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A review of survivability and remedial actions of tidal current turbines

Long Chen [a,b], Wei-Haur Lam [a,b,*]

[a] State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, People's Republic of China
[b] Marine Renewable Energy Research Group, Department of Civil Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur 50603, Malaysia

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ABSTRACT

Tidal current energy is one of the most predictable ocean renewable energies. Survivability of the device used to harness tidal power and its remedial actions are critical to ensure a successful power generation. Marine environment is harsh with the continuous attacks of waves, current, saline water and microorganism. Support structures are discussed including gravity base, monopile, tripod/piled jacket and floating structure. Extreme weather increases the wave height and current speed to produce high loading at the turbine. Support structure is designed to sustain the loadings from the extreme weather. Protective seabed unit should be included to prevent the seabed scouring. Corrosion reduces the strengths of rotor, support structure and nacelle. Penetration of sea water into nacelle may damage the generator. Scheduled examination is important to ensure water tight condition of nacelle. Marine fouling from microorganism needs the proper painting as protection. The study presents the survivability of tidal current turbine and suggests the remedial actions to protect the device.

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1. Introduction

Brundtland Report from United Nation coined the term “sustainable development” in 1987. Sustainable development refers to the development that meets today's generations needs without compromising those future generations [1]. As world population grows at an average rate of 0.9% per year to an estimated 8.7 billion population in 2035, the energy consumption will sharply increase when more peoples move to urban areas [2]. Energy demands depend on the world energy policies, global GDP growth, world population growth, energy pricing, fossil-fuel subsidies CO_2 pricing and development of energy technologies as described in World Energy Outlook 2013 [2]. Future energy demands are hard to meet without burning of fossil fuels continuously or depending on nuclear power. Exploration of renewable energy is one of the expected solutions to achieve the sustainable development.

* Corresponding author. Tel.: +60 3 79677675; fax: +60 3 79675318.
E-mail address: joshuawhlam@hotmail.com (W.-H. Lam).

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The oceans have tremendous untapped natural resources, which are able to make significant contribution to our future energy demands. Several types of ocean sources have been defined as potential sources to generate electricity including tidal barrage, tidal current energy, wave energy, ocean thermal energy and salinity gradient energy [3,4]. Researchers face many barriers on finding highly applicable and cost effective technologies to develop these sources.

Tidal current is one of the most advantageous resources, which can be extracted from the rise and fall of sea levels caused by the gravitational force exerted by the moon and sun and the rotation of the earth. Tidal current energy is more predictable compared to wind and wave energies. Tidal current sources are easier to be quantified and predicted [5,6]. A number of devices have been designed to harness tidal energy with wide range of shapes, sizes and forms [6]. These inventions harness potential kinetic energy of tides and convert the energy to electricity principally. Tidal current turbine can be categorised as horizontal axis and vertical axis tidal turbines [8]. Horizontal axis tidal current turbines (TCTs) are the most common device with the rotation axis in parallel to the direction of current stream [9]. Vertical axis TCTs rotates about a vertical axis in perpendicular to the current stream [10].

Extracting the kinetic energy from ocean is more challenging compared to the wind on land. Wind turbine is vulnerable to the cyclones in the extreme weather [11]. For the marine environment, extreme sea conditions have to be considered for the survivability of TCTs. Sole consideration of the extreme weather in ocean is not able to ensure the survivability of tidal current turbine. The effectiveness of mooring system to hold the tidal current turbine under extreme condition is examined to provide guideline in design. The current work firstly introduced the mooring systems of gravity base, monopile, tripod and floating structure. Tidal current turbines are vulnerable to the damage of seabed scour. The potential scour of various foundations are discussed and followed by the discussion on the fatigue failure of blades, corrosion failure of saline water attack and the hydrodynamic failure of befouling at the blades. Installation and operation of TCTs are harsh in the marine environment. The current work unveiled the potential damages of the tidal current turbine in ocean and provided protective actions to ensure the survivability of turbine.

2. Support structures

The support structure of TCTs is of significant importance in tidal current energy system. Prior assessment of the support structure of TCTs was carried out before approaching the survivability of TCTs. Based on the current status of TCTs, four basic support structures for TCTs are as follows [6]:

(1) *Gravity structure*: this gravity structure is made up of large steel or concrete base column. It can resist overturning by its self-weight. The steel component of this gravity structure adds some advantages to itself, such as ease of production, transportation, and installation.
(2) *Monopile structure*: this type of structure is made up of a large-diameter hollow-steel beam. The beam is penetrated approximately 20–30 m into seabed while the seabed conditions are soft. If the rock is harder, pre-drilling, positioning and grouting may be the methods to install this structure.
(3) *Tripod/piled jacket structure*: each of the corners of the structure's base is anchored to the seabed by using steel piles. The steel piles are driven approximately 10–20 m into the seabed depending on the seabed conditions. This type of structure is well understood since it has been widely applied in the oil industry. Compared to other structures, this structure has lighter structural loading.
(4) *Floating structure*: floating structure provides the optimum solution for the placement of devices in deeper water conditions. This type of structure is made of mounting device and floating vessel which is moored to the seabed using chains, wire or synthetic rope. The illustration of all the aforementioned support structures can be found in works [12,13].

Monopile structure has been applied on the Seaflow and Seagen from marine current turbine (MCT). Monopile was used to support the single rotor of Seaflow rated 330 kW and twin-rotor of Seagen rated 1.2 MW. Monopile is able to provide firm support with the lifting ability to rise up the rotor for maintenance. The cost is higher compared to the floating structure. Size and weight of turbine are increasing in parallel to the demand of higher rated power for a single device. Tripod is more suitable to hold the heavier turbine. However, tripod and gravity base structures have larger contact area between the structure and seabed leading to higher chances of seabed scour. Rourke et al. [6] has summarised all the devices in detail including their dimensions, features and status of development. The condition of TCTs under the extreme weather, seabed scour, blade failure, corrosion and biofouling are discussed by relating to the support structures.

3. Survivability of tidal current turbine

3.1. Extreme weather

The impacts of extreme weather to the TCTs and its support structure are discussed substantially in this section. Sea environment is harsh due to the intrinsic nature of sea state. Extreme events occur frequently such as hurricane, typhoon, tsunami and storm. The extreme events bring along the extreme wave and strong wind which would have severe impacts on the survivability of TCTs.

McCann et al. [14] stated that the extreme conditions considered are based on the combined probabilities of governing environment, such as current speed and wave height. Identification of the maximum loadings of storm can prevent the turbine components from damages. The generic tidal blade model used requires the blade root and tower base to withstand the moment approximately at 5 and 50 MN m, respectively. The simulated environmental condition is a 50-year return storm with 13 m wave height and 10 s wave periods. The detail of the simulation is shown in Table 1 [14].

Grogan et al. [15] presented a combined hydrodynamic-structural design methodology for a commercial scale (1.5 MW) tidal turbine. The loading analysis of the turbine blades has been conducted. Grogan et al. [15] found that the high bending moments of the turbine blades during operation life may prohibit the up-scaling of

Table 1
Extreme 50-year storm design load case conditions.

Design load case	50-Year return storm
Wind speed	25 m/s at 10 m height
Wind-induced surface current	0.625 m/s
Extreme 50 year regular wave	
H_s (wave height)	13 m
T_p (wave period)	10 s
Normal current speed at hub height	2.2 m/s
Current direction	Co-direction with wind and waves
Water level	40 m (MWL[a])+2 m (storm surge)

[a] MWL: mean water level.