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Hydrodynamic modelling of marine renewable energy devices: A state of the art review

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ABSTRACT

This paper reviews key issues in the physical and numerical modelling of marine renewable energy systems, including wave energy devices, current turbines, and offshore wind turbines. The paper starts with an overview of the types of devices considered, and introduces some key studies in marine renewable energy modelling research. The development of new International Towing Tank Conference (ITTC) guidelines for model testing these devices is placed in the context of guidelines developed or under development by other international bodies as well as via research projects. Some particular challenges are introduced in the experimental and numerical modelling and testing of these devices, including the simulation of Power-Take-Off systems (PTOs) for physical models of all devices, approaches for numerical modelling of devices, and the correct modelling of wind load on offshore wind turbines. Finally, issues related to the uncertainty in performance prediction from model test results are discussed. The paper is based on the report of the International Towing Tank Conference specialist committee on Hydrodynamic Modelling of Marine Renewable Energy Devices to the 27th ITTC held in Copenhagen, Denmark in 2014 (ITTC Specialist Committee on Hydrodynamic Modelling of Marine Renewable Energy Devices, 2014a. Final Report and Recommendations to the 27th ITTC Proc. 27th International Towing Tank Conference, Copehagen, Denmark, vol. 2, pp. 680–725).

1. Overview

1.1. Technology readiness level

The stages of development of marine renewable energy devices are commonly described in the industry in terms of Technology Readiness Levels (TRLs). These provide a consistent process enabling identification of the stage of development of a device and identification of suitable test procedures for evaluating device performance at a defined stage of development. This information can then be used to provide an unbiased assessment of a device for investment/development purposes independent of device type or scale.

In the case of the renewable energy industry, the following stages of Technology Readiness Levels (TRLs) are commonly considered (e.g. Mankins, 1995). TRL 1-3 correspond to research stages up to and including proof of concept, TRL 4-5 correspond to component, sub-system and system validation in laboratories and/

Abbreviations: BIEM, Boundary Integral Equation Method; BEM, Blade Element Method; BEMT, Blade Element Momentum Theory; CFD, Computational Fluid Dynamics; EMEC, European Marine Energy Centre; FOWT, floating offshore wind turbine; HACT, horizontal axis current turbine; IEA, International Energy Agency; ITTC, International Towing Tank Conference; MRE, marine renewable energy; TLP, tension leg platform; TRL, Technology Readiness Level; TSR, Tip Speed Ratio; OC3, Offshore Code Comparison Collaboration; OC4, Offshore Code Comparison Collaboration, Continuation; OC5, Offshore Code Comparison Collaboration, Continuation, with Correlation; OWC, Oscillating Water Column; OWT, offshore wind turbine; PIV, Particle Imaging Velocimetry; PTO, Power Take Off; RANSE, Reynolds-Averaged Navier–Stokes Equation; RMS, root-mean-square; RPM, revolutions per minute; VACT, Vertical Axis Current Turbine; WEC, Wave Energy Converter

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or simulated operational environments and TRL 6-9 correspond to prototype demonstration in operational environment through to system proving via successful deployment.

1.2. Wave Energy Converters

1.2.1. Device types

Wave Energy Converters (WECs) are devices designed to convert wave energy into another useful form of energy. In most cases the target is electricity generation but other uses have been proposed, such as fresh water production by desalination.

Wave energy is characterised by a wide diversity of concepts and technologies. At present, more than one hundred projects are in development around the world. More than one thousand patents have been filed, the earliest being as old as 1799 by Girard and Sons (Girard Père et fils, (1799)). Excellent reviews of wave energy technologies can be found in Falcao (2010) and Falnes (2007). The majority of devices use one of three following working principles:

Overtopping devices: In these devices, waves run over a ramp in order to fill a reservoir in which the mean water level is higher than the mean sea water level. Potential energy in the reservoir is then converted into electricity using conventional low head turbines. Fig. 1 shows two examples of prototypes.

Oscillating Water Columns: Oscillating Water Columns (OWCs) have a partly submerged structure with an inner chamber with an internal free surface. Pressure variations in the incident waves excite the internal free surface to oscillate via a submerged opening in the chamber. The free surface oscillation forces the air above to flow through an air turbine that drives a generator. Examples of well-known prototypes are shown in Fig. 2.

Oscillating bodies: In these devices, incident waves make one or several bodies oscillate. Relative motions between the bodies and the sea bottom or between the bodies themselves are used to drive a Power Take Off system (PTO), often based on hydraulic components. The working principles and examples of well-known prototypes are shown in Fig. 3.

Other devices: Some devices may use other working principles. Wave turbines have been proposed for instance, in which wave induced flow velocity is used with lifting surfaces in order to drive rotary generators (Siegel et al., 2013). Partly or even fully flexible devices have also been considered (Bellamy and Peatfield, 1986; Farley et al., 2011).

1.2.2. WEC classification

WECs may be classified in a number of ways. One approach often used is to classify by the working principle; Fig. 4, taken from Falcao (2010), shows a well-known example.

WECs may also be classified using the location of installation. Some Wave Energy Converters are designed to be installed at the shoreline, some in near-shore shallow-water regions while other can be installed in deep water offshore.

A final approach to classification of WECs uses considerations of size. Devices of small dimensions with respect to wavelength are called “point absorbers”. Examples are Carnegie’s *Ceto* device or the Aquamarine’s *Oyster*. Large devices with the longest dimension parallel to the wave crests are called “terminators”, whereas devices with the longest dimension parallel to the wave propagation direction are called “attenuators”. The *Wavedragon* is an example of a terminator and the *Pelamis* is an example of an attenuator.

1.2.3. Landmark studies

Modern studies in wave energy can be traced back to the paper by Salter (1974) and the paper by Budal and Falnes (1975) in Nature, and the paper by Evans (1976) in Journal of Fluid Mechanics. This pioneering work initiated a considerable amount of research on wave energy until the mid-1980s, when funding stopped partly because of the decline in the oil price. References to many interesting studies which were conducted at that time can be found in the review paper by Falnes (2007) and in McCormick (1981), Berge (1982) and Evans and Falcao (1985).

Interest in wave energy started again in the mid-1990s, due to increasing awareness of issues associated with climate change and thus the need for renewable energy. From 1998 to 2002, an experimental program investigated several wave energy concepts in Denmark (Meyer et al., 2002). A techno-economic study of the deployment of WEC arrays based on early 2000s technologies was carried out in the US in 2004 (Previsic et al. (2004)). Books were

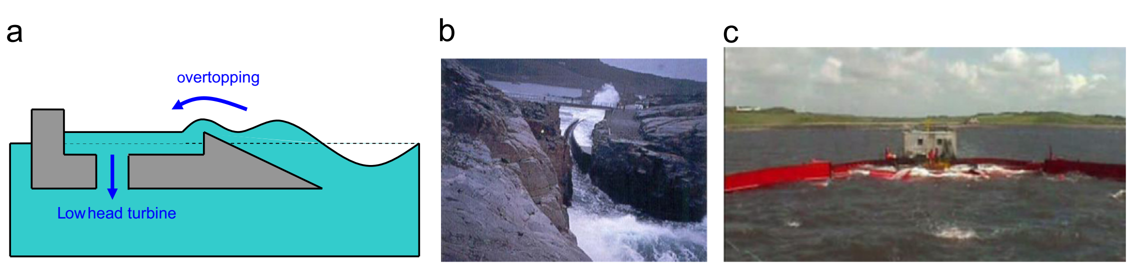

Fig. 1. Overtopping devices: (a) schematic diagram; (b) *TAPCHAN* built onshore in Norway in the 1980s; (c) 1/4.5 scale model of floating device *Wavedragon* deployed in Denmark in 2003.

Fig. 2. Oscillating Water Column devices: (a) schematic; (b) *Pico* shore-based OWC built in the Azores in 1999; (c) *Oceanlinx* floating OWC deployed in 2010 in New South Wales, Australia.