A World First: Swansea Bay Tidal Lagoonlagoon in Reviewreview

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Abstract

Global energy focus is turning more and more towards renewable energy. With legally binding agreements requiring a drastic increase in the percentage of national energy demand created with renewable sources, tidal energy holds an important advantage – predictability. The UK is fortunate, having the greatest potential for this energy in the world, which if exploited, would be able to provide approximately 20% of the national energy demand. The most discussed tidal energy site has been the Severn estuary barrage, with repeated proposals outlined and rejected throughout the last 100 years. The reasons for this refusal were due to both high costs and environmental concerns. However, a new proposal for a tidal lagoon in Swansea Bay has been able to circumnavigate both of these downfalls by reducing both the investment needed and effects to the surrounding environment. Subject to a tidal range of 10.5 m and situated next to a largely populated city with excellent grid connections, Swansea bay is a perfect location. If the lagoon project goes ahead, it would be able to produce a rated output of 320 MW using bulb turbines, powering 155,000 homes. Being the first tidal lagoon project, what is certain is: the UK and Wales in particular are sending out a strong message regarding renewable energy and it has the whole worlds attention. This paper sets out to bring together current literature regarding the planned Swansea Bay tidal lagoon into one concise document.

Keywords: Tidal lagoon; Swansea Bay; Tidal energy; Tidal Rangerange; Bulb turbine; Renewable energy

1 Introduction

By 2020, the UK is legally obliged to meet 20% of its electrical demands with renewable sources [1]. Currently, renewable sources account for as little as 5%, meaning drastic action is required to meet this target [2]. The UK is also committed to reduce CO_2 emissions by 60% by 2050 [3].

Using clean energy is not just important to help combat climate change, but also to allow the UK to have more control on its energy. With the decline of the North Sea oil and gas industry, there is more and more reliance on importing these fuels through costly negotiations. Furthermore, being in control of our energy sources and especially with renewable energy, the cost for electricity can be stable and independent of any price fluctuations or politics.

The UK is fortunate with an abundance of renewable energy options, including the greatest potential for tidal energy in the world. This type of energy holds an important advantage over other forms of renewable energy – predictability. With comprehensive tide data for years in advance, any tidal energy project can have a known output the national grid is able to plan for. The successful utilisation of tidal energy alone could provide in excess of 20% of the nations energy demand [4].

The repeated proposals for the Severn barrage since the 1920's have proved the necessity to evolve techniques used for tidal range generation, with each proposal turned down due to high costs and environmental concerns [5–7]. Other UK sites that have been investigated for a barrage scheme also include the Solway [8,9], Mersey [10], Loughor, Duddon, Wyre and Thames Estuaries [11]. However, unlike Swansea Bay lagoon, these projects are not currently progressing.

Currently the most advanced project in the UK is the Swansea Bay Tidal lagoon, which is making rapid progress and will hopefully be generating electricity in 2019. The power generated would be able to provide energy for approximately 155,000 homes [12]. As the project is the first of its kind in the world, its construction would send a clear statement of the UK's commitment to clean, renewable energy.

The aim of this paper is to bring together the current and existing information regarding tidal lagoon developments while focusing specifically on the planned Swansea Bay Lagoon.

2 Background/Tidal Lagoons

Tidal lagoons are a new concept based on the adaptation of an existing, proven technology – tidal barrages. Like any tidal range project the success is heavily dependant on the chosen location and with Swansea Bay being part of the

Severn Estuary with the largest tidal range (10.5 m) available within the EU [13]. With easy connection to the national grid available and a largely populated city nearby, the electricity generated will be able to be utilised easily.

In the same way as a barrage, a tidal lagoon uses a man made structure to create a head difference between the flood and ebb tides. Using this head difference, water is allowed to pass through the turbines when the sluice gates are open, generating electricity. The unique aspect revolves around the size and shape of the dam – a barrage spans the entire width of a river, whereas a lagoon uses a circular shape to encompass part of it, not fully spanning the Estuary [13].

There are currently two different types of lagoon structures: offshore and onshore. An offshore lagoon is comprised of a circular dam, with the electricity transported to shore through cables below the seabed [16]. For the onshore lagoons, the dam forms a horseshoe shape, with the remainder of the circle is formed of the coastline it is attached to [17]. This will be the case for the Swansea Bay lagoon (Fig. 1).

Fig. 1 What the Swansea Bay Lagoon will look like [15].

alt-text: Fig. 1

3 Swansea Bay Lagoon

3.1 Cost

The estimated initial costs to construct the lagoon are substantial at £1bn. However, when this is compared with the £34bn required to construct a Severn barrage, this figure is much lower [19].

The project has already been backed by several large investment schemes to generate the required initial equity. Financial firms Prudential and InfraRed have each backed £100million towards the project [20,21]. This combined with several other smaller scale investor and shareholders has easily surpassed the required equity to begin the project, with the remainder provided as debt.

To make not only this project, but also other renewable energy projects profitable the government has created a variety of incentives to encourage green energy. One of these incentives is a “Feed-in Tariff Contract for Difference”. This contract means that the revenue gained through selling each megawatt of electricity is topped up to an arranged ‘strike price’ (the amount required for the project profitable). The amount required for Swansea Bay lagoon is £168/MWh for 35 years, which is more than the amount required for wind or solar and the strike price is needed for a longer amount of time [22]. However, when the lifetime of the project is taken into account (120 years) this is approximately 5 times that of an offshore wind farm (20-25 years) and twice that of nuclear (60 years) [22]. The long lifetime of the project means it will produce very low cost electricity for years after the contract of difference has been completed.

Aside from the still large initial costs, the project is guaranteed to help not only the local economy but also the UK economy as a whole. Besides creating almost 2,000 short term and over 80 permanent jobs [15,12], there will be a substantial increase in tourism to the area, as seen in France. Over 70,000 tourists flock to visit the La Rance tidal barrage in Brittany each year [23].

Furthermore, to boost the UK economy, over 65% of capital spent on parts and construction will be contracted to UK firms, with all the generators and the majority of turbine parts all created in UK [24]. Furthermore, due to the presence of the lagoon, the effect on the Welsh Gross Value Added is estimated to be an added £76 million each year [25].

3.2 Planning and Construction

As set out in Table 1, if all goes to plan and government consent and licences are issued on time, construction will begin in the late stages of 2015 and be fully operational at the beginning of 2019 (36 months) [24]. The lagoon structure will last for at least the operational life of 120 years, be able to withstand even 500 year storms and has taken into account climate change [27]. The structure will also provide coastline protection against these storms and act as a flood defence [28].

Table 1 Construction timeline for Swansea Bay Lagoon [26].

alt-text: Table 1

Construction timeline

2010–2012	Feasibility investigations and project scoping.
	Optimising construction and engaging with consultees.
2012	Continued engineering and design.
	Informal consultation on proposals with broad stakeholder audience.
October 2012	Submission of Environmental Impact Assessment.
	Scoping report to the Planning Inspectorate.
December 2012	Environmental Impact Assessment commence.
July 2013	Formal consultation (minimum 28 days).
February 2014	Submission of application for Development Consent Order to the Planning Inspectorate for determination by the Secretary of State for Energy and Climate Change. Submission of application for a marine license to Natural Resources Wales on behalf of the Welsh Government.
Mid 2015	Planning and marine licence decisions expected.
Late 2015	Construction and installation could commence.
Early 2019	**Earliest connection and first generation into the Grid.**

The lagoon wall will be created out of three main materials: sand, concrete and rock [27]. Sand will be dredged from the lagoon basin area and used to fill complex geotubes. These are a low cost, durable plastic textile that is a proven technology having been used in large-scale operations in South Korea and others [29]. The tubes will be carefully positioned until the dredged sand is mixed with water and fed into the tubes filling them to capacity, creating the bunds.

The space between these bunds is then filled with sand (Fig. 2). The final stage involves layering larger and larger grades of rock on top of the tubes as a form of armour to protect the wall from storms and the elements [2]. The rock used will be high-density gabbro rock, mined from Cornwall and transported by barge.

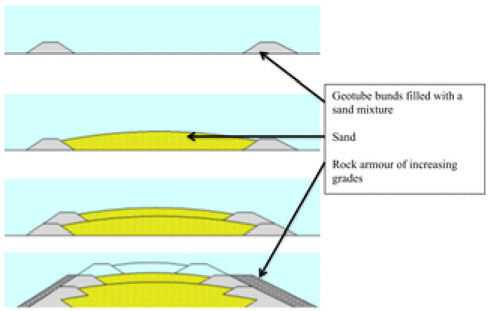

Fig. 2 Construction methods for lagoon wall, using geotubes and sand [30].

alt-text: Fig. 2

Similarly to La Rance, cofferdams will be necessary to allow the 500 m long, 76 m wide turbine housing to be built. This involves the construction of an extra, temporary circular dam [31]. Once built, the water inside the cofferdam would be drained and the ground inside dried out, thus creating a working environment for the construction of the permanent barrage wall [32].

However there are some different methods used for the construction of Swansea Bay, which are both less costly and more time effective. The turbines themselves and the construction they are housed within are more modular in design. For example, the same type of turbine used in hydro energy is put together in 17 stages; the turbine to be used in this project will be completed in just 4 stages [27]. The fewer number of stages means only two years is required to go from an empty cofferdam to the completed turbine housing. By reducing the stages to completion, there is less risk and less time required to complete the turbines, greatly reducing the construction costs.

It was decided that the Swansea Bay lagoon would be the first built as it is the smallest and also due to its location next to a national grid site, it has the easiest grid connections. As the smallest, it requires the lowest initial investment and also if any money saving methods are discovered during its construction they can be put to use on the bigger projects, therefore saving money overall.

3.3 Environmental Effects

There are two main environmental aspects that have previously hindered the development of a tidal range project in the Severn: concerns for fish safety and the delicate flood plains that are vital to migrating birds. By operating bi-directionally, the tide cycle is affected as little as possible by allowing the natural ebb and flow of the tide continue as much as possible by delaying them rather than altering. Which allows the important mud flats to be left exposed. The mud flats are essential to migrating birds therefore must be protected at all costs [33]. A barrage scheme in the same area would result in these inter-tidal areas within the barrage being submerged [34].

Since the development of the first bulb turbine there has been significant advancements in fish friendly technology. The physical construction and placement of the lagoon wall is also designed to avoid and discourage fish from entering the turbine structure by not interrupting natural fish migration patterns [35]. However, it is inevitable there will be some fish mortality associated with the project, but this figure is low (3.6% mortality rate for adult salmon and sea trout smolts) and although this is regretful, it is considered an acceptable amount [36]. These values for predicted fish mortality were obtained through the extensive use of computer modelling of fish migration and movement patterns.

On the other hand, there are benefits to the surrounding environment by having the lagoon. Much of the structure can be used for recreational activities, with the water inside the basin being very suitable for swimming and sailing. The lagoon wall also offers plenty of opportunities for running and cycling [12].

The lagoon itself would create a brand new environment for a variety of marine life and fauna. Within the lagoon, the native oyster among others will be reintroduced alongside a 10 km sea reef [37].

The lagoon walls, created to withstand even one in 500 year storms, would also act as a breakwater and sea defence, protecting the vastly populated city it is connected to from flooding and erosion [28,14].

Through the creation of clean energy the project will produce is able to offset over 236,000 t of CO_2 per year. This is a considerable amount, both saving money and is a move in the right direction when it comes to tackling climate change [38]. Even when taking into account the CO_2 produced during the construction (642,000 t), the project will become carbon neutral within four years [12].

3.4 Turbine Technology

Like La Rance, the Swansea bay lagoon will utilize Kaplan bulb turbines each producing 16 MW to generate the 320 MW rated output (Fig. 3).

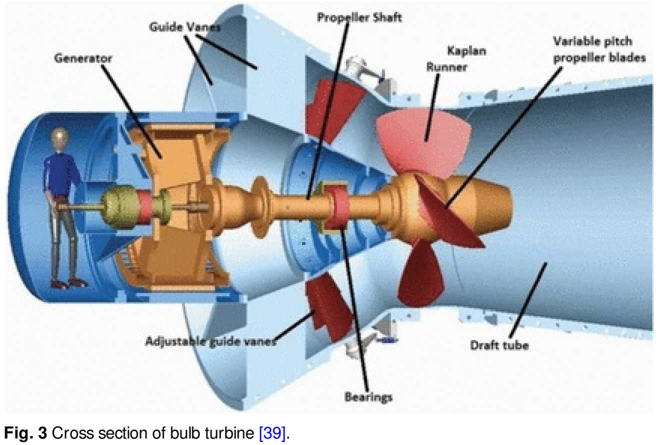

Fig. 3 Cross section of bulb turbine [39].

alt-text: Fig. 3

First created in 1913 they have evolved from large vertical devices to compact bulb turbines and have become the go-to turbine for tidal range projects around the world [40]. The first large-scale application was in the La Rance tidal barrage, 1967. Up until now, bulb turbines have operated in a double regulation method, where the guide vanes and runner blades are adjustable, while being constantly altered depending on the combination of head/flow values. However, the turbines used for this project will involve a triple regulation method by using an induction generator with variable speed drive. Not only are these types of generators cheaper and more robust and have fewer parts to go wrong [27]. Triple regulation means the device is able to always operate at the RPM value that offers maximum efficiency, creating a flat efficiency curve.

Irrespective to the type of regulation the turbine uses, the normal operation of a bulb turbine can be split into three distinct sections [41]:

1. Water entering the inlet of the turbine and passing through the guide vanes. With the ability to constantly adjust, these are used to guide the incoming water in the optimum position
2. The water then impacts with the runner blades. Like the guide vanes, these too are able to change inclination angle in order to achieve maximum efficiency
3. The water then leaves the turbine through the draft tube.

Each of the main components, inlet, guide vanes, runner blades and draft tube all require careful optimisation to suit the application.

With over 40 years of operational data and information from the La Rance plant, using similar turbines, downtime and yield can be easily predicted. Furthermore, these turbines have operated exceptionally well, with cathodic protection successful in improving the lifetime of the devices [42].

However, with the very complicated nature of the turbine, they are also very expensive, costing approximately 25+% of the overall project. The shear complexity also requires an assembly facility to be constructed near to the site.

To make the turbines more fish friendly, there have been some adaptions, mainly with the runner blades. By having only 3 blades, there is more space for fish to pass through safely, greatly reducing the amount of mechanical injuries.

3.5 Operating Methods

The turbines can be designed to generate electricity in a variety of three distinct ways: Flood, ebb or two-way generation. Both flood and ebb create electricity once per tidal cycle, either when the tide comes in or goes out [43]. Like La Rance, the planned UK lagoon projects will operate in this manner with the more complex bi-directional generation method. This results in electricity being generated four times each day. As the tide comes in the closed sluice gates until an operational head difference is created. When this point is reached, the gates open and water passes through the turbines (generating electricity) and into the lagoon. At high tide, the gates close once more until the tide has receded enough to create an operational head difference. At this point, the sluice gates open again allowing the water trapped inside the lagoon to flow back through the turbines and out to sea, producing energy once again [44]. This method of generation produces approximately the same as an ebb generation scheme, and more than flood only generation.

As the tide flows out, during the ebb cycle the turbines are able to achieve a very high efficiency of 93%. However, on the flood part of the cycle, the efficiency drops sharply to 75% [27]. This is natural for Bulb turbines, as the set of guide vanes are able to improve the efficiency by guiding the water onto the blades for one direction only.

Pumping is an extra method that will be employed. This involves using the turbines in reverse as pumps to increase the head difference between the lagoon basin and the sea. The amount of energy generated by a tidal lagoon is very related to the amount of head difference available between the lagoon basin and the sea (Eqn. 1). The energy used for pumping can easily be regained, as a 1 m increase in head difference from 3 m to 4 m results in 7x more potential power [45].

$$E = \frac{1}{2} A \rho g h^2 \quad (1)$$

[46] Where:

h =difference in head between the lagoon basin and the sea

ρ =density of water

A =area of the barrage basin

4 Future

Following the successful completion of Swansea Bay Lagoon, there are plans for an additional five locations for tidal lagoons around the country (see Fig. 4), with an additional lagoon situated in Cardiff, rated with an estimated 1800-2800 MW [47]. As the locations of these projects surround the UK, with staggered tide times it is theoretically possible to produce a base layer of electricity through renewable sources for the first time.

Fig. 4 Planned tidal lagoons around the UK [48].

alt-text: Fig. 4

Aside from the added benefits to the economy and the reduction of the carbon emissions, the combined lagoon projects would be able to provide 8% of the UK's energy demand for an estimated £30bn investment [18,49]. This would be a giant step towards both meeting EU targets and becoming more energy independent.

Each of the following lagoon projects would be more cost effective, with the third lagoon levelised costs falling in line with that of onshore wind, solar, nuclear and gas generation at £92/MWh [22]. This is due to the larger lagoon basin areas used for the subsequent lagoons.

With the ever-increasing threat of flooding in the Somerset area, talks of flood prevention in this area are rapidly becoming a priority. Professor Roger Falconer of Cardiff University believes that the creation of a lagoon in the Bridgewater bay area would provide better protection than dredging and greatly reduce the present flood risk [50]. Recent flooding in these areas has caused millions of pounds of damage and destroyed peoples homes and livelihoods. It has been suggested that flooding due to high tides in the Solway Estuary could be mitigated through the use of a lagoon/barrage structure [8]. The successful application of a lagoon in Swansea Bay could pave the way to further sites used jointly for the purpose of energy production and coastline protection.

5 Conclusion

The face of large-scale tidal range power is changing rapidly, with lagoons set to be the future environmentally friendly version of barrage schemes. The two main issues with tidal range plants revolve around cost and environmental effects. The overall costs of Swansea bay lagoon (£1bn) are vastly lower than the £34bn required for a Severn barrage. Furthermore, as the lagoon only encompasses part of the estuary instead of blocking it off completely, there is much less interruption to fish passage, while protecting key environmental sites such as the mud flats and bathing beaches. They also offer rapid expansion, with sites outlined all around the UK.

With strong financial backing, government and local support, the project looks to be progressing on time. This project is to be the template for other tidal lagoon projects both in the UK, but also elsewhere. Countries all around the globe are monitoring the progress of this project, including China, United States, Mexico, India and Korea [51]. The company behind Swansea Bay Lagoon is leading the way, bringing in a new era of large scale tidal energy that has never been seen before and the whole world is paying attention.

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Queries and Answers

Query:

Please confirm that given names and surnames have been identified correctly and are presented in the desired order.

Answer: Yes