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Developments in large marine current turbine technologies – A review

Zhibin Zhou[a,*], Mohamed Benbouzid[b,c], Jean-Frédéric Charpentier[a], Franck Scuiller[a], Tianhao Tang[c]

[a] French Naval Academy, IRENav EA 3634, 29240 Brest Cedex 9, France
[b] University of Brest, FRE CNRS 3744 IRDL, Rue de Kergoat, CS 93837, 29238 Brest Cedex 03, France
[c] Shanghai Maritime University, 1550 Haigang Avenue, 201306 Shanghai, China

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ABSTRACT

Increasing concerns about environmental issues and depletion of fossil resources lead to a global need for producing more clean energy from renewable sources. For coastal areas or some remote islands, marine tidal current energy is a promising renewable power source due to its high predictability. During the last decades, prototypes of various horizontal and vertical axis marine current turbines (MCT) have been developed around the world. Although reviews on MCTs can be found in some state-of-the-art research papers in the last few years, many of the reported MCT projects were only at the planning/design stage when the papers were written. In fact, some projects do not have any further developments during the several years after their first reporting; and others have already upgraded their original designs and adopted up-scaled versions. In this paper, up-to-date information on large tidal turbine projects over 500 kW is focused. The newest achievements of these large tidal current turbine technologies with their developing histories are presented. These technologies represent the industrial solutions for several pre-commercial MCT farm projects in the coming years. New developments in floating MCT technologies are also included. This paper provides a useful background for researchers in the tidal current energy domain and allows them to know the newest developments in large MCT projects around world.

1. Introduction

Although various kinds of energy can be extracted from the ocean such as tidal current energy, wave energy, thermal energy, ocean osmosis (salinity gradients) energy and biomass energy; the kinetic energy available in tidal currents can be converted to electricity using relatively mature turbine technologies. The exploitable marine current power with present technologies is estimated about 75 GW in the world and 11 GW in Europe. UK and France have highest marine current potentials (6 GW and 3.4 GW respectively) among the European countries [1].

It should be noted that the distinguish advantage of tidal current energy is related to the high predictability of the tidal current resource. The astronomic nature of tides is determined by the gravitational interaction of the Earth-Moon-Sun system, and this makes marine tidal currents highly predictable with 98% accuracy for decades [2]. Basically, there are two ways of harnessing powers from marine tidal resources: either by building a tidal barrage across an estuary or a bay, or by extracting kinetic energy directly from flowing tidal currents. The main drawback of the barrage solution is that large barrage system could change the hydrology and may have negative impacts on the local ecosystem [3]. During the last few decades, technologies that directly capture the kinetic energy from tidal-driven marine currents have been developed. One advantage of tidal current turbines over tidal barrages is the flexible system scalability. Tidal barrages are more costly and are usually aimed for GW capacities, which could exceed the needs for small coastal villages or remote islands.

In recent years, various original horizontal axis and vertical axis marine current turbines (MCT) have been developed and reported in the literatures [4–6]. Academic research progresses on the turbine hydrodynamic designs and farm configurations during the last 10 years are detailed in [7]. Numerical models for investigating the blade hydrodynamics and possible cavitation assessment are important for MCT designs [8]. Majority of industrialized MCT devices are horizontal axis turbines with rotation axis parallel to the current flow direction. The main disadvantages associated with vertical axis turbines are relative low self-starting capability, high torque fluctuations and generally lower efficiency than horizontal axis turbine design. Based

* Correspondence to: Brest Ecole Navale et Groupe des Ecoles du Poulmic, CC 600, 29240 Brest, France.
E-mail addresses: zhibin.zhou@ecole-navale.fr (Z. Zhou), Mohamed.Benbouzid@univ-brest.fr (M. Benbouzid), franck.scuiller@ecole-navale.fr (J.-F. Charpentier), jean-frederic.Charpentier@ecole-navale.fr (F. Sciuller), thtang@shmtu.edu.cn (T. Tang).

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Table 1
Pilot MCT Farms in the Coming Years [10–14,42,43].

Companies	Location	Turbine Name	Pitchable Blades	Turbine Number	Total Capacity (MW)	Operational Year
DCNS, EDF	Paimpol-Bréhat (France) Nova Scotia (Canada)	OpenHydro	No	2 2	1 4	2016/2017 2017
MeyGen	Pentland Firth (Scotland, UK)	AHH turbine AR1500	Yes	3 1	4.5 1.5	2016
MCT-Atlantis Resources	Kyle Rhea (Scotland, UK) Anglesey (Wales, UK)	SeaGen S	Yes	4 5	8 10	> 2016 > 2016
Atlantis Resources, Andritz Hydro Hammerfest (AHH)	Sound of Islay (Scotland, UK)	AR 1500 or AHH turbine	Yes	10	10	unknown
Sabella	Fromveur (France)	Sabella	No	4	4	2019
GE & Alstom Energy DCNS, EDF	Raz Blanchard (France)	GE-Alstom turbine OpenHydro	Yes No	4 7	5.6 14	2017/2018 2018

on the available literature and reports, horizontal axis MCTs appear to be the most technologically and economically feasible solution for large-scale marine current turbines with power capacity over 500 kW at the present stage.

Although various turbine projects have been reported in some state-of-the-art research papers, many of these projects were only at the design stage when the papers were published several years ago [2,4]. It should be noted that, some projects are abandoned or never have been built, as for instance, the Lunar Energy Tidal turbine and Blue Energy Tidal turbine. And some projects do not have further developments during several years after the first announcement, such as Atlantis Resource Nereus/Solon turbines and Gorlov turbines. Moreover, some turbine projects have been renamed and up-scaled during recent years, for example, the E-tide turbine was renamed as HS300 and the Hydroelix project was developed to the Sabella project. Recent review paper [40] focuses on the numbers of different turbine types and total turbine numbers developed by different countries, however the information presented in this paper is collected from 2009 to 2012 and only the SeaGen turbine is detailed concerning the turbine technologies development. The most recent paper [41] published in 2016 summarizes technical characteristics of different kinds of tidal power devices (vertical- and horizontal-axis turbines, ducted turbines, oscillating hydrofoils and tidal kites, tidal barrages); these devices include both industrialized and design-stage prototypes. However, the future MCT farm projects and some large MCTs (OpenHydro, Sabella, GE-Alstom turbines) are not detailed. Reference [9] is the first paper to focus on the industrial developments of large turbine technologies, which may appear in pre-commercial MCT farms in the near future. However, two years have been passed since its publication and much information should be updated. Therefore, efforts have been made in this paper to analyze up-to-date information of the megawatt-level MCTs and to provide a more comprehensive review on industrialized MCTs. Moreover, the floating MCT technologies are also presented in this paper to indicate some feature trends in the developments of tidal current turbine technologies.

In this paper, up-to-date information and the newest achievements of large tidal current turbine technologies (from 500 kW to 2 MW) will be focused. It should be noted that MCTs with power capacity over 500 kW represent the nowadays-industrial solutions for future MCT farm applications around the world. In Section 2, the up-to-date pilot MCT farms information is presented and the industrialized large turbine technologies are reviewed. In Section 3, the newly developed floating MCT solutions are discussed. The conclusions are then given In Section 4.

2. Industrialized large marine current turbine systems

There are several horizontal axis turbine technologies, which have been developed for more than one or two generations during the last decade. The majority of these turbine technologies has now achieved megawatt-level power capacity and has been chosen by some leading industrial consortiums to build pilot demonstrative MCT farms which are the final step before the final commercial stage. These projects reflect the promising developments of tidal current turbine technologies which will be used to supply electricity to coastal areas or remote islands in the coming years.

Some of these MCT farm projects and their planned/estimated operational years are illustrated in Table 1. It can be noted that most of these turbine technologies have attended megawatt-level power capacity and several of them adopt fixed pitchable blades.

It should be noted that although MCT technologies share the similar power harnessing principals with wind turbines (WT), some specific options might be more favorable for MCTs than for WTs. Generally, two competitive options can be identified in these MCT projects. One design option is close to major WT design with pitch control and gearbox. The system should include a way to access to the turbine in case of maintenance: such as a lifting structure (Seagen S) or buoyant turbine (GE-Alstom's turbine). Another option is specific design for MCTs with direct-drive generator and nonpitchable blades, such as OpenHydro, Sabella and Voith turbines. Eliminating variable pitch mechanism can be an interesting design option for MCTs. Considering statistical causes of failures in classical wind turbines [45], it is reasonable to consider that eliminating these systems enables to increase reliability and decrease system complexity and maintenance requirements.

2.1. OpenHydro turbine technology

OpenHydro turbine is an open-center turbine technology originally developed by the Irish company with the same name. A 250 kW prototype with 6 m rotor diameter was installed and tested at European Marine Energy Center (EMEC) off Orkney Islands in Scotland and it was connected to the UK national grid in 2008. This open-center turbine technology is chosen by the French industrial group DCNS and French electric utility company EDF to build a first demonstrative MCT farm off the coast of Paimpol-Bréhat in Brittany, France.

The first 500 kW OpenHydro turbine (Fig. 1) was tested in September 2011 near Brest, France. This 850 t turbine has a diameter