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EXPERIMENTAL INVESTIGATION OF WAVE ENERGY FOR ELECTRIC GENERATION: CASE STUDY OF IRAQ

A Thesis Submitted to the Council of College of Engineering/University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering

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Chapter One

Introduction

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1.1 Background

In the forthcoming years, managers and business executives will encounter various challenges, with two of the most crucial being the development and use of carbon-neutral materials. Wave energy stands out as one of the most promising renewable sources owing to its immense potential and limited environmental effects, such as visual pollution. This chapter provides a summary of both ocean and sea energy and the present state-of-the-art in wave energy. The primary objectives of the thesis are then outlined, followed by an overview of its structure.

1.2 Conventional Energy

Non-renewable energy sources, also known as conventional energy sources, are limited in availability. These sources can be classified as either trade or non-trade energy. The decline of fossil fuels, compounded by their negative environmental impacts, renders them inadequate for meeting the increasing energy demands required for the development of modern civilization [1]. Recycling of these sources is challenging once they are depleted and they cannot be replenished at a comparable rate to their usage [2]. Fossil fuels, including petroleum, coal, natural gas, and their derivatives, represent the most abundant conventional energy source. These fuels are characterized by a high carbon concentration due to their derivation from carbon-based organisms. Conventional energy production encompasses a variety of forms but is constrained within defined limits. On the other hand, the power plants that operate over conventional energy sources are ranked among the power systems with high capacity. This means that the energy generated by these power plants is transmitted to users through power transmission lines or by utilizing areas of decentralized energy supply. Generally, the advantages and disadvantages of these energies can be summarized as the spread of thermal power plants creates the greenhouse effect due to the production of large amounts of sulfur oxides, soot, ash, and nitrogen oxides cause acid rain.

1.3 Global Energy Demands

Global energy needs to increase the utilization of natural resources derived from all fossil fuels, pushing academics to develop essential innovations to justify using these resources. The surge in energy consumption necessitates researchers to come up with novel techniques for monitoring and curbing greenhouse gas emissions. It appears that energy consumption is becoming increasingly eco-friendly, specifically due to the anticipated rise in demand for electricity as a primary energy source.

Figure (1.1) shows the projected global energy demand from 1980 to 2050 (EIA, 2021).

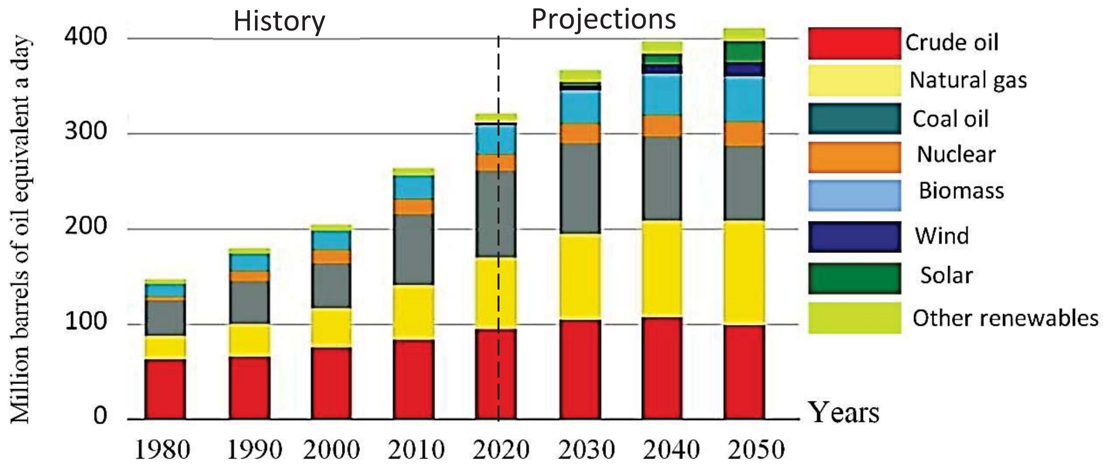

Figure 1.1: Global energy demand projected to 2050, (EIA, 2021)

By the close of 2021, an expected 4.5% increase in electricity demand was attributed to a recovering global economy and significant growth in emerging economies, particularly China [3]. To reduce reliance on fossil fuels, research efforts should be directed towards two primary areas. The first area pertains to the exploration and discovery of alternative energy sources, while the second area focuses on optimizing existing renewable energy sources and identifying strategies for enhancing energy generation stability.

1.4 Renewable Energy

Renewable energy refers to a novel form of energy, which is replenished naturally and remains sustainable over time. However, its energy output per unit of time is subject to limitations [4]. Renewable energy technologies provide clean energy from the sun, wind, wave, geothermal, and biomass, with the assistance of favorable policies implemented by an administration focused on tackling climate change. Nonetheless, certain obstacles persist due to the escalating global demand for electricity [5]. Figure (1.2) shows the global percentage of renewable energy consumption in total electricity consumption.

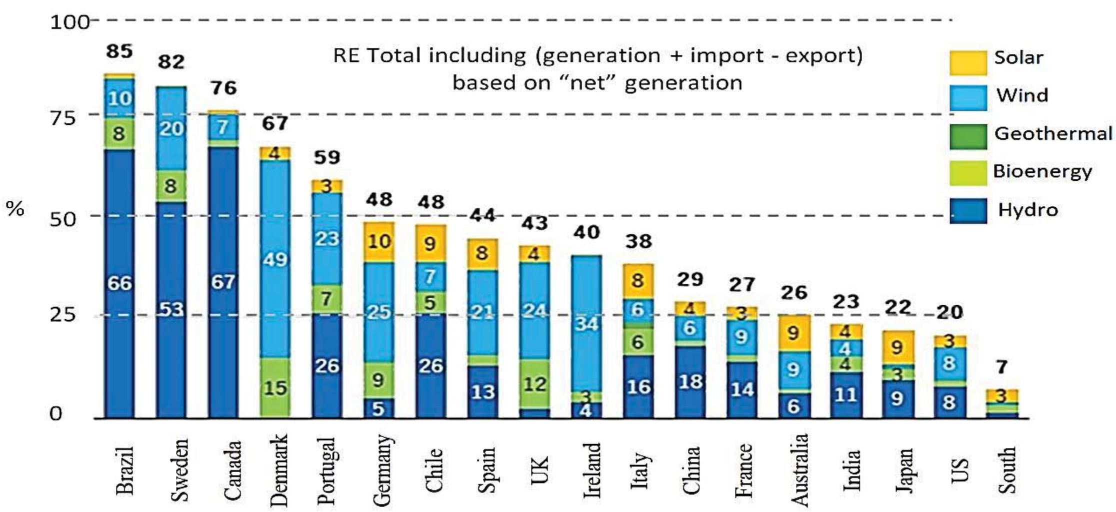

Figure 1.2: The global percentage of renewable energy consumption in total electricity consumption(2020) [6].

Renewable energy is a globally significant resource that offers sustainable solutions for fulfilling the varying heat, power, and fuel requirements, ranging from the most trivial to the most critical ones. The year 2020 witnessed a record high in global electricity production from renewable sources, which accounted for nearly 29% of the total. This Figure is anticipated to rise by as much as 12% between 2021 and 2030, representing a significant increase from the period spanning 2011-2020 [7].

The global wave and tidal energy market was estimated at USD 298.68 million in 2021 and it is expected to surpass around USD 7.46 billion by 2030. It is forecasted to grow at a CAGR of 42.98% from 2022 to 2030, as illustrated in the Figure (1.3) below.

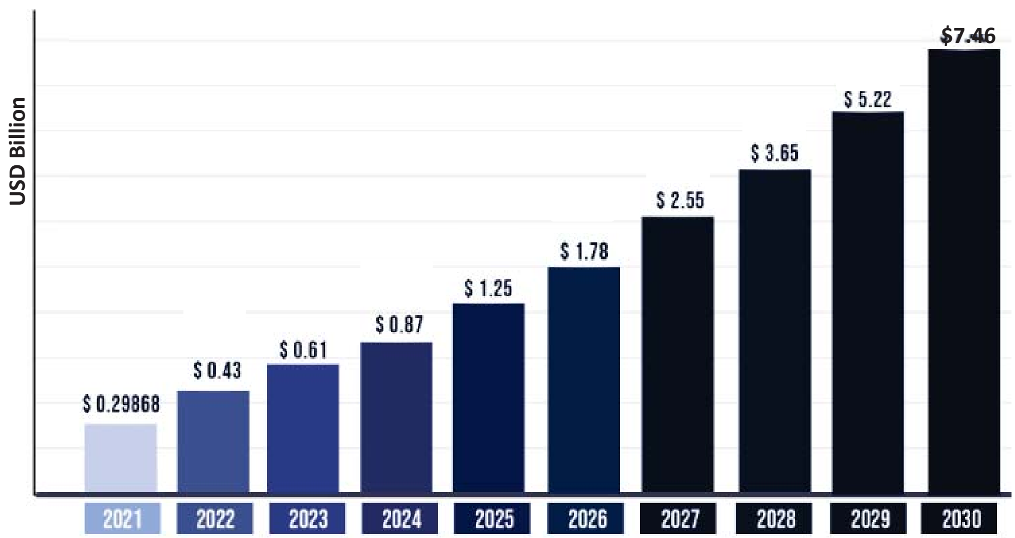

Figure 1.3: The global wave and tidal energy market ,2021–2030 [8]

The increasing demand to replace current energy sources such as coal, gas, and oil, coupled with the growing investment from both public and private sectors. In addition, factors such as high technological advancements and ease of development deployed along with growing funding from the public & private sectors in the wind and tidal industry have resulted in higher adoption of the market worldwide [□]. The table below shows the comparison of the renewable and conventional energy system.

Table 1.1: Comparison of renewable and conventional energy system [7]

	Renewable energy supplies (green)	Conventional energy supplies (brown)
□xample	□ ind, solar, biomass, tidal, wave	Coal, oil, gas, radioactive ore
Source	□atural local environment.	Concentrated stock.
□ormal state	A current or flow of energy. An ‘income	Static store of energy. Capital.
Initial average intensity	Low intensity, dispersed: ≤ 300 □ □m^2	Released at ≥ 100 kW m^2
□ifetime of supply	Infinite	Finite
□quipment capital cost per k□ capacity	Expensive, commonly ≈$1,000	moderate increased cost, maybe □ □00without emissions control□yet □□1,000 with emissions reduction
□ocation for the use	Site and society specific	General and global use
Scale	Small-scale often economic, medium-scale common	□arge-scale frequently favored
Dependence	Self-sufficient systems encouraged	Systems dependent upon outside inputs
Safety	□ocal ha□ards possible in operation: usually safe when out of action	It must be protected and enclosed to minimi□e potential ha□ards, including downtime
□ollution and environmental damage	Usually little environmental harm, especially at moderate scale. □a□ards from excessive wood burning. Soil erosion from excessive biofuel use. □arge hydro reservoirs disruptive.	□nvironmental pollution common, especially of air and water □ermanent damage common from mining and radioactive elements entering water table. Deforestation and ecological sterili□ation from excessive air pollution. Greenhouse gas emissions causing climate change
□ariation and control	The variable is best controlled by changing the load using positive control feeding and supplemental sources	Steady, better control by tuning the source with negative feedback control.

1.5 Renewable Energy Resources

Renewable energy is derived from natural resources that are replenished at a faster rate than their consumption. These sources comprise the sun and wind, among others, which are constantly renewed. □urning fossil fuels releases dangerous greenhouse gas emissions, such as carbon dioxide, into the atmosphere[9, 10].

□ ore emissions are produced by burning fossil fuels than by producing electricity from renewable sources. The key to solving the climate catastrophe is switching from fossil fuels, which now produce the ma□ority of emissions, to renewable energy. Renewable energy has become more cost-effective than fossil fuels in many countries and is also responsible for generating three times more employment opportunities [10].

1.6 Common Sources of Renewable Energy

1. Solar □nergy

Solar energy is the most plentiful energy source available and may be used in cloudy conditions. The □arth absorbs solar energy at a pace that is around 10,000 times greater than the rate at which people use energy. Through photovoltaic panels or mirrors that concentrate solar radiation, solar technologies transform sunlight into electrical energy [11]. □ot all countries have equal access to solar energy, but it can still be a significant contributor to any nation□s energy blend. [12].

2. □ ind □nergy

□y deploying big wind turbines that are either on land (onshore) or offshore (in saltwater or freshwater), wind energy captures the kinetic energy of moving air. Despite the variability in average wind speeds across locations, the technical potential for wind energy worldwide exceeds global electricity output, with most locations possessing sufficient potential to support substantial deployment of wind energy [13, 14].

3. Geothermal Energy

Geothermal energy makes use of the thermal energy that is available from the Earth's interior. Geothermal reservoirs can be heated through a variety of means, including the use of wells. These reservoirs can be categorized into two types: hydrothermal and enhanced geothermal systems. Hydrothermal reservoirs are naturally hot and permeable, while enhanced geothermal systems are naturally hot but have been improved through hydraulic stimulation [15].

4. Hydropower

Hydropower is generated through the exploitation of the kinetic energy of water in motion from higher to lower elevations. Two primary origins of hydropower are rivers and reservoirs. In contrast to run-of-river hydropower plants, reservoir hydropower plants rely on water that has been stored in a reservoir to generate electricity [16] .

In the electricity industry, hydropower now represents the largest source of renewable energy. It depends on largely stable rainfall patterns and may suffer from droughts brought on by climate change or from changes to ecosystems that affect those patterns. [17, 18].

5. Ocean Energy

Ocean energy is produced using methods that harness the kinetic and thermal energy of the ocean's waves and currents to generate heat or electricity. While several prototype wave and tidal current devices are being investigated, ocean energy systems are still in the early stages of development. The theoretical potential for energy in the ocean exceeds current human energy needs [19, 20].

The advantages of utili□ing renewable energy sources are diverse and extend to numerous areas including national security, environmental well-being, economic welfare, and public health. Using renewable energy has a number of advantages, including the following [21]:

- □nhanced national power grid resilience, security and reliability
- Generation of □obs across all sectors utili□ing renewable energy
- Reduced air pollution and carbon emissions from energy generation greater American energy independence
- Affordability since various forms of renewable energy can compete on price with conventional energy sources

1.7 Wave Energy

□ ave energy is characteri□ed as an intermittent source of energy due to its uncontrollable fluctuations in power availability over time [22]. This attribute poses a challenge for utility companies seeking to harness energy from intermittent sources, such as wind, wave, and solar, which are typical of most renewable energy sources [23]. These sources□intermittency renders them insufficient to provide all the energy required by a society. This is because, without the availability of significant electric energy storage, energy must be produced at the time of consumption [24]. The need for an alternative source of renewable energy has shifted parts of the market□s attention to wave energy conversion [2□].

□arious □ ave □nergy Conversion (□ □C) solutions have been proposed since the 1970s and have shown proof of concept. □owever, no □ □C concept has successfully transitioned to commerciali□ation due to the high cost of power production outweighing the returns from sales. It is anticipated that costs will decrease once a successful □ □C concept enters large-scale production [26]. □oth ships and dykes are perpetually engaged in a battle against these waves, as they are aware of the potential destruction that can be caused by a single tsunami wave, capable of wiping out entire cities. Another well-experienced phenomenon about ocean waves is that a storm on one side of the ocean basin can be the origin of waves measured on the other side. Figure (1.4) shows waves traveling over large distances with very little energy loss. The scope is limited by looking at ocean surface waves with periods in the ranging of (0.□-30) seconds.

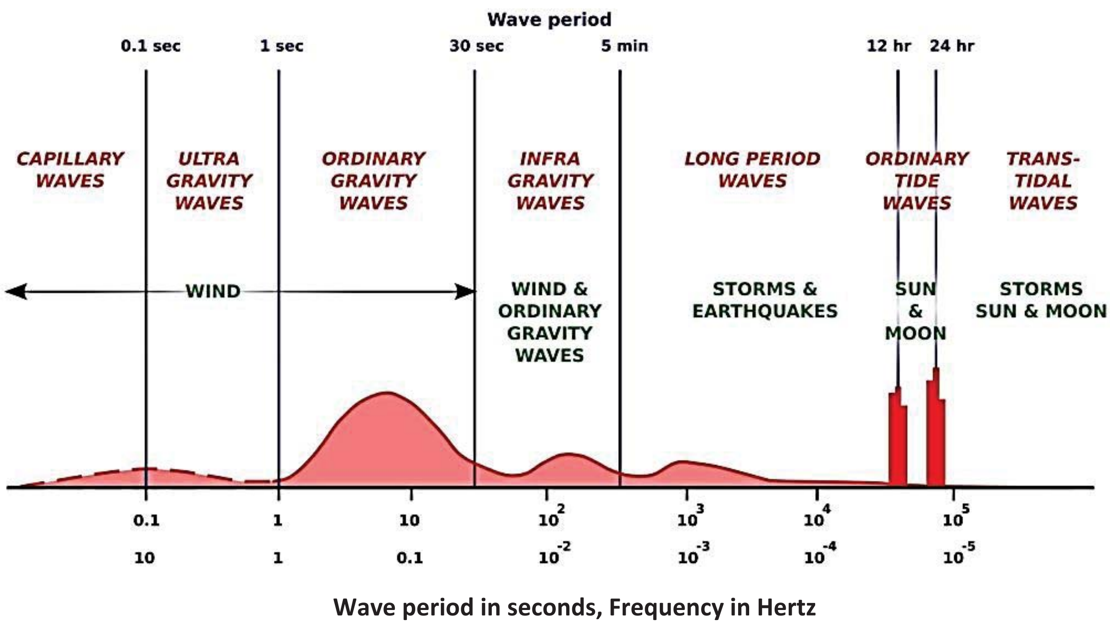

Figure 1.4: Classification of ocean waves by wave period[27]

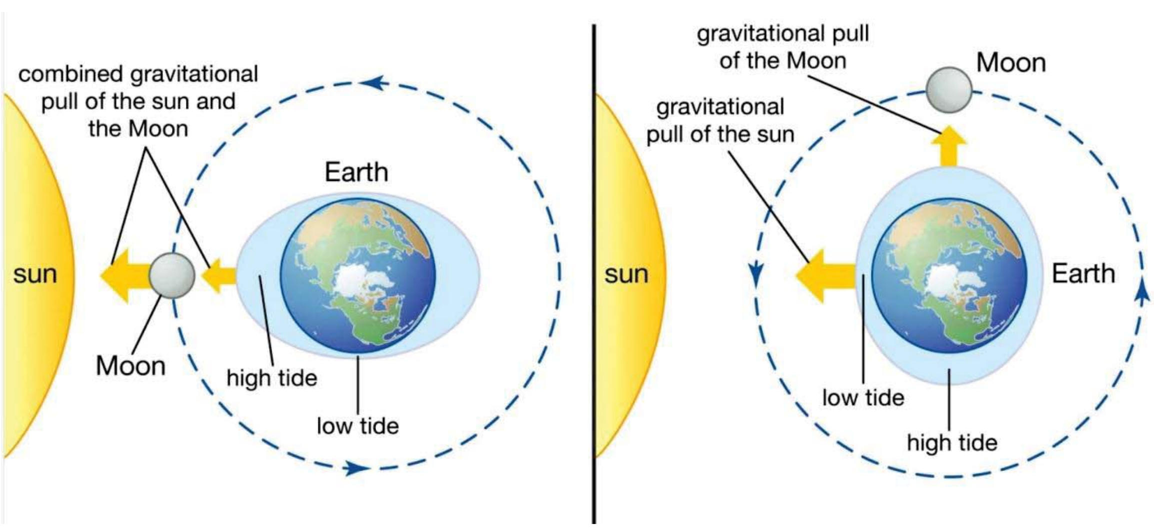

Figure 1.□ how the Sun and □oon cause tides[28]

The energy produced from larger periodic waves is defined as tidal energy, □long-period waves and tidal waves, 30s to 24h and more□[29]. □ong-period waves, which are primarily attributed to the positioning of the □arth in relation to the sun and moon, may also be caused by other phenomena such as seiches, which only occur within bays or gulfs due to the movement of the entire enclosed body of water[30].

Additionally, storm surges resulting from □ ind changes and atmospheric pressure caused by the storms or tsunamis resulting from shifting landmasses are other factors that contribute to wave formation [31, 32].

The distribution of pressure on the ocean surface generates shear stresses along the crests, leading to enhanced wave celerity and growth in the direction of wind. The study is restricted to ocean surface waves with periods ranging from 0.□to 30 seconds [33].

1.7.1 Wave Energy Convertor

□ aves □nergy Conversion (□ □C) is the creation of usable energy from the oscillating water mass below a surface wave in sea water. □ aves are predominantly generated through prolonged and sustained interaction with wind [34], as well as brief and intense exposure to turbulent winds during stormy conditions. In the context of □ □C, waves are the elevation of the water surface within periods of 0.□s to 30s [3□].

Figure(1.□) shows the estimates of the global oceanic wave power resource based on quantitative analysis and suggests that the annual coastal wave power exceeds 2 T□ [36].

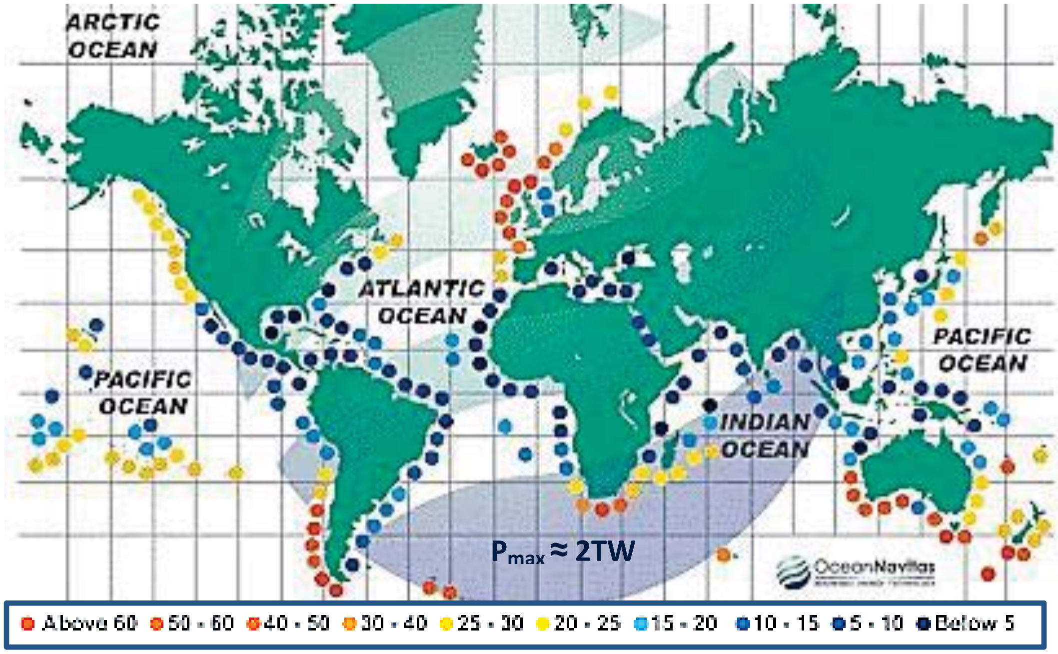

Figure 1.**6:** □orld wave power availability in □□/m of wave front[36]

It has been suggested that □urope can achieve a feasible target of 100 G□ of installed ocean energy capacity (encompassing wave and tidal technologies) by 20□0. Recent advancements in test-berth sites have contributed to the global deployment of grid-connected □□C-devices, resulting in a doubling of installations and a total installed capacity of 8 □□ in 2021 [37].

□umerous patented techniques for ocean wave energy conversion exist worldwide, classified into three types based on their location of application: □nshore devices, □earshore devices and □ffshore devices[38]. □earshore wave energy devices can be installed on the seabed, however, they must have sturdy structures to withstand wave impacts. □ne such device is the C□T□ technology, which harnesses the kinetic energy from ocean swells to generate electrical power. In addition, smaller and less complex floating wave energy converters can also be utili□ed for nearshore applications[39]. □ffshore devices are typically situated in waters deeper than 40 meters, as indicated by Figure (1.6).

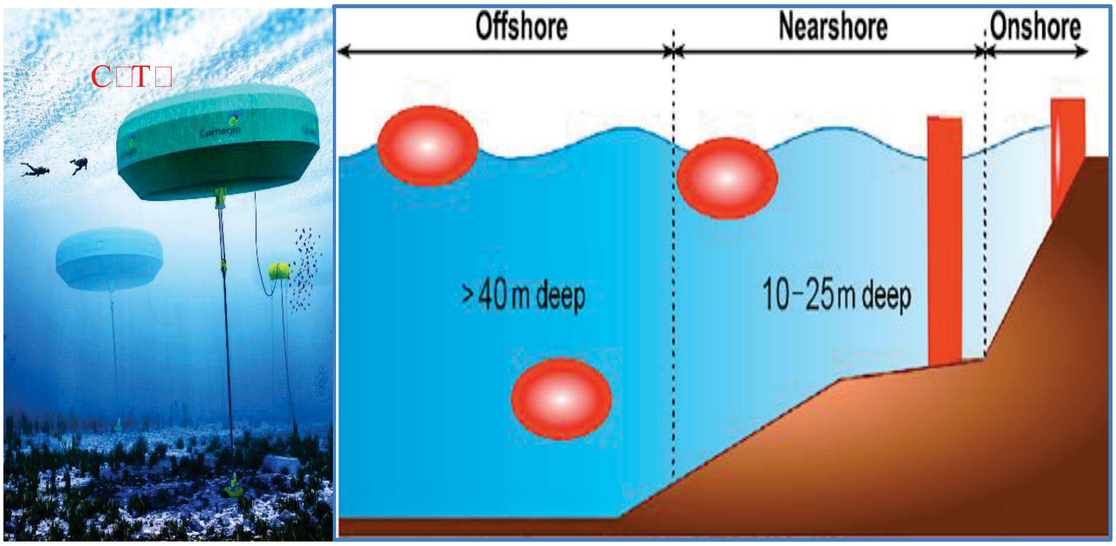

Figure 1.7 Classification of wave energy converters according to their location[39]

1.7.2 Wave Energy Converters Based On Power Take Off (PTO)Systems

The □T□ system is one key component of a □ □C device, which transforms the mechanical power from the □ □C motion to electricity as shown Figure (1.8). The □T□ system has its own dynamics which, allied to those of the floater hydrodynamics, determines the overall frequency response characteristics of the system, which needs to be tuned to the relevant sea state via the control system. Consequently, a reliable and robust □T□, together with an appropriate control strategy, will improve commercialisation potential. [40].

The type used in the current study is the Direct mechanical drive systems convert wave energy directly into electricity by utili□ing an electric generator. The mechanical transmission system and gearbox are typically employed to drive the electrical generator, which is directly linked to the gearbox. □arious prototypes of □□Cs that utili□e direct mechanical drive technology have been designed and implemented [41].

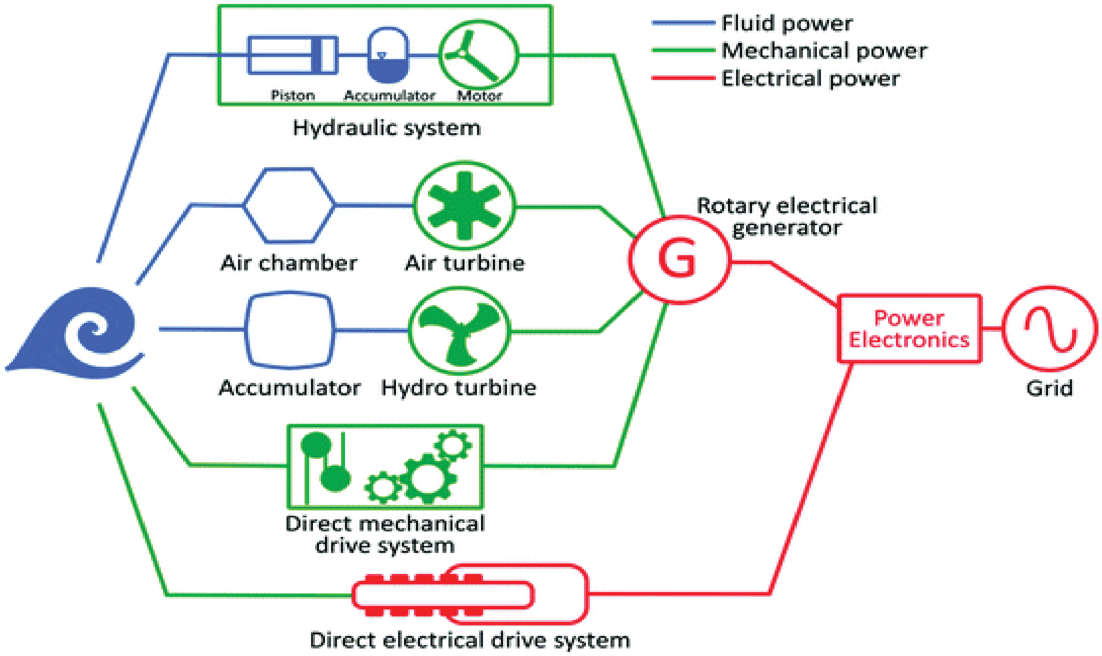

Figure 1.8: □T□ systems for wave energy technology[42].

1.7.3 Wave Energy Research Site

The coastal region of Iraq features low cliffs and deep waters, rendering it a favorable location for the establishment of wave power stations.

The region of AlMa'qal, Abu Flus, Umm □asr, and □hour Al □ubair is of great significance to Iraq as it serves as the only waterfront and economic hub of the country[43]. □ithin this map, the specific area marked by the dashed line in Figure (1.7) designates the proposed pro□ect□ wave energy research site. The (□hor Al- □ubair) channel is a semi-closed marine tongue from the Arabian Gulf, which takes the □□□ -SS□ direction for about (40 km) and (18 m mid-cannel depth). The width of this channel varies based on the phase of the tide, with measurements indicating a possible range of 1-2 km during periods of high tide [44].

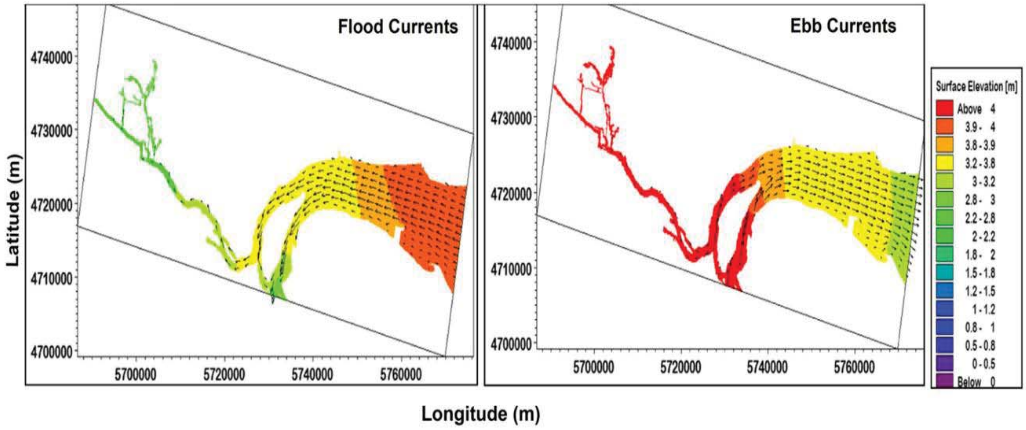

Figure 1.7: Surface Evaluation (m) in the study area [37]

There are two types of waves in (Khor Al- Zubair) [4□]:

1. The first type: Plunging is the form of breaking where the upper part of the wave breaks over its own lower part in one big splash whereby most of the energy is lost. This form of breaking takes place in cases of moderately steep waves on moderately sloping shorefaces.
2. The second type: Surging is when the lower part of the wave surges up on the foreshore in which case there is hardly any surf-zone. This form of breaking takes place when relatively long waves (swell) meet steep shorefaces as shown Figure (1.8).

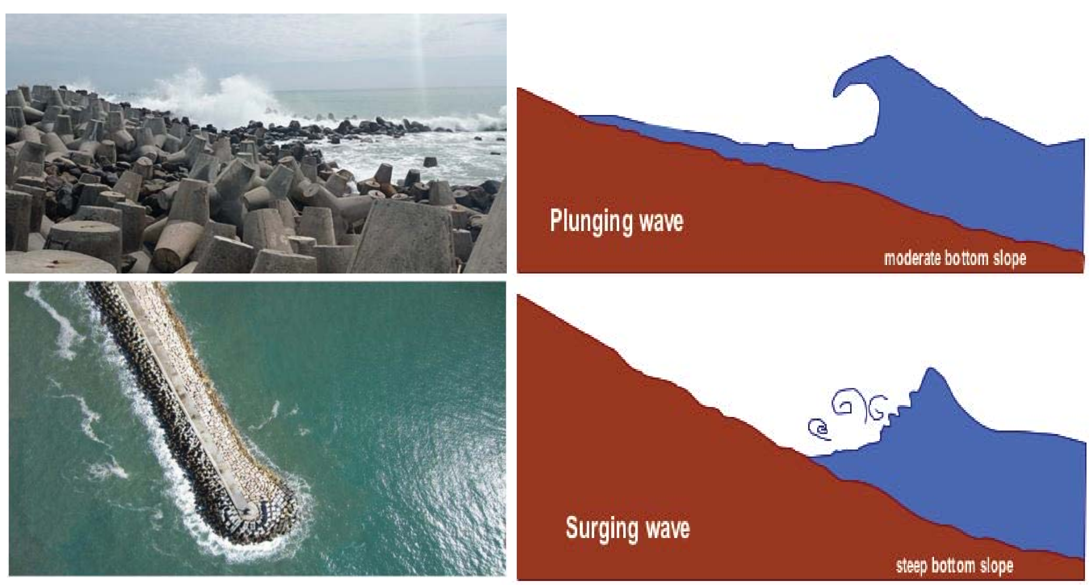

Figure 1.8: Types of waves breaking

1.8 Aims and Objectives of the Research

- Fabrication unique, economic, technological □ □C for ocean energy electrical energy converting to reduce dependency on the available convention source of energy .
- this study aims to experimentally investigating and analy□ing of converting the wave energy to electricity
- Design clean source energy system with low environmental effects .
- The system should be installed without harming the marine organisms.
- □ow manufacturing and maintenance costs system
- □perates in variety of sea conditions and wave direction ,even with small wave .

1.9 Outlines of Thesis

❖ Chapter □ne : Introduction

❖ Chapter Two: □iterature Review

❖ Chapter Three: □ athematical

❖ Chapter Four: □xcremental Setup

❖ Chapter Five: Results and Discussions

❖ Chapter Six: Conclusion and Recommendation

ABSTRACT

The research about sustainable energy resources stills the very interested research topics. Therefore, this study aims to experimentally investigating and analy□ing of converting the wave energy to electricity. The experimental tests were achieved in two stages. The first stage has been tested at laboratory in both rotation directions (one direction and bidirectional). Further, the second stage has been conducted locally at the Arabic gulf-South of Iraq□□asra (□hor Al□ubayr).

The local tests were performed in three cases named: “ before the starting of tidal” (tested in one direction),”after happening the tidal” (tested in one direction) and “at the increasing of the sea water” (tested in bidirectional). The results of local tests (at the sea) show that the maximum power of test were recorded value about 68 □ in case of happening the tidal with an increase percentage of 7□% over the case of starting the tidal and 92.6% over the case of bidirectional. □oreover, the electric generating during tidal has more chance of generating electricity relative to other times. □hereas, the energy reached about 1200 □oule at accumulated time (□0 minutes) when the tidal is available. In contrast, it is reached about 200 □oule at the same time when absence the tidal. Therefore, the results show very promising findings.