Energy 122 (2017) 25–36

Contents lists available at ScienceDirect

Energy

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

Influence of storm surge on tidal range energy

M.J. Lewis [a,*], A. Angeloudis [b,c], P.E. Robins [a], P.S. Evans [c], S.P. Neill [d]

[a] Centre for Applied Marine Sciences, School of Ocean Sciences, Bangor University, United Kingdom
[b] Department of Earth Science and Engineering, Imperial College London, United Kingdom
[c] School of Engineering, Cardiff University, United Kingdom
[d] School of Ocean Sciences, Bangor University, United Kingdom

ARTICLE INFO

Article history:
Received 17 November 2016
Received in revised form
11 January 2017
Accepted 12 January 2017
Available online 13 January 2017

Keywords:
Tidal energy
Barrages
Lagoons
Storm surge
Resource
Reliability

ABSTRACT

The regular and predictable nature of the tide makes the generation of electricity with a tidal lagoon or barrage an attractive form of renewable energy, yet storm surges affect the total water-level. Here, we present the first assessment of the potential impact of storm surges on tidal-range power. Water-level data (2000–2012) at nine UK tide gauges, where tidal-range energy is suitable for development (e.g. Bristol Channel), was used to predict power. Storm surge affected annual resource estimates −5% to +3%, due to inter-annual variability, which is lower than other sources of uncertainty (e.g. lagoon design); therefore, annual resource estimation from astronomical tides alone appears sufficient. However, instantaneous power output was often significantly affected (Normalised Root Mean Squared Error: 3%–8%, Scatter Index: 15%–41%) and so a storm surge prediction system may be required for any future electricity generation scenario that includes large amounts of tidal-range generation. The storm surge influence to tidal-range power varied with the electricity generation strategy considered (flooding tide only, ebb-only or dual; both flood and ebb), but with some spatial and temporal variability. The flood-only strategy was most affected by storm surge, mostly likely because tide-surge interaction increases the chance of higher water-levels on the flooding tide.

© 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

The population of the world is approaching 7.5 billion, with high energy usage and an over-reliance on fossil fuels. Climate change and energy security concerns have driven an interest in renewable energy sources to provide electricity (e.g. Refs. [6,15]). For example, 24–30% of UK electricity is planned to be generated by renewable sources by 2020, and almost entirely de-carbonised by 2050 [15,28]. The transition from predictable and reliable energy sources (e.g. coal and nuclear) to intermittent renewable sources (e.g. wind and solar) is a major concern [10,11,14,28].

Electricity generation must match demand (unless large amounts of energy storage or interconnectors are constructed), hence the development of significant amounts of renewable energy schemes may jeopardise the inherent stability of the power grid [27]. One solution could be the development of tidal energy schemes, which are often presented as a firm, predictable, baseload renewable energy source [9,34]; here we seek to investigate the predictability and reliability of tidal-range power due to storm surges.

1.1. Tidal range energy

Tidal energy is an attractive form of renewable energy because of the reliable and predictable nature of the astronomical tides [23,26]. The Earth-moon and Earth-sun systems are responsible for the astronomical tide, which is caused by gravitational forces in combination with the rotation of the Earth. The result of the astronomical tide is observed as regular, and predictable, rise and fall of the sea's surface; see Ref. [31] for further details. Tidal range power utilizes the potential energy (E) from the water-level difference between two bodies of water, often called head (h), within the regular rise and fall of the tide; as described in Equation (1) derived by Ref. [30]. A wall and hydraulic structures block the incoming (flooding) or outgoing (ebbing) tide, separating these two bodies of water and creating the head (h) that drives flow through turbines [36], as described in Equation (1) (where A is the area of the internal basin, ρ is the density of water and g is acceleration due to gravity), and thus generates electricity. Further details can be

* Corresponding author.
E-mail address: m.j.lewis@bangor.ac.uk (M.J. Lewis).

http://dx.doi.org/10.1016/j.energy.2017.01.068
0360-5442/© 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

found in Ref. [34]; who provide a review of tidal range energy, including descriptions of lagoon or barrage design and strategies.

$$E = \frac{1}{2} A\, g\, \rho\, h^2 \qquad [1]$$

Tidal range power stations can be thought of in two forms: barrages and lagoons. Barrages span the entire width of a channel, with turbines embedded in the retaining wall, whilst lagoons work in the same way as barrages, except that a perimeter embankment is employed to impound the water (further details, see Ref. [34]). For both tidal lagoon and tidal barrage schemes, electricity can be produced during the flooding tide (i.e. flow through turbines to fill up the landward basin) or ebbing tide (i.e. flow through turbines as the basin empties); hence there are three operating designs: "flood only", "ebb only", or two-way (both flooding and ebbing tides) - which we call "dual" here.

Flood only generation schemes have been calculated to be less efficient than ebb-only or dual (both flooding and ebbing tides) generation schemes in some cases (e.g. Ref. [35]), but could be more useful in flood defence (see Ref. [3]), as water-levels in the basin must be kept low [5]. Dual generation designs will produce more power, but require turbines to operate in both directions, and thus may be more costly [2,34]. All strategies have the option of "pumping" to optimise electricity generation (see Ref. [27]), and it should also be noted that tidal-range schemes have been suggested for energy storage. No consensus on the tidal range electricity generation strategy exists, each having benefits and penalties that are not discussed here; however the power produced from any tidal range power scheme will depend on the square of head (h^2) within Equation (1), used to drive a flow (Q, in m^3/s) through the turbines (e.g. Refs. [4,34]). Therefore, small variations in tidal elevation (i.e. h of equation (1)) may result in large changes to power generation, and so we aim to investigate the reliability and predictability of tidal range power from small changes to water-levels due to non-astronomical tide effects.

Around 30 sites throughout the world have been identified as suitable for tidal range power [8], with schemes already in operation (or under development) in France, South Korea, Russia and China; see Ref. [15]. The UK is a macro-tidal region that includes one of the largest tidal ranges in the world (the Bristol Channel, see Ref. [21]); hence tidal energy in UK is extremely attractive [26]. A number of sites within UK waters have been noted as suitable, which is defined as where the mean tidal amplitude is above 2.5 m (i.e. mean tidal range greater than 5 m, see Ref. [5]); for example, Mersey, Conwy and the Solway Firth (see Ref. [34]). Indeed [36], states that a configuration of eight tidal lagoon power stations could produce ~10% of all UK current electricity demand, and so the predictability and reliability of tidal power in the UK should be investigated - with results having a global application for the tidal energy industry.

1.2. Tides and storm surges

The gravitational forcing of the Earth-moon system results in a semi-diurnal tide at potential tidal range sites (period of 12 h 25 min and thus around two high waters a day), described by the principal semi-diurnal lunar constituent harmonic called M2. The spring-neap cycle, which arises from the interaction between the sun-Earth-moon systems, is described by the interaction of the M2 harmonic and the principal semi-diurnal solar constituent harmonic (S2); giving the fortnightly cycle of variation in tidal range called the spring-neap cycle (e.g. Refs. [26,32]). Much research has focused on the variability and predictability of the astronomical resource (e.g. Ref. [18,25,32]), with increasing attention being made to predicting resource variabilities from non-astronomical effects, including implications of waves on the tidal-stream resource (e.g. Ref. [22]); however, no research has yet investigated storm surge impact to tidal range power.

Storm surges are the sea-level response to meteorological conditions (see Ref. [31]), and in combination with the astronomical tide, result in the total still water level (i.e., excluding waves); often referred to as the storm tide [19,20]. It is this storm tide that tidal range power will use to generate electricity. Negative storm surge events can counteract the astronomical tide, reducing the total storm tide, whilst positive storm surges raise sea-level above the astronomical tide and can result in coastal flooding; such as the disastrous 1953 North Sea flood [17,24].

In the UK, the magnitude of tidal amplitude is such that storm surges only represent a flooding threat in combination with high water, which has led to research into tide-surge interaction [16]. The interaction of storm surges with the astronomical tide, due to shallow water and bottom friction, alters the magnitude and timing of high water (see Ref. [29]). A negative surge would retard tidal propagation, whilst a positive surge would advance the time of high water [33], with the water-level time-series also affected, as the surge peak is most likely to occur during a rising tide due to this tide-surge interaction (e.g. Ref. [16]). The result of tide-surge interaction is such that positive storm surges are more likely to occur on a flooding tide; see Ref. [16].

1.3. Storm surges and tidal range energy

Uncertainty in tidal height, due to interaction of tidal range power stations and the resource, has been investigated within the context of annual power estimation (i.e. resource assessment) for tidal range energy (see Refs. [36,37]); however the effect of storm surges to the predictability and reliability of power has not been investigated. If tidal power is to become a significant source of renewable electricity, then it is essential to understand the reliability and predictability of the resource (see Ref. [18]). We hypothesise that storm surges will have a significant effect on the reliability of electricity supply from tidal range schemes: positive storm surges will increase water-levels and the resource, whilst negative surges will reduce the amount of electricity generated. Furthermore, resource estimates may be over-predicted by tide-only hydrodynamic modelling methods, due to tide-surge interaction processes (storm surge more likely to occur on a rising tide — see Ref. [16]), which would reduce the tidal range available for generating electricity.

Here, we investigate the effect of storm surges to the predicted power from tidal range energy, determining if "tide-only" (i.e. no storm surge) hydrodynamic models are acceptable for resource estimation, and if variability on power output due to storm surges warrants a tidal power electricity supply prediction system for grid planning measures. In a site of (a) known tidal conditions, (b) a given plant operation sequence and (c) appropriate formulae that represent the performance of constituent hydraulic structures, it is feasible to simulate the overall performance of a tidal range power plant over transient conditions [2]. The operation can be modelled using a water level time series as input. This corresponds to the 0D modelling approach of tidal range energy. Differences in the power estimated by the 0D modelling approach of [3,4] will be investigated using tide gauges records of storm tide and the tide-only water-levels at all potential tidal range energy sites around the UK.

2. Methodology and power estimation

Quality controlled data from all UK A-class tide gauges is available from the National Tidal and Sea Level Facility (ntslf.org),

Download English Version:

https://daneshyari.com/en/article/5476234

Download Persian Version:

https://daneshyari.com/article/5476234

Daneshyari.com