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Publication date:
2017

Citation for published version (APA):
Barradas-Berglind, J. J., Muñoz Arias, M., Wei, Y., Prins, W., Vakis, A. I., & Jayawardhana, B. (2017). *Energy-based Modeling of the Ocean Grazer Power Take-off System*. 121. Abstract from 36th Benelux Meeting on Systems and Control, Spa, Belgium.

Energy-based Modeling of the Ocean Grazer Power Take-off System

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1 Abstract

Wave Energy Converters (WECs) are devices designed to extract the latent energy in ocean waves and transform it into electrical energy. In recent years, several near- and off-shore WECs have been proposed, whose main objective is to maximize the energy capture and minimize the loads exerted on the device (Ringwood, et. al. (2014)). In particular, the novel semi-submersible Ocean Grazer (OG) energy harvesting platform has been recently proposed, which is projected to obtain its bulk energy intake from ocean waves by means of a Power Take-Off (PTO) system consisting of a collection of adaptable *point-absorber* type devices. This specific PTO, termed as the multi-piston power take off (MP^{2}PTO), consists of an array of piston pumps with engageable pistons of different sizes that through a suitable control algorithm allow the extraction of energy from irregular waves. See Vakis & Anagnostopoulos (2016) for details. The main two advantages of the OG-WEC are: (a) its adaptability to extract energy from ocean waves with varying heights and periods; and (b) its loss-less storage capabilities.

In Figure 1, a sketch of the OG-WEC illustrates the MP^{2}PTO concept depicting an array of point-absorbers composed of floaters, termed as a *floater blanket*, connected to a series of pumping systems. In this figure, the point-absorber (PA) type element is shown as the main building block of the OG-WEC. In this work, we focus on the modular modeling of the point-absorber element, which can be interconnected to other PA type elements. Accordingly, we describe the following subsystems: (i) a moving water body (wave) model; (ii) a mechanical subsystem consisting of a buoy-piston ensemble; (iii) a hydraulic subsystem that pumps internal fluid from a lower to an upper reservoir; and (iv) a switching coupling stage that allows energy transfer from the mechanical to the hydraulic system and prevents backflow from the upper to the lower reservoir.

This work is centered on the model of the Ocean Grazer PA system composed of the aforementioned subsystems in the port-Hamiltonian (PH) framework. The PH framework introduced by Maschke & van der Schaft (1992) has been used in a wide variety of application domains, notably because of its passivity preservation and non-linear control synthesis properties. Consequently, we employ the PH framework to investigate the energy conservation of the OG point absorber-hydraulic system, which is also beneficial since the coupling and decoupling modes of the piston-pump can be included, providing the opportunity to synthesize controllers in a more straightforward fashion. In particular, we show: (I) the passivity of the interconnected PA system with respect to its external port, and (II) that the Hamiltonian of the loss-less hydraulic subsystem is non-decreasing. Furthermore, its energy properties are illustrated and corroborated through simulation results, which show the potential energy obtained from the incoming wave force being stored. Lastly, the modularity that the PH framework offers can be useful to interconnect several point-absorber devices in order to model the complete PTO.

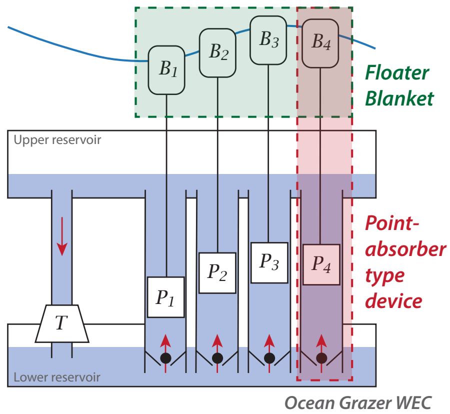

Figure 1: OG-WEC schematic illustrating the MP^{2}PTO concept consisting of an array of floaters B_1, B_2, B_3, B_4, a floater blanket, attached to pumping systems P_1, P_2, P_3, P_4. Lastly, a turbine system T converts the stored potential energy into electrical energy.

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