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ScienceDirect

Energy Procedia 125 (2017) 250–259

Energy Procedia

www.elsevier.com/locate/procedia

European Geosciences Union General Assembly 2017, EGU
Division Energy, Resources & Environment, ERE

Hydrodynamic Impacts of a Marine Renewable Energy Installation on the Benthic Boundary Layer in a Tidal Channel

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Abstract

Field measurements of the flow in the benthic boundary layer (BBL) of a tidal channel are presented which compare data collected in the wake of a marine renewable energy installation (MREI) with control data representative of the natural conditions. The results show significant flow modification in the wake of the MREI including a reduction in mean velocity, enhanced turbulence, and the breakdown of the natural structure and dynamics of the BBL. This study provides new information relevant to the environmental impact assessment of MREIs and to the design and consenting of marine renewable energy projects.

Peer-review under responsibility of the scientific committee of the European Geosciences Union (EGU) General Assembly 2017 – Division Energy, Resources and the Environment (ERE).

Keywords: Hydrodynamic impact; marine renewable energy; benthic boundary layer; tidal channel; turbulence; ADV; wake dynamics

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1. Introduction

In the last decade there have been significant advances in tidal stream technologies with various turbine designs tested and numerous marine renewable energy installations (MREIs) deployed at sites around the world [1]. MREIs are designed to be deployed in energetic environments with high tidal flows where the available energy resource is maximized. These environments are found in tidal channels, where the local coastline and bathymetry constrain the flow leading to increased mean flow velocities and enhanced kinetic energy [2]. Tidal channels currently considered

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Peer-review under responsibility of the scientific committee of the European Geosciences Union (EGU) General Assembly 2017 – Division Energy, Resources and the Environment (ERE).
10.1016/j.egypro.2017.08.169

for industrial developments typically have peak spring flow velocities in excess of 2.5 m s^{-1} and water depths in the range 25 - 50 m [3]. These sites are characterized by high levels of turbulence over a range of scales with high temporal and spatial variability [4-6].

Friction with the seabed leads to the formation of the benthic boundary layer (BBL) in tidal flows which is substantially non-stationary [7]. Early observations of the BBL in tidal channels focused on characterizing the velocity profile and shear stress across different bed configurations to understand sediment transport mechanisms [8]. Following the discovery of bursting phenomena in laboratory experiments [9-10] it was recognized that the dynamics of the BBL in tidal channels can be controlled by large, intermittent, and well-organized motions [11]. Bursting motions generated in the BBL have also been shown to interact with stratification in tidal channels and surface wave dynamics [12]. Further, these processes can interact with the larger scale dynamics related to the coastline and bathymetry, for example vortex shedding from islands and large eddies in the wake of headlands [13–14]. Consequently, the natural dynamics of the BBL in tidal channels involves highly complex turbulence which presents a challenge for the survivability of tidal turbines [15] and the effectiveness of environmental monitoring technologies [16-17].

It is not yet clear how exactly the presence of MREIs will affect the natural characteristics of the BBL in tidal channels. A detailed understanding of the dynamics of the wake flow behind MREIs is essential for understanding the ecological impacts [18], the effects on physical processes [19], and for the design of device arrays for optimal power output [20]. Extensive numerical modelling work has been undertaken over recent years to investigate the wake dynamics of tidal stream turbines [21]. Further insights are available from various experimental studies using scaled model turbines in laboratory simulations [22] which have shown that wake characteristics are strongly dependent on the natural turbulence conditions [23]. The highly complex structure of turbulence in tidal channels makes field observations essential to validate models of wake flows and gain confidence in predictions relevant to the design and optimization of devices.

Most recent hydrodynamic measurements in tidal channels have been collected by moored acoustic Doppler current profiler (ADCP) deployments [5,24-25] which can have the advantage of depth coverage over most of the water column. However, the analysis of turbulence from ADCP data is limited as the instantaneous three-dimensional velocity cannot be reliably resolved due to the assumptions of horizontal homogeneity between beams. In contrast, an acoustic Doppler velocimeter (ADV) can provide reliable velocity measurements at high sampling rates and within a small sampling volume to obtain detailed information on the properties of turbulence relevant to understanding the dynamics of the BBL [26] and the nature of unsteady loading on tidal turbines [15]. Previous studies have utilized ADVs mounted several meters from the seabed in tidal channels to characterize the natural turbulence at turbine hub height [6,14,27]. However, ADV assessments of the BBL in tidal channels are lacking and there are very few hydrodynamic field observations from around full-scale MREIs due to the operational difficulties of data collection.

In this study, analysis of ADV data provides information on the mean flow and turbulence characteristics in the BBL of a tidal channel. Results from a control site representative of the natural conditions are compared to results from the wake of a tidal stream turbine foundation to provide essential information on the hydrodynamic impacts of MREIs.

2. Method

2.1. Study site

The data used in this study were collected at the Fall of Warness (FoW) tidal test site at the European Marine Energy Centre (EMEC), UK, during summer 2013. FoW is a tidal channel located in the Orkney Islands between the islands of Eday and Muckle Green Holm (59°7’ to 59°11’N, 2°47’ to 2°50’W) and is an energetic marine environment which is representative of the sites targeted for tidal stream energy extraction globally. FoW is characterized by semidiurnal tidal currents exceeding 3.5 m s^{-1} during peak spring tides. The principal semidiurnal lunar (M_2) and solar (S_2) tidal constituents dominate the dynamics of the site which is subject to strong tidal currents due to the interaction of the North Sea and North Atlantic [28]. The tides flow from the north-west to the south-east during the flood tidal phase, and from the south-east to the north-west during the ebb tidal phase.