is versatile: the use of Wi-Fi allows a wide physical range and a direct connection to the Internet via a Wi-Fi router, while using Bluetooth allows user to easily connect to phone or broadcast low energy beacons for its detection. The sleep current of the ESP32 chip is less than 5 µA, making it suitable for battery-powered and portable electronic applications. The module supports a data rate of up to 150 Mbps, and an output power of 20 dBm at the antenna to ensure the widest physical range. As such, the module offers industry-leading specifications and best performance for electronic integration, range, power consumption, and connectivity.

The operating system chosen for ESP32 is free RTOS with Lw IP; TLS 1.2 with hardware acceleration is integrated as well. Secure (encrypted) over-the-air (OTA) upgrade is also supported, so users can upgrade their products even after release, with lower cost and effort.

FigureIV.5: ESP 32

IV.2.2.2Esp32 shield: [13]

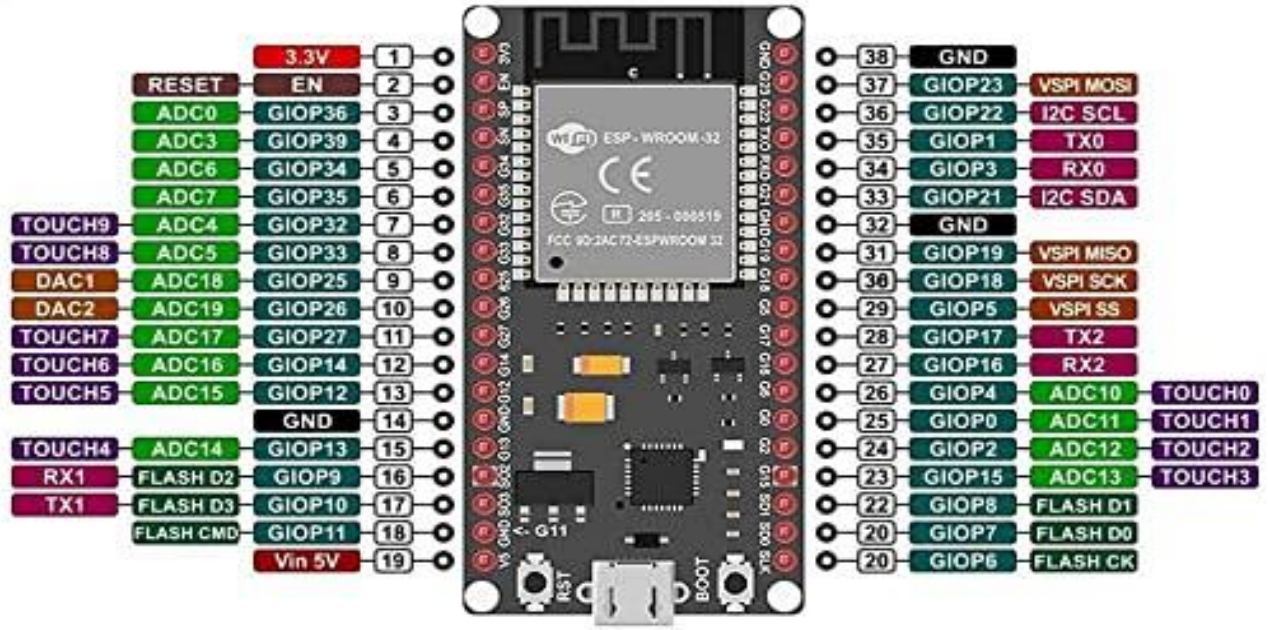
An ESP32 Shield is a module or expansion board designed to interface with a development board based on the ESP32, a powerful microcontroller chip developed by Espressif Systems. Shields are used to extend the basic functionality of the ESP32 by adding peripherals, sensors, interfaces, or other specific electronic components.



FigureIV.6: ESP 32 shield

IV.2.2.3 Pin Definitions: [13]

a) Pins lay-out:



FigureIV.7: ESP 32 pins layout

b) Pin description:

Table IV.1: pin description

Name	*No.*	*Type*	*Function*
GND	1	P	Ground
3V3	2	P	Power supply
EN	3	I	Module-enable signal. Active high.
SENSOR_ VP	4	I	GPIO36, ADC1_CH0, RTC_GPIO0
SENSOR_ VN	5	I	GPIO39, ADC1_CH3, RTC_GPIO3
IO34	6	I	GPIO34, ADC1_CH6, RTC_GPIO4
IO35	7	I	GPIO35, ADC1_CH7, RTC_GPIO5

IO32	8	I/O	GPIO32, XTAL_32K_P (32.768 kHz crystal oscillator input), ADC1_CH4, TOUCH9, RTC_GPIO9
IO33	9	I/O	GPIO33, XTAL_32K_N (32.768 kHz crystal oscillator output), ADC1_CH5, TOUCH8, RTC_GPIO8
IO25	10	I/O	GPIO25, DAC_1, ADC2_CH8, RTC_GPIO6, EMAC_RXD0
IO26	11	I/O	GPIO26, DAC_2, ADC2_CH9, RTC_GPIO7, EMAC_RXD1
IO27	12	I/O	GPIO27, ADC2_CH7, TOUCH7, RTC_GPIO17, EMAC_RX_DV
IO14	13	I/O	GPIO14, ADC2_CH6, TOUCH6, RTC_GPIO16, MTMS, HSPICLK, HS2_CLK, SD_CLK, EMAC_TXD2
IO12	14	I/O	GPIO12, ADC2_CH5, TOUCH5, RTC_GPIO15, MTDI, HSPIQ, HS2_DATA2, SD_DATA2, EMAC_TXD3
GND	15	P	Ground
IO13	16	I/O	GPIO13, ADC2_CH4, TOUCH4, RTC_GPIO14, MTCK, HSPID, HS2_DATA3, SD_DATA3, EMAC_RX_ER
SHD/SD2*	17	I/O	GPIO9, SD_DATA2, SPIHD, HS1_DATA2, U1RXD
SWP/SD3*	18	I/O	GPIO10, SD_DATA3, SPIWP, HS1_DATA3, U1TXD
SCS/CMD *	19	I/O	GPIO11, SD_CMD, SPICS0, HS1_CMD, U1RTS
SCK/CLK*	20	I/O	GPIO6, SD_CLK, SPICLK, HS1_CLK, U1CTS
SDO/SD0*	21	I/O	GPIO7, SD_DATA0, SPIQ, HS1_DATA0, U2RTS
SDI/SD1*	22	I/O	GPIO8, SD_DATA1, SPID, HS1_DATA1, U2CTS
IO15	23	I/O	GPIO15, ADC2_CH3, TOUCH3, MTDO, HSPICS0, RTC_GPIO13, HS2_CMD, SD_CMD, EMAC_RXD3
IO2	24	I/O	GPIO2, ADC2_CH2, TOUCH2, RTC_GPIO12, HSPIWP, HS2_DATA0, SD_DATA0
IO0	25	I/O	GPIO0, ADC2_CH1, TOUCH1, RTC_GPIO11, CLK_OUT1, EMAC_TX_CLK
IO4	26	I/O	GPIO4, ADC2_CH0, TOUCH0, RTC_GPIO10, HSPIHD, HS2_DATA1, SD_DATA1, EMAC_TX_ER
IO16	27	I/O	GPIO16, HS1_DATA4, U2RXD, EMAC_CLK_OUT
IO17	28	I/O	GPIO17, HS1_DATA5, U2TXD, EMAC_CLK_OUT_180

IO5	29	I/O	GPIO5, VSPICS0, HS1_DATA6, EMAC_RX_CLK
IO18	30	I/O	GPIO18, VSPICLK, HS1_DATA7
IO19	31	I/O	GPIO19, VSPIQ, U0CTS, EMAC_TXD0
NC	32	-	-
IO21	33	I/O	GPIO21, VSPIHD, EMAC_TX_EN
RXD0	34	I/O	GPIO3, U0RXD, CLK_OUT2
TXD0	35	I/O	GPIO1, U0TXD, CLK_OUT3, EMAC_RXD2
IO22	36	I/O	GPIO22, VSPIWP, U0RTS, EMAC_TXD1
IO23	37	I/O	GPIO23, VSPID, HS1_STROBE
GND	38	P	Ground

c) Specification:

Categories	Items	Specifications
Certification	RF certification	FCC/CE-RED/IC/TELEC/KCC/SRRC/NCC
	Wi-Fi certification	Wi-Fi Alliance
	Bluetooth certification	BQB
	Green certification	RoHS/REACH
Test	Reliablity	HTOL/HTSL/uHAST/TCT/ESD
Wi-Fi	Protocols	802.11 b/g/n (802.11n up to 150 Mbps)
		A-MPDU and A-MSDU aggregation and 0.4 µs guard interval support
	Frequency range	2.4 GHz ~ 2.5 GHz
Bluetooth	Protocols	Bluetooth v4.2 BR/EDR and BLE specification

	Radio	NZIF receiver with –97 dBm sensitivity
		Class-1, class-2 and class-3 transmitter
		AFH
	Audio	CVSD and SBC
Hardware	Module interfaces	SD card, UART, SPI, SDIO, I2C, LED PWM, Motor PWM, I2S, IR, pulse counter, GPIO, capacitive touch sensor, ADC, DAC, Two-Wire Automotive Interface (TWAI®, compatible with ISO11898-1)
	On-chip sensor	Hall sensor
	Integrated crystal	40 MHz crystal
	Integrated SPI flash	4 MB
	Operating voltage/Power supply	3.0 V ~ 3.6 V
	Operating current	Average: 80 mA
	Minimum current delivered by power supply	500 Ma
	Recommended operating tem perature range	–40 °C ~ +85 °C
	Package size	(18.00±0.10) mm × (25.50±0.10) mm × (3.10±0.10) mm
	Moisture sensitivity level (MSL)	Level 3

IV2.2.4 The LORA Module: [14]

a) Definition:

The Lora (Long Range) model is a wireless communications device designed for long-distance, low-power data transmission. It operates in the unlicensed ISM band, typically 868 MHz in

Europe and 915 MHz in North America. Using optical transmission, the Lora module provides reliable communication over distances of up to 15 kilometers in rural areas and several kilometers in urban areas. They are widely used in the Internet of Things (IoT) to connect hardware and optional devices. Lora mode makes the network more efficient and extends the battery life of remote monitoring and control systems.

FigureIV.8: LORA module

IV.2.2.5 The Lora WAN network protocol [14]

This networking protocol is developed for Lora and specifies the system architecture (point to multipoint), control (frequencies used and data rates), and communication within deployed LoRa networks. Individual networked devices will transmit only where they have data to send. Transmitter data is related through multiple upstream nodes to the network's central server in a star topology. LoRa networking can be limited in that there is no provision for acknowledgments of data receipt to be transmitted to downstream nodes. Coverage can be anything up to 15 kilometers (10 miles). There are three classes of node communication:

- **Class A:** involves the asynchronous broadcasting of nodes (whenever they need to). When they have no data, they remain dormant.
- **Class B:** involves central communication to nodes via beacon messages broadcast at regular intervals. The receiving nodes are battery powered and therefore capable of listening at scheduled intervals for the transmitted signal.
- **Class C:** are continuously powered, 'active' nodes that can receive signals at any time. This is not a low energy endeavour and usually needs AC power.

IV 2.2.6 Gyroscope sensor: [15]

A gyroscope, a type of sensor found inside an Inertial Measurement Unit (IMU), is used to measure rotation on a particular axis. The device consists of a rotor, which is a freely rotating disk. This rotor is mounted on an axis of rotation located at the center of a larger wheel. The gyroscope's design allows it to maintain its orientation regardless of external movements, making it essential for applications requiring precise orientation and stability measurements, such as in navigation systems, smartphones, and drones.

Figure IV.8: gyroscope sensor

IV.3 Arduino software:

The Arduino IDE (Integrated Development Environment) is a multi-platform application designed for writing and uploading programs to Arduino-compatible boards. It includes a code editor with syntax highlighting, a message area, a text console, and a toolbar with buttons for frequently used functions, streamlining the coding and hardware interaction process. Additionally, the software features a serial monitor for communication between the computer and the Arduino board during program execution, making it indispensable for Arduino development projects.[16]

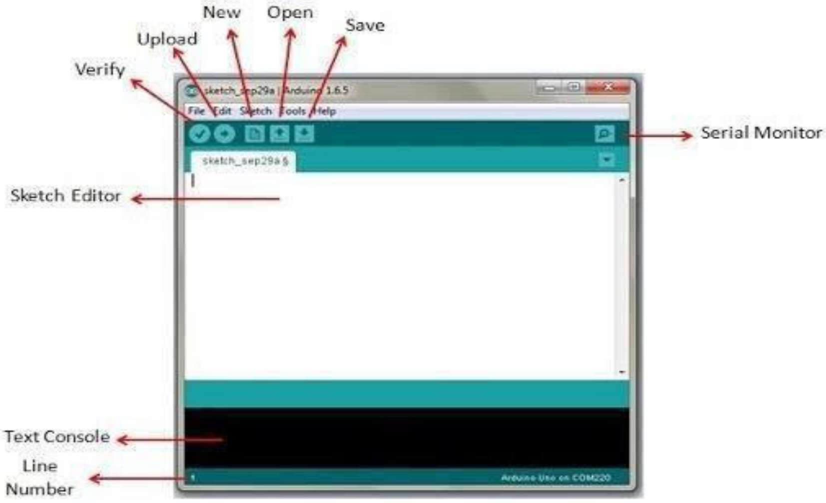


Figure IV.9: Arduino Software

IV.3.1 Programming the command part:

IV.3.1.1 Programming ESP32 with MPU-6050 Accelerometer, Gyroscope: [17]

This is the program done with arduino software

```
// Basic OLED demo for accelerometer readings from Adafruit MPU6050

// ESP32 Guide: https://RandomNerdTutorials.com/esp32-mpu-6050-
accelerometer-gyroscope-arduino/
// ESP8266 Guide: https://RandomNerdTutorials.com/esp8266-nodemcu-mpu-6050-
accelerometer-gyroscope-arduino/
// Arduino Guide: https://RandomNerdTutorials.com/arduino-mpu-6050-
accelerometer-gyroscope/

#include <Adafruit_MPU6050.h>
#include <Adafruit_SSD1306.h>
#include <Adafruit_Sensor.h>

Adafruit_MPU6050 mpu;
Adafruit_SSD1306 display = Adafruit_SSD1306(128, 64, &Wire);

void setup() {
  Serial.begin(115200);
  // while (!Serial);
  Serial.println("MPU6050 OLED demo");

  if (!mpu.begin()) {
    Serial.println("Sensor init failed");
    while (1)
      yield();
  }
  Serial.println("Found a MPU-6050 sensor");

  // SSD1306_SWITCHCAPVCC = generate display voltage from 3.3V internally
  if (!display.begin(SSD1306_SWITCHCAPVCC, 0x3C)) { // Address 0x3C for
128x64
    Serial.println(F("SSD1306 allocation failed"));
```

```
    for (;;)
      ; // Don't proceed, loop forever
  }
  display.display();
  delay(500); // Pause for 2 seconds
  display.setTextSize(1);
  display.setTextColor(WHITE);
  display.setRotation(0);
}

void loop() {
  sensors_event_t a, g, temp;
  mpu.getEvent(&a, &g, &temp);

  display.clearDisplay();
  display.setCursor(0, 0);

  Serial.print("Accelerometer ");
  Serial.print("X: ");
  Serial.print(a.acceleration.x, 1);
  Serial.print(" m/s^2, ");
  Serial.print("Y: ");
  Serial.print(a.acceleration.y, 1);
  Serial.print(" m/s^2, ");
  Serial.print("Z: ");
  Serial.print(a.acceleration.z, 1);
  Serial.println(" m/s^2");

  display.println("Accelerometer - m/s^2");
  display.print(a.acceleration.x, 1);
  display.print(", ");
  display.print(a.acceleration.y, 1);
  display.print(", ");
  display.print(a.acceleration.z, 1);
  display.println("");

  Serial.print("Gyroscope ");
  Serial.print("X: ");
  Serial.print(g.gyro.x, 1);
  Serial.print(" rps, ");
  Serial.print("Y: ");
  Serial.print(g.gyro.y, 1);
  Serial.print(" rps, ");
  Serial.print("Z: ");
  Serial.print(g.gyro.z, 1);
  Serial.println(" rps");

  display.println("Gyroscope - rps");
  display.print(g.gyro.x, 1);
  display.print(", ");
  display.print(g.gyro.y, 1);
  display.print(", ");
  display.print(g.gyro.z, 1);
  display.println("");

  display.display();
  delay(100);
}
```

IV.3.1.2 The data logger program: [18]

```
/*
  Rui Santos
  Complete project details at https://RandomNerdTutorials.com/esp32-
datalogging-google-sheets/

  Permission is here by granted, free of charge, to any person obtaining a
copy of this software and associated documentation files.
  The above copyright notice and this permission notice shall be included
in all copies or substantial portions of the Software.
  Adapted from the examples of the Library Google Sheet Client Library for
Arduino devices: https://github.com/mobizt/ESP-Google-Sheet-Client
*/

#include <Arduino.h>
#include <WiFi.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_BME280.h>
#include "time.h"
#include <ESP_Google_Sheet_Client.h>

// For SD/SD_MMC mounting helper
#include <GS_SDHelper.h>

#define WIFI_SSID "REPLACE_WITH_YOUR_SSID"
#define WIFI_PASSWORD "REPLACE_WITH_YOUR_PASSWORD"

// Google Project ID
#define PROJECT_ID "REPLACE_WITH_YOUR_PROJECT_ID"

// Service Account's client email
#define CLIENT_EMAIL "REPLACE_WITH_YOUR_CLIENT_EMAIL"

// Service Account's private key
const char PRIVATE_KEY[] PROGMEM = "-----BEGIN PRIVATE KEY-----\
REPLACE_WITH_YOUR_PRIVATE_KEY\n-----END PRIVATE KEY-----\n";

// The ID of the spreadsheet where you'll publish the data
const char spreadsheetId[] = "YOUR_SPREADSHEET_ID";

// Timer variables
unsigned long lastTime = 0;
unsigned long timerDelay = 30000;

// Token Callback function
void tokenStatusCallback(TokenInfo info);

// BME280 I2C
Adafruit_BME280 bme;
// Variables to hold sensor readings
float temp;
float hum;
float pres;

// NTP server to request epoch time
const char* ntpServer = "pool.ntp.org";

// Variable to save current epoch time
```

```
unsigned long epochTime;

// Function that gets current epoch time
unsigned long getTime() {
  time_t now;
  struct tm timeinfo;
  if (!getLocalTime(&timeinfo)) {
    //Serial.println("Failed to obtain time");
    return(0);
  }
  time(&now);
  return now;
}

void setup(){

    Serial.begin(115200);
    Serial.println();
    Serial.println();

    //Configure time
    configTime(0, 0, ntpServer);

    // Initialize BME280 sensor
    if (!bme.begin(0x76)) {
      Serial.println("Could not find a valid BME280 sensor, check
wiring!");
      while (1);
    }

    GSheet.printf("ESP Google Sheet Client v%s\n\n",
ESP_GOOGLE_SHEET_CLIENT_VERSION);

    // Connect to Wi-Fi
    WiFi.setAutoReconnect(true);
    WiFi.begin(WIFI_SSID, WIFI_PASSWORD);

    Serial.print("Connecting to Wi-Fi");
    while (WiFi.status() != WL_CONNECTED) {
      Serial.print(".");
      delay(1000);
    }
    Serial.println();
    Serial.print("Connected with IP: ");
    Serial.println(WiFi.localIP());
    Serial.println();

    // Set the callback for Google API access token generation status (for
debug only)
    GSheet.setTokenCallback(tokenStatusCallback);

    // Set the seconds to refresh the auth token before expire (60 to 3540,
default is 300 seconds)
    GSheet.setPrerefreshSeconds(10 * 60);

    // Begin the access token generation for Google API authentication
    GSheet.begin(CLIENT_EMAIL, PROJECT_ID, PRIVATE_KEY);
}

void loop(){
```

```
    // Call ready() repeatedly in loop for authentication checking and
processing
    bool ready = GSheet.ready();

    if (ready && millis() - lastTime > timerDelay){
        lastTime = millis();

        FirebaseJson response;

        Serial.println("\nAppend spreadsheet values...");
        Serial.println("----------------------------");

        FirebaseJson valueRange;

        // New BME280 sensor readings
        temp = bme.readTemperature();
        //temp = 1.8*bme.readTemperature() + 32;
        hum = bme.readHumidity();
        pres = bme.readPressure()/100.0F;
        // Get timestamp
        epochTime = getTime();

        valueRange.add("majorDimension", "COLUMNS");
        valueRange.set("values/[0]/[0]", epochTime);
        valueRange.set("values/[1]/[0]", temp);
        valueRange.set("values/[2]/[0]", hum);
        valueRange.set("values/[3]/[0]", pres);

        // For Google Sheet API ref doc, go to
https://developers.google.com/sheets/api/reference/rest/v4/spreadsheets.val
ues/append
        // Append values to the spreadsheet
        bool success = GSheet.values.append(&response /* returned response
*/, spreadsheetId /* spreadsheet Id to append */, "Sheet1!A1" /* range to
append */, &valueRange /* data range to append */);
        if (success){
            response.toString(Serial, true);
            valueRange.clear();
        }
        else{
            Serial.println(GSheet.errorReason());
        }
        Serial.println();
        Serial.println(ESP.getFreeHeap());
    }
}

void tokenStatusCallback(TokenInfo info){
    if (info.status == token_status_error){
        GSheet.printf("Token info: type = %s, status = %s\n",
GSheet.getTokenType(info).c_str(), GSheet.getTokenStatus(info).c_str());
        GSheet.printf("Token error: %s\n",
GSheet.getTokenError(info).c_str());
    }
    else{
        GSheet.printf("Token info: type = %s, status = %s\n",
GSheet.getTokenType(info).c_str(), GSheet.getTokenStatus(info).c_str());
    }
}
```

IV.3.1.3 adding battery charger to ESP 32: [19]

To power an ESP32 with a battery charger, connect a TP4056 module to a 3.7V Li-Po/Li-Ion battery for charging. Use a step-up/down converter to ensure the ESP32 gets a stable 3.3V supply. Connect the TP4056's output to the converter, and then connect the converter to the ESP32's power and ground pins, allowing for portable and safe power management.

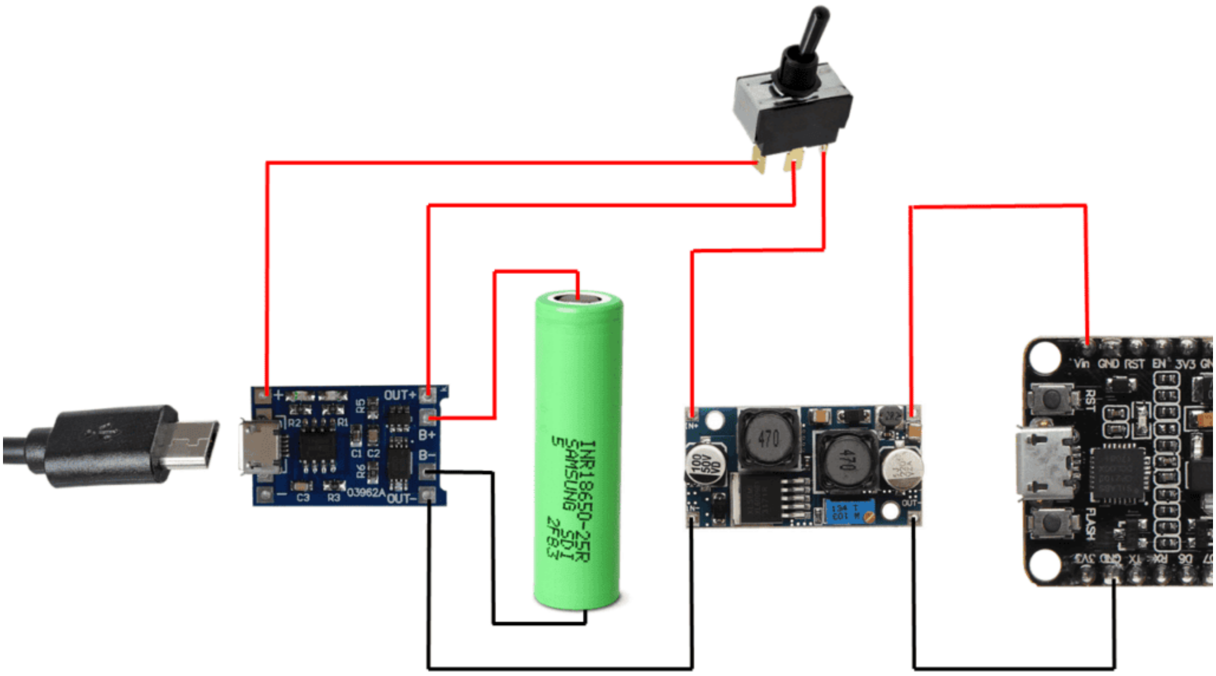
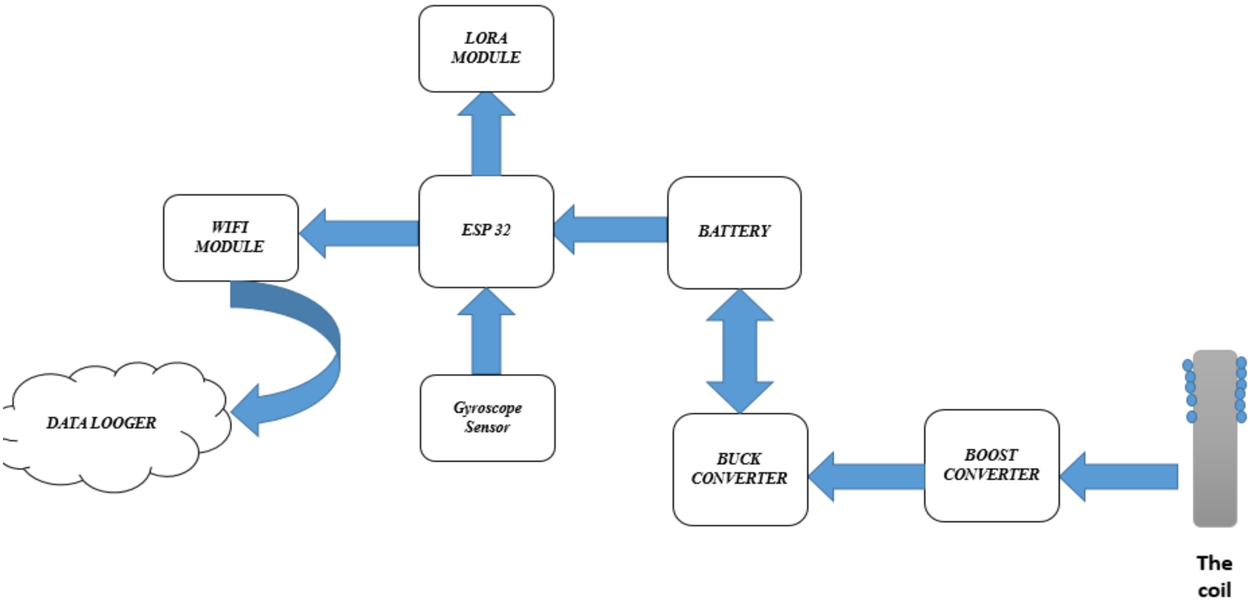


Figure IV.10: Adding battery charger to ESP 32

IV.3.2 General Diagram of our prototype:

This diagram shows a system based on an ESP32 microcontroller connected to several modules. The gyroscope sensor is connected to ESP32 to detect direction. The WiFi module enables data communication and data input, while the LoRa module supports large-scale Internet communication. A battery powers the system. It is controlled by a step down converter (to reduce voltage) and a step up converter (to increase power). The coin on the right represents the input or load governed by the power boost.



FigureIV.11: General Diagram of our prototype

IV.4 Production part: [20]

Electromagnetic induction can be effectively utilized in the design and operation of wave energy converters (WECs) to transform the kinetic energy of ocean waves into electrical energy. This process involves capturing the motion of waves and converting it into mechanical energy, which is then converted into electrical energy using the principles of electromagnetic induction.

the intent of our project is to test and decide on the effectiveness of it being used as a generator, there are certain electrical outputs desired. Since predicting wave amplitudes and frequencies is impossible, specifications of the generator are calculated under ideal circumstances. The ideal circumstance in this case is when a branch is vertical and a magnet falls freely due to gravity. EMF is generated by a change of flux through turns of wires given by the following equation:

$$emf = -N\, \Delta\varphi / \Delta t \qquad \text{(emf calculations) … [IV.5]}$$

This equation would mean that the strongest magnet should be selected because as it falls through turns of wire it will yield the largest change of flux (Δφ). This equation also dictates that the more turns of wire the larger induced voltage. However, there are both financial and physical limitations to our selections. Each branch should be able to output a measurable voltage under “normal” ocean conditions and a sizable voltage under ideal conditions.

IV.4.1 Process Description: [21]

Consider a cuboid immersed in a fluid, its top and bottom faces orthogonal to the direction of gravity (assumed constant across the cube's stretch). The fluid will exert a normal force on each face, but only the normal forces on top and bottom will contribute to buoyancy. The pressure difference between the bottom and the top face is directly proportional to the height (difference in depth of submersion). Multiplying the pressure difference by the area of a face gives a net force on the cuboid the buoyancy equaling in size the weight of the fluid displaced by the cuboid. By summing up sufficiently many arbitrarily small cuboids this reasoning may be extended to irregular shapes, and so, whatever the shape of the submerged body, the buoyant force is equal to the weight of the displaced fluid.

Weight of displaced fluid = weight of object in vacuum − weight of object in fluid

The weight of the displaced fluid is directly proportional to the volume of the displaced fluid (if the surrounding fluid is of uniform density). The weight of the object in the fluid is reduced, because of the force acting on it, which is called upthrust. In simple terms, the principle states that the buoyant force (Fb) on an object is equal to the weight of the fluid displaced by the object, or the density (ρ) of the fluid multiplied by the submerged volume (V) times the gravity (g)

We can express this relation in the equation:

$$F_A = \rho * g * V \quad \text{.. [IV.5]}$$

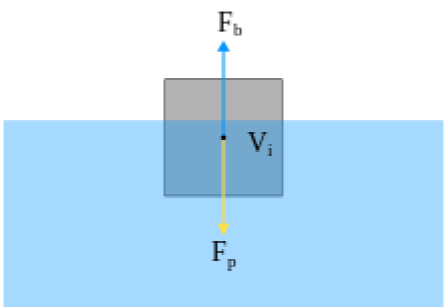


Figure IV.12 Example about Archimedes' principle

IV.4.2 Material Selection:

IV.4.2.1 piping material:

The use of PVC pipes can therefore increase the efficiency, sustainability and cost-effectiveness of wind energy conversion and contribute to sustainable and economic solutions.

Figure IV.13: PVC Tubing

IV.4.2.2: The Magnets:

They have high magnetic power and can produce even large amounts of magnetic force.

IV.4.2.3: The wire:

Many variables are associated with higher voltages, so the ability to produce more voltage would make the attractive. The way to meet this requirement is to use the smallest diameter wire possible.

IV.4.2.4: The data logger:

ESP32 is highly regarded as a data logger due to its many important functions. First, its low power consumption makes it ideal for battery-powered applications, allowing devices to run longer without frequent recharging. Secondly, built-in Wi-Fi and Bluetooth capabilities facilitate easy data transfer and remote monitoring, making it easy to access and manage data from anywhere. Third, powerful processing and memory devices help process and store data. The enables the ESP32 to process various data inputs efficiently.

IV.5. conclusion:

Integrating the electromagnetic induction converters (WECs) is important for several reasons. First, it allows energy to be converted from ocean waves into electrical energy, making the process more efficient. Second, it reduces the need for complex equipment, which can reduce maintenance costs and extend system life. Third, electromagnetic induction can increase the size of WECs, allowing them to be used in different sizes and capacities. Additionally, this technology can also improve the reliability and stability of electricity as it can work well under different conditions. Finally, integrated electricity generation contributes to reducing greenhouse gas emissions and dependence on fossil fuels by supporting the development of sustainable and renewable energy sources.

Chapter 05:

The test results

V.1. Introduction:

In this chapter, we will present the design of our wave energy converter our work was carried out at the Faculty of Sciences and technologies laboratory "FABLAB"

V.2. Making of the coil:

Concerning the production of the coil it was done manually due to lack of material (winding machine) we surrounded the enamelled copper wires around the PVC always keeping the same direction as shown in the figure (V.1)

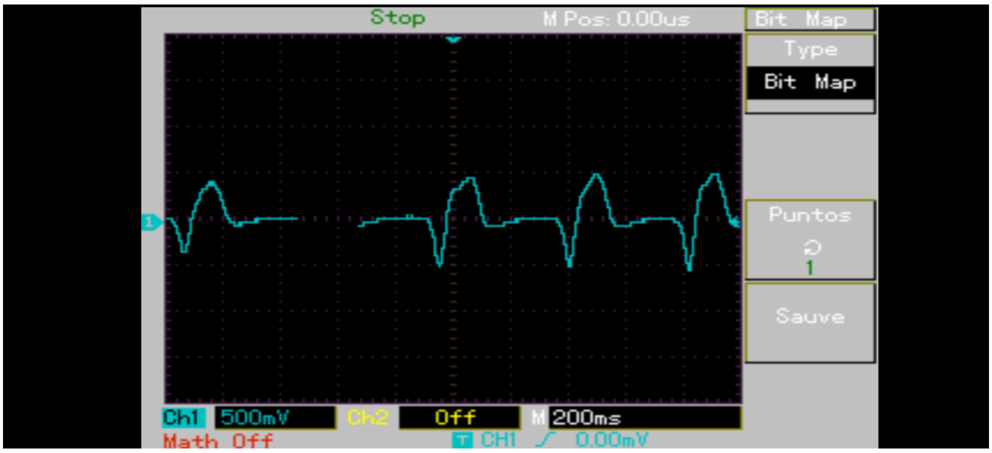
The important point is our converter Convert wave motion into electrical energy through magnetic induction.

FigureV.1: the Coil

V.3.The test with magnets:

The pictures below represent the test of the coil with the magnets:

The test was done on a coil of wire with length 7.5 cm and 1150 turns wired along a PVC pipe.



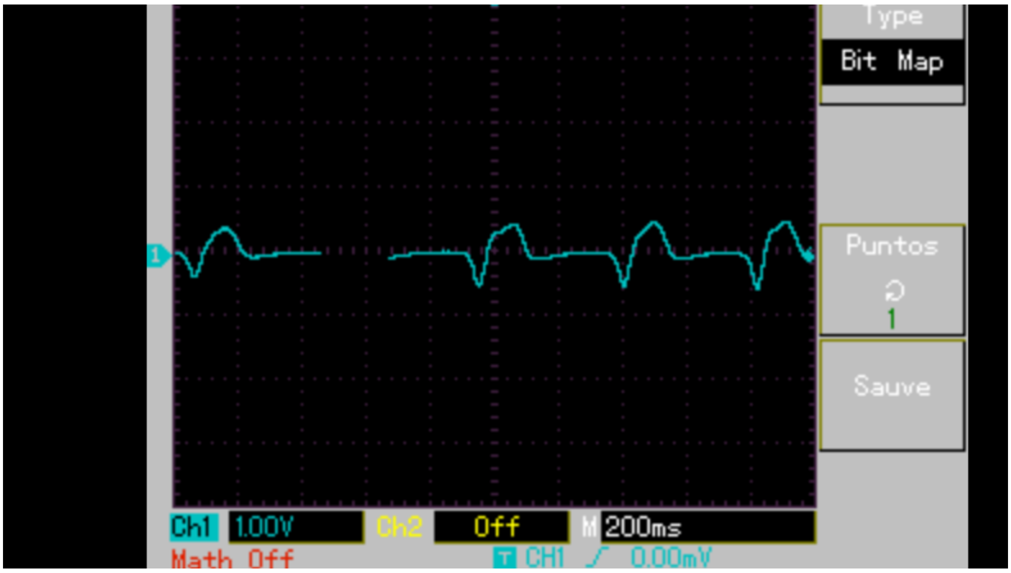


Figure V.2 The test with magnets

This oscilloscope trace displays the voltage signal produced by a coil when a permanent magnet moves nearby. The waveform shows periodic spikes, reflecting the magnetic field's interaction with the coil and the resulting changes in induced voltage. These spikes likely correspond to the magnet's poles passing by the coil, creating alternating current (AC) signals through electromagnetic induction.

Remark:

We repeat the test with now a three coil as it is shown in the figure below:

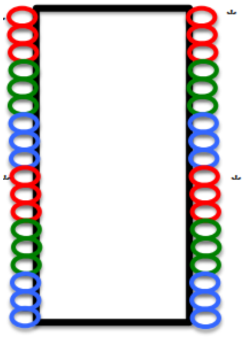
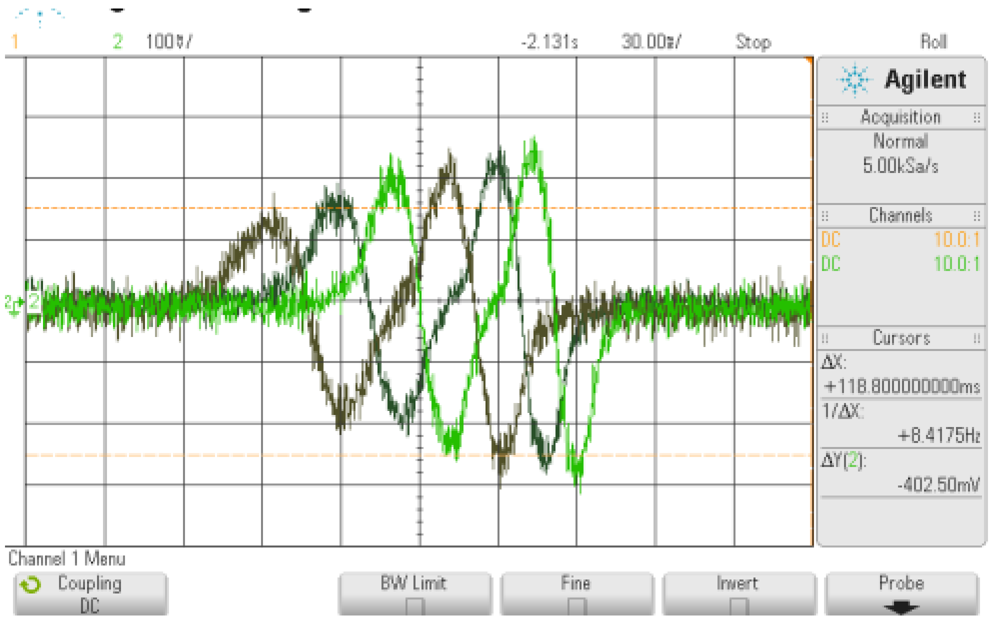


Figure V.2 Concept of a three-wire design

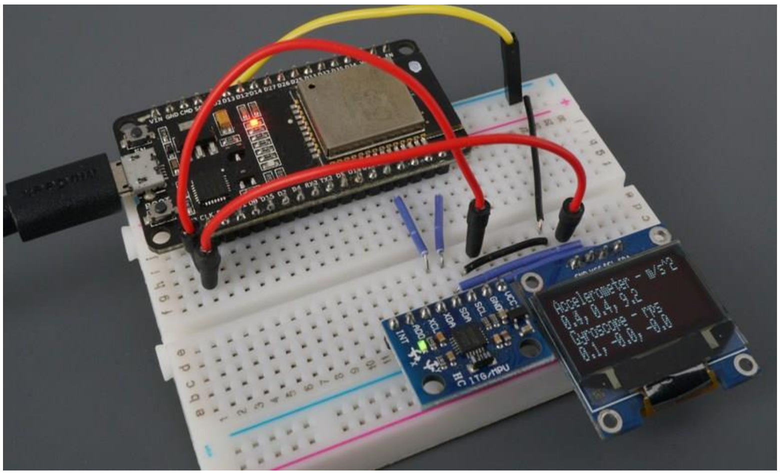
The result on oscilloscope:



FigureV.3 The result of the test with 3 wire design

V.4. The test of the command part:

The gyroscope sensor is employed to track the orientation and movement of the markers, providing essential operational data.



FigureV.3: The test of gyroscope sensor with the ESP 32

V.5. the Data logger test:

Our data logger will understand the data communicated by the ESP it will analyse temperature, system status, GPS position, sea state on a spreadsheet

V.6. Assembly of the prototype:

The purpose of using polystyrene is to allow the coil to float easily

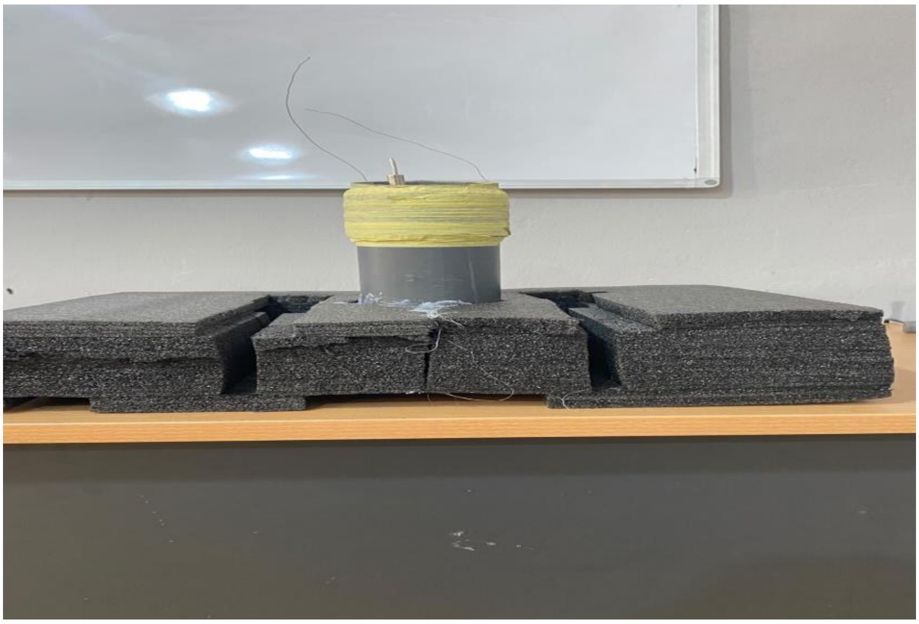


Figure V.4 Assembly of the prototype

V.7 Conclusion:

This chapter outlines the design and development journey of our wave energy converter prototype, conducted within the confines of the Faculty of Sciences and Technologies laboratory "FABLAB". The initial phase involved the manual construction of the coil using enamelled copper wires wound around a PVC pipe, a method necessitated by limited resources but executed with precision to optimize electromagnetic induction. Subsequent testing involved magnets, where we observed notable voltage spikes on an oscilloscope, demonstrating the coil's responsiveness to magnetic field changes during motion. Further experimentation included integrating a gyroscope sensor with an ESP 32, facilitating additional functional tests, and employing a dedicated logger to record and analyse data. These cumulative efforts culminated in the successful assembly of our prototype, marking significant strides toward achieving our wave energy conversion objectives.

General conclusion

Wave energy represents an important solution to our search for clean and sustainable energy sources. The benefits are many: it provides a constant and renewable energy supply, reduces carbon emissions and provides economic opportunities to local communities. Additionally, wave energy is geographically diverse, complements other renewable energies, and minimizes environmental impact. Harnessing wave energy not only fuels our transition to a low-carbon future, but also promotes innovation, economic growth and energy independence.

The principles of wave energy conversion hold great promise for renewable energy production. By harnessing the power of ocean waves, we can reduce dependence on fossil fuels and mitigate climate change. Despite challenges such as resource variability, technological complexity, and environmental impacts, on-going research and development efforts continue to improve wave energy conversion technologies. With advances in technology, grid integration solutions and supporting policies, wave energy has the potential to become a major player in the global transition to a more sustainable energy future.

Maritime navigation is essential to the safety and efficiency of maritime operations. It provides clear, regular signals to guide ships through safe channels, around hazards and through key locations such as ports. Buoy systems help prevent accidents, falls and collisions by marking hazardous areas, waterways and clear water.

Integrating the electromagnetic induction converters (WECs) is important for several reasons. First, it allows energy to be converted from ocean waves into electrical energy, making the process more efficient. Second, it reduces the need for complex equipment, which can reduce maintenance costs and extend system life. Third, electromagnetic induction can increase the size of WECs, allowing them to be used in different sizes and capacities. Additionally, this technology can also improve the reliability and stability of electricity as it can work well under different conditions.

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