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Review on electrical control strategies for wave energy converting systems ☆

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ABSTRACT

Renewable energy techniques are now gaining more and more attention as the years pass by, not only because of the threat of climate change but also, e.g. due to serious pollution problems in some countries and because the renewable energy technologies have matured and can be depended upon an increasing degree. The energy from ocean waves bares tremendous potential as a source of renewable energy, and the related technologies have continually been improved during the last decades. In this paper, different types of wave energy converters are classified by their mechanical structure and how they absorb energy from ocean waves. The paper presents a review of strategies for electrical control of wave energy converters as well as energy storage techniques. Strategies of electrical control are used to achieve a higher energy absorption, and they are also of interest because of the large variety among different strategies. Furthermore, the control strategies strongly affect the complexity of both the mechanical and the electrical system, thus not only impacting energy absorption but also robustness, survivability, maintenance requirements and thus in the end the cost of electricity from ocean waves.

Contents

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1. Introduction

Oceans cover two thirds of the earth's surface and large amounts of energy is contained within its motion. This vast source of renewable energy has the potential of meeting an important part of the demand for non-polluting electricity for mankind.

Since the 1970s, following the oil crisis, research on renewable energy has gained increasing support and this has also affected the research on wave energy. So far, many types of wave energy converters (WECs) have been invented, developed and tested in small and large scale experiments.

When the electricity production from WECs depends on and varies synchronously with the wave movement then the amplitude and frequency of the converted electricity will naturally vary dramatically during each wave period. This electricity is incompatible with the electric grid since electricity supplied to the grid has to have a voltage that is of constant amplitude and frequency. Hence, some strategies of electrical control and storage as part of the energy conversion play a significant role in wave energy systems.

This paper is mainly concerned with electrical control strategies for wave energy conversion. In Section 2 a short introduction to wave energy absorption is presented. The purpose of this section is to help the uninitiated reader to understand what the control strategies are trying to achieve in terms of the interaction with, and absorption of energy from the wave. In order to facilitate relevant comparisons among control methods, the different types of wave energy converters are classified with respect to their mechanical structures in Section 3. In Section 4, electrical control strategies with devices as examples are discussed. Section 5 presents energy storage strategies that are used during the energy absorption.

This paper focuses on the control strategies and only provides a brief overview of existing wave energy technologies, for a more thorough review and classification of wave energy converters see [10]. It is necessary to mention that for various reasons, such as mechanical problems or lack of financial support, not all the control strategies have been experimentally verified as proposed and studied in their academic publications.

2. Energy absorption

Oceans transport huge amounts of energy, this energy is transported in form of polychromatic waves. An ocean wave is water particles moving in elliptical orbits, where the radius decreases with the water depth [1]. The power transport per unit width of wave front is given by the hydrodynamic pressure and the water particle velocity, according to

$$J=\int_{-z}^{0} p_i v_i \, dz \left[\frac{W}{m}\right] \tag{1}$$

The integral is calculated from bottom to still water level. An object or something else interacting with this incident wave will create a radiated and a diffracted wave that will change shape of the incident wave. To be able to take away energy from this incident wave this “object” has to interact in an advantage way to this wave. Being able to absorb energy from the waves, radiated and diffracted waves has to be created to interfere destructively with incident waves. A good wave absorber has to be a good wave maker [2]. Assume an arbitrary shaped area of the ocean surface (Fig. 1). The energy flux into this volume is denoted as E_i, and the energy flux out from the area is denoted E_o. According to energy balance the possible absorbable energy from the waves in the given volume is given by $E_i = E_o + E_{abs}$. Being able to absorb energy an outgoing wave has to be created by the absorber.

Assume an undisturbed incident wave has the water particle velocity, $v_i = (v_{i,x}, v_{i,y}, v_{i,z})$ and a hydrodynamical pressure p_o. The same for the diffracted/radiated wave from the wave absorber unit inside the volume, i.e. the outgoing wave from a wave absorber unit have water particle velocity,$v_o = (v_x, v_y, v_z)$, and a hydrodynamical pressure p_o. The total net flux of the energy in an arbitrary volume of the ocean during a time $2t$ is then given by

$$E_{abs}=\int_{-t}^{t}\oint_{S}\int_{-z}^{0}(p_i-p_o)(v_i-v_o)\cdot\hat{n}\,dz\,ds\,dt \tag{2}$$

Note that for an undisturbed wave the absorbed energy is zero, because the incoming energy to the volume is the same as the outgoing energy.

In order to maximize the energy absorption from the ocean wave, Eq. (2) has to be maximized. It can be seen in Eq. (2) that the interaction is not momentarily, to maximize outtake of energy the incident wave has to be known in advance.

Absorption is about to create a wave with right amplitude, frequency and phase angle to cancel out incident wave.

3. Classification of wave energy converters based on mechanical design

Several systems for the classification of WECs have been proposed through the years, ranging from detailed to rough, see [3,4]. For simplicity we have chosen a basic separation into three types: Oscillating Water Column devices (OWCs), overtopping devices, and attenuators (Fig. 2). OWCs and overtopping devices are both available for offshore and inshore installations. The attenuators are predominantly offshore devices.

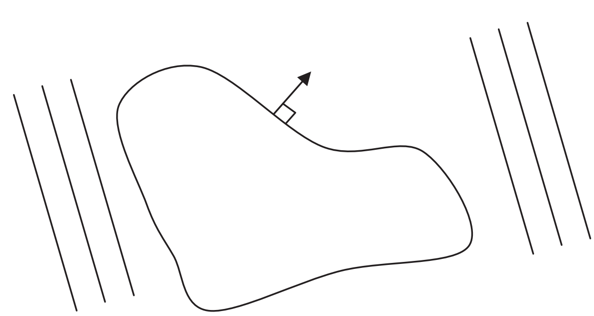

Fig. 1. An arbitrary area of the ocean surface.