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Wave–current interaction effects on tidal stream turbine performance and loading characteristics

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ABSTRACT

The transient interaction between tidal currents and the rotation of a horizontal axis turbine rotor have the potential to induce high asymmetric loadings, which are subsequently transmitted to the drive shaft and potentially high speed drive train components. To mitigate the potential for early component failure, analysis of asymmetric loading on marine turbines is fundamental to the design process. To investigate these loads a turbine mounted on a circular stanchion has been used to highlight the effects of introducing more realistic boundary conditions. Depending on their wavelength, waves can also have a significant effect on the overall design decisions and placement of devices. Thrust loading and bending moments applied to the drive shaft can be of the order of hundreds of kN and kN m respectively.

Knowledge of the flow regime can allow designers to evaluate material selection for components and incorporate some deformation capability of the turbine blades to increase the power output and potentially alleviate some of the stress distribution through key structural points. The resulting data can then be used to estimate component life via fatigue prediction.

This paper includes a multi-physics approach to modelling tidal energy devices and the potential for modelling to inform device condition monitoring.

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Nomenclature

Cp	power coefficient (–)
Ct	thrust coefficient (–)
L	wavelength (m)
k	wavenumber (m^{-1})
H	wave height (m)
λ	tip speed ratio (–)
ω	angular velocity of wave (rad s^{-1})
g	gravity (m s^{-2})
T	wave period (s)
h	water depth (m)

1. Introduction

The EU has targeted renewable energy to provide 20% of the total energy mix by 2020 [1] in comparison the UK target is 15% of the UK energy demands from renewable sources by 2020 [2]. In order to meet and sustain the targets set by 2020 and beyond, the UK and EU at large must continue to address the imbalance in the renewable energy mix. The potential for sustainable production through wave and tidal energy conversion has resulted in large investment from industry and governments. A practical and economical resource of tidal current and wave energy resource of 70 TWh/year around the UK shores has been identified, which would contribute to 20% of UK's total industrial, commerce and domestic electricity demands [3].

The long term predictability of tides is the main advantage of tidal power over other renewable energy sources since it allows any phase change in power productions between wind and or other tidal stream and wave sites to be balanced. The two leading techniques in energy conversion for tidal range power generation are impoundment schemes such as a barrage or tidal lagoon and tidal stream turbines (TSTs). The impoundment schemes offer large scale solutions, as documented in the La Rance Tidal Power Plant run by EDF Energy which produces 0.54 TWh/year [4], whilst TSTs offer bespoke solutions to fit the local environment and since they are submerged, they are less intrusive than impoundment schemes and minimise the impact on the marine and costal environment.

The introduction of TSTs into the UK energy mix can only be a positive step since the UK has some of the strongest currents in the world, with a number of areas identified as viable sites for installing tidal energy devices [3]. Ideal conditions for tidal stream turbines are; a free stream velocity of 2–3 m/s and a depth of 20–30 m, at least for early stage implementation with deeper water designs (>40 m) introduced as the industry matures. Current developments include the DeltaStream device which is being installed in the Ramsey Sound, Pembrokeshire [5], and the array, of SeaGen S turbines, in the Skerries site off Anglesey [6]. The success of these initiatives is dependent on a thorough understanding of the hydrodynamic forces applied to the TST, its scale, blade design and experiential knowledge acquired from environmental monitoring, which for example has led to actively pitch controlling the blades to limit the maximum rotational speed of the rotors to 14 rpm [7]. The hydrodynamic forces cause considerable loading on the blades, resulting in blade deformation. The magnitude of the deformation will be dependent on the design of the blades, their internal structure and materials used. However, the combined loading on the blades and hub of the rotor is transmitted to the drive shaft, and knowledge of these resultant transient forces is essential for developers to optimise the success of their design.

The simplest scenario for determining the hydrodynamic forces is to consider the effects of a uniform tidal current. However, in reality, the current is typified by a high shear in the velocity profile through the water column, turbulence and surface waves and these all need to be considered in determining the loads on a TST. Work on the effects of highly shearing profiles and levels of turbulence have

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