Research method for hydrodynamic characteristics of tidal current turbine

Xu Junhui

College of Energy and Electrical Engineering, Hohai University, Nanjing 210098, China

*Corresponding author’s e-mail: junhuixu111@163.com

Abstract: Tidal energy is a very rich Marine resource, which has high energy concentration, small geometric scale and strong predictability. The research status, development and utilization of tidal current turbine at home and abroad are expatiated, and two research methods for hydrodynamic characteristics of tidal current turbine, including numerical calculation and simulation experiment, are introduced, which are of certain significance to the performance optimization of tidal current turbine.

1. Introduction
With the growth of global economy and the explosive growth of population, human beings are increasingly dependent on energy. According to the survey [1], natural gas, coal, oil and other primary energy consumption in the total social consumption accounted for as high as 85.9%. However, these primary energy sources belong to non-renewable energy sources, which will be exhausted if the current situation continues. Therefore, the development and utilization of renewable energy sources is imminent.

Tidal energy uses the kinetic energy of the periodic and reciprocating horizontal movement in the sea water, called tides due to the moon and the sun. It is a kind of clean and renewable energy. As one of the important forms of ocean energy utilization, it has high energy concentration, small geometric scale and strong predictability. The energy density of tidal current energy is relatively high, which is about 4 times that of wind energy and 30 times that of solar energy. This is mainly because the density of sea water is about 800 times higher than that of air. At present, the development level both at home and abroad is relatively high, and the application scope is relatively wide. The more mature development mainly includes horizontal-axis and vertical-axis tidal current turbines.

2. Research status of tidal current turbine at home and abroad

2.1. Development and utilization of foreign tidal current energy
The UK “SeaGen” turbine adopts advanced variable dip technology to change the pitch of the slurry at multiple angles. The impeller and hub can be lifted and lowered on the pile, which is convenient for maintenance and installation. In 2008 OpenHydro, an Irish company, designed OpenCentre, a horizontal axial power turbine with an installed capacity of 250kW, which has been integrated into the National Grid of the UK [2]. RTT (RotechTidalTurbine) turbine was developed by LunarEnergy in the UK in 2007. When the blade diameter is 16m, the guide hood diameter is 21m, and the flow velocity is 3.1m/s; the power can reach 1.5wm. The RITE of VerdantPower company (VerdantPower
's Roosevelt Island Tidal Energy project, began in 2002, the East river in New York. The project is divided into three phases: test phase, demonstration phase and commercial operation. The specific schedule is as follows: The first phase (2002-2006) model test, the second phase (2006-2008) demonstration and verification, and the third phase (2009-2012) megawatt level project construction. Hammerfest Strom, Norway, has developed a three-blade, base-mounted horizontal shaft turbine. The model was installed in Kvalsund, Norway in 2003. After four years of operational testing, it will be installed again in 2009 for further research and testing, and will be put into operation. The company will design a 1MW full-size prototype HS1000, which is scheduled to be installed in 2010[3]. Atlantis Resources Co. Singapore has completed 400kW Nereus and 500kW Solon tidal turbines and plans to test 1MW and 2MW models in 2009 and start installing a commercial array fleet in 2012.

The research and development of the above tidal current energy is listed in Table 1.

| Serial number | State     | Company                  | Project   | Installed capacity (kW) |
|---------------|-----------|--------------------------|-----------|-------------------------|
| 1             | England   | OpenHydro                | OpenCentre| 250                     |
| 2             | England   | Lunarenergy              | RTT       | 16                      |
| 3             | America   | Verdantpower             | RITE      | 35                      |
| 4             | Norway    | Hammerfest Strom         | BlueConcept | 300              |
| 5             | Singapore | Atlantis Resources Co.   | Nereus wsolon | 500              |

2.2. Domestic trend energy development and utilization

Since the beginning of this century, China's ocean energy has developed rapidly and achieved many achievements. The 2×300kW tidal current turbine engineering machine of Zhejiang University has been put into use in Zhoushan, and its system conversion efficiency has reached 40%. The University of Ocean University of China used flexible blades to study the tidal current turbine, which improved its flow field characteristics and energy utilization rate. At the same time, model experiments were carried out on the product and good experimental results were obtained. Harbin engineering university of universal I type turbine is the world's first floating type power station. They are studying the universal II type turbine, which was installed in daishan fairy chau bridge. Northeast Normal University has carried out the project of "Research and Experiment on the Key Technology of 5KW Modular Tidal Power Supply for Ocean Observation Platform", and its prototype has also been tested at sea.

The main advantages of horizontal axis tidal current turbine are: (1) easy and low installation requirements. When the water depth is 20-30 meters, it can be installed. There are a large number of sea areas in the world where horizontal axis tidal power turbines can be installed, such as the coastline of the United Kingdom, the waters near the Japanese archipelago, China, Indonesia and the Philippines, where tidal power plants can also be installed. (2) The operation of the unit has relatively little impact on the Marine ecological environment. Because the horizontal axis tidal current turbine rotates slowly, it has little influence on the surrounding Marine life and will not destroy the ecological balance. (3) High power quality and cost-effective performance. Because the running velocity of the horizontal axis tidal current energy turbine is relatively low, as long as the surrounding tidal current velocity reaches 2m/s, the unit can operate safely and stably, and generate high-quality electricity. The turbine is highly capable of generating electricity. It needs only 15m in diameter to produce the same amount of power as a 60m diameter wind turbine. In addition, the two-way power generation function of the turbine can effectively avoid intermittent phenomena such as tidal weirs.

Although tidal current turbine has many advantages, the related research on tidal current turbine is not perfect. There are still a lot of problems that have not been solved, and the application technology of tidal power turbine is not mature yet. The key problem of tidal current turbine research is the study of hydrodynamic characteristics of tidal current turbine. Because the rotating effect of tidal current turbine will affect the surrounding flow field, the local environment, seabed sediment scouring, the ecological environment and so on, therefore, it is of great significance to study its hydrodynamic characteristics.
3. Numerical calculation and simulation experiments

With the deepening of research on tidal power turbine, many experts, scholars and researchers have carried out a lot of work on the planning and construction of tidal power turbine, and made a lot of achievements in the research on the hydrodynamic characteristics of tidal power turbine. At present, the research methods of hydrodynamic characteristics of tidal power turbine mainly focus on two aspects: (1) numerical calculation: mainly simulate the actual situation of tidal power turbine, using software for calculation, thus cost is low, and operation and data acquisition is simple. With the improvement of computer hardware capability, the method of numerical calculation has been paid more and more attention by experts at home and abroad. (2) Model experiment: simulate the actual situation mainly by building and testing and collecting the required data of the model, according to the scale effect. The results of model experiment have higher accuracy, but the investment is larger than that of numerical calculation.

3.1. Numerical calculation

Although the operating environment of horizontal axis tidal current turbine is very different from that of wind turbine, the research method of tidal current turbine mainly refers to the research method of wind turbine. From the perspective of simulation, there are two common research methods for tidal power turbine, which are the Method based on Blade Element Method and computational fluid dynamics (CFD). At the beginning, BEM method was mainly applied to the simulation of wind turbines, and it was first applied to the exploration of the performance of aircraft propellers, proposed by Glauert. Subsequently, Wilson optimized Glauert's model by adding tip loss and hub loss into it, which gradually evolved into Wilson's theory. Through this method, better blade design parameters can be obtained\textsuperscript{[4-5]} Rojagopalan etc.\textsuperscript{[6]} And Sørensen, etc\textsuperscript{[7]} Relevant theories are applied to the exploration of improving the function of helicopter and wind turbine respectively. In recent years, with the world's continuous attention to tidal power, BEM method has been gradually applied in the development of horizontal axis tidal power turbine. J. I. Whelan et al\textsuperscript{[8]} According to BEM method, the hydrodynamic characteristics of horizontal axis tidal current turbine are studied, and a lot of results have been obtained.

As the CFD technology has been paid more and more attention, a large number of CFD technology has been applied in the research of tidal current turbine. At present, the related research methods mainly focus on the real blade simulation method and the actuation method. The actual blade simulation method is mainly based on the relevant parameters of the original model, and focuses on the treatment of the runner model to obtain the relevant data of the hydrodynamic characteristics of the tidal current turbine. Afgan et al. obtained the flow field around the blade by simulating the real geometry of the runner. However, due to the relatively large distortion of the blade, in order to obtain accurate results, many grids must be used to capture the model parameters, so as to obtain the accurate flow pattern near the runner and the flow field state in the rotating domain of the runner. In addition, this method not only requires the computer to have very strong hardware capability, but also has a great dependence on the grid quality of numerical calculation process. Relatively speaking, the actuating method can save the resources of the computer and reduce the demand on the quantity of the grid. The main method of braking is to modify the source term of N-S equation and obtain the hydrodynamic characteristic parameters of the unit by using the physical related parameters generated by the equivalent real model runner. At present, the widely used braking methods mainly include brake disc method, brake line method and brake surface method. In the process of numerical calculation, these methods can not only reduce the hardware requirements and grid dependence of the computer, but also save the research cost. However, in the braking method, the relevant equations are added to the source terms to replace the blade solid model. Therefore, in the process of numerical calculation, the braking method reduces the accuracy of the influence of blade body on the flow regime near the turbine. If we want to improve the accuracy of numerical calculation of turbine blade, we must adopt the method of real blade simulation.
Domestic and foreign scholars have obtained a lot of research results by using CFD method. Lee, etc.[9] The CFD method and the BEM method are used to study the hydrodynamic characteristics of the horizontal axis tidal current turbine. Through comparative analysis, it is found that the CFD method can better simulate the change of the water flow near the turbine, and the accuracy of the simulation of the hydrodynamic characteristics is higher than that of the BEM method. Chen Cunfu et al. designed a tidal current turbine blade based on the theory of blade velocity, and carried out comparative verification using BEM theory, CFD method and physical experiments, which provided a theoretical basis for the hydraulic performance analysis of tidal current turbine. Sheng Qihu et al. designed a horizontal axis tidal power turbine with Wilson model based on blade velocity theory. Through CFD technology, the power characteristics and three-dimensional flow characteristics were compared and analyzed, and the correctness of the Wilson model design method was confirmed. It was found that the three-dimensional effect would produce obvious interference to the hydrodynamic characteristics of the relevant units.

3.2. Model Experiment

With the continuous improvement of relevant CFD technology research, model experiment, as the most important part of the research trend, has gradually received people's attention. Although the model experiment requires a large investment, but the relevant research results are also a lot. McAdam et al. carried out model experiments in the wind and wave flume, and proposed some ideas about relevant experimental schemes by comparing the characteristics of the units when the water depth changed and the velocity changed. M.E. Harrison et al. made use of the model experiment and found that the simulation results of the brake disc theory were consistent with the results of the model experiment. In the near wake flow, the velocity decreases with the increase of thrust coefficient. Tedds etc.[10] A series of experiments were carried out on the tidal current turbine by using the dopron current meter and other equipment to study the flow state at several positions behind the turbine runner, and the disturbance characteristics of the turbine to the rear wake of the runner were found. Galloway etc.[11] It is found that the performance of the turbine is not disturbed by the dislocation of wave and blade, but the dislocation of wave and blade will directly affect the wake flow field and bring great harm to the long-term stable operation of the turbine.

Wang Lubing et al. carried out theoretical analysis and experimental verification on the hydrodynamic characteristics of the vertical axis tidal current turbine, and concluded the influence law of the chord length ratio, blade number and other basic parameters on the hydrodynamic characteristics of the tidal current turbine, which provided a reference basis for reasonable hoist performance and improvement of unit layout. Wang Dandan et al. adopted a three-blade hydraulic turbine model and obtained the torque and speed of the turbine through the torque sensor. The axial force of the turbine is measured by strain gage, and the influence law of different flow rates on the turbine performance is obtained. Wang Shujie et al. adopted flexible materials to establish a new type of tidal power turbine, and innovatively developed the flexible blade turbine. By using the wind and wave flume of Ocean University of China, a large number of model experiments were carried out to study its hydrodynamic characteristics. Zhang Yachao et al. studied the influence of different initial velocity and reasoning coefficients on the wake flow of a single tidal current turbine through the experiment of porous disk, and found that the faster the initial velocity is, the faster the wake convergence will be. The influence of the inference coefficient on the wake is concentrated in the range of 5D downstream. After 15D downstream, the thrust coefficient has nothing to do with the convergence value. Chen Yaling et al. carried out an experimental study on a three-blade tidal current turbine model by using the hanging fixed method. Through ADV and thrust measuring equipment, the velocity of a large number of measuring points and the thrust of the turbine were measured, and the wake flow data and thrust coefficient were obtained. It was found that the near wake flow structure was mainly affected by the tip speed ratio. Li Linjie carried out model experiments on different arrays of horizontal axis tidal current turbine, and drew the velocity curve, which laid a foundation for the subsequent research of the turbine array. Jing Fengmei et al. put the vertical axis tidal current energy
turbine in the circulating water tank of Harbin Engineering University for model experiments. Through strain gauges, the strain values under different working conditions were measured. The experimental results were compared and verified with the unidirectional fluid-structure coupling algorithm, and the one-cycle structural response was obtained, which provided a reference for structural fatigue analysis.

Through the research results of numerical technique and model experiment, it can be found that the research prototype for the hydrodynamic characteristics of tidal power turbine is relatively mature. However, a large number of studies mainly use the suspension turbine or porous disk for experiments. Few people conduct relevant experimental studies on the tidal power turbine model with a single pile to analyze the interference law of the single pile structure on the hydrodynamic characteristics of the tidal power turbine. There are few researches on the influence of single pile structure on unit characteristics and wake flow. The research on tidal current turbine with single pile structure is not mature yet. It cannot provide reliable basis for the influence mechanism of installation height, incoming flow velocity and unit arrangement on the turbine in the research process of tidal current turbine. Therefore, it is of great significance to study the hydrodynamic characteristics of tidal current turbine with single pile structure. In addition, there are few studies on the influence of multi-unit layout on unit performance, so it is impossible to optimize the configuration of power flow turbine power plant. Therefore, the study on the optimal layout of multi-unit is of great help for rational utilization of power flow energy resources.

4. Conclusion
Energy problem has always been a major concern of the world, especially in recent years. Tidal energy, as a predictable, renewable and clean energy, is of great significance to the construction of national economy and national life. The trend of development of European and American countries can be relatively early compared to China but the gap of advancement is reducing. This paper mainly describes two main methods used to study the hydrodynamic characteristics of tidal power turbine at the present stage: (1) Numerical calculation: mainly simulate the actual situation of tidal power turbine. With the improvement of computer hardware capability, the method of numerical calculation has been paid more and more attention by experts at home and abroad. (2) Model experiment: simulate the actual situation mainly by testing a model, usually according to the scale effect. The results of model experiment have higher accuracy, but the investment is larger than that of numerical calculation. Through the research in this paper, it can provide a certain basis for the selection design, performance prediction and simulation of turbine blades in the future.

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