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Design procedure of an innovative turbine with rotors rotating in opposite directions for the exploitation of the tidal currents

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ABSTRACT

In this work an innovative on-shore marine turbine has been deployed. The peculiarity is the anchoring system, consisting in a rope subjected only to a tensile stress, a central deflector, responsible of the equilibrium in the horizontal plane, and a floating stabilizer, keeping the machine in vertical position. The introduction of a couple of rotors, instead of one, has been an important step in the machine design. By rotating in opposite direction the rotors make the machine free from any torsional effects. Based on the experience gained, the design procedure of this turbine is described. Considering the equilibrium conditions as a key point of the design, the equations in the horizontal and vertical plane are obtained. In the horizontal plane the equilibrium is guaranteed by a central deflector while in the vertical one is guaranteed by a buoyant stabilizer. After several calculations and simulations, carried out for the site of Punta Pezzo (Messina – Italy), the energy output and the payback time has been evaluated.

1. Introduction

In the last years the share of renewable energy sources to the total energy production has been determining a substantial increase of the interest in marine energies (waves, tidal, marine currents) for several reasons: great energy potential not yet fully exploited, nonexistence of extreme flows, high load factor, minimal visual impact. Within these resources, tidal currents are especially attractive because of their predictability, being generated by the gravitational interaction moon-earth [1].

The configurations actually working, for exploiting these resources [2], are characterized by high costs and environmental impact as well as a low energy production. The main challenge is to develop plants with a competitive payback times. In this context the installation has to be easy, fast, not requiring high skilled personnel or special equipment, but despite that, the machines actually working by tidal currents, like Kobold [3], Darreius [4], Cormat [5], Seagen turbines [6], are moored to floating structures or wide supporting pylons, civil works very expensive and hard to realize. Recently hydrokinetic turbines [7] are gaining ground thanks to their simplicity.

For exploiting a large amount of energy, the common tidal plants installation schemes are focusing on the wind farm configurations taking also into account the storage problems [8]. A tidal farm installation involves a detailed study of the environment [9] also useful for evaluating its economic convenience [10].

In order to face and solve these issues, a scientific collaboration between the DIMEG (Department of Mechanical, Energetic and Management Engineering – University of Calabria, Rende, CS, Italy) and the company SintEnergy (TechNest Incubator, Rende, CS, Italy) has been developing. Thanks to their experience they have conceived a way to make a wide turbine operates in the sea like a kite, moored directly to the coast, by an easy and cheap frames, and steel ropes subjected only to a traction force [11–12]. This is possible by using a central deflector installed in the middle of the blades disc which makes possible the machine to reach an equilibrium position when it operates in a stream flow. The turbine can work in sites with bidirectional currents, being able to overturn itself when the current changes direction, but also in rivers, or, with some tricks, through wind currents.

Moreover, starting from an initial layout, characterized by one rotor and a floating structure hosting the generator, the authors improved the design, achieving an easy configuration with two contra-rotating rotors working at the same speed in opposite directions, with no or low torsional effects [13–14] and a permanent magnet generator built in the stator. Only a little stabilizer is needed, helpful for the machine equilibrium and for diving and

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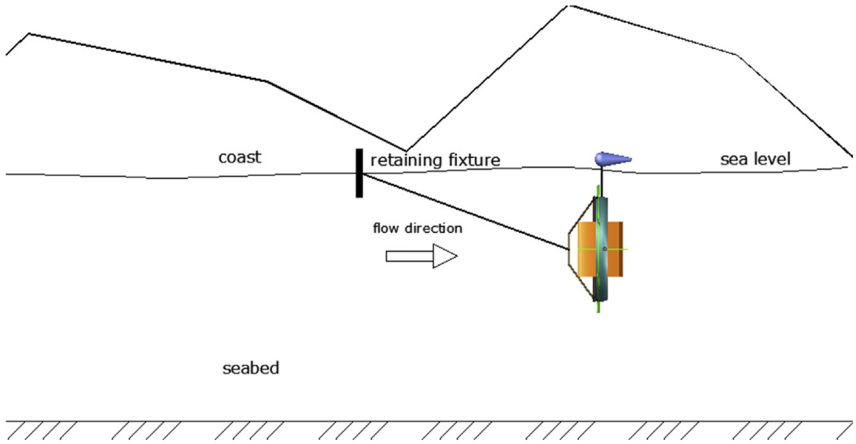

Fig. 1. Working scheme.

surfacing operations, when a change of current direction occurs or any maintenance activities are required.

The variability of the involved currents, the environmental constraints, the coastline shape and seabed are some of the factors which suggest to adopt a design algorithm able to identify the optimal machine configuration.

In the present work a procedure, carried out for calculating the optimal machine design with two contra-rotating rotors, is described, together with the main results obtained for a hypothetic installation of a pilot plant in the Calabrian site of Punta Pezzo, near the Messina Strait (Italy). In addition, a first machine transients analysis is carried out, aimed to have a detailed framework of the operating conditions.

2. Description of the machine

The turbine, see Fig. 1, has been conceived for collecting energy from the tidal currents near to the coast.

The basic idea involves the elimination of structures, supports or foundations – expensive and complex to be built – maintaining the machine in equilibrium in the water (see Figs. 1–3) by a simple rope (3) subjected to a tensile stress, in a correct position which doesn't change during the work. The rope is driven by a rigid rod (2) hinged to the coast (see Figs. 2 and 3) [11–14]. The working principle is quite similar to a kite: the weight (W) – reduced by the Archimedes' thrust (T_A) – and the rate of change of the axial momentum (T), the forces which sink or aground the machine, are balanced by the lift produced by the tidal current on the central deflector installed in the middle of the blade discs. This last force (L_r – see Fig. 2) pushes off the turbine, but the combined action of the forces W, T_A, T and R (Fig. 3) makes the turbine able to be in equilibrium in a position, related to the coast, which doesn't change when the tidal velocity changes.

This position depends only on the geometrical configuration of the turbine. Figs. 4 and 5 show a turbine prototype with two rotors, each of them equipped with 6 blades. The blades of each rotor are connected by circular rings sliding through the stator (4): the two rotors – the external (8) and the internal (7) one – rotate in opposite direction so that they produce equal and opposite torques.

The vertical deflector (6) is installed in the middle of the blade discs: when the current laps it, the lift force produced (L_r) begins to drag off the turbine. This last force, together with the other ones (T, T_A and W), produces a resultant R (Fig. 3) stretching the rope (3) connected to the machine. The connection rope-turbine is done by a rigid frame (9). In order to maintain the machine in vertical position, to tighten the rope and balance any possible unbalanced stresses, a floating level stabilizer (5), with an aerodynamic shape, has been introduced. This is connected to the stator by a vertical bar (11).

Fig. 5 shows a machine breakdown which highlights the deflector (6), the rigid frame (9) whose the rope is connected, the stator (4), the external rotor (8), the internal rotor (7), the floating stabilizer (5).

3. Equilibrium equations

The equilibrium of the main forces moments, related to the hinge, (at this step the drag force could be considered negligible, compared to the other involved ones) can be calculated considering the horizontal plane and the vertical one (containing the rope).

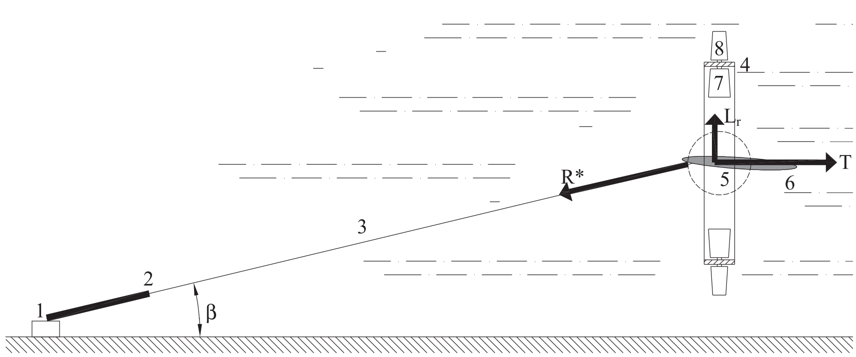

Fig. 2. Top view of the machine.

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