Ocean Wave Energy Harvesting Buoy for Sensors

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Abstract **– Methodology and results are presented for the numerical simulations and experimental measurements on ocean energy harvesting systems that utilize anchored linear generators, driven by heaving surface buoys that convert ambient ocean wave energy into useful electrical power. The results demonstrate the feasibility of using ocean wave energy harvesting buoys and simple linear generators to provide sufficient electrical power for ocean sensor applications (1-10 W range). Experimental results for a small scale linear generator, directly driven in a test bed with realistic ocean wave spectra, demonstrate power in the 5-10 W range. Simulations for buoy/generator systems using imperfectly wave-compliant surface buoys and two different anchoring approaches show that the wave compliance of the buoy and the method of anchoring have a major effect on performance. These simulations for practical system designs show performance in the 1-4 W range.**

Index Terms**—energy conversion, wave energy harvesting, linear generator, ocean energy, heaving buoy, wave spectra.**

I. NOMENCLATURE

A ***rigid-drive-system*** is an energy harvesting system which forces the linear generator armature to perfectly track (or mirror) the ocean wave surface elevation without amplification or attenuation of amplitude.

A ***direct-drive-system*** is an energy harvesting system which attempts to force the linear generator armature to track (or mirror) the ocean wave surface elevation, but is unable to do so perfectly, resulting in attenuation of the amplitude.

A ***resonant-drive-system*** is an energy harvesting system which allows the linear generator armature and/or the buoy to resonate with, and amplify, the ocean wave surface elevation.

II. INTRODUCTION

Ocean wave energy harvesting systems, designed for sensor buoys, convert wave motion into electricity, to allow operation under all weather conditions, while enabling enhanced functionality, higher performance and continuous operation. Such systems generate and accumulate energy that can be used to indefinitely power remote buoys, equipped with sensors arrays, as well as electronics for processing and communications. These power sources can be integrated with buoy systems to minimize the size of batteries, or eliminate the need for batteries if super-capacitors are used.

While various wave energy conversion approaches have been proposed or are under investigation [1]-[2], this work[†] targets relatively low-power, distributed, point absorption *direct-drive-systems* consisting of a simple small Linear Electric Generator (LEG) mounted vertically and directly driven via a surface buoy's wave-induced heave motion. This configuration, which provides reliable operation without the need for additional gearing, has the ability to harness electrical power in the 1 to 10 W range, in small seastates (as required in many sensing and communication applications), when using relatively small buoys and LEGs.

This research differs from that aimed at developing large *direct-drive-systems* [1], intended for high power electrical grid contributions. Here, the goal is to store accumulated energy and form a completely self-contained, persistent, energy source platform, suitable for a variety of sensor payloads. The approach also differs from the *resonant-drive-system*, that is developed in parallel in our research group [2], operating off of an inertial mass and resonant tuning, in that power is directly obtained from the "stiff" drive provided by a nearly wave compliant surface buoy, as well as some method of bottom anchoring (e.g., sea-anchor/resistance-plate, or a rope-line tied to the ocean floor). This avoids the problems of mismatch of the dominant ocean wave frequency with system resonances and allows power accumulation in all sea states, with relatively simple electrical and control systems.

This work provides detailed results of a particular *direct-drive-system* approach, but also outlines the analysis tools to apply in other methods. For example, the methodology has been applied to *resonant-drive-systems* with suitable model extensions to calculate roll/pitch motion of heaving spar buoys. Hence, an important contribution of this work is the development of accurate wave-to-wire simulation models that enable optimization of the various energy harvesting systems, while including the important sub-system interactions. The theoretical system equations are structured as a nonlinear state-space model with a finite number of states, which lends itself to efficient numerical techniques, and is well suited to simulation using the well-established Simulink tool, which allows reliable and fast implementation of coupled and complicated nonlinear state-space system equations.

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