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Feasibility Study: Effect of Tidal Turbines Cut-in Speed for Power Generation in New Zealand

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This paper proposes and evaluates an optimized system of tidal turbines as a renewable energy generating unit in New Zealand. A comprehensive simulation model has been set up, using several available commercial software packages to test the performance, capacity and efficiency of the proposed system. Available tidal records have been used to find four regions that are suitable for tidal energy generation and conduct simulation model runs at one of them, Foveaux, to provide the electricity for the isolated area of Stewart Island. Generation of electricity with tidal turbines depends on the water currents and cut-in speed of the tidal turbines. In other words, to reach maximum efficiency from tidal power, the first step is to analyse the water currents of the site where turbine will be located and then estimate the generated power from that turbine. To do it, it is necessary to find the range of water currents and the tidal directions with demonstrating tidal rose and also find how to get maximum power by choosing a proper tidal turbine. Based on tidal flows of the Foveaux straight, two tidal turbines (Schottel 54 kW and 70 kW) with different cut-in speeds are selected. The results indicate that choosing Schottel 54 kW with 0.2 m/s less cut-in speed in comparison to Schottel 70 kW can generate 4.7 times more power.

1. Introduction

Globally electricity demand is provided from different sources such as fossil fuels, i.e., coal, oil, and natural gas. The issues with fossil fuels are that they have limited resources and cause pollution. Other sources of electrical energy which are economically viable are renewable energies from solar, wind and hydro, and can be used for commercial purposes to solve the vast demand for electrical energy (Mathew 2006).

The use of offshore energy commenced in the 1990s, and its potential has been estimated as greater than onshore (Esteban et al., 2011). But no offshore energy installations have been installed in New Zealand yet. However, to ensure their better operation in an offshore environment, some technical challenges remain to be resolved (Nasab et al., 2020). The speed at which tidal turbines needs to rotate and produce sufficient torque to generate electrical power is called cut-in speed. The cut-in speed is an essential parameter in designing or selecting a tidal turbine system to provide any electricity demand. Generally, a tidal current less than 1 ms^{-1} in most turbines cannot generate electricity. So, the selection of the turbine needs to be compatible with the strength of tidal power. In this paper, the Foveaux Strait between Steward Island and the mainland of the South Island in New Zealand is selected for providing electricity demand of Stewart Island. Currently, the cost of electricity in Stewart Island is higher than the available grid-connected network in New Zealand and electricity for 456 (as recorded in 2017) customers is provided by a central diesel power station consisting five diesel gensets by the Stewart Island Electrical Supply Authority (SIESA). Proposing a solution of electricity generation with lower cost is a priority for Stewart Islanders (P. Botha, G. M., 2018). What is novel about the project described in this paper is that it investigates the technical feasibility of Stewart Island's renewable power output by tidal turbine installation. The results will be optimized by decreasing the cut-in speed switching design from Schottel 70 kW to Schottel 54 kW.

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2. Methods

The MetOcean atmospheric model of tidal currents, as shown in Figure 1, indicates that most areas have very low mean current speeds (<1 m/s), and only four areas have mean current speeds that exceed this value (MetOcean Solutions is a science-based consultancy providing specialist numerical modeling and analytical services in meteorology and oceanography); From north to south, Cape Reinga, Cook Strait, Foveaux Strait, and south of Stewart Island (Huckerby, et al., 2008).

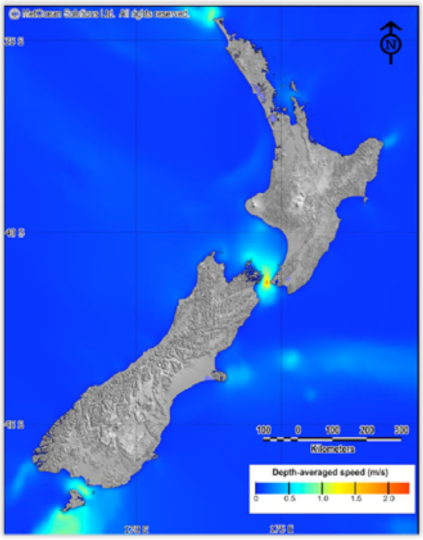

Figure 1: Goring model of tidal flow speeds around New Zealand

Cape Reinga and the south of Stewart Island were not considered further, since both areas are significant distances from existing electricity infrastructure and potential markets, both of which would considerably increase the cost of potential projects in these areas (Huckerby, et al., 2008).So, the rest areas which can be considered are: The first one is in Cook Strait in south of northern island and second one is in the Foveaux strait which is in south of southern island. Among these points, Foveaux is selected in terms of closer distance to provide power for Stewart Island. The geographical coordinates of Foveaux are summarised in Table 1.

Table 1:The geographical coordinates of the site

Location	Latitude (deg)	Longitude (deg)	Water Depth (m)	Annual Water Speed (ms^{-1})
Foveaux	−46.6325 °S	168.2025 °E	30	0.52

The speed at which turbines start to turn while there is insufficient torque is called the cut-in speed. Cut-in speed is an important parameter in design of a system to provide the electricity demand of any site. Tidal flows less than 1 ms^{-1} in most of the turbines can not generate electricity. Also, the selection of turbine needs to be compatible to strength of tidal power. This means that to select a turbine, it is necessary to look at tidal currents of site at first and then according to power curves of tidal turbines, select a suitable turbine. Based on tidal flows of Foveaux, the results will show how the cut-in speed can affect power generation. According to characteristics of Foveaux, two tidal turbines (Schottel 70 kW and Schottel 54 kW) are compared in this section to show how a turbine with lower cut-in speed can make a big difference in power generation. The pertinent details for the tidal turbines are set out in Table 2. As can be seen, the cut-in speed of Schottel 54 kW and 70 kW is 0.7 m/s and 0.9 m/s, respectively.

Table 2: Tidal turbines details("Homer Pro,").

Parameter	Schottel [70 kW]	Schottel [54 kW]
Rated Capacity (kW)	70	54
Cut-in Speed ($m{\times}s^{-1}$)	0.9	0.7
Cut-out Speed ($m{\times}s^{-1}$)	6.75	4.6
Rated Power at ($m{\times}s^{-1}$)	3.8	2.6
Swept Area (m^2)	7.06	7.06
Rotor Diameter (m)	3	3

An example of the ocean tide data from the TPXO9 (2021) model over the period of year 2020 (with 1-hour data sampling interval) is shown in Figure 2.

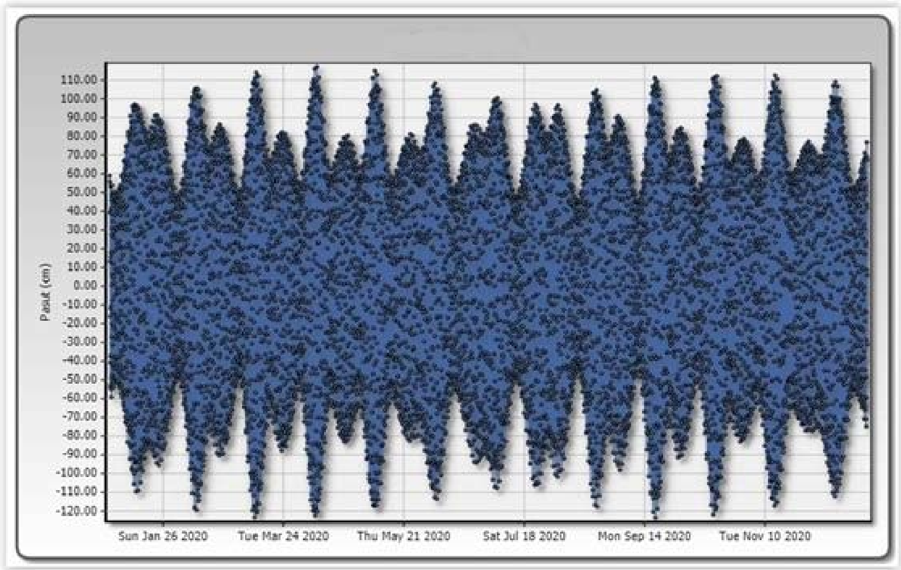

Figure 2: The TPXO9 Results for Foveaux in year,2020 (1-hour data sampling interval).

For plotting tidal roses, the flow speeds in x directions (u) and y directions (V) of National Institute of Water and Atmospheric Research (NIWA) used. Figure 3 shows that this site has a single distinct ebb and flood direction separated almost exactly by 180°.

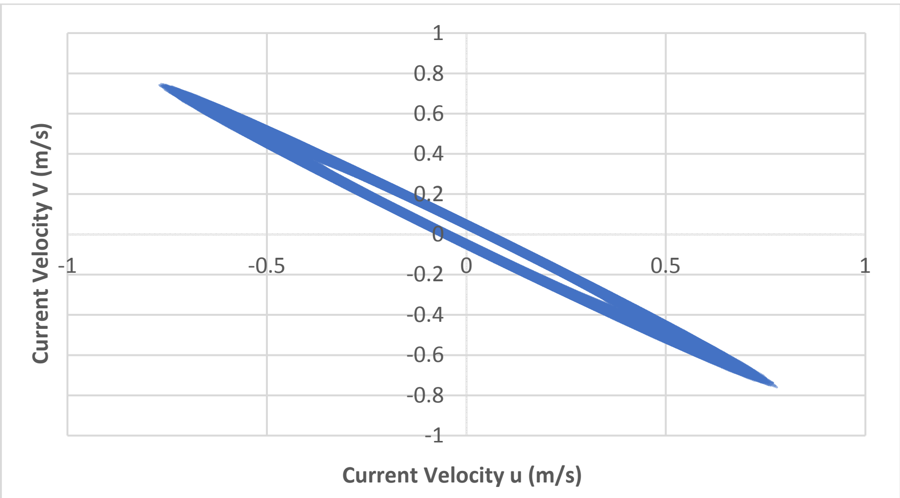

Figure 3: Tidal flow components in Foveaux

The tidal rose of Figure 4, which is plotted with WRPLOT (2021), indicates an NW-SE direction for tidal currents. It is categorized into three tidal classes: Current speeds of 0-0.7 m/s when electricity can not be generated in both tidal turbines, 0.7-0.9 m/s when electricity is produced in only Schottel 54 kW and, more than 0.9 m/s when electricity produces in Schottel 70 kW and as well Schottel 54 kW.
Figure 5 shows the tidal distribution for different speeds in Foveaux. It indicates that 35.4% of tidal currents are more than 0.7 m/s when a Schottel 54 kW can generate electricity, while using Schottel 70 kW makes electricity generation possible for only 10.6% of tidal currents.
Based on NIWA 's flow currents, the yearly hours tidal flows from different directions in Foveaux are shown in Figure 6. NW and SE with 3,776 and 3,772 h/y are prominent directions.

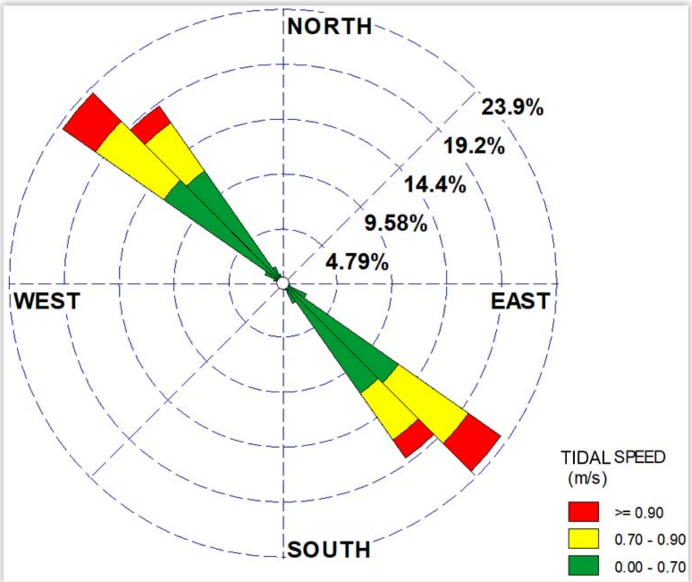

Figure 4: Tidal Rose of Foveaux

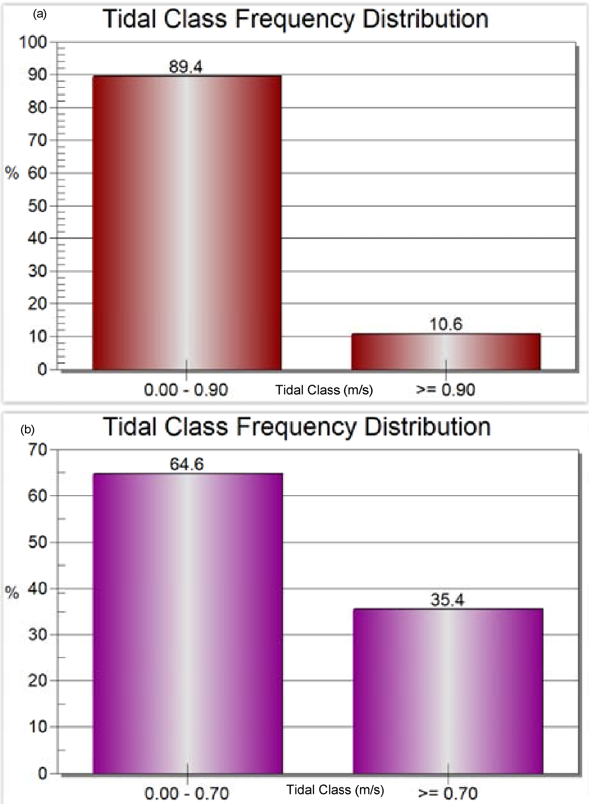

Figure 5: Tidal distribution for different speeds in Foveaux using Schottel (a) 70 kW, (b) 54 kW

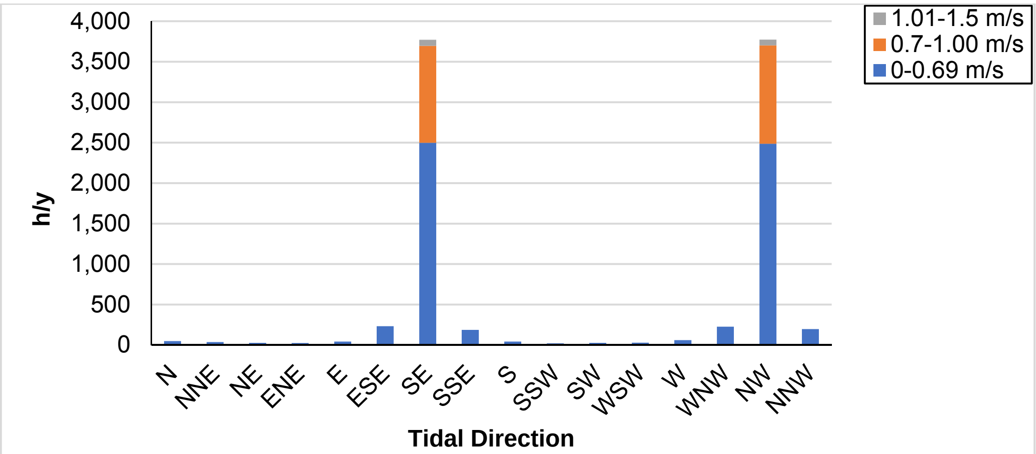

Figure 6: The yearly hours tidal flows from different directions in Foveaux

3. Results

According to characteristics of Foveaux, two tidal turbines (Schottel 70 kW and Schottel 54 kW) are compared in this section to show how a turbine with lower cut-in speed can make a big difference in power generation. Figure 7 shows the annual tide run at instantaneous speed, within specified direction range. From this Figure, it can be seen that SE and NW directions with 7,128 and 7,120.8 km/y tidal run are superior using 70 kW turbine. Changing turbine to 54 kW increases these values to 10,924 and 10,936 km/y.

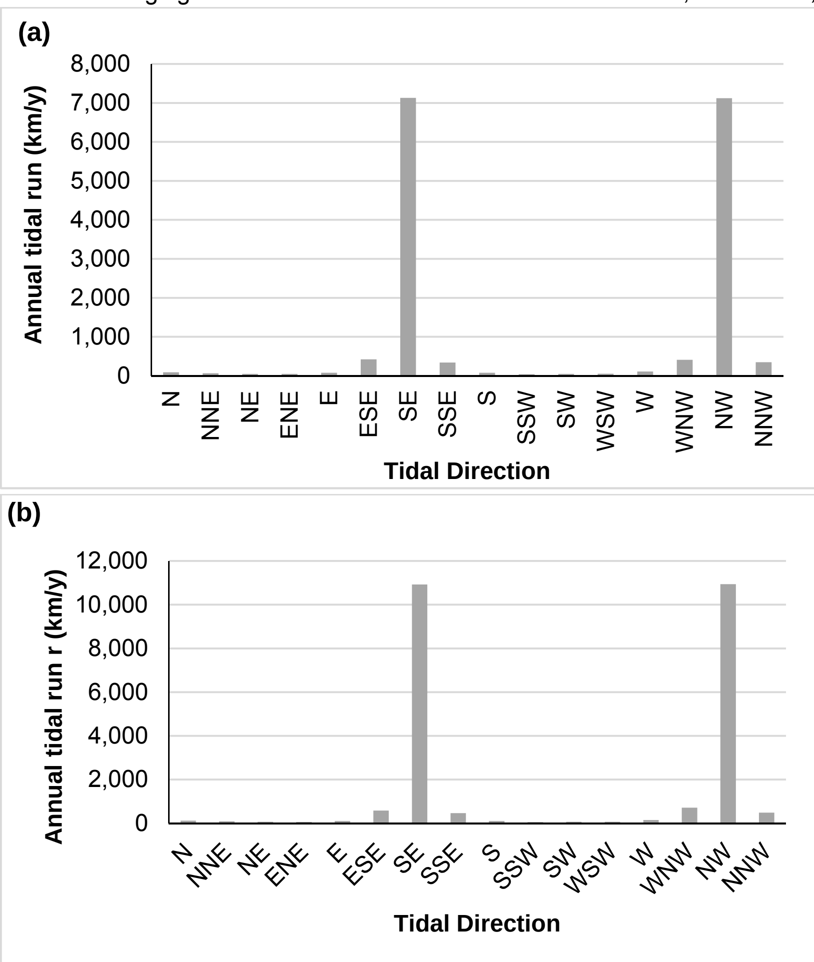

Figure 7: Annual tide run obtained when tide flows, within specified direction range in Foveaux using Schottel (a) 70 kW, (b) 54 kW

Figure 8 shows the annual power output obtained while turbine generates, within specified direction range. It indicates that power generation in SE and NW directions for 70 kW turbine is only 940 and 900 kWh/y, respectively. Changing turbine to 54 kW increases these values to 4,341 and 4,362 kWh/y.

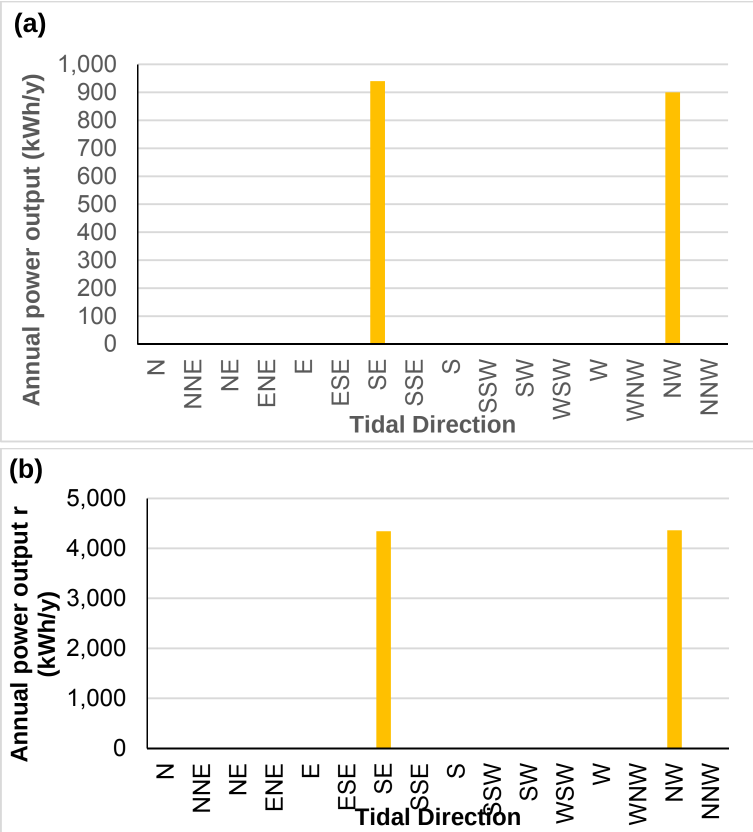

Figure 8: The annual power output obtained while tidal turbine generates, within specified direction range in Foveaux using Schottel (a) 70 kW, (b) 54 kW

4. Conclusions

The cut-in speed of Schottel 54 kW tidal is 0.7 m/s which is 0.2 m/s less than 70 kW turbine. This means in the range of 0-0.69 m/s, power generation is zero. Using this turbine increases electricity generation 4.7 times more in comparison of Schottel 70 kW tidal turbine. Considering this point is important that rated capacity of 70 or 54 kW is achievable only after rated speed which according to Table 2 is 2.6 and 3.8 m/s for Schottel 54 and 70 kW respectively and before these speeds turbine can not generate its nominal capacity. Definitely, the rated water speed of 2.6 m/s rarely occurs during a year. That is why it is important to consider a turbine at a lower cut-in speed.

References

Esteban M.D., Diez J.J., Lopz J.S., Negro V., 2011, Why offshore wind energy?, Renewable Energy, 36, 444 - 450.

Homer Pro, 2020. Make Efficient, Informed Decisions About Distributed Generation and Distributed Energy Resources, <www.homerenergy.com/>, accessed 02.05.2021.

Huckerby J., Johnson D., Nobs Line N.P., 2008. New Zealand's wave and tidal energy resources and their timetable for development. International Conference on Ocean Energy, October 1, Brest, France, 15-17.

Mathew, S., 2006. Wind energy: fundamentals, resource analysis and economics (Voi. 1): Springer.

Nasab, N. M., Kilby, J., Bakhtiaryfard, L., 2020 (2020). Wind Power Potential Assessment for Three Locations in New Zealand. Chemical Engineering Transactions, 81, 73-78.

P.Botha, G. M., 2018. Stewart Island Wind Investigation Retrieved from <www.mbie.govt.nz/dmsdocument/5768-stewart-island-wind-investigation>, accessed 08.08.2021.

TPX09, 2021. Tidal Predictions Using TPX09, <www.oceanomatics.com/>, accessed 02.03.2021.

WRPLOT, 2021. WRPLOT View™ - Freeware, <https://www.weblakes.com/products/wrplot/index.html>, accessed 02.01.2021.