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Energy production from tidal currents in an estuary: A comparative study of floating and bottom-fixed turbines

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ABSTRACT

In a tidal stream project the selection of the most appropriate device is of major importance. The aim of this work is to investigate the difference between two tidal farms, one with floating TSTs (Tidal Stream Turbines), the other with bottom-fixed TSTs, in terms of annual performance and its monthly variability. This investigation is carried out considering real operational conditions in a case study: Ria de Ortigueira (NW Spain), a drowned river valleys which is one of the most promising sites for tidal stream energy exploitation in the Iberian Peninsula. A 3D, high-resolution, numerical model is applied to simulate the hydrodynamics of the ria during an entire year with either the floating or bottom-fixed TSTs, and, on these grounds, determine the most representative performance parameters. Significant differences emerge in the performance of both plants; these are due to a great extent to the vertical variation in the flow velocity, which is relevant at many sites of interest for tidal stream energy exploitation such as Ria de Ortigueira. Finally, relevant variations were identified in the intra-annual performance which must be borne in mind in dimensioning the plant.

1. Introduction

In the late 90's social pressure emerged claiming for a new, sustainable energy production and utilisation model [1]. This, together with a number of policies aimed at curbing greenhouse gas emissions and the realisation that the current energy model, with fossil fuels at its core, is necessarily limited in time, has resulted in companies and governments around the world being currently working intensively on the development and efficient utilisation of new and renewable energy sources [2].

Tidal stream energy is one of the most attractive and promising renewable energy sources owing to its advantages relative to other renewables: no land occupation, a high load factor (water density is ~800 times higher than air density), flow predictability and consequently power production predictability, inexistence of extreme flows (which might otherwise damage the conversion devices), etc. are some of the advantages of tidal stream energy exploitation [3–6]. However, due to the relatively recent interest in this type of energy (in comparison with other renewables such as wind or solar energy), only a few TECs (Tidal Energy Converters) have achieved at this point a commercial or pre-commercial stage [7,8]. The conversion principle varies between the different TECs developed or in a development stage. Generally speaking, there exist two types of TECs, based on either the reciprocating or rotating principle. The latter, also known as TSTs (Tidal Stream Turbines), is the most popular. TSTs can be: (i) floating beneath the surface and anchored to the bottom by means of chains or cables (floating TSTs), or (ii) rigidly attached to the bottom by means of a structure (bottom-fixed TSTs) [9,10]. As a result of their different configuration, despite them being installed at the same coastal site, their performance may differ due to the varying hydrodynamic conditions throughout the water column (each type of TST is located at a different position within the water column). However, the implications for the power performance of opting for either floating or bottom-fixed devices have not been investigated as far as the authors are aware.

The aim of this study is to examine the differences in the power performance in real conditions of operation of two tidal stream plants, composed by either floating or bottom-fixed TSTs, proposed in a previous work [11], where their impacts on the estuarine hydrodynamics were analysed. For this purpose, a 3D high-resolution numerical model is implemented in the Ria de Ortigueira, a drowned river valleys which is a promising site for tidal stream energy exploitation located in Galicia (NW Spain) (Fig. 1). On the basis of the numerical results a detailed intra-annual power performance assessment of floating and bottom-fixed tidal plants have

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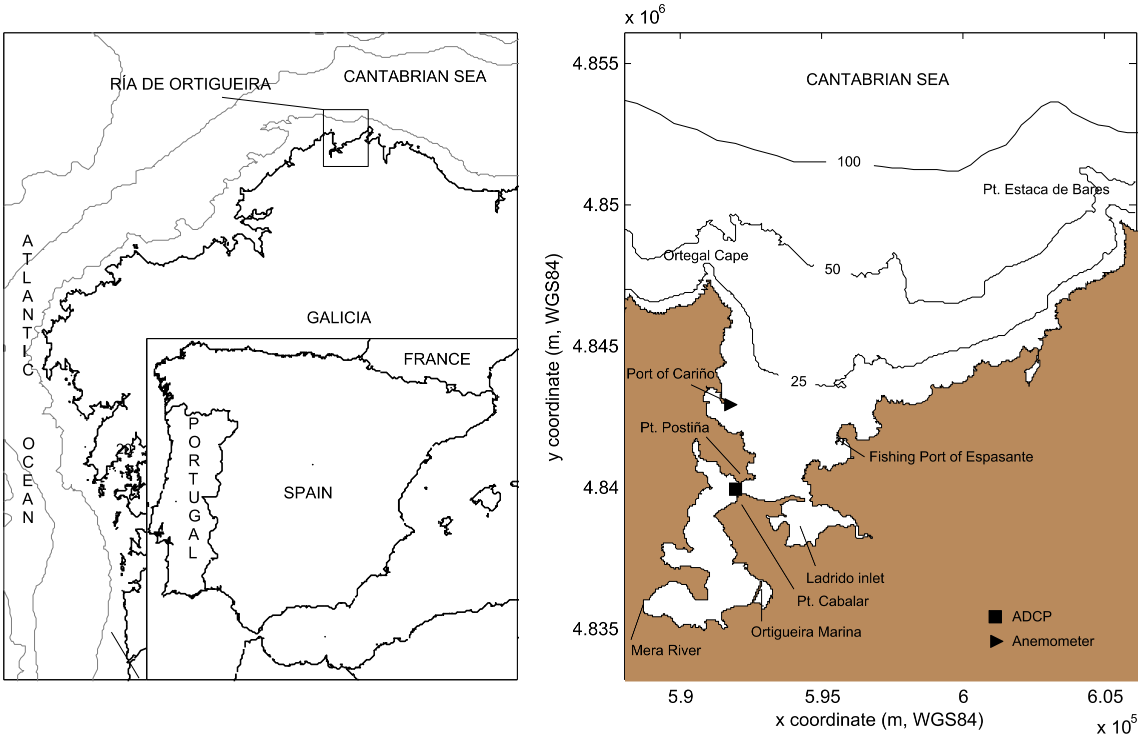

Fig. 1. Situation of Ria de Ortigueira in the Iberian Peninsula (left-hand side plots) and detailed view of the ria (right-hand side plot).

been conducted so as to investigate the importance of selecting the type of TST that performs best considering the specific hydrodynamic conditions of the area of interest.

2. Methodology

2.1. Three-dimensional hydrodynamics model

The 3D hydrodynamics model Delft3D-FLOW was used to compute the flow conditions in Ria de Ortigueira in the presence of a tidal stream farm. This model has been widely used to investigate coastal hydrodynamics in semi-enclosed water bodies [5,12–19]. Given that the Galician Rias usually present a stratified flow pattern (e.g. [20–22], to properly analyse the ria's hydrodynamics, and as a result to conduct reliable energy computations, in this work a 3D model was implemented.

Delft3D-FLOW is a finite-difference code that solves the three-dimensional Navier–Stokes equations for incompressible free surface flow coupled to the transport equation [23]. In this manner baroclinic effects, which can be of great importance in the case of rias or estuaries [24], can be taken into account. The model equations are as follows:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=Q, \tag{1}$$

$$\left.\begin{aligned}\frac{Du}{Dt}&=fv-g\frac{\partial\zeta}{\partial x}-\frac{g}{\rho_0}\int_{z'=z}^{z'=\varsigma}\frac{\partial\rho}{\partial x}dz'+\upsilon_h\left(\frac{\partial^2u}{\partial x^2}+\frac{\partial^2u}{\partial y^2}\right)+\upsilon_v\left(\frac{\partial^2u}{\partial z^2}\right)\\ \frac{Dv}{Dt}&=-fu-g\frac{\partial\zeta}{\partial y}-\frac{g}{\rho_0}\int_{z'=z}^{z'=\varsigma}\frac{\partial\rho}{\partial y}dz'+\upsilon_h\left(\frac{\partial^2v}{\partial x^2}+\frac{\partial^2v}{\partial y^2}\right)+\upsilon_v\left(\frac{\partial^2v}{\partial z^2}\right)\end{aligned}\right\}, \tag{2}$$

$$\frac{\partial p}{\partial z}=-\rho g, \tag{3}$$

$$\frac{Dc}{Dt}=D_h\left(\frac{\partial^2c}{\partial x^2}+\frac{\partial^2c}{\partial y^2}\right)+D_v\frac{\partial^2c}{\partial z^2}-\lambda_d c+R_s. \tag{4}$$

Equation (1) represents the conservation of mass under the assumption of incompressibility; Equation (2) represents the conservation of momentum in the x- and y-directions; Equation (3) expresses the conservation of momentum in the vertical direction which under the shallow-water assumption simplifies to the hydrostatic pressure distribution; finally, Equation (4) is the transport equation, which is solved in the present study for both salinity and temperature. In these equations, x, y and z represent the east, north and vertical directions, respectively and u, v and w the velocity components in the aforementioned directions; ζ is the free surface elevation above the datum; Q represents the intensity of mass sources per unit area; f is the Coriolis parameter; g is the gravitational acceleration, υ_h and υ_v are the horizontal and vertical eddy viscosity coefficients respectively, and ρ and ρ_0 are the density and the reference density of sea water, respectively. Finally, in the transport equation, c stands for salinity or temperature; D_h and D_v are the horizontal and vertical eddy diffusivity coefficients, respectively; λ_d represents the first order decay process; and R_s is the source term.

2.2. TSTs modelling

The flow conditions within a ria change as a result of the operation of the TSTs and the energy that they extract from the flow. If the flow at the locations of the TSTs and, consequently, their yield are to be accurately determined, it is therefore necessary to take them into account in the model. The operation of a turbine can be simulated by considering its effect on the flow, i.e., by adding a retarding force with the same magnitude as that exerted by the