Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-23 (2016) 373–379

Dynamic Model and Nonlinear Control for a Two Degrees of Freedom First Generation Tidal Energy Converter ⋆

L. Fernández * E. Segura * M.P. Portilla ** R. Morales * J.A. Somolinos **

* *Escuela de Ingenieros Industriales de Albacete, Universidad de Castilla-La Mancha, 02071 Albacete, Spain.(e-mail: lorenzo.fernandez, eva.segura, rafael.morales@uclm.es)*

** *Escuela Ténica Superior de Ingenieros Navales, Universidad Politécnica de Madrid, 28040, Madrid, Spain. (e-mail: joseandres.somolinos; marinap.portilla@upm.es)*

Abstract: Several manufacturers have developed devices with which to harness tidal/currents power in areas where the depth does not exceed 40 meters. These are the so-called first generation tidal energy converters (TEC). The maintenance tasks carried out on these devices therefore require them to be extracted from their bases to the sea surface and subsequently placed back on the bases. Special high performance ships are required for these tasks, signifying high maintenance costs. The automation of emersion and immersion maneuvers will undoubtedly lead to lower costs, given that ships with less demanding requirements will be required for the aforementioned maintenance tasks. This work presents a very simple dynamic modeling for a first generation TEC composed of only two lumped masses, which are handled solely by hydrostatic forces (conceived as volume-increasing devices). We propose a nonlinear control law based on friction terms compensation for closed loop depth and/or orientation control in order to ensure an adequate behavior when the TEC performs emersion and immersion maneuvers with only passive hydrostatic forces. A control scheme based on nonlinear input transformation, a proportional-derivative (PD) linear action and nonlinear compensation term are also proposed in order to ensure a global asymptotic stability of the TEC posture. Finally, the effectiveness of the dynamic model and the controller approach is demonstrated by means of numerical simulations when the TEC is carrying out an emersion maneuver for the development of blade-cleaning maintenance tasks.

Keywords: Tidal Energy Converters, Marine Renewable Energy, Dynamic Modeling, Nonlinear Control, Emersion/Immersion Maneuvers.

1. INTRODUCTION

Tidal energy is a renewable source that can help to attain the EU climate change targets and can provide an additional value in a future energy market with regard to other renewable energy sources thanks to its high predictability (Brito et al. (2014) and Hardisty (2009)). Some of the principal opportunities and benefits include energy independence, job creation, decarbonisation or serve as a complement to other renewable sources within the global energy mix. Several manufacturers are developing devices with which to harness tidal/current power in areas where the depth does not exceed 40 meters (Alstom (2016), VerdantPower (2016), Andritz (2016)). Fig. 1 depicts an example of Tidal Energy Converters (TEC) based on open rotor configuration for marine current harnessing. These devices are usually supported on a base which is fixed to the seabed with different anchoring systems, and these are the so-called first generation TEC.

It is necessary to promote awareness of ocean technologies and increase their actual potential, and this depends on cost-effectiveness, reliability, survivability and accessibility. This can be achieved by reducing installation, operation and maintenance costs by performing the emersion and immersion maneuvers in an automatized way, which will help the acceleration and sustainability of these energy systems (SI Ocean (2012), SI Ocean (2013)). One of the possible options implies the use of a ballast management system to generate vertical forces, thus enabling the devices emersion and immersion movements to be controlled. The automation of emersion and immersion maneuvers will have a direct influence in the following respects: (a) the development of improved installation procedures that will reduce the number and length of installation operations; (b) a reduction in the cost of energy; (c) an increase in the profitability of the project; (d) less human intervention; (e) the maximization of the weather window; and (f) the

⋆ This work has been partially supported by the Spanish Ministerio de Economía y Competitividad under Research Grant DPI2014-53499R and hiring of Miss Marina P. Portilla was funded by the GITERM research group from the Universidad Politécnica de Madrid.

10.1016/j.ifacol.2016.10.433

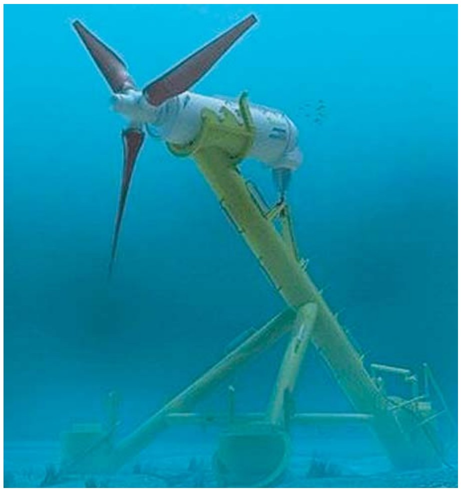

Fig. 1. TEC based on open rotor configuration for marine current harnessing (Andritz (2016)).

possibility of using cheaper general purpose ships rather than high cost special vessels for maintenance purposes.

One of the first steps that should be taken to accomplish these maneuvers automatically is that of implementing a closed loop depth and/or orientation control in order to: i) extract the main power generation unit from its normal depth of operation (on the base placed on the seabed) to the sea surface and then, ii) return it from the sea surface to the base. These automatic maneuvers can be performed by controlling the inner ballast water inside the device and with the help of small guide wires (Espín (2015)). As a previous step to performing automatic emersion/immersion maneuvers, it is necessary to obtain dynamic models of submerged bodies, with good correspondence with real responses, which requires minimum computational effort, from which control schemes can be developed (Somolinos et al. (2002), Morales et al. (2012)).

This work presents a very simple dynamic modeling and a nonlinear control for a first generation TEC. The dynamic model for an approximately cylindrical body is composed of only two lumped masses handled solely by hydrostatic forces, which are conceived as volume-increasing devices. It is, meanwhile, necessary to design the nonlinear control law based on nonlinear terms compensation for the closed loop depth and/or orientation control in order to ensure adequate behavior when the TEC performs emersion and immersion maneuvers with only passive buoyancy forces.

The paper is structured as follows: Section 2 describes the dynamic model proposed for the first generation TEC when performing two degrees-of-freedom motions. The derivation of the nonlinear control law is presented in Section 3. Section 4 shows the numerical simulations obtained to validate the proposed dynamic model and the proposed control algorithm when the TEC is carrying out an emersion maneuver for the development of blade-cleaning maintenance tasks. Finally, Section 5 shows our conclusions and proposals for future works.

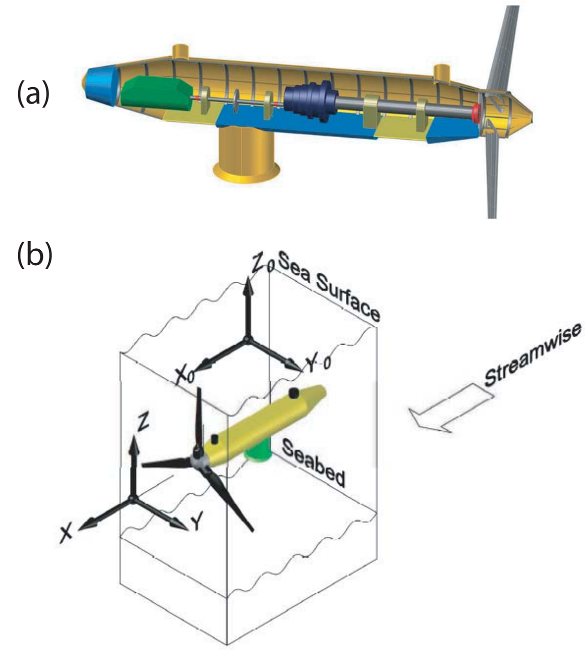

Fig. 2. (a) TEC aspect of the ballast tanks and the main elements distribution; (b) Absolute and local reference frames.

2. DYNAMIC MODEL OF A FIRST GENERATION TIDAL ENERGY CONVERTER

The first generation TEC presented in this work is designed to be able to perform automatic emersion/immersion maneuvers. This behavior is accomplished by controlling the inner ballast water inside the device and with the help of small guide wires. Fig. 2(a) illustrates the distribution equipment of the proposed TEC. In this figure, it is possible to observe that the gearbox, which is responsible for converting the low speed rotor motion into the high rotational speed required by the generator to produce electricity, is located after the rotor, which converts the tidal energy into a rotary mechanical movement. A low speed and high torque axis connects the rotor to the gear, while a high speed and low torque axis connects the gear to the generator. Other equipment, such as a brake system, electronic converters, lubrication, cooling, heating, light protection, etc., can also be considered. In order to achieve depth control operations, the design of the nacelle needs to include the following modifications: (a) the location of the ballast tanks and the associated pumping system and; (b) the modification of the shape of the nacelle in order to obtain neutral buoyancy when the ballast tanks are 50% full. Fig. 2(a) shows that the nacelle has been longitudinally elongated rather than increasing its diameter in order to reduce the hydrodynamic performance as little as possible (see the two hatchways located on the upper part of the gondola, used to gain access to the device) (Espín (2015)).

The derivation of the dynamic model of the first generation TEC plays an important role in the analysis of the behavior of the device, the design of control algorithms and the generation of optimized trajectories. The dynamic model chosen must be sufficiently precise to describe the behavior