Renewable Energy 43 (2012) 9–17

Contents lists available at SciVerse ScienceDirect

Renewable Energy

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

Tidal range turbines and generation on the Solway Firth

G.A. Aggidis *, O. Feather

Lancaster University Renewable Energy Group, Engineering Department, Engineering Building, Bailrigg, Lancaster, Lancs LA1 4YR, UK

ARTICLE INFO

Article history:
Received 26 October 2010
Accepted 30 November 2011
Available online 16 December 2011

Keywords:
Renewable energy
Turbines
Tidal barrage
Tidal range
Hydropower

ABSTRACT

This paper assists in determining the realistic amount of power available from tidal range generation on the Solway Firth, utilising the latest turbine information for the estimates. The barrage location that is to yield the largest amount of energy output has been highlighted, standing between Workington and Abbey Head at a length of 30 km, spanning the outermost part of the estuary. Double regulated turbine models from Sulzer Escher Wyss of Zurich and also Andritz Hydro are used to determine the flow and power characteristics for individual turbines over a range of heads. Combining the up to date Andritz model with bathymetry sourced from the Department of Energy, and tidal characteristics (modelled from tidal constituents), the model for the behaviour of a barrage on the Solway for ebb generation is constructed.

1. Introduction

In the past the Solway Firth has been subject to a range of investigations with studies taking into account small run off river schemes as well as larger tidal barrage schemes [1–6,18]. This paper discusses the potential of a tidal barrage spanning the outermost part of the estuary from Workington to Abbey Head (Fig. 1), housing power generating turbines to exploit the high tidal ranges associated with the estuary [6–8]. It also aims to give a more accurate estimate to the total power output for a tidal range barrage scheme on the Solway over one year of operation based on ebb generation. It is the first time a model of this nature has been used on the Solway.

Kaplan bulb turbines are expected to be used for this type of project with generators housed within the bulb. A runner diameter of around 9 m was proposed by Binnie & Partners [3] with a total of 180 units across the barrage.

2. Background

Although there is a large array of different types of turbines for use in tidal or large head applications, the one of most interest for this investigation is the bulb turbine unit. These are widely used around the world in tidal power schemes such as the Rance Tidal Barrage near Saint Malo in France. Here, the bulb turbines have a runner (turbine blade) diameter of 5.4 m coupled to 10 MW generators [9–12]. The main advantages of using bulb type units for this application are they are one of the most efficient units for low head applications. There are also smaller associated civil costs for the construction of the barrage as there are no external generator shafts as the generator is housed within the bulb itself.

There is also a wealth of operating experience with bulb turbines making them favourable for large tidal projects. For these reasons, this paper investigates the use of bulb turbine units in terms of modelling the performance of a tidal barrage scheme.

3. Turbine 'hill charts'

For those less familiar, turbine 'hill' charts are graphical models created by the turbine manufacturer for a particular turbine design which displays the characteristics during operation of the turbine. This is represented in terms of non-dimensional formula known as affinity laws. In order to test the performance of a specific turbine, the manufacturer will construct a scale model of the turbine to run the tests (generally around 300 mm in diameter). The data recorded is then used to draw up a hill chart, usually plotting unit speed against specific discharge. The significance of the affinity laws are that they allow the model to be scaled up or down depending on the desired specifications, be it a 4 m or 8 m diameter turbine. The model shows how the specific discharge varies with the unit speed of the turbine to allow further calculations to be carried out relating head to outflow through the turbine.

One such hill chart, used by Baker [13], and also others around the time of his investigation [14], was produced by Sulzer Escher Wyss of Zurich. This shows such characteristics however due to the

* Corresponding author.
E-mail address: g.aggidis@lancaster.ac.uk (G.A. Aggidis).

0960-1481/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.renene.2011.11.045

Fig. 1. Position of the investigated barrage on the Solway.

sensitivity of the data in terms of confidentiality, the efficiency percentages have been replaced by percentages of maximum efficiency as seen in Fig. 2:

The values on the hill chart are functions of the following equations, which enable such scaling to take place and allow head, flow and efficiency characteristics to be determined leading to a power output calculation:

$$n_{11} = \frac{Sp \cdot D}{\sqrt{H}}, \tag{1}$$

$$Q_{11} = \frac{Q}{D^2 \cdot \sqrt{H}} \tag{2}$$

Where:

$$S_p = \frac{2 \times 60 \times f}{G_p} \tag{3}$$

Where n_{11} can then be rearranged to give head which can then be used in the Q_{11}:

$$H = \left(\frac{n \cdot D}{n_{11}}\right)^2 \tag{4}$$

H can then be introduced into a rearranged Q_{11} equation to give:

$$Q = Q_{11} \cdot D^2 \cdot \sqrt{H} \tag{5}$$

Power output can then be calculated as:

$$P = \rho \cdot g \cdot H \cdot Q \cdot \eta \tag{6}$$

These equations are to be used as the main means of calculating the power output for a single turbine unit when running at different levels of head. It is to be expected at this stage that where there is a higher head, there will be a higher power output. It is worth noting at this stage that cavitation effects of the turbine have been neglected due the likelihood that the barrage location is at a basin depth of around 30 m. Even during a low spring tide, the depth of the turbines should still be sufficient to prevent cavitation.

4. Andritz Hydro turbine model

Until now, all previous work regarding tidal schemes, such as Baker's research, used the Sulzer Escher Wyss of Zurich turbine model. However, exclusively for this research, a turbine model has been created by Andritz Hydro featuring cutting edge tidal turbine characteristics. At this point in time this is only research of this type that has been able to utilise such direct data from Andritz Hydro, and so makes it unique and a huge step in terms of having the latest information available. This was made possible by the project supervisor who has links with Andritz Hydro- one of the world's largest turbine manufacturers. Fig. 3 below shows the hill chart which again is a double regulated bulb turbine with unit speed plotted against unit discharge. The chart also has a maximum output curve defined especially for the project:

A key feature of this model is that the efficiencies stated are actual values, unlike the Escher Wyss chart which were a percentage of 80% efficiency and is not fully representative of modern turbine performance. It can be seen that the maximum possible efficiency as defined on the maximum output curve on the Andritz model is around the 89% mark compared to the 79% efficiency defined on the Escher Wyss model.

5. Turbine modelling

In order to extract the data from the hill chart, it is necessary to digitise it to allow curves to be assigned to the extracted values for the data, allowing them to be defined as equations. This is especially useful when attempting to generate a programme that will carry out calculations automatically, as if one value on an axis is know, the other can be found by substituting the value into the derived equation thus acquiring the value of the unknown variable.

To extract the maximum performance from the turbine in operation, a maximum performance curve is plotted on the hill

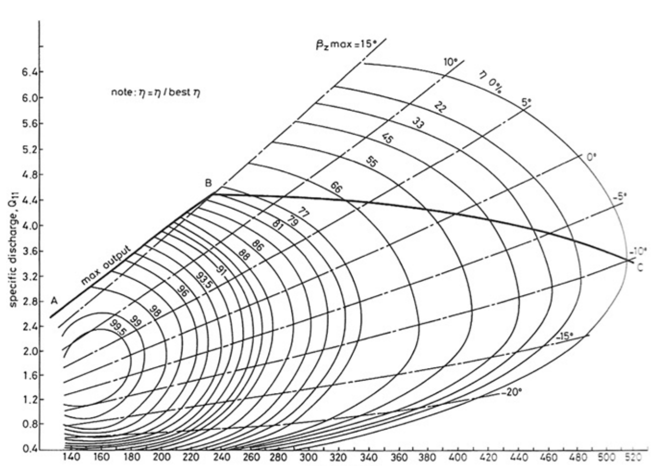

Fig. 2. Performance 'hill' chart for double regulated turbine supplied by Sulzer Escher Wyss.

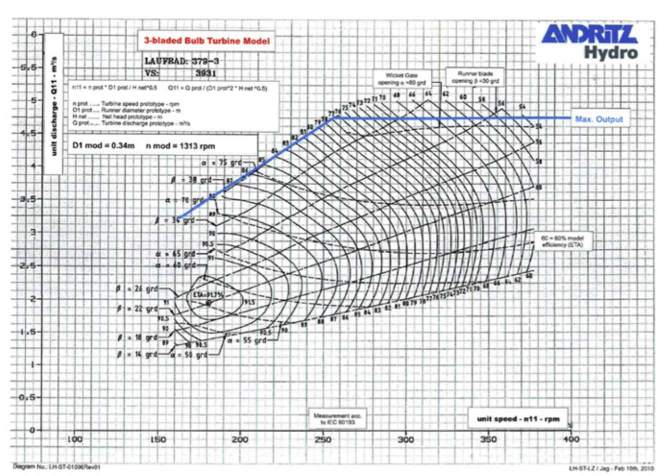

Fig. 3. Andritz Hydro hill chart for a double regulated bulb unit.