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Tidal energy leasing and tidal phasing

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A B S T R A C T

In addition to technical and economic constraints, tidal energy leasing is generally governed by demand for sites which contain the highest tidal streams, and does not take into account the phase relationship (i.e. the time lag) between sites. Here, the outputs of a three-dimensional tidal model are analysed to demonstrate that there is minimal phase diversity among the high tidal stream regions of the NW European shelf seas. It is therefore possible, under the current leasing system, that the electricity produced by the first generation of tidal stream arrays will similarly be in phase. Extending the analysis to lower tidal stream regions, we demonstrate that these lower energy sites offer more potential for phase diversity, with a mean phase difference of 1.25 h, compared to the phase of high energy sites, and hence more scope for supplying firm power to the electricity grid. We therefore suggest that a state-led leasing strategy, favouring the development of sites which are complementary in phase, and not simply sites which experience the highest current speeds, would encourage a sustainable tidal energy industry.

1. Introduction

Making use of the tides to perform work is not a novel concept – for example around 750 tide mills are known to have been in operation at one time or another along the shores of the Atlantic [1]. However, a relatively new concept is making use of the tides, particularly the kinetic energy of tidal streams, to contribute to significant electricity generation [2]. Concerns about energy security and global warming has fuelled an interest in marine renewables, particularly in nations like the UK which are equipped with an energetic tidal resource [3]. Although tides and tidal currents are predictable, this form of electricity generation, in common with other forms of renewable energy like wind, wave, and solar, is intermittent [4], from the semi-diurnal (twice daily) flood and ebb of the tides, through to spring–neap (fortnightly) variability. However, the timing of high and low water, and flooding and ebbing tidal currents, varies considerably along our coastlines – for example, high tide in Dover (English Channel) occurs around 8 h later than high tide in Leith (Edinburgh) (locations shown on Fig. 1). Therefore, there is scope for exploiting our knowledge of the phase relationship between tidal energy sites by aggregating the electricity generated by a number of geographically distributed sites, leading to firm power supply to the electricity grid [5].

Consideration of the phase relationship between sites is not reflected in the current leasing process for tidal energy schemes. For example, in the UK, The Crown Estate (as manager of the UK seabed) grants rights for tidal energy developers to operate on the seabed. Although technical and economic factors are important, at present, with the exception of Holyhead Deep (Minesto UK Ltd), developers are exclusively interested in high tidal energy sites (e.g. peak spring tidal currents $\geq$2.5 m/s [6]), as evidenced by the 31 tidal stream sites that are currently leased from The Crown Estate (Table 1). However, it has been suggested that there is minimal phase diversity among these high tidal energy sites [7], and if all such sites were to be developed in parallel, the aggregated electricity supplied to the grid would be characterised by strong semi-diurnal intermittency [3]. The time lag between occurrence of peak flood current at Dover and peak flood current at each of the Crown Estate leased sites is also included on Table 1. This time lag relates to currents, and if we assume that a tidal energy device will generate electricity equally during the flood and ebb phases of the tidal cycle, then an optimal complementary time lag between two sites would be 3.1 h, i.e. a quarter of a tidal cycle. On examination of the timing of peak flood (or ebb) currents, there seems to be more scope for phase diversity among these leased sites than has been suggested by previous studies [3,7]. However, the current study is not constrained by an examination of only the presently leased sites, nor UK waters, and extends such analysis to the wider context of the NW European shelf seas in providing firm power to the electricity

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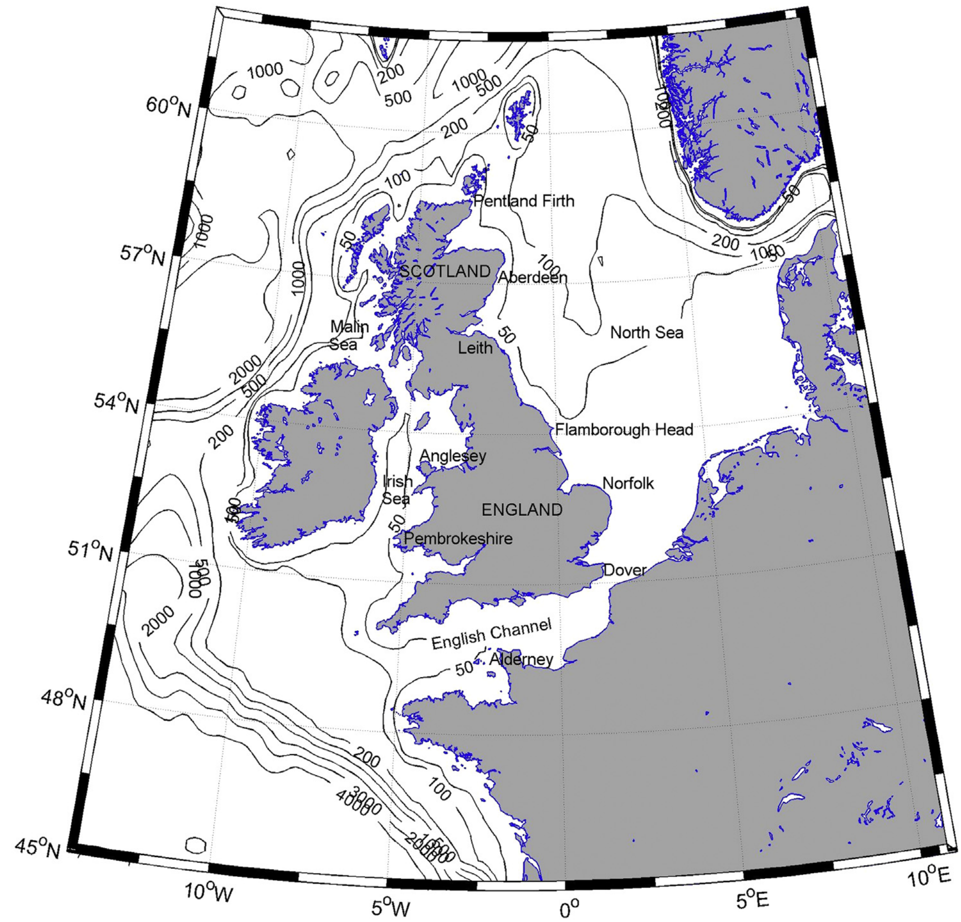

Fig. 1. The northwest European shelf seas. Contours are water depths in metres.

grid in the future, by aggregating sites that exhibit a variety of characteristics, including a range of tidal current amplitudes and phases, and a range of water depths.

Here, we discuss the implications of a leasing strategy that is governed by demand for exclusively high tidal stream regions, and suggest ways in which phase diversity could be increased, such as developing lower tidal stream sites (e.g. peak spring tidal currents $\geq$1.5 m/s [6]) in parallel with high tidal stream development. We also discuss how a state-controlled leasing system, working in conjunction with privatised or centralised electricity networks, could lead to increased phase diversity, and hence the ultimate success of a sustainable tidal energy industry.

We first introduce the study region (the NW European shelf seas; Section 2), then provide an overview of generating electricity from tidal streams (Section 3), discussing tide generating forces, tidal currents, tidal power, and the concept of tidal phasing. We next present the results from a three-dimensional (3D) tidal model of the NW European shelf seas (Section 4), demonstrating the phase diversity that would result from aggregating the electricity generated across a range of tidal current amplitudes. Finally, we consider the characteristics of lower tidal stream sites, and discuss the implications of tidal phasing on leasing strategies, and other considerations such as energy storage, supergrids, and practical and economic constraints on tidal energy extraction (Section 5).

2. The northwest European shelf seas

The NW European shelf seas provide Europe with a world leading resource for the development of a marine renewable energy industry, and are therefore host to a large number of commercial projects and test centres, such as the EMEC wave and tidal test centre in Orkney, and the MeyGen project in the Pentland Firth (Table 1). Although the wave resource is substantial (e.g. Ref. [8]), and there is scope for exploiting the potential energy contained in the vertical tide (e.g. Ref. [9]), the focus of the present work is on the horizontal tide, i.e. tidal streams.

The NW European shelf seas, located on the northeastern margin of the North Atlantic, are generally shallower than 200 m (Fig. 1). The Celtic Sea, Malin Sea and northern North Sea are exposed to Atlantic waters, with water depths in the range 100–200 m, with the exception of the deeper (600 m) Norwegian Trench in the northeastern North Sea. The Celtic Sea borders the Irish Sea to the north, a semi-enclosed water body containing a north–south orientated channel of depth 250 m. To the east of the Celtic Sea, the English Channel connects to the southern North Sea.

There are regions of the NW European shelf seas which contain some of the largest tidal ranges in the world, e.g. the Bristol Channel and the Gulf of St. Malo. There are three M2 (principal lunar semi-diurnal constituent) amphidromic points of near-zero tidal range in the North Sea, a further one in the North Channel of the Irish Sea, and two degenerate amphidromic points: one in the English Channel, and the other in St. George's Channel [10]. Tidal currents are generally high in the Irish Sea and English Channel, and moderately high in the Celtic Sea and in the southern and western North Sea [11,12]. Since friction gradually removes energy from the tides at the bottom of the water column, the total attenuation in