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Review on the blade design technologies of tidal current turbine

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ABSTRACT

Tidal current turbine (TCT) is a kind of device which converts the tidal current energy into electricity and its technology has got rapid progress in last decade. The design of TCT includes the blade, power train, electrical system and power converter, sealing system and foundation, etc. In spite of the principle similarity to the wind energy, the design of the blade should be specially carried on for its characteristics of cavitation, corrosion resistance and the big force on the blades. In this paper, the technology developments of the TCT blade design are reviewed, including the hydrodynamics design and the structure design. Subsequently the key technologies to be researched for the TCT blade design are concluded and forecasted.

Contents

1. Introduction

Because of the people's concerns about the environmental pollution and the shortage of traditional fossil energy, the renewable energy receives more and more attentions, such as the wind energy, ocean energy and solar energy, etc. The tidal current energy becomes a research hotspot in recent years, whose principle is like the wind energy. Both of them capture the kinetic energy of the flowing fluids. Based on the developed wind turbine technology, the TCT has got rapid development in last decade and the power capacity of a single device has reached megawatt scale.

Tidal current energy is an eco-friendly energy source, and compared with wind and wave energy which are intermittent and variable, tidal current energy has the distinct advantages of high predictability and regularity, which makes the exploitation of tidal current energy more attractive. Therefore, many countries have started the research of tidal current energy at the end of the last

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century, such as UK, USA, Canada, Korea, China and Italy, etc. Some megawatt scale TCT were designed or tested or planed by some corporations such as Andritz Hydro Hammerfest (HS1000), Marine Current Turbine (SeagenS, SeagenU, SeagenF), Openhydro, Voith Siemens Hydro, Atlantis resource Corporation, and Alstom, etc. [1] though few of them gave the design details of the devices.

Just as mentioned above, TCT capture the kinetic energy of the flowing seawater, so the blades play a vital role, whose performance will influence not only the efficiency of the TCT system, but also the load characteristics of the rotor and the power train. In this paper, the technology development status of the TCT blade design will be firstly reviewed, including the problems the developers are facing. Followed by the introduction of the traditional hydrodynamic design methods and some new design methods. Then the mechanical design methods of the blade including the structure layout, material selection, are also given. At last in the author's opinion, the key technologies to be researched or the development trend for the TCT blade design will be concluded and forecasted.

2. State of the art

According to the rotor configuration, the TCT can generally be divided into two categories, namely the horizontal axis tidal current turbine (HATCT) and the vertical axis tidal current turbine (VATCT). This paper will mainly introduce the HATCT blade design because it has gained its popularity in the exploitation of tidal current energy.

Despite the analogy with wind turbines, there are major differences in the engineering of a TCT because of the higher density of water compared with air and the much slower speed of rotation [2], such as the loads exerted on the turbine, the blade cavitation, and the wear caused by the high turbidity of the coastal waters, etc. This has been confirmed by the blade faults that occurred in some prototype tests such as Verdant Power Company (Fig. 1), Marine Current Turbine company SeaGen system and Openhydro's turbine, the 75 kW TCT by Zhejiang University (ZJU) of China (Fig. 2). So the special design and analysis of the blade of TCT need to be carried out and some works have been done [3]. The ability to design efficient TCT blades and to accurately predict their performance is critical for the commercialization of the TCT industry.

2.1. Hydrodynamics design of the blade and its performance prediction

The aim of the hydrodynamics design is to obtain a favored external shape of the blade which satisfies the desired performances,

Fig. 1. Failed blade of a TCT.

such as high efficiency, low mechanical load, delayed stall, cavitation-free, etc. In [4], based on the Blade Element Momentum (BEM) theory, the procedure of the tidal blade design was outlined, and a 550 kW blade design was carried out through a developed code used for wind turbine, but the cavitation was not introduced in detail. Bahaj and his colleagues designed a TCT rotor with a diameter of 800 mm based on BEM theory, and both numerical simulation and towing tank test were undertaken to analyze the performance of the rotor. Moreover, the occurrence of cavitation was studied in a tunnel [5–7]. In above literatures, the BEM theory was widely used. However, one of the main limitations of the BEM method is that it cannot be used to analyze the influence of a rotor on the surrounding flow, and for where an analysis of wake dynamics is required, alternative modeling approaches must be employed. Chapman, etc. proposed a modified correction for the tip/hub losses and high induction conditions of the TCT to predict the performance of the turbine [8]. In [9], the design procedure based on the combined methods of BEM theory and CFD was used to study the performance of the blade. Malki also researched on a coupled blade element momentum – computational fluid dynamics model [10], in which some source terms were used to link the BEM to the CFD flow domain based on the conservation of momentum equations of a typical finite volume computational fluid dynamics solver. Besides, some other design methods were adopted and tested. In [11] a design method was presented which was based on a lifting line model to produce the maximum output power and then an analysis method based on a vortex-lattice scheme and a nonlinear optimization method were used to optimize the blade shape. Liu introduced the propeller based panel method for the simulation and design optimization of the TCT [12].

Generally speaking, after the hydrofoils are chosen, the hydrodynamics design procedure of the TCT blade design can be divided into three stages: parameterization of the blade, prediction of the hydrodynamic performance and design optimization (Fig. 3). Such a methodology can also be applied to hydrofoil study.

2.1.1. Design and analysis of the hydrofoil

In the design of the TCT blade, the selected hydrofoil is important for the performance of the blade, and generally, the largest lift-drag ratio is expected, at the same time the delayed stall and free-cavitation are also required. Some works has been done for the airfoil studies. In [13] the authors presented a series of hydrofoils named as HF10XX, HF might be the abbreviation of hydrofoil, 10 indicated the maximum chamber was 10% and the XX was the percentage of maximum thickness. These hydrofoils were amendments of airfoil S1210, new hydrofoils with different thickness were used at different part of the blade, and a maximum efficiency of 47.5% was achieved. And in [14] Grasso used the multidisciplinary design optimization approach and an advanced sequential quadratic programming gradient based algorithm to design two new airfoil G-hydra –A, G-hydra-B, subsequently their hydrodynamic performance were numerical simulated and compared with the known data. Based on the existing foils, Patrick Mark Singh and his colleagues studied a new hydrofoil MNU26 by combining the suction side of DU91-W2-250 airfoil and the pressure side of S814 airfoil [15], then the CFD simulation was used to study its power coefficient, pressure and velocity distributions. In [16] the authors optimized airfoil NACA63815 to obtain new hydrofoils, the process was a multiple objective optimization based on NSGA-II, lift-to-drag ratio and cavitation performance were used as objective functions in this genetic algorithm. In [17] the author presented the current status of the blade used in the wind turbine and TCT in detail and characteristics of different airfoils were presented, such as Seri AIRFOILS, DU AIRFOILS, RISф AIRFOILS, CAS-W1 AIRFOILS.

In order to understand the hydrodynamic performance well, the flow field around the hydrofoil should be researched [18,19]. The research focus was the characteristics of the near and far wake profiles, such as the tip vortex roll-up in the near field region of