Increasing Efficiency in Renewable Energy Generation: Optimizing Wave Energy Conversion Power Plants

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INTRODUCTION

This project is concerned with the EU-commissioned ocean wave energy power plant located on Ilha do Pico, part of the Portuguese Azores. A theoretical model was developed to simulate the energy conversion, from ocean wave to turbine shaft, in this oscillating-water-column (OWC) plant equipped with a Wells turbine or impulse turbine. An optimization routine applied to the plant model evaluates average power output of the operating air turbine, identifying the optimal diameter and rpm. The plant’s geometry was taken from the OWC Pico plant’s dimensions and the marine climate was representative of the plant’s local sea state.

OBJECTIVES

- Understand the operating principles of the Pico OWC wave energy plant and its equipment
- Model the energy conversion from the open ocean to the turbine output
- Optimize the turbine’s performance based on turbine size and rotational speed

THE PICO PLANT

The Pico plant is a 400kW rated pilot OWC. It is a permanent shoreline installation, operating one horizontally exhausting, fixed-blade Wells turbine. The plant sits in a nominal mean water depth of 8m on the north-western shore of Ilha do Pico in the path of the Azores Current. In this location, significant wave heights range between 1.0 and 3.5 meters and periods range between 8.0 and 12.0 sec. The energy per meter crest length is found to be about 30W/m offshore and 13W/m at the plant site.

OPERATING PRINCIPLE

Extracting power from waves requires equipment capable of absorbing a wave’s energy and then transferring that energy to a piston or a turbine. The technique used in the Pico plant, illustrated below, is based upon the principle of an oscillating water column (OWC). Oscillating water columns use the energy of incident waves to create a rising and falling water surface which alternately compresses and decompresses air in a pneumatic chamber. The low frequency wave energy is effectively converted into low pressure, high volume air flow. The reciprocating air flow is allowed to exhaust to the atmosphere through the turbine duct. The turbine is attached to an asynchronous induction generator which produces electricity for the island grid.

The type of turbine used in OWC plants is designed to rotate in one direction irrespective of the flow direction. OWC plants have traditionally employed Wells turbines. In this type of plant design, the power-take off equipment is required to convert an irregular energy flux. This oscillatory energy flow causes material stress and electrical spikes, both preferably avoided. In recent designs the Wells turbine has been replaced by an impulse turbine, which maintains a constant rpm and therefore generates power that is more compatible with the grid.

SYSTEM OVERVIEW

This model employs a combination of techniques to solve for the conversion of energy through the plant. At each sea state the average power output, dependent on the turbine size and rotational speed, was simulated. The model begins by calculating the energy contained in waves which come in contact with the plant. Next, a theoretical model, conventionally used in conjunction with floating bodies, was adapted to the OWC system. The adjusted code has been well validated with published test cases so that it accurately predicts the hydrodynamic behavior of waves interacting with an OWC plant. The code can generate the front wall submergence depths and the obtained results were in agreement with empirical expectations. The geometry of the Pico plant as well as the typical local wave energy climates were applied to the model. The velocity field on the water free surface corresponds to both the piston-like motion of the waves and the sloshing of waves confined in the chamber. From the water free surface elevation, it is possible to find the change in volume of the air in the chamber and then the volumetric flow rate of the air through the turbine.

FUTURE WORK

Immediate goals include completing the model and running the optimization for the impulse turbine as well as the Wells turbine. This will allow for a comparison of the power outputs. From the outputs it should be possible to determine which equipment is better suited for the Pico plant.

A long term goal for my work includes expanding the program applicability to other sites. The Scottish plant LIMPET can provide empirical data corresponding to their local conditions, from which I can make further software refinements. By April I hope to have run the simulation for LIMPET.

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