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Modelling, simulation and testing of a submerged oscillating water column

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A B S T R A C T

This paper presents the development of a time-domain simulation model, with experimental verification, for a submerged oscillating water column (OWC). The Stellenbosch Wave Energy Converter (SWEC) makes use of series of these submerged chambers in order to create a rectified flow through a single turbine. The main objective of this research was to produce a verified and validated simulation model for a single chamber of the SWEC. The mathematical model was derived from first principles and then coded in Simulink. The simulation results were verified using measurements from a scale model in a wave tank test. The model provides a better understanding of the hydrodynamics and thermodynamics associated with the submerged chamber. The submerged chamber achieved a peak conversion efficiency of 22%. The device achieved a conversion efficiency of 13% at the expected operating conditions when orientated at 45° with regards to the incident waves. The simulation model predicted the transmissibility of the device with errors which ranged from 0% to 20% with the majority of the errors being less than 5%. The model predicted the conversion efficiency of the device with errors which ranged from 0% to 43% with the majority of the errors being less than 15%.

1. Introduction

Until the twenty-first century global electricity needs have been predominantly met by converting fossil fuels into electricity with the associated emissions leading to significant environmental impacts. South Africa is an example of a country that meets the majority of its electricity needs through burning coal. South Africa is suffering from a lack of electricity supply which resulted in rolling blackouts in 2014 and 2015. Thus, there is an urgent need for power from alternative, renewable and sustainable energy sources. Renewable energy is defined as energy sources which are naturally and continuously replenished at a rate exceeding the use thereof. This study will focus on how to convert the energy in ocean waves to useful electricity.

The global wave power resource is estimated at 2 TW, with the United Kingdom's wave power potential ranging from 7 to 10 GW [1]. To put this in perspective, the UK's total grid capacity is about 80 GW, this means that up to 15% of the UK's peak electricity demand could be supplied using wave energy [1]. The southwest coast of South Africa is approximately 700 km long, with the southern tip of this coastline recording an annual average wave power resource of up to 40 kW per meter

Abbreviations: SWEC, Stellenbosch Wave Energy Converter.

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wave front [2]. If this energy could be efficiently harnessed it will support South Africa's electrical grid in areas of higher consumption but with less generation. The Stellenbosch Wave Energy Converter (SWEC) developed in the 1980s may provide a means of converting this renewable energy source into electrical energy [3].

In this paper a simulation model of the hydrodynamic, pneumatic and thermodynamic behaviour of a single submerged chamber of the SWEC device is presented. The model is validated with experimental test data obtained in a wave flume. The experimental test data and simulation model can be used to investigate the viability of the device as well as increase the understanding of the fluid-dynamic behaviour of the SWEC and other oscillating water columns (OWCs) in general.

The SWEC consists out of two 160 m long submerged arms which are positioned in a 'V' like shape fixed to the sea floor as illustrated in Fig. 1. Each arm has 12 chambers which act as submerged OWCs. The chambers are connected by high and low pressure ducts to direct the resulting, rectified airflow through a single turbine to convert the wave energy to mechanical energy. The high and low pressure ducts run along each arm to the tower where the air from the high-pressure duct is forced through the turbine before returning via the low-pressure duct to the chambers. The single turbine drives an electrical generator both placed above water on a concrete tower for ease of maintenance.

The SWEC was designed to operate off the southwest coast of South Africa in typical wave conditions shown in Table 1. As the crest of a wave moves overhead, water is forced into the submerged chambers. This increases the pressure in the chamber and forces air into the high pressure duct. As the trough of a wave passes overhead the pressure decreases again and air is replenished out of the low pressure duct, see Fig. 2.

The SWEC was invented in the early 1980s by Retief and his team of researchers [3] at Stellenbosch University. Research concerning the SWEC was put on hold due to the decrease in the oil price in the late 1980s. After a resurgence in interest in renewable energy due to climate change Joubert [2] carried out a wave energy resource analysis on the South African coastline in 2008. Studies carried out after 2008 concerning the SWEC include Ackerman [4], Meyer [5], Joubert [6] and Fairhurst [7]. In general, these studies found that there is a need to accurately model the SWEC system to better understand the fluid- and thermodynamic behaviour in order to predict the efficiency of the system.

A single chamber of the SWEC comprises of hydrodynamic and pneumatic subsystems. Early studies carried out to model the hydrodynamics of OWCs include Evans [8,12], McCormick [9], Revil [10] and Szumko [11]. Gervelas et al. [13] modelled the hydrodynamics of a system similar to the submerged chambers using well documented work carried out on trapped air cavities. The model of the submerged chambers developed in this paper draws heavily on the research carried out by Gervelas et al. [13].

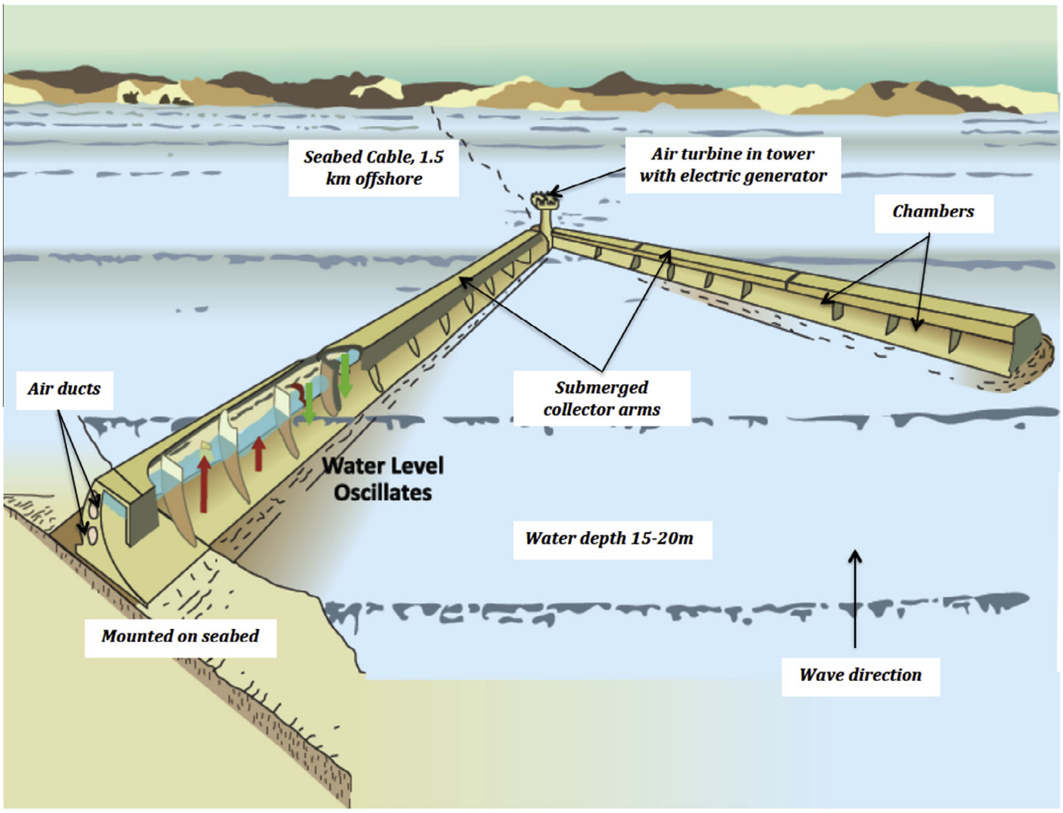

Fig. 1. SWEC 'V' adapted from Retief et al. [3].