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Design of the dual-buoy wave energy converter based on actual wave data of East Sea

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ABSTRACT: *A new conceptual dual-buoy Wave Energy Converter (WEC) for the enhancement of energy extraction efficiency is suggested. Based on actual wave data, the design process for the suggested WEC is conducted in such a way as to ensure that it is suitable in real sea. Actual wave data measured in Korea's East Sea (position: 36.404 N° and 129.274 E°) from May 1, 2002 to March 29, 2005 were used as the input wave spectrum for the performance estimation of the dual-buoy WEC. The suggested WEC, a point absorber type, consists of two concentric floating circular cylinders (an inner and a hollow outer buoy). Multiple resonant frequencies in proposed WEC affect the Power Ttake-off (PTO) performance of the WEC. Based on the numerical results, several design strategies are proposed to further enhance the extraction efficiency, including intentional mismatching among the heave natural frequencies of dual buoys, the natural frequency of the internal fluid, and the peak frequency of the input wave spectrum.*

KEY WORDS: Dual-buoy wave energy converter; Multiple resonance; Measured wave data; Relative heave motion; Extracted power; Linear electric generator.

INTRODUCTION

With the increasing demand for renewable energy sources, many countries are responding positively by taking constructive measures such as the reduction of carbon emissions in an effort to improve the global environment. Renewable energy is sustainable, clean, and unlimited, and comes in diverse forms, such as solar thermal energy, solar photovoltaics, geothermal energy, wind energy, and wave energy. The most suitable method for obtaining renewable energy can be chosen according to the regional and environmental characteristics. While some forms of renewable energy have been successfully commercialized, most are still being researched and developed.

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Of the various sources of renewable energy, wave energy has the highest energy density. Wave Energy Converters (WEC), which extract electrical energy from wave energy, are known to be the least hazardous to surrounding environments (Drew et al., 2009). In addition, WEC technology has been researched extensively in Europe and Japan for use with the abundant wave energy available in those regions. Thus, some WECs have been successfully commercialized (Power Buoy, LIMPET), and many WECs are still being researched for commercialization (Mekhiche et al., 2014; Boake et al., 2002).

The WECs developed thus far are classified into attenuators, point absorbers and terminators, according to their method of power generation (Drew et al., 2009; Soares et al., 2014). Of these, the point absorber type, which extracts wave energy from the heaving motion of a WEC device, is not affected by the direction of the incident waves and its motion is highly amplified when its natural frequency agrees with the wave frequency. Since the beginning of wave energy research, research into increasing energy absorption has been focused on tuning the system to oscillate in resonance with the incoming wave. It is well known that a point absorber system in resonance with the incident wave will achieve increased amplitude and speed, and therefore, transfers more energy than a system working off resonance (Budar and Falnes, 1975; Falnes, 2002).

However, the frequency bandwidth capable of producing the highly amplified motion responses by resonance is limited. Therefore, although the energy extraction efficiency may increase by resonance, the narrow resonant frequency bandwidth restricts the ability to obtain a larger amount of energy from irregular waves that contain many different frequencies. To overcome such limitations, this study proposes a dual-buoy WEC that can generate multiple resonances. Multiple resonances constitute the most significant feature of the proposed dual-buoy WEC and enable the resonance of the wave converter system at different frequencies, thereby allowing for the extraction of energy from a wider frequency bandwidth.

The PowerBuoy, Wavebob (Weber et al., 2009) and AquaBuOY (Weinstein et al., 2004), which are currently utilized, are typical floating two-body WECs of the point absorber variety. The PowerBuoy does not use the resonance concept. It consists of an inner buoy with a relatively long draft, and a hollow outer buoy with a shorter draft. In this model, the inner buoy's heave motion is considerably reduced by the damping plate attached to the bottom of the inner buoy, and the outer buoy tends to follow the waves. The relative heave motion between the two is used to extract electrical energy. Wavebob, with a shape similar to the power buoy, can extract a larger amount of power using the resonance of the inner buoy, compared to the PowerBuoy. To solve the radiation problem of concentric dual-buoy WECs, Mavrakos (2005) used the matched eigenfunction expansion method to compute the hydrodynamic properties of each buoy, taking into account the interference effects. Bae and Cho (2013) investigated the diffraction and radiation problems of hollow circular cylinders and addressed the characteristics of heaving motion using the eigenfunction expansion method. Sinha et al. (2014) investigated the optimal array method and the wave interaction due to multiple point absorber WECs for maximizing wave energy extraction as possible as they can.

Numerical results obtained from investigating the effect of a dual-buoy's hydrodynamic interactions on the performance characteristics of a WEC are presented here. The numerical model based on the ANSYS AQWA commercial code included all interactions among the participating dual buoys arranged concentrically. The relative heave responses of a dual-buoy WEC, using the input wave spectrum measured at two sites in Hupo Harbor, were examined for the on/off status of the device. A considerable increase in the absorbed power was observed if multiple resonant frequencies were distributed around the peak frequency of the wave spectrum. We intentionally applied a mismatch between the heave resonant frequency of the outer buoy and the resonant frequency of the internal fluid by attaching a concentric external torus. Future work is currently under way to investigate in more detail the various damping mechanisms associated with the mechanical friction between the two buoys as well as with the LEG and the PTO system.

MULTIPLE RESONANCE OF A DUAL-BUOY WEC

The conventional WEC system consists of a cylindrical inner buoy and a hollow outer buoy, with a gap between the two. The PTO system used for the generation of electrical energy employs a LEG, consisting of a permanent magnet fixed to the outer buoy and a coil attached to the top of the inner buoy. Electrical energy is produced from the relative heave motion of each buoy. Thus, it is very important to increase the relative heave motion of the two buoys. To that end, the multiple resonance concept is adopted herein.

The proposed WEC system has three natural frequencies: the two heave natural frequencies, one for the inner buoy and another for the outer buoy, and the piston-mode natural frequency of the internal fluid that exists between the inner and the