Renewable Energy 102 (2017) 380–389

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Close-proximity tidal phasing for 'firm' electricity supply

Andrew N. Commin*, John McClatchey [1], Magnus W.H. Davidson, Stuart W. Gibb

Environmental Research Institute, North Highland College, University of the Highlands and Islands, Ormlie Road, Thurso Caithness, Scotland, UK

ARTICLE INFO

Article history:
Received 29 February 2016
Received in revised form
20 October 2016
Accepted 26 October 2016
Available online 27 October 2016

Keywords:
Tidal energy
Tidal phasing
Firm capacity
Electricity supply

ABSTRACT

Tidal generation is highly predictable and thus an attractive renewable energy source to develop; however, output varies over short time scales. This can be mitigated through phasing of output between sites, as different locations have different timings of output. Phasing can be increased by geographical diversity; unfortunately areas with tidal resources suitable for generation are few, so the opportunity for this is limited.

The Pentland Firth and Orkney Waters (PFOW) contain the World's first leased sites for tidal stream generation. This paper focuses on close-proximity phasing between these leases and their ability to provide firm power, i.e. a guaranteed level of output. Results show phasing across individual leases and over the PFOW; combined output from all the lease areas exceeds 1% of nameplate capacity for 97.9% of the study, compared to 83.4%–94.5% for the individual leases. Relatively little storage makes significant levels of firm capacity obtainable; 255 MWh of storage means electricity demand of the two counties the developments fall within would be met ~94% of the time.

The methodology identifies lease suitability, high energy locations within leases, and quantifies the complementary characteristics of different tidal sites. This could inform strategic development of tidal sites, to maximise firm capacity.

1. Introduction

Renewable generation has a large potential to displace the production of energy from fossil fuels, thereby helping to mitigate climate change [1]. However, as the share of renewables increases in an electricity system the issue of security of supply becomes increasingly prevalent due to the inherent variability of most renewable electricity sources [1]. Variability is an important issue in Scotland, where the government has set a target of generating the equivalent of 100% of Scotland's electricity demand from renewables by 2020 [2]. There is political will that a portion of this target will be met by tidal stream energy generation for three reasons: one, Scotland has an estimated tidal resource equating to 25% of the total available across Europe [3]; two, tidal power differs from the other potential sources in Scotland's future renewable portfolio (wind, hydro, solar and wave) in that it is independent of weather and predictable over decadal timescales; and three to support economic growth with first mover advantage, through supply chain development, employment, and export potential [4]. This provides electricity network operators with a high degree of certainty as to what the tidal power input to the grid will be, making a unit of electricity generated by a tidal turbine a more 'valuable' commodity than a unit of electricity generated from wind turbines [5].

Tidal output does, however, vary. Two tidal cycles have a particularly noticeable impact on output: The flood/ebb cycle (approximately twice daily) and the spring/neap cycle (approximately 14.8 days period) e.g. Sinden [6] quantifies this for the UK, showing mean tidal output can be 70% of installed capacity during a spring phase and as little as 6% during neaps. Variation of electricity supplies arising from the flood/ebb cycle could be reduced by development around the UK, exploiting phased tides with slack water occurring at different times at different locations. Several studies explore the potential of this as a means of providing 'firm capacity' output [6–10]; i.e. the ability to provide a guaranteed level of output at all times. It has been suggested that intermittency of supply may be mitigated through wide geographic distribution of tidal energy developments. However as the tidal resource is not evenly spread around the UK (Fig. 1) it has been suggested [7] that under-exploiting high–capacity sites may be required in order to increase the benefit of phasing.

* Corresponding author.
E-mail address: andrew.commin@uhi.ac.uk (A.N. Commin).
[1] Deceased 30th April 2015.

http://dx.doi.org/10.1016/j.renene.2016.10.058
0960-1481/

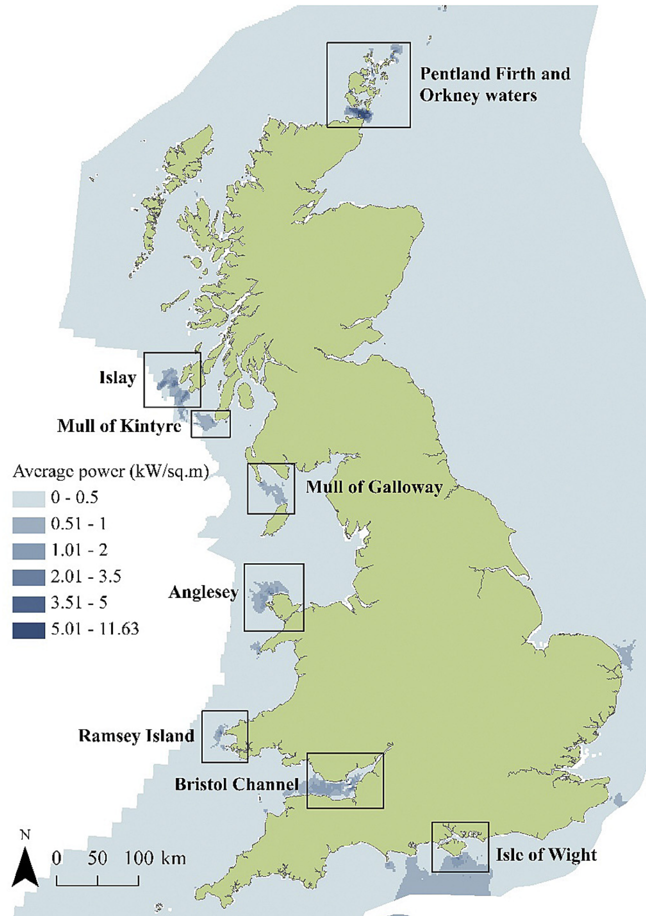

Fig. 1. Potential areas for tidal stream development around the UK. Tidal data is from ABPmer [11], background map is Crown copyright©.

The Pentland Firth and Orkney Waters (PFOW) is the UK site with the greatest tidal energy potential, as shown by it having the highest power densities in Fig. 1. Lying between the north coast of the Scottish mainland (Caithness) and the Orkney Islands, the area is a narrow sea corridor (~27 km long and ~10–13 km wide) connecting the North Sea to the North Atlantic Ocean characterised by strong tidal currents [12]. The constrained nature of the area led Iyer et al. [8] to not consider the separate arrays, instead modelling the output from the area as a whole.

Iyer et al. [8] suggest 7.3 GW of tidal stream generation capacity spread around the UK in areas most suitable for development could only achieve 75–150 MW of firm capacity (i.e. the minimum amount of electricity which will be available at any given time). This 7.3 GW covers seven main areas (Orkney, the Pentland Firth, Islay, Anglesey, Ramsey Island, the Isle of Wight, and the Race of Alderney in the Channel Islands), five of which are outside the PFOW region. The presence of phasing within the PFOW was not addressed by Iyer et al. [8] but could extend the achievable level of firm capacity.

An additional benefit of phasing is that it reduces the likelihood of transmission bottlenecks. The PFOW are on the extremity of the national transmission grid: this makes congestion a potentially significant issue for large scale renewable development [5]. If peak output is experienced simultaneously across all tidal sites the resulting load may be too great for the grid connection to cope with, so some generation may need to be curtailed or dumped. Any smoothing due to phasing will reduce the stress on the grid and therefore the need for curtailment, making the developments more beneficial.

Initially concentrating tidal Scottish and UK tidal in the PFOW offers substantial benefits beyond the area's high-value resource. The proximity to EMEC offers access to the trained staff and supply chain which has built up both around the site and the tidal resource and leases. Studies have already been carried out and companies formed for the collaboration of vessels with the tidal sector [13,14]. Beyond a specialised tidal supply chain the PFOW would also benefit from the infrastructure (including grid) and supply chain of the nearby large scale offshore wind developments in the Moray Firth [15,16] (Beatrice Offshore Wind Ltd and Moray Offshore Renewables Ltd). In addition, site characterisation and environmental data collection remain to be of high cost and risk for developers, but are reduced in the PFOW by the work already carried out in the area [17]. This includes coordinated efforts to understand the environmental implication of developing tidal power in the PFOW, highlighted by the publication by the Scottish Government of a Marine Spatial Plan for the area [18]; which should assist with the consenting process.

The benefit of remotely located sites in Scotland, and the UK as a whole, is limited due to the nature of co-tidal lines and these correspond to areas with a large tidal resource, this is explored and quantified in detail in Ref. [8].

In March 2010 the Crown Estate leased 1000 MW of tidal stream development sites in the PFOW; these were the first such leases in the World. The PFOW leases, being some of the most economic and advanced in terms of development, are likely to be constructed before there are other tidal farms of a scale which can contribute to smoothing overall tidal power output. Consequently, the objective of this work was to establish and quantify the extent to which 'close proximity' phasing of tidal output within the PFOW can be expected to contribute to 'firm capacity'.

2. Methodology

The Crown Estate 2010 PFOW leasing round contained five tidal stream sites: 100 MW at the Ness of Duncansby, 200 MW at Cantick Head, 200 MW at Westray South, 100 MW at Brough Ness, and 400 MW at the Inner Sound of Stroma. The locations of these are shown in Fig. 2. Most of the arrays are closely grouped; Brough Ness, the Ness of Duncansby, the Inner Sound and Cantick Head arrays cover an area of only 17 km by 18 km.

Tidal sites were defined according to the coordinates for the leased areas from The Crown Estate [19]. A grid was draped over the development areas in ArcGIS and centroid co-ordinates of each grid square ('nodes') extracted, 856 nodes in total.

The spatially smaller development areas of the Inner Sound, Ness of Duncansby and Brough Ness were assigned 150 × 150 m grids squares, whilst the Cantick Head and Westray South sites were assigned 200 × 200 m and 250 × 250 m squares respectively. This gave a balance between size of data sets and resolution. The resolution is fine compared with, for example, Clarke et al. [9] who used just one point from the UK Admiralty tidal charts for their three study sites, and Iyer et al. [8] who used 1.8 km^2 grid cells.

Tidal current velocities were obtained at ten minute intervals for one year (2009), for each of the 856 nodes, from the POLPRED Orkney model (ORKM). POLPRED is a suite of tidal prediction software, developed by the Proudman Oceanographic Laboratory [20]. The ORKM uses 26 tidal harmonics, derived from a high-resolution numerical circulation model, to provide two-dimensional depth-averaged current for a desired location.

There is no mature tidal turbine in use, and thus no definitive power curve for modelling applications [21]. A review of existing devices was conducted and the Atlantis AR1000 selected. The