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Viability of the application of marine current power generators in the south Brazilian shelf

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HIGHLIGHTS

- The authors found the best location on the southern Brazilian shelf for the installation of hydrokinetic turbines.
- Two different scenarios using farm of hydrokinetic turbines were simulated.
- The current pattern and energy conversion rates were studied in both scenarios.
- Temporal and spatial variability of the energy conversion were analyzed.
- The results indicate that wake pattern affect nearby turbines impacting the conversion rates.

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ABSTRACT

The continuing growth in the world population has increased the demand and competition for energy, such that immense efforts are required to make non-renewable energy sources available. Using marine currents to generate electricity offers a distinct advantage over other renewable energy sources because of the regular and predictable nature of the resource. Therefore, in addition to promoting the development of new technologies, global policies for the generation of renewable and clean energy are being strengthened. Several methods of energy conversion have been developed over the years: the turbine-based current energy converter, in particular, has demonstrated high energy generation capacity and is already in operation. In this study, the three-dimensional model TELEMAC3D was used to investigate the hydrodynamic processes. This model was coupled with an energy conversion module to determine the best energy sites for marine current energy generation in the southern Brazilian shelf. Two viable regions were found in the region of study that exhibited high potential for energy generation from marine currents; however, the northern region has been found to be a more viable region for the installation of current converters and can reach an average power of approximately 10 kW per day and integrated values of 3.5 MW per year. The highest levels of power generation were found at 16-day intervals, showing a high correlation with events associated with the passage of meteorological fronts along the region of study. In this study, we design a turbine farm with ten helicoidal turbines. Three grids were used in a one-year simulation of the TELEMAC3D model that was coupled with an energy conversion module. The simulation results were used to identify a suitable region for trial tests on a model turbine farm. For a simulation with physical structures, the northern region site was notable because high conversion rates were maintained during events of high potential energy. This enhanced electricity generation occurred because of the intensification of the current field by a physical structure that enhanced the efficiency of the site. No significant differences in the temporal variability pattern were estimated between simulations with and without structures; thus, the presence of structures did not change the temporal energy conversion pattern on the time scales considered in this study. An annual power output of 59.39 GW h was predicted for the turbine configuration that was chosen for this study, which was equivalent to 0.22% of the entire energetic consumption of Rio Grande do Sul State in 2010.

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1. Introduction

The continuing growth of the world population has increased the demand and competition for energy, such that immense efforts are required to make non-renewable energy sources available. Therefore, in addition to promoting the development of new technologies, global policies for the generation of renewable and clean energy are being strengthened.

The oceans are an important and infinite source of renewable energy [1]. Such energy can be obtained from waves, tidal oscillations or tidal currents, thermal energy, osmotic gradient and ocean currents. Two ways to obtain energy from the currents are through potential energy (variations in the sea level) and kinetic energy (ocean currents and their water masses). In general, the technique is defined as marine hydrokinetic energy extraction. According to [2], the energy from river and estuary flow, tidal currents and other artificial water channels is considered a viable source of renewable energy.

The Canadian Hydrology Center (CHC) conducted a survey of the available marine energy along the Canadian coastal region [3]. This study demonstrated that the average electrical power at 190 study points would constitute approximately 63% of Canadian energy demand. A similar study was carried out by [4] for the United States, where the authors identified regions with the highest potential for hydropower.

Defne et al. [5] investigated the energy potential of waves and tidal currents along the southeastern coast of the United States and identified a power conversion that ranged between 1.0 and 3.0 MW/year. Additionally, the Electric Power Research Institute (EPRI) documented 16 TWh/year in Alaska and 0.6 TWh/year in Puget Sound [6–11].

Studies and effective energy conversion from the astronomical and meteorological tides are in advanced stage of development. Several countries as: United States [4,5,12,13], Canada [3], United Kingdom [14,15], Ireland [16], Scotland [17], among others have an inventory about the potential of their hydrological resources. Instead of this high potential, on the structural point of view, the systems for marine energy conversion still have high production costs.

In this sense, the development of modern and efficient converting structures, with lower costs and environmental friendly, like the triple helicoidal turbines have increased the applicability for the marine energy conversion around the world [18]. Khan et al. [2] analyzed the existing turbines and suggested the dominance of the axial turbines with commercial capacity. On the other hand, the choice of the turbine used for each local depends on economical, political, technical and environmental factors [19–23].

Technology for energy conversion through the oceanic currents still under development with only few models connected to the electric grid [14]. The large scale turbines installed nowadays are the SeaGen and the SeaFlow turbines [24,25] (Marine Current Turbines), Tidal Stream Turbine (Hammerfest Strom AS, Norway) and the scale model from the Open Centre Turbine (Open-Hydro Ltd., Ireland).

Some countries already have some prototypes installed. Since 2003, a prototype was successfully installed 1 km off Foreland Point, near Devon (UK), at 30 m depth. This prototype has a simple rotor of 15 m diameter and generates 300 kW of electric power with currents of 2.3 m/s on bidirectional way. After 2006, the responsible company received permission to install a turbine with double rotor capable to produces 1 MW of electric power in Strangford Lough, near the North Ireland coast, in order to convert energy and confirm the commercial purpose of this technology [26].

Another example is the Kobold, that consists in a turbine with vertical axis under development since 1995. An important characteristic of this turbine is that the rotation is independent from the direction of the currents. After 2002, one prototype was installed at the Messina strait, 200 m off the Italian coast. This turbine still in operation connected to the electric grid and preliminary tests indicated that the turbine produces 25 kW with current velocities of 1.8 m/s [27].

In Brazil, approximately 80% of the population lives within 200 km of the coastline [28]. However, there is no mapping of the coastal zones regarding the energetic potential viable for conversion using hydrokinetic turbines. A recent study have showed two spots of high power availability off the shores of the Rio Grande do Sul state, that can generate 3.5 MW of power during a year [29]. Marques et al. [23] studied the effect of hydrodynamic and morphodynamic processes on the installation of six hydrokinetic turbines that attained 5 GW of power annually.

Tavora et al. [30], applied Geographic Information System (GIS) analysis in order to evaluate the social, economic and environmental strains in the Rio Grande do Sul state regarding the usage of marine current turbines. These authors verified that in the northern SBS there is a spot of high power availability which is also the less impacted region for this purpose.

The Southern Brazilian Shelf (SBS) is located between 28°S and 35°S (Fig. 1), is continentally bounded by Rio Grande do Sul state and has a slightly rugged shoreline that is oriented Northeast – Southwest. The bathymetry of this region is quite soft, with a high slope and a shelf break near the 180 m isobath [31]. The region of study is located near the Brazil–Malvinas confluence, which is known for its high spatial and temporal variability [32,33] and the convergence of several water bodies [34,35].

Thus, the Southwest Atlantic Ocean is one of the most dynamic regions of the global ocean [36,37] and is characterized by large thermohaline contrasts and intense mesoscale activity [38]. The high seasonality of the wind fields [39,40] is dominated by northeast (NE) winds during the summer and southwest (SW) winds during the winter that drive the coastal circulation through the SW and NE, respectively [23,35,41,42]. These winds can be enhanced by El Niño Southern Oscillation (ENSO) events [39].

The recent annual energy report of the Rio Grande do Sul state [43] briefly mentioned the use of marine currents as a potential energy source for power harvesting that could easily enhance the Brazilian matrix of energy. In this context, the aim of this study is to study the potential of using energy converters (turbine-type) along the SBS by applying a three-dimensional model of ocean circulation coupled with an energy model to evaluate the energy conversion and local circulation pattern of a turbine farm.

2. Methodology

2.1. Hydrodynamic numerical model

The hydrodynamic processes patterns along the southern Brazilian shelf were studied using the three-dimensional finite-element open-source TELEMAC3D model.[1] In the TELEMAC3D model, the Navier–Stokes equations are solved by considering local variations in the free surface of the fluid, while neglecting density variations in the mass conservation equation, using the hydrostatic pressure and Boussinesq approximations.

In the model, finite element techniques are used to solve the hydrodynamic equations [44], and the sigma coordinate system is used to follow the surface and lower boundaries for vertical discretization [45]. The Multidimensional Upwind Residual Distribution (MURD) [44] method is applied for the advection of three-dimensional variables under TELEMAC3D. On the other

[1] http://www.opentelemac.org.