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An innovative design of wave energy converter

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ABSTRACT

The aim of this research is to develop an innovative approach for electric power conversion of the vast ocean wave energy. A floating-buoy wave energy converter (WEC) using hydrostatic transmission (HST), which is shortened as HSTWEC, has been proposed to enhance the wave energy generation from wave fluctuations. In the HSTWEC device, the power take-off system (PTO) was combined with an HST circuit and an electric generator to convert the mechanical energy generated by wave energy into electrical energy. Design concept and working principle of the HST circuit were firstly derived. Next, a mathematical model, control concepts and selections of main components of the HSTWEC system has been carried out for an adequate investigation of the suggested system. Finally, simulations using MATLAB/Simulink and AMESim software have been performed in order to verify the effectiveness of the proposed HSTWEC. The simulation results show that more than 65% of wave energy can be absorbed by using the HSTWEC device.

1. Introduction

Sustainable and renewable energy is becoming increasingly important due to the expected exhaustion in current energy resources and the reduction of environment pollution. One of the most promising sustainable sources is wave energy. The development of wave energy generation (WEG) has been taking place for about 35 years. In most devices developed or considered so far, the final product is electrical energy to be supplied to a grid.

In practice, three main methods of energy storage have been adopted in WEG. An effective WEG way is storage as potential energy in a water reservoir, which is achieved in some overtopping devices, like the Wave Dragon [1] and the Tapchan [2]. The working principle of these devices is shown in Fig. 1(a). The overtopping wave energy converter works in much the same way as a hydroelectric dam [3]. The second WEG method is based on the oscillating water column. This WEC type depends on the air column and the difference in pressure generated by waves as in Fig. 1(b). In this device, the size and rotational speed of the air turbine rotor make it possible to store a substantial amount of energy as kinetic energy (flywheel effect - the Wells turbine) [4]. The third energy conversion way which is paid more attention to in recent years is floating-buoy wave energy converters as shown in Fig. 1(c) (see Refs. [5–9]). In a large class of these devices, the oscillating (rectilinear or angular) motion of a floating body (or the relative motion between two moving bodies) is converted into the flow of a liquid (water or oil) at high-pressure by using hydraulic systems. Falcão [8] focused on a study of oscillating-body wave energy converters with hydraulic power take-off and gas accumulator. The author carried out a general modeling analysis, system performance and design as well as a simple control method. Yang et al. [9] studied on a heaving-buoy wave energy converter equipped with high-pressure hydraulic power take-off machine. The mathematical model was derived in order to investigate the wear damage in the hydraulic machine. Although some valuable investigations were obtained by adopting these floating devices, their working efficiencies were not so high. For example, the power absorption efficiencies in [5], [7], and [8] were about 60%, 50%, and 20%, respectively.

In summary, many of these existing technologies seem very complex, expensive devices with a poor mass to output power ratio, and in most cases they are difficult to scale down or use offshore and on shorelines. Therefore, this paper introduces an innovative floating-buoy hydrostatic transmission-based wave energy converter (HSTWEC) for generating electric energy from ocean wave power. In addition, proper control concepts are proposed to manage the system operation for a highest working efficiency. As a result, by adopting the controlled HSTWEC device, electric energy can be easily obtained from wave energy absorption in both directions (up and down) of wave fluctuations.

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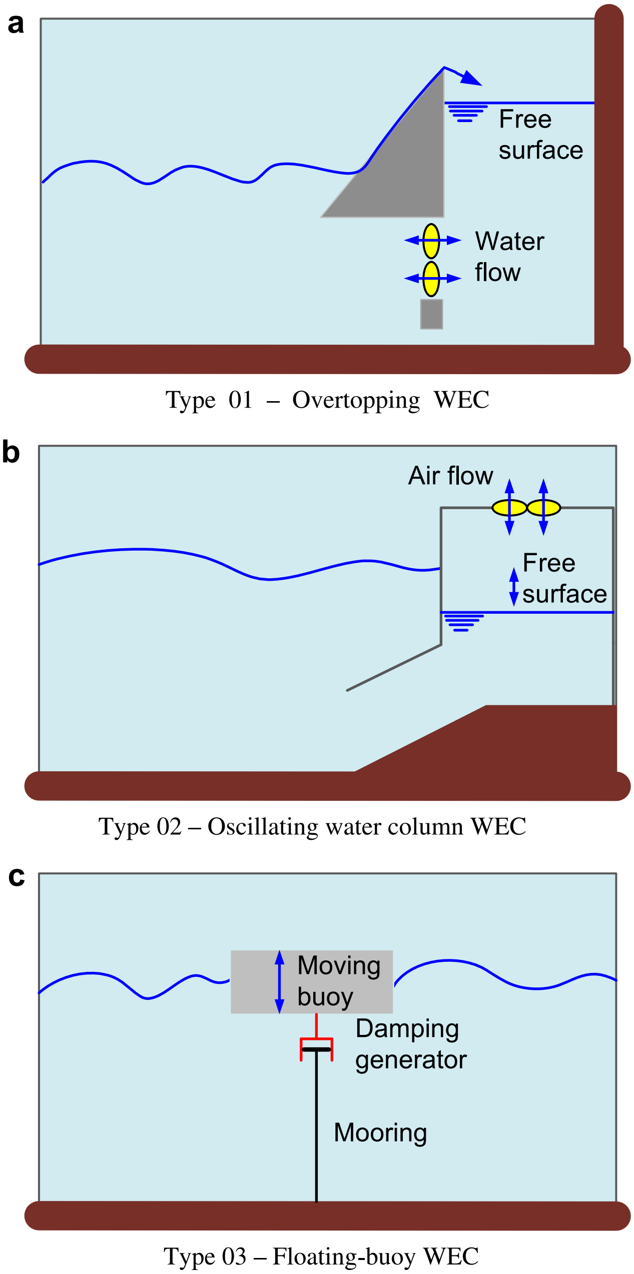

Fig. 1. Working principles of three main methods for WEG.

The remainders of this paper are then organized as follows: Section 2 gives a description of the HSTWEC design concepts while the system model and proper control concepts are presented in Section 3; Section 4 give a solution to select the main components of the HSTWEC device; Simulation using MATLAB/Simulink and AMESim software is shown in Section 5; Finally, concluding remarks are mentioned in Section 6.

2. HSTWEC design concepts

2.1. HSTWEC general concept

The system configuration is depicted in Fig. 2. The proposed HSTWEC includes three main components: a sub-buoy, a main-buoy system and a ballast system. The sub-buoy is linked to the ballast system by a timing belt while the main-buoy is fixed at the seabed with the help of two steel bars and a massive fundament. As seen in Fig. 2, inside structure of the main-buoy, there is the HST circuit which is a combination of a variable bi-directional hydraulic pump, a hydraulic valve block, a fixed displacement one-directional hydraulic motor, an electric generator, an electric converter and an electric storing device. Here, the pump is driven by the sub-buoy and pulley-timing belt mechanism; the motor is then operated by the pump through the valve block; and the motor output shaft is connected to the electric generating part for WEG purpose.

2.2. HSTWEC working principle

The design principle of this proposed system is to convert the ocean wave potential energy into electrical energy in high efficiency by using electric generator. Based on the floating-buoy concept, the wave forces the sub-buoy to move up and down. To increase the energy regeneration efficiency, the electricity should be generated in both directions of the sub-buoy moving. As a feasible means, the HST circuit has been proposed to realize the energy generation in both directions. By adopting the timing belt-pulley mechanical transmission, the linear movement of the belt causes the bi-directional rotation of the pulley, consequently, making the pump operate with the same speed as that of the pulley in both directions.

To increase the rotation speed of the pump, a gear box can be installed within the pump and pulley. The inlet and outlet lines from the pump are connected to the check valve circuit. This circuit contains three valves in which two separated valves allow the fluid to move in unidirection from the reservoir to the pump ports while the shuttle valve is used as a switch to connect only the pump inlet or outlet to the inlet port of the hydraulic motor. The outlet port from the motor is connected to the reservoir. As a result, although the pump works in both directions, the motor always operates in its defined unidirection. Consequently, the generator is activated in all cases by connecting its shaft to the motor output shaft. The generated electricity can then be converted and stored in the storing device (for example: a battery) by using the converter or can be transmitted to an electric grid.

For a maximum capacity in wave energy absorption, the generator needs to be driven to and kept at a desired speed which is defined by the manufacturer (normally above 85% of maximum speed). From Fig. 2, the electric generator is operated by the wave fluctuation through the hydraulic circuit in which the generator speed or the hydraulic motor speed depends on the motor input flow. Subsequently, the pump is selected with variable displacement – piston pump. By adjusting the pump swash plate angle, the pumping flow rate can be controlled with respect to the variations of wave fluctuations in order to keep the speed of the generator to the desired value. Consequently, the HSTWEC can work with highest efficiency.

3. HSTWEC modeling and control analysis

In order to investigate the HSTWEC operation as well as to select the design parameters for later fabrication, a mathematical model of the system is indispensable. In addition, the method to control the HSTWEC, including: pump displacement control, tension adjustment control and ballast weight control, is also discussed in this paper.

3.1. Mathematical model analysis

Ocean wave fluctuation is performed from many different wave excitation frequencies and amplitudes. For simplicity, the wave