A HYBRID WIND-WAVE ENERGY SYSTEM WITH BATTERIES FOR OFFSHORE OIL AND GAS PLATFORMS

By

Ahmad Mohammad Saber Abdelsamie

A thesis submitted to the

Faculty of Engineering at Cairo University

In Partial Fulfilment of the

Requirements for the Degree of

MASTER OF SCIENCE

In

Electrical Power and Machines Engineering

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Thesis Title:	**A Hybrid Wind-Wave Energy System with Batteries for Offshore Oil and Gas Platforms**
Key Words:	**Energy Storage; Offshore Hybrid Renewable Energy systems; Power reliability; Wave energy; Wind energy.**

Summary:

The offshore Oil and Gas (OOnG) sector accounts for a great portion of Greenhouse gases (GHG) emissions. The idea of the electrification of OOnG platforms by clean sustainable energy sources, namely wind and wave, was a turnaround. Combining wind energy turbines (WETs) and wave energy converters (WECs) for less generation variability has been recently proposed in literature. OOnG electric loads are of high sensitivity, and though require a high level of reliability, which contradicts with the intermittent nature of winds and waves. The usage of battery packs could help decrease these variations. But practical batteries are known to degrade over many factors. In this thesis, a comprehensive study is presented on quantifying the change in reliability of electric supply caused by coupling of a wind-wave (WW) hybrid offshore energy converter unit (HOEC) with Lithium-based energy storage (LBESS), while considering LBESS's degradation. A case study on USA's largest oil port was carried out to demonstrate this hypothesis. A variety of WW ratios were studied. For each ratio, the maximum possible load level and the optimal battery size were calculated. The optimisation problem was solved using a simple-yet-robust systematic approach.

Simulations showed that the proposed concept, regardless the battery ageing, not only saves area, but also provides a good reliability level in an OOnG environment. Therefore, integrating such WWB-HOECs could be a key solution for cutting down GHG' emissions from OOnG platforms, and related applications.

DISCLAIMER

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references sections.

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Alhamdulillah*…

* Alhamdulillah: The ultimate gratitude and praise be to God; in Arabic language.

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LIST OF SYMBOLS AND ABBREVIATIONS

1- Symbols

C	:	Battery capacity	MWh
cd	:	Cycle depth	%
C_{fade}	:	Capacity fade	%
C_{fade_cal}	:	Capacity Calendar fade	%
C_{fade_cyc}	:	Capacity Cyclic fade	%
C_O	:	Nominal battery capacity	MWh
C_S	:	Vector of ascending values of C_Os	Dimensionless
ȸ	:	Ratio of $(P_L 1 / P_O)$	%
ΔP_L	:	Incremental step in P_L	MW
ELF_{MAX}	:	Maximum allowable ELF	Dimensionless
ELF_{MIN}	:	Minimum ELF value in a certain *ELFs*	Dimensionless
ELFs	:	A vector of ELF values corresponding to C_S	Dimensionless
h	:	Height	m
H	:	Total number of hours in the year	Hours
H_S	:	significant save height	Meters
L(t)	:	Loss of power at hour (*t*)	MW
nc	:	Number of cycles	Dimensionless
$\boldsymbol{nP}$	:	Required number of HOECs	Dimensionless
P_B	:	Battery power capability	MW
P_{Bat}	:	Battery produced power	MW
P_{Bat_MAX}	:	Maximum P_{Bat}	MW
P_{Bat_MIN}	:	Minimum P_{Bat}	MW
P_{BO}	:	Nominal battery power capability	MW

PC_{fade}	:	Power capability fade	%
PC_{fade_cal}	:	Power capability Calendar fade	%
PC_{fade_cyc}	:	Power capability Cyclic fade	%
P_{HOEC}	:	Output power from a HOEC	MW
P_L	:	Load power	MW
$P_L 1$	:	Maximum P_L a WW-HOEC can satisfy	MW
$P_L 2$	:	Maximum P_L a WWB-HOEC can satisfy	MW
P_O	:	Rated power of an HOEC system	MW
P_{REN}	:	Total generated renewable power by HOEC's parts	MW
P_{WAVE}	:	Power generated from waves.	MW
P_{WIND}	:	Power generated from winds.	MW
Pn	:	Nominal power	MW
φ	:	Ratio of $(P_L 2 / P_O)$	%
SOC	:	State of charge	%
SOC_{MAX}	:	Maximum SOC	%
SOC_{MIN}	:	Minimum SOC	%
t	:	Time	Hours
T	:	Temperature	K
T_W	:	average wave period	Seconds
v	:	Wind velocity at a certain height	m/s
$\boldsymbol{\Sigma Po}$	:	Total required power capacity to be installed	MW