Assessing the Possibility of Using a Framo Electrical Generator for Marine Current Tidal Stream Technology

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Abstract

As high and low tides occur with such predictability, harnessing this energy has big potential. Tidal energy can be divided into two main technologies, namely tidal range technology and tidal stream technology. This thesis will focus mainly on tidal stream technology to access the possibility of using a Framo Innovation generator for tidal stream power. The tidal power technologies are examined with current status and technical overview. Concepts such as levelised cost of energy (LCOE), maturity and learning, as well as policies are also presented. These are all important for the sake of tidal power. The literature review of the proven solutions may be used as a comparison to possible future Framo Innovation development. A tidal stream numerical model, using the Froud number and the relative height as main variables, is presented to obtain one valid and one invalid solution. As the efficiency of a generator is an important factor to evaluate, the two given possible Framo Innovation generators have been estimated in regards to this.

Tidal stream technology is very costly and is therefore currently unable to compete with other economically feasible technologies. The results of this thesis show that using the given location and parameters, one of the suggested generators gives better results than the other, although not optimal and desired efficiency. Nevertheless, Framo has great experience and resources to develop a tidal stream generator in the future.

Keywords: tidal energy, tidal stream technology, actuator disc theory, generator efficiency.

1 Introduction

Tidal power is one of the most reliable and predictable energy sources in terms of renewable energy [1]. The occurrence of low and high tide happens twice daily per tide [2]. The time interval between each of the high tides is 12 hours and 26.5 minutes, where in-between the interval, approximately 6 hours and 13.25 minutes after the first high tide, there occurrence of a low tide also with the same interval [3]. The unique predictability of the high and low tides is possible during the day, as well as for a long-term perspective. The tides are reliant on the sun, the moon and the gravitational forces they contribute, and the tidal waves may in some places be affected by weather conditions such as temperature and wind [4].

Nevertheless, there are no external obstacles that disturb or disrupt the tidal waves, and they may therefore be predicted in the far future. Thus, tidal power is an interesting source of energy for future development and investment.

2 Goals

This thesis aims to assess the possibility of using a novel electrical generator developed by Framo Innovation for tidal turbines without gearboxes. The thesis will explore possibilities (technological and geographical areas) and “proven” solutions for tidal power. Key parameters should be established to compare different solutions (e.g. unit power rating, size, weight, cost etc.) and evaluate them (e.g. units built, power produced etc.) This master thesis will mainly include tidal stream turbines' applications, presenting a numerical model for this application. The overall efficiency of the novel Framo electrical generator will also be examined and presented. Tidal barrages will be investigated briefly.

The following four research questions will be answered in the discussion of the thesis

1. What are the advantages and disadvantages of tidal power compared to other renewable energies?
2. Is there a specific key parameter-target, e.g. kW/kg (investment) or kW/€ (total cost over 5/10 years), one should aim for?
3. What are the optimal tidal turbine parameters for the available Framo generators?
4. Are any of the Framo motors feasible for a tidal turbine?

The review of advantages and disadvantages can be helpful for weighing for and against the technology. The investigation of key parameters, and if there are any specific key parameters to aim for in the sense of investment or total cost over a period of time, can also be useful for to evaluate the feasibility of a future tidal power project.

There are two Framo motors investigated in this thesis, which the final research question is regarding. The literature review and results in this thesis can be used to investigate the above research questions, and the motivation is to present an informative thesis on the topic of tidal power. This may be useful for Framo Innovation and possible future tidal energy development.

3 Literature review

There are two main different types of harnessing tidal power, namely tidal range and tidal stream [1]. The fall of sea level is commonly referred to as ebb tide, whiles rise of sea level is referred to as flood tide [2]. Tidal range power uses the potential of the tidal ranges from the ebb and flood tides, and the oscillating levels due to the tides. Tidal range power can often be built in dams and are also often referred to as tidal barrages. Tidal stream is the harnessing of the kinetic energy from a tidal current and may sometimes be referred to as tidal current or channel flows. The tidal range and tidal stream technologies are categorised under the group of Ocean Energy Technologies, together with wave energy, deep ocean currents, ocean thermal energy and salinity gradient technology [5]. If not mentioned otherwise, the thesis will mainly focus on the tidal stream technology but will explain basic matters regarding the tidal range technology.

3.1 Tidal barrages

A tidal barrage is the technology used to harness the potential energy from the tidal waves. In other words, they are using the tidal range to generate electricity. Another name frequently used is the tidal range, and as the name implies, this technology uses the tidal range potential energy to capture the energy [6]. Tidal barrages are often dams or barriers with turbines placed in the foundation, similar to hydropower technology. Tidal range generation is no new technology, and has been generating electricity on a large scale since 1966 in France, making the tidal range the most mature ocean energy technology [5].

For an economically viable tidal range power plant, a tidal range of 5 meters is required [7]. Due to this, and other reasons like cost and environmental issues, there are limitations to implying tidal range and barrages. Although, research and development are still ongoing to find smart solutions for a technology that is limited in many ways. Even though the costs are high, the tidal range is an ocean energy technology that has shown economically viable and reliable projects.

3.2 Tidal stream

Tidal stream power is the energy obtained in the tidal stream in a channel or river, or in the ocean [6]. Utilizing the kinetic energy from the stream of water, tidal stream power can generate electricity. The capture of the kinetic energy of the tidal waves can be done by multiple technologies and many that are still under development. The main trend for today's development of tidal stream is horizontal axis turbines and vertical axis turbines. In contrast, according to the International Renewable Energy Agency, IRENA, 76 % of tidal turbines are horizontal axis, being a large superiority of the tidal stream technologies [8].

For tidal stream, the demand of a current at 2-3 m/s is given for a location to make the generation economically viable [7]. This makes tidal stream generation very limited to locations where only certain areas are fitted for this application. Throughout the thesis, horizontal axis turbines will be the main concern regarding tidal stream technology if not mentioned otherwise.

3.3 LCOE

Levelised Cost of Energy (LCOE) is a measurement used to calculate the cost of energy for a certain energy plant generating electricity over a period of time so that it is possible to compare different energy technologies up against each other [9][10]. Currently, the LCOE for tidal power is higher than for other technologies, and therefore not competitive against cheaper sources [5]. To obtain a commercial and competitive technology, the LCOE needs to be reduced to meet other technologies costs of energy. Reducing costs and improving reliability are large challenges and must be solved for the technology to survive in the market.

3.4 Maturity and Technology Readiness Level (TRL)

Maturity is a concept used on how well developed and advanced a state or form is [11]. Technology Readiness Level (TRL) is a measurement of the maturity of the technology, often rated from the level TRL 1 to TRL 9, where 1 is the lowest level of maturity and 9 is the highest level of maturity [5]. Based on Det Norske Veritas Germanischer Lloyd (DNV GL) data from 2014, the tidal stream is classified between TRL 7 and TRL 8, whereas tidal range has a classification on TRL 9 [5].

3.5 Important concepts

Important factors for further calculation implies the Froud number [12],

$$Fr = \frac{u}{\sqrt{gh}}\ , \tag{1}$$

the blockage ratio

$$B = \frac{Area\ of\ turbine}{Cross - sectional\ area\ of\ channel} = \frac{A}{bh}\ , \tag{2}$$

the power coefficient,

$$C_P = \frac{P}{\frac{1}{2}\rho u^3 A}, \tag{3}$$

and the thrust coefficient

$$C_T = \frac{T}{\frac{1}{2}\rho u^2 A}. \tag{4}$$

4 Methods

A tidal stream numerical model, using the Froud number and the relative height as main variables, is presented to obtain one valid and one invalid solution. As the efficiency of a generator is an important factor to evaluate, the two given possible Framo generators, the SR2000 and SR2000E, have been estimated in regards to this.

The figure below shows the stream channel boundaries [13]. The core flow is the fluid streaming through the disc, and the bypass flow is the flow passing by the disc [12]. Upstream is defined as the flow before the turbine, and downstream as the flow after the turbine. The subscript *t* is for the turbine, *b* is for the by-pass flow, and 1-5 is the channel cross-section position.

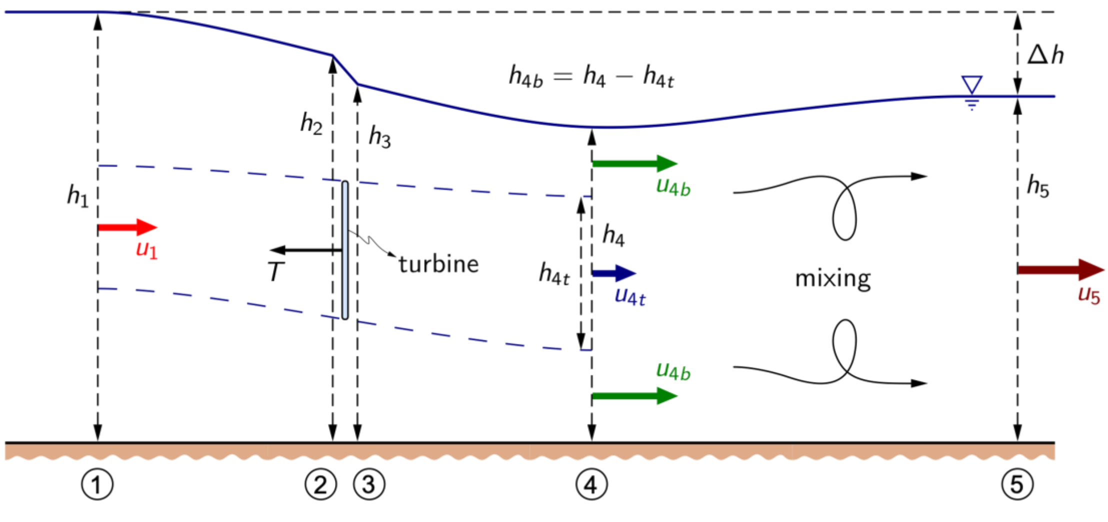

Figure 1: Channel stream boundaries [11]

5 Framo generator

Framo's SR2000, is currently used within the aquaculture sector as a flow generator for fish farms with lice skirts [14]. The solution is installed within the net pens and provides and distributes continuous flow of fresh water at an optimal water temperature for the fish. The motor utilizes permanent magnets and is rim-driven, gear- and shaftless, which are optimal factors for large volume of water and low pressure conditions. Whereas the SR2000 has an internal rotor, the motor SR2000E has similar characteristics, though with an external rotor and blades outside the rotor. Thus, the diameter of this solution will be much larger than the SR2000.

Using the python code with the given data from Framo regarding the motors SR2000 and SR2000E, as seen in the table below, the results can be made [15, p. 200] [16, p. 200].

Table 1: Coding parameters

Parameters	Value
Rated power, P_{rated} [kW]	60
Maximum rotational speed, N_{max} [rpm]	20
Cut-in velocity, u_{ci} [m/s]	0.4
Power coefficient, C_P [-]	0.48
Sea water density, ρ [kg/m^3]	1025

5.1 Mathematical model

Using the linear momentum actuator disc theory (LMADT), and assuming an inviscid and impressible flow in a frictionless, free surface channel, the following numerical model has been concluded [12]. The model is a simplification of the formulation of Garrett and Cummins theories, and Houldsby and Vogel, and was carried out by professor Prof. João Carlos de Campos Henriques [17][18].

Applying the model, and solving the system of equations for Fr_{4t}^2, we obtain

$$Fr_{4t}^2 = \frac{-Fr_{4b}\zeta_{4b} + Fr_1 - B\sqrt{B^2Fr_{4b}^2 + 2BFr_{4b}Fr_1 - 2BFr_1^2 + B\zeta_4^2 - B + Fr_{4b}^2\zeta_4^2 - 2Fr_{4b}Fr_1\zeta_4 + Fr_1^2}}{2}, \quad (5)$$

giving a valid solution

$$Fr_{4t} = \frac{C_1 + \sqrt{C_2}}{B}, \quad (6)$$

and an invalid solution

$$Fr_{4t}^{inv} = \frac{C_1 - \sqrt{C_2}}{B}, \quad (7)$$

where

$$C_1 = Fr_1 - Fr_{4b}\zeta_4, \quad (8)$$

and

$$C_2 = B^2Fr_{4b}^2 + B(2Fr_1(Fr_{4b} - Fr_1) + \zeta_4^2 - 1) + C_1^2. \quad (9)$$

The results of the tidal stream model will be given by three graphs, namely C_P versus C_T, $\frac{Q_i}{Q_1}$ versus C_T and lastly Fr versus C_T in the results chapter [18].

6 Results

6.1 Mathematical model

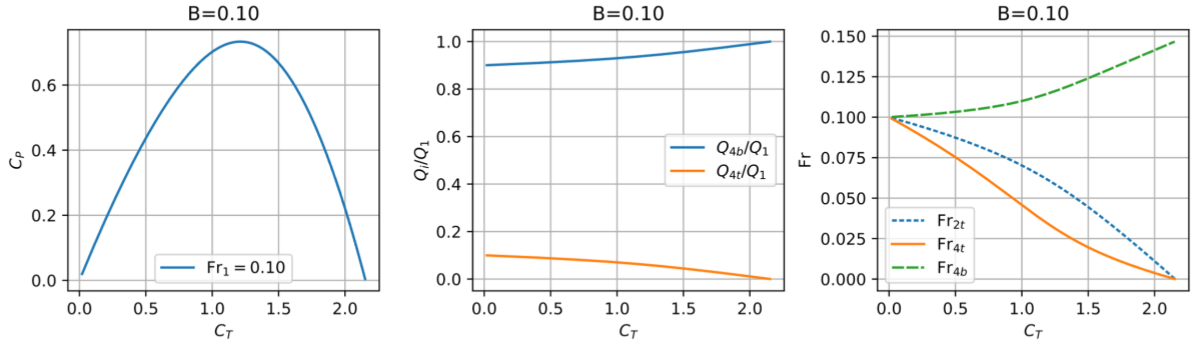

Figure 2: $B = 0.1$ and $Fr_1 = 0.1$

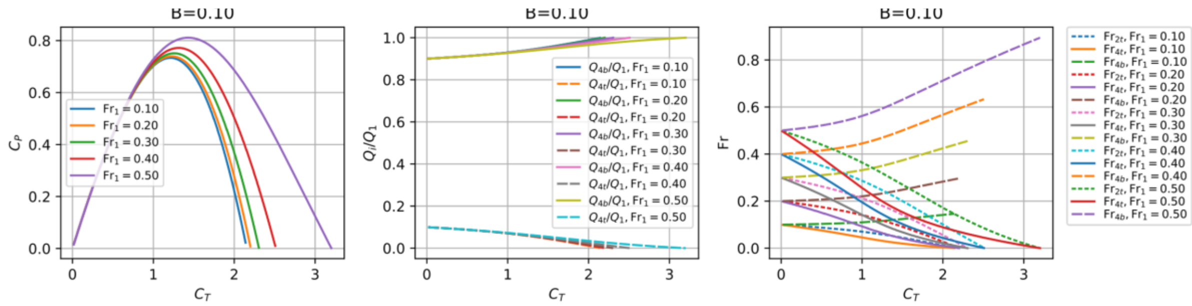

Figure 2: $B = 0.1$ and variable Fr_1

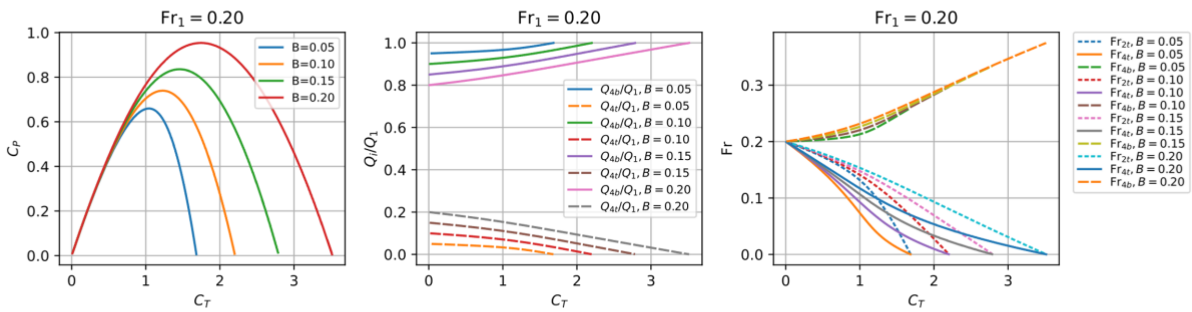

Figure 4: $Fr_1 = 0.2$ and variable B

Using values of blockage ratio between 0.05 and 0.2, and varying the inlet Froud number at point 1, Fr_1, from 0.1, 0.2, 0.3, 0.4 and 0.5, the above figures can be made. The model shows factors and variables which all are important for modelling a tidal stream turbine. Changing the values of the blockage ratio and Froude number, the mathematical model presented allowed us to plot and graphically present the relationships between C_P and C_T, $\frac{Q_i}{Q_1}$ and C_T and Fr and C_T.

The graphs from figure 1, 2 and 3, further show that increasing the blockage ratio increases both power coefficient and thrust coefficient, which proves that a higher blockage ratio on turbines is more efficient than lower blockage ratios.

6.2 Framo generator

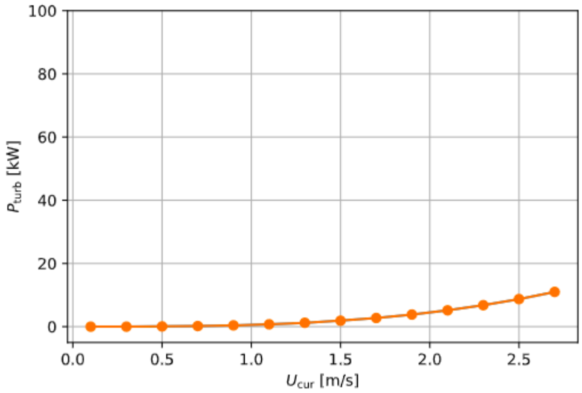

Figure 5: Power curve SR2000

For the two generators, the results can be presented using a power curve and a power coefficient curve. For SR2000, and what can be seen in figure 5, is the very low power produced by the turbine, with a maximum of 10 kW, and that the turbine never reached the rated power of 60 kW. Figure 6 show how the maximum and constant C_P of 0.48 is obtained at 0.5 m/s.

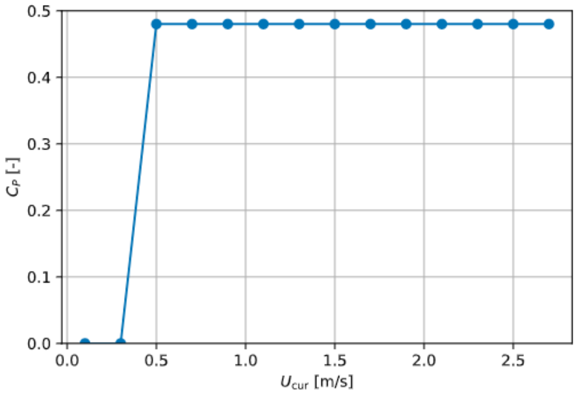

Figure 6: Power coefficient curve SR2000

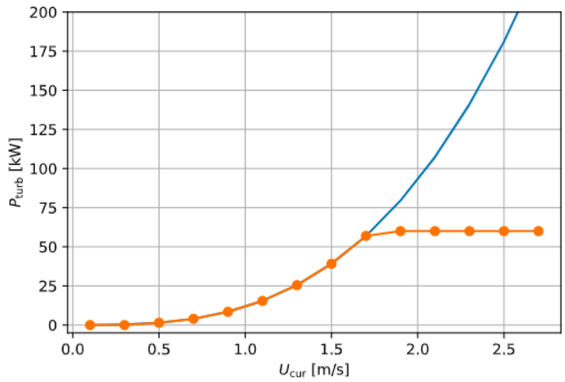

Figure 7: Power curve SR2000E

For the case of SR2000E, the resulting graphics are much better than for SR2000. The power curve, figure 7, describe much better conditions than for the SR2000 where at 1.9 m/s the turbine power reaches 60 kW. The blue curve in figure 7 is the ideal power curve. For the second curve, figure 8, also this curve is of better results compared to SR2000. C_P is constant from cut in speed at 0.5 m/s, and stays constant until approximately current speed of 1.7 m/s, before it decreases until cut-out speed, u_{co}.

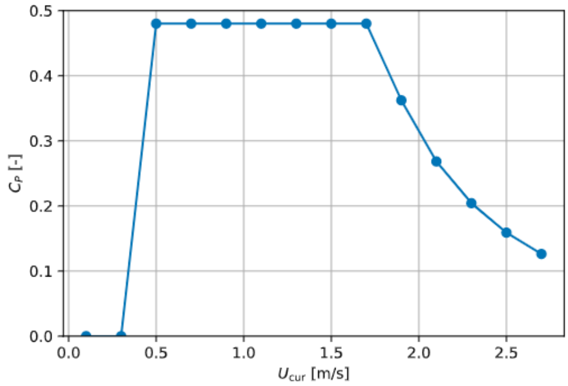

Figure 8: Power coefficient curve SR2000E

7 Discussion

There are great advantages to harvesting tidal energy. However, there are also disadvantages to consider before deciding on a tidal energy project. As with many technologies, there will always be challenges and hurdles to overcome, and the importance is that the technology is more advantageous than anything else. Discussing the advantages and disadvantages of tidal energy technologies in 2021, the one must separate the two main technologies namely tidal stream and tidal range. The technology seem to be on hold for tidal range, as the environmental and infrastructure challenges are in such a scale that they outweigh the advantages. For the case of tidal stream, it is mainly the large capital costs involved in the development of the technology that is a big challenge. Nevertheless, as discussed in previous chapters, with innovation and maturity gained, these costs may decrease in the coming years, making the tidal stream a mainly promising technology, in the renewable energy market.

The results chapter show that the SR2000E gives the best results for the efficiency of the two generators. And compared to the SR2000, the SR2000E is the better option for a tidal stream turbine with the given parameters and the given location. Nevertheless, it is also seen that it is hard to maintain good efficiency over a big spectre of speed. Also, for the given location, the generator never reaches an efficiency above 90 %, and therefore lies below the efficiency of a typical tidal stream turbine of 92-95 % [19].

8 Conclusion

Tidal energy is a reliable and trustworthy renewable energy source with many advantages, although the technology also has downsides. Disadvantages such as location restrictions and intermittent time restrictions may be the most critical disadvantages related to costs. The LCOE for tidal stream energy at this current time is well above other competitive energy sources. There are multiple ways of reducing costs, and as the LCOE for tidal stream energy is predicted to fall, so are the LCOEs for competing technologies. The tidal stream energy may take some time to reach the level of competitiveness of the mature renewable energy technologies such as wind. Consequently, it is not economically feasible to invest in tidal stream technologies today due to the need for investors and external subsidies and funding. Whether or not a Framo generator is feasible, is therefore strongly related to the costs of a future project. Nevertheless, tidal stream energy is said to be 15 years behind wind energy development, so with gained experiences, the future might hold promising opportunities for tidal stream energy [1].

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