بسم الله الرحمن الرحيم

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بقسم التوثيق الإلكتروني بمركز الشبكات وتكنولوجيا المعلومات دون أدنى مسئولية عن محتوى هذه الرسالة.

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AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Engineering Physics and Mathematics Department

Mechanical Parameters Optimization to Enhance the Wave Energy Conversion System Performance

A Thesis submitted in partial fulfillment of the requirements of the degree of

Master of Science in Engineering Mechanics

(Engineering Physics and Mathematics Department)

by

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Statement

This thesis is submitted as partial fulfillment of Master of Science in Engineering Mechanics, Faculty of Engineering, Ain shams University, Cairo, Egypt.

The work included in this thesis was carried out by the author, and no part of it has been submitted for a degree of qualification at any other scientific entity.

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Thesis Summary

Wave energy is very important source of energy; since it is clean, environment friendly and renewable. A massive amount of energy can be generated from waves if the wave energy converter is well chosen and designed. Thus, the objective of this thesis is to maximize the wave power extraction by optimizing the wave energy converter parameters. Relatively new optimization techniques are used in this work to maximize the power extraction from incident wave energy corresponding to the wave height. Also, for determining of the best deep-water length and maximizing the applied damping ratio. Moreover, these optimization techniques are used in this thesis also to tune the conversion system controller gains to maximize the output power of wave energy converter.

Three controllers are proposed and tuned by these optimization techniques. MATLAB/Simulink is the software used to implement the model used for this research. The results show that the optimization of mechanical parameter can increase the output power of wave energy converter much better than tuning the system controller gains. Moreover, the Equilibrium Optimizer (EO) proved its superiority than Harmony Search Algorithm (HS) and Teaching Learned Based Optimization (TLBO). The results also show the superiority of model predictive controller (MPC) than proportional–integral–derivative controller (PID controller) and Linear Quadratic Regulator controller (LQR controller).

Keywords: Wave Energy, Optimization, Mechanical Parameters, Maximum Power, Equilibrium Optimizer

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List of Abbreviations

PTO	Power Take Off
SWL	Still Water Level
WEC	Wave Energy Converter
OWC	Oscillating water Column
OPT	Ocean Power Technologies
EMEC	European Marine Energy Centre
DOF	Degree of Freedom
HS	Harmony Search
GA	Genetic Algorithm
GSA	Gravitational Search Algorithm
LIMPET	Land Installed Marine Powered Energy Transformer
HS	Harmony Search
TLBO	Teaching Learning-Based Optimization
EO	Equilibrium Optimizer
LQ R	Linear Quadratic Regulator
PID	Proportional–Integral–Derivative
MPC	Model predictive controller

List of Symbols

k = wave number = $2\pi/L$

x **=** the horizontal coordinate parallel to wave propagation

$\boldsymbol{\omega}$ **=** wave frequency = $2\pi/T$

t **=** time

L **=** wave length

T **=** wave period

h **=** water depth

z **=** vertical coordinate relative to still water

$\boldsymbol{\rho}$ **=** Density of fluid, fresh water ~ (1000 kg/m3), seawater ~ (1025 kg/m3)

g **=** Acceleration due to gravity (9.8 m/s2)

H **=** Wave height (m)

Po**=** Wave power flux (W/m)

Cg **=** group speed (m/s***)***

m = total mass of the system

μ = rate of wave radiation damping for the buoy

ν = rate of wave radiation damping for the WEHD

Kz = static restoring force

$\mathbf{F_0}$ = Force amplitude

CHAPTER 1

Introduction

1.1 General

Nowadays, the energy problem required more and more attention that happens because the natural reserves of oil, gas, and coke are on their way to be finished. In addition, fossil fuels are very polluting and that particular opens the way for new research and studies about the so-called renewable energy. One of the most recent subjects of study, among these renewable energies is wave energy [1]. Approximately in 2050, 15% of world electric energy production can be obtained with this new technology, at present in this time the studies of wave energy show a strong increase [1]. In this way, the combination of renewable energies and fossil fuels partially resolves the problems of environmental pollution and electric energy production.
The power in a wave is proportional to the wave amplitude and to the wave period. Therefore, for long period around (7–10 s), large-amplitude around (5 m) waves have an average power density between 85 and 120 kW per meter [2].

There are several advantages to using the wave energy as follows [3]: -

- By its high-power density, it is one of the lowest-cost renewable energy sources.
- Wave energy is more predictable than other renewables, making it more likely to be dispatched to a power grid system.
- The transformation of ocean energy to electricity is thought to be one of the most environmentally friendly methods of producing power; hence, it produces no trash that must be stored or harms the environment.
- The wave energy converters are often located far enough off from the shore (offshore) that they're generally not visible

It’s important to appreciate the difficulties that wave power development is facing. The most common of them are:

- Strong irregularity in wave amplitude, frequency, and phase; obtaining a device that can be employed over the whole excitation frequency range is challenging. [1].
- The structural loading in event of extreme weather conditions, such as hurricanes, may be 100 times as high as the normal average loading [2].
- The coupling of slow-motion around (0.1 Hz) and irregular frequency of a wave to electrical generators required around 500 times greater frequency [4].

The magnitude of accessible ocean energy is staggering. “It has been predicted that if just round 0.1 percentage of the world ocean energy resource were harnessed, scientists could

supply the entire world five times over." (Merry 2005). Ocean surface waves, also called gravity and wind waves, are an oversized part of the world's ocean energy resource. It is documented that surface waves (wind and gravity) contain the highest energy levels in the ocean wave energy spectrums as illustrated in Figure 1. As a conservative estimate, at 15 percent overall efficiency, 4 percent of surface waves could power all energy consumption of humanity 5 times over, and it will be decades or centuries into the future before global energy consumption increases beyond available ocean wave energy. Note that the highest wave energy is resulted in the 1 to 30-second wave periods. Long-term annual wave periods of North America, ranging from Canada to Mexico, are very consistent at approximately 12 seconds which provides the United States an excellent opportunity to become a world leader in wave energy conversion [5].

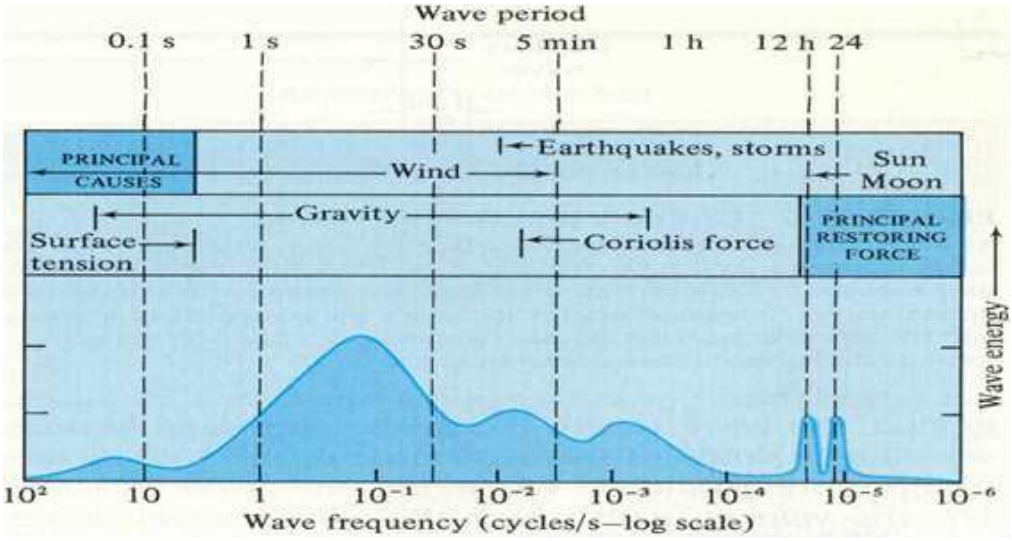

Figure 1. Ocean Energy Spectrum [5]

Let's now consider all the places on Earth to use ocean surface waves. The surface area of Earth's oceans is approximately 350 million square kilometers (km). Hence, if wave energy was harvested at 15 percent efficiency, the world could be powered by a small wave farm near regions which contain high concentrations of surface wave energy flux as illustrated in Figure 2. Equivalently, four-wave energy farms in each of those regions could power the planet. Harvesting ocean energy near Canada, California, Washington, Maine, Massachusetts, and Connecticut big apple could energize the complete of North America [6].