Renewable Energy 51 (2013) 343–357

Contents lists available at SciVerse ScienceDirect

Renewable Energy

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

Variability and phasing of tidal current energy around the United Kingdom

A.S. Iyer*, S.J. Couch, G.P. Harrison, A.R. Wallace

Institute for Energy Systems, School of Engineering, University of Edinburgh, Mayfield Road, Edinburgh EH9 3JL, UK

ARTICLE INFO

Article history:
Received 1 February 2011
Accepted 11 September 2012
Available online 31 October 2012

Keywords:
Renewable energy
Tidal current energy
Intermittency
Tidal phasing

ABSTRACT

Tidal energy has the potential to play a key role in meeting renewable energy targets set out by the United Kingdom (UK) government and devolved administrations. Attention has been drawn to this resource as a number of locations with high tidal current velocity have recently been leased by the Crown Estate for commercial development. Although tides are periodic and predictable, there are times when the current velocity is too low for any power generation. However, it has been proposed that a portfolio of diverse sites located around the UK will deliver a firm aggregate output due to the relative phasing of the tidal signal around the coast. This paper analyses whether firm tidal power is feasible with 'first generation' tidal current generators suitable for relatively shallow water, high velocity sites. This is achieved through development of realistic scenarios of tidal current energy industry development. These scenarios incorporate constraints relating to assessment of the economically harvestable resource, tidal technology potential and the practical limits to energy extraction dictated by environmental response and spatial availability of resource. The final scenario is capable of generating 17 TWh/year with an effective installed capacity of 7.8 GW, at an average capacity factor of 29.9% from 7 major locations. However, it is concluded that there is insufficient diversity between sites suitable for first generation tidal current energy schemes for a portfolio approach to deliver firm power generation.

1. Introduction

The European Union's ambitious target of meeting 20% of energy demand from renewable energy by 2020 [1] is driving interest and investment in the renewable sector. The UK 2020 target of 15% renewable energy implies a need for around 34% reduction in emissions [2]. Meeting these targets will require substantial investment in new on and offshore wind, wave and tidal energy developments, drawing on the UK's abundant resource potential. There is however concern regarding the integration requirements of the large capacities of new renewable generation implied by these targets given the inherent variability of the major renewables, and the relative timing of their output with electricity demand. In reality, no energy source is 100% reliable and scheduled or unscheduled outages do occur. Demand patterns are also variable, hence the power system and network have historically, and will continue to be required to be designed and managed to handle variability [3]. As tidal current energy generation is driven by the gravitational interaction of the Earth–Sun–Moon system, tidal energy production patterns can be reliably predicted over short timescales, some as short as a few hours (which can include non-tidal events) and longer timescales which can be as much as days to years, to assess the Annual Energy Production (AEP) over the project life time. Accurate predictions of the output and variability of individual tidal current sites and the impact of aggregation of output from various sites will be highly desirable to facilitate network planning and operation.

The Carbon Trust has commissioned a number of studies that have been used to assess the tidal current resource, its variability and its implications for development [4–6]. As part of the Marine Energy Challenge, Black and Veatch (B&V) [4] estimated the extractable tidal current resource to be 18 TWh/yr (±30% uncertainty) [4], that this 'Technically Extractable Resource' can meet about 5% of current UK demand and that the UK has around 50% of the EU tidal current resources. The study used output from the DTI Atlas of UK Marine Renewable Energy Resources [7], Admiralty Chart data from the UK Hydrographic Office [8], and local current meter data to select and characterise specific locations of tidal energy generation. It also applied a 'Significant Impact Factor' (SIF)

Abbreviations: AEP, Annual Energy Production; ADCP, Acoustic Current Doppler Profiler; BODC, British Oceanographic Data Centre; EMEC, European Marine Energy Centre; B & V, Black and Veatch; GEBCO, General Bathymetric Chart of the Oceans; GIS, Geographical Information System; IDW, Inverse Distance Weighting; NOAA, National Oceanic Atmospheric Administration; SIF, Significant Impact Factor; SPR, Scottish Power Renewables; TAP, Technically Acceptable Power.

* Corresponding author. Tel.: +44 (0) 131 650 5612; fax: +44 (0) 131 650 6554.
E-mail addresses: A.Sankaran-Iyer@ed.ac.uk (A.S. Iyer), Scott.Couch@ed.ac.uk (S.J. Couch), Gareth.Harrison@ed.ac.uk (G.P. Harrison), Robin.Wallace@ed.ac.uk (A.R. Wallace).

0960-1481/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.renene.2012.09.017

Nomenclature and units

A	area, m^2
a_o	amplitude/local tidal elevation, m
c	wave celerity, m/s
C_p	device efficiency, %
d	distance, m
g	acceleration due to gravity, m/s^2
h	water depth, m
P	power, W
p	peak weighting function
Q_{max}	maximum flow discharge, m^3/s
T,t	time, s
u, v	velocity, m/s
u	velocity at a known location, m/s
x,x_k	value at an unknown/known point
ρ	density (water), kg/m^3
λ	wavelength, m

to assess the 'Technically Acceptable Resource' that places a limit on the amount of available kinetic energy that can be harvested without undue impacts on the environment and the tidal current resource itself. This SIF value was estimated as being 20% of available kinetic energy flux [4], although understanding of the extraction limits has since advanced considerably as presented by Refs. [9,10]. It has also been demonstrated by other studies that the flux method has no physical justification and is an unsuitable way of assessing the resources as presented in Ref. [11].

Analysis of tidal current energy generation potential has been further progressed by Sinden [5] by extracting power output time series for wave and tidal energy. Comparing the variability of the identified tidal sites was conducted using data extracted from the Proudman Oceanographic Laboratory POL CS20 tidal model [12] (also the basis for the DTI Atlas tidal component [7]). Although the variations were examined at specific locations, and SIF constraints (as in [4]) were taken into account, the analysis assumed a scenario where all the sites are fully developed without any further constraints. Furthermore, this study also neglects any feedback effect at individual sites or between different sites.

First generation devices are considered to be the driver for tidal current energy development until at least 2025. Installation and operation in deeper water requires more radical 'second' and 'third' generation approaches that are, as yet, only in the very early stages of research and development. Therefore, an analysis based on just first generation device specification is required. The application of the SIF has since been superseded, for this reason a revision of the 'Extractable Power' considered by B&V [4] and Sinden [5] is also necessary.

Boehme et al. [13] examined tidal current resource variability in Scotland as part of the 'Matching Study' for the (then) Scottish Executive. It used the DTI Atlas and Admiralty charts to define current flows within Scottish waters. It applied a generic twin-rotor tidal turbine to estimate production levels and variability. The study estimated the Scottish tidal resource as 2.2 TWh/yr when a 750 MW installed capacity development scenario is considered. However, this study did not look at the far field effect of extraction power from tidal currents and no feedback effects were considered either.

1.1. Firm tidal power generation

An important area that these studies have not tackled directly is whether the aggregate outputs from tidal sites can represent a form of 'firm' or continuous (base load like) generation through diversity in the phasing of energetic sites. Two other studies have offered some analysis of this issue. Clarke et al. [14] suggest that aggregate output from a number of sites can provide base load. Unfortunately, the sites selected are less energetic and/or generally too deep for first generation deployment. For example, Sanda (Mull of Kintyre) has tidal current velocity above 2.5 m/s but the water depth at this site ranges from 100 to 120 m. While this site may eventually be developed for tidal current energy harvesting, it is not credible for first generation tidal projects. Hardisty [15] also reports that by careful selection of tidal current site locations, a continuous level of generation could be achieved. However, when interrogating the same data source as referenced in Ref. [15] (Admiralty TotalTide software [16]), the authors were unable to reproduce this outcome as the sites selected generally had current velocities below 1 m/s. For instance [15], purports to use data relating to tidal diamond SN040A (in Clyde, Scotland) and suggests that it has a Spring peak velocity of 2.1 m/s. Interrogating the same tidal diamond using [16] indicates that SN040A only reaches a Spring peak of 0.57 m/s, a value inappropriate for tidal current energy development. Other discrepancies with reported tidal diamond data were also found while attempting to recreate this analysis. The analysis concluded that a constant level of 45 MW can be generated from an installed capacity of 200 MW, a rather uneconomical scenario.

Additionally, considering the local bathymetric data using the BERR Marine Atlas [17], which is an updated version of the DTI Marine Atlas [7], indicates that some of the sites identified in [15] are too shallow for full scale device deployment. Hence, the authors contend that the locations identified in [15] are not likely to be considered for large scale development of tidal current energy even if they are out of phase, as a majority of the sites suggested in this study are inappropriate for economic tidal current energy generation.

Given the identified deficiencies of existing efforts to assess the potential for firm tidal current energy generation, this paper is concerned with understanding the scope for portfolios of credible first generation[1] tidal current development scenarios to provide firm power. This involves a reassessment of the UK tidal current resource by identifying appropriate development locations incorporating the latest thinking on power extraction limits and examines aspects of generation yield, variability and temporal phasing.

1.2. Data sources

The majority of the data used in this study are publically available. Two different datasets are used to provide spatial and temporal accuracy. With additional processing, the datasets are combined to achieve considerable improvement in analysing the resource. The data obtained from the DTI Atlas of UK Marine Renewable Energy Resource [7] has been taken forward by The Department for Business, Enterprise and Regulatory Reform (BERR) and the underlying Marine Atlas data is now available through a web interface [17]. The Geographic Information System (GIS) data layers downloadable from the web interface are interrogated in the analysis presented using ArcGIS and integrated with manipulated Admiralty chart data [8] accessed utilising Admiralty TotalTide software [16] to provide time series at identified locations.

[1] In order to set the context of the analysis presented in this study, 'First Generation Technology' is defined as iterations of existing prototype devices that are already undergoing pre-commercial demonstration. A *second generation* of technology is defined as being able to be deployed in deep water of greater than 50 m. Examples of such generation technology solutions are under development, but are currently at the early stages of technology readiness, and hence unlikely to make a significant contribution to meeting 2020 electricity generation targets.