Title: **Translating Shuttle Foils: A New Hydropower**
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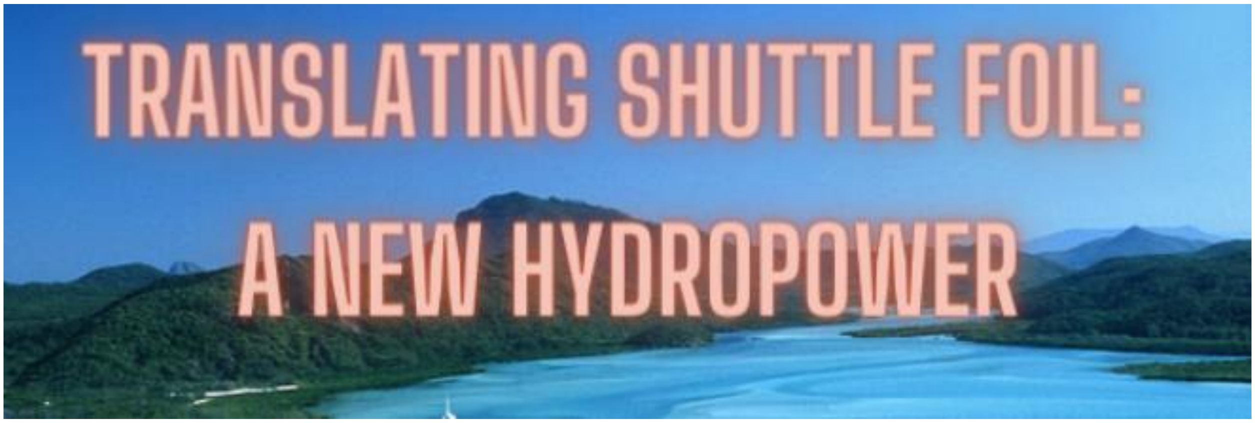
Grade: **9**



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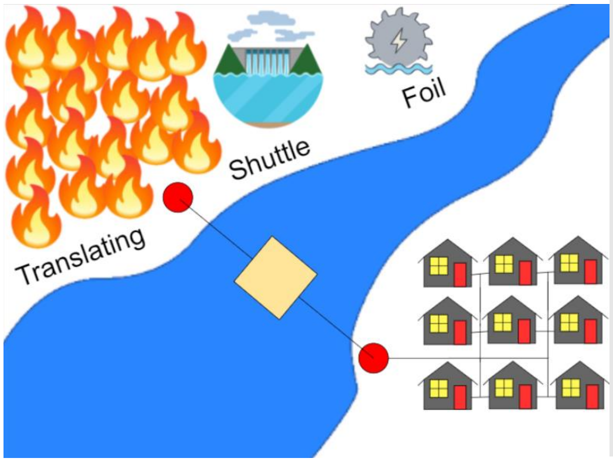

Introduction and Hypothesis (Tab: Problem)

I am investigating into utilizing Translating Shuttle Foils (TSF), a technology using the same principles as reaction ferries, to generate electricity. Generating electricity from fossil fuels is one of the causes of climate change. Using the TSF, which is a form of hydropower, is a possible solution.

Currently, the world is heating up at the rate of about 0.14ºC each decade (Lindsey & Dahlman, 2021). This increase in temperature has led to various issues. Known as the hottest place in Canada, the town of Lytton in British Columbia recorded the highest temperature ever in Canada on June 29, 2021. It beat the previous record by almost 5ºC (Judd, 2021a). Unfortunately, the high temperatures caused the town and surrounding area to be very dry. As a result, the town of Lytton was devastated by wildfires on June 30, 2021 (Judd, 2021b). The extreme temperatures are just one of the effects of climate change that Canada is facing.

Figure 1: Picture of Lytton Before and After the wildfire (Mangione, 2021)

The dire situation regarding climate change has countries rethinking how their actions are affecting the environment. One of the solutions that many are turning towards is renewable energy (Roberts, 2019). Renewable energy is a way to generate electricity and other forms of energy used by humans with close to zero greenhouse gas emissions, using a natural energy source that is non-depleting. Currently, the most popular type of renewable energy generation is hydropower. About 17% of the world's electricity was produced using hydropower plants in 2018 (Water Science School, 2018a). As of 2019, Canada has 650 hydropower plants in use (Canadian Dam Association, 2019). From this, we know that hydropower is a reliable way to generate electricity.

Lytton is known for more than its hot temperatures. It is also known for the Lytton Reaction Ferry (Government of British Columbia, n.d.). Just like hydropower plants, reaction ferries use the motion of water to operate too. Instead of generating electricity like the hydropower dams and run-of-the-river hydropower plants, reaction ferries transport people and cargo across the river.

Hypothesis

Translating shuttle foils is a technology that uses the same principles as the reaction ferry. Now, what if we could use the translating shuttle foil to generate electricity instead? I hypothesize that this can be done since there are already patents online describing how it would be able to generate electricity (Dysarsz, 2017).

Methodology (Tab: Method)

I have been gathering information since August of 2021 and recording my findings in a scientific logbook.

For my research, I used online articles from numerous sources such as National Geographic, government websites and industry websites. I also used videos to help me understand how reaction ferry's function. Additionally, I reviewed the patents available through Google Scholar to gain a deeper understanding of the translating shuttle foil. I also used high school textbooks to research about generators where I learned about Faraday's Law of Electromagnetic Induction. To ensure my information was credible and not opinionated, I cross-checked the information between different sources when possible.

I also built a miniature model of the translating shuttle foil system using items that I found in my house. With this model, I was able to demonstrate how it could generate electricity.

I took feedback from my family and friends to help me improve my research. A couple of university professors and industry subject matter experts in hydropower design also provided me with some valuable advice.

Background Research (Tab: Research)

Reaction Ferry

Reaction ferries are an ingenious but relatively unknown invention that uses the energy found in water currents to propel the ferry across the river (Lee, n.d.). The figure below is a picture of the operational ferry in Lytton.

Figure 2: Picture of a reaction ferry in action. (British Columbia Provincial Government, n.d.)

A reaction ferry has oar boards on the bottom of the ferry (Scott, 2018). These oar boards are angled to redirect the water while using the water for propulsion. In a reaction ferry, there are three cables. There is one overhead cable and two ferry cables. As the name implies, the overhead cable is just a cable that is above the ferry with both ends secured to the shore on both sides of the river. The purpose of this cable is to prevent the ferry from floating downstream. Then, the ferry cables are connected to the overhead cable through a big triangular pulley. When the ferry moves, the triangular pulley will then slide across the overhead cable. Refer to Figure 3 for the different parts of the reaction ferry.

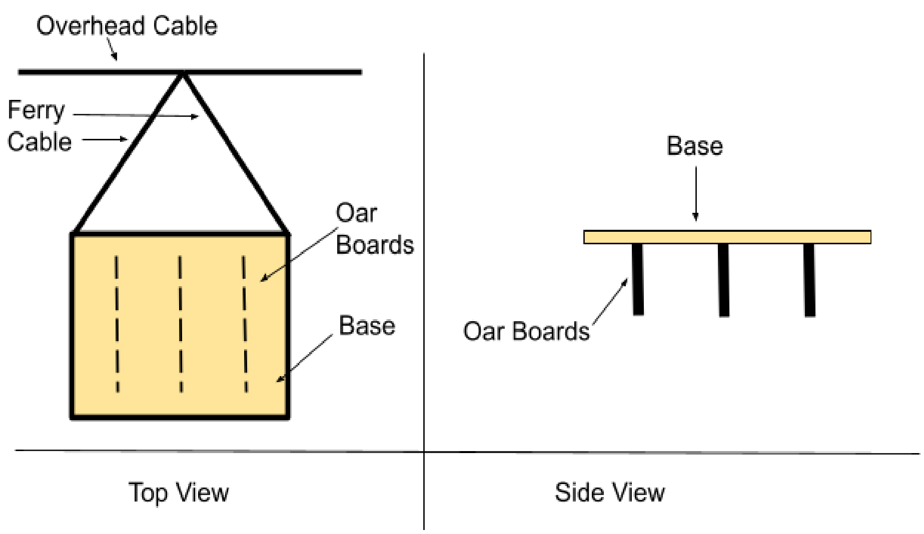

Figure 3: Top view of a reaction ferry (left) and a side view of a reaction ferry (right). Drawing created by author (Tan, 2022).

All reaction ferries travel across rivers by changing the lengths of the two ferry cables. As you can see in Figure 4, when the left cable is longer, the oar boards are slanted to the right. This will propel the ferry to the left. When the right cable is longer, it causes the oar boards to be slanted to the left and the ferry will be propelled to the right. Thus, by changing the length of the cable on each side, the orientation of the boards can be adjusted allowing the ferry to move in both directions.

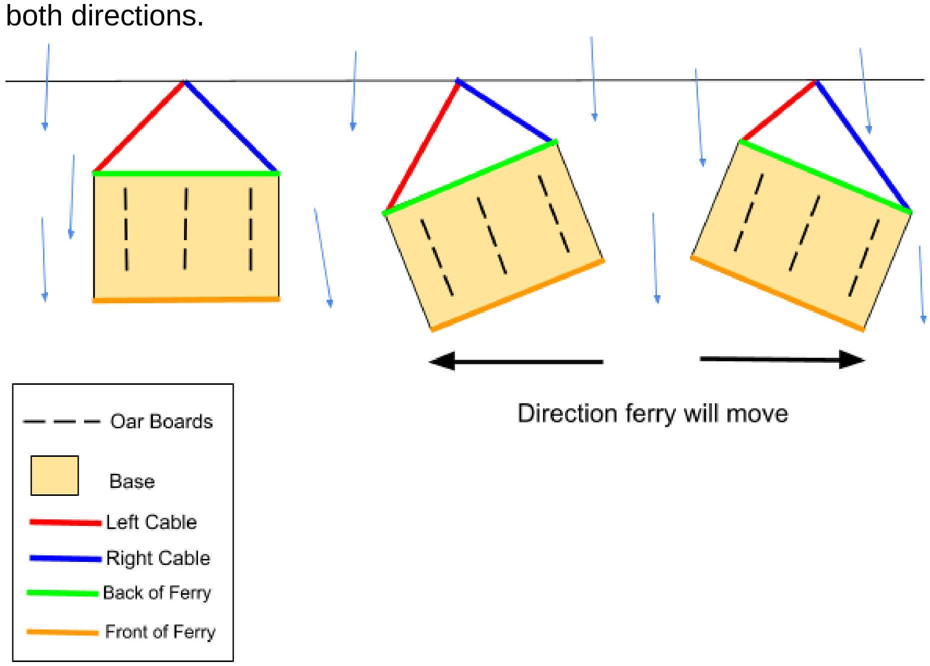

Figure 4: The underlying principles behind reaction ferries. Drawing created by author (Tan, 2022).

Generators

To understand Faraday's law of induction, we need to understand magnetic flux. Magnetic flux is a measurement of the total amount of the magnetic field passing through a given area (Khan Academy, n.d.b).

The next thing we need to know is the relationship between electricity and magnetic fields. In 1820, a Danish professor by the name of Hans Christian Ørsted observed that whenever an electric current passes through a wire, a magnetic field would temporarily be generated around the wire (Chew, Chow & Ho, 2013).

It was Michael Faraday who figured out how to reverse this principle and generate electric current from magnetic fields. Faraday's Law states that if there is a change in magnetic flux, a voltage is induced in the wire that surrounds the area through which the magnetic flux is changing (Lucas, 2016). Many factors can cause a change in magnetic flux. One way is to change the orientation of the collecting area as shown in Figure 5 (Khan Academy, n.d.b). When the cable in the translating shuttle foil system moves, it spins the shaft of the generator. This changes the orientation of the collecting area, which in turn induces a voltage in the wire surrounding the area.

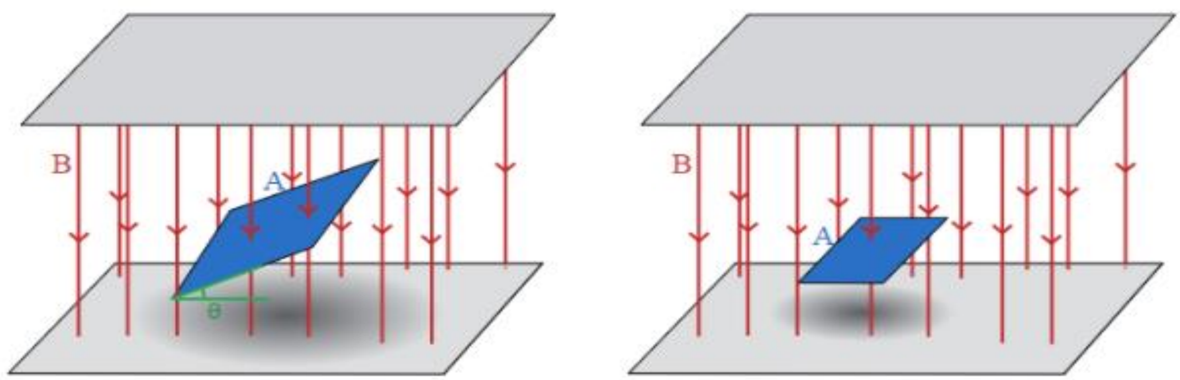

Figure 5: The collecting area (blue) on the right has a higher amount of magnetic flux because it is perpendicular to the magnetic field lines (red). (Khan Academy, n.d.b)

Research Results (Tab: Data)

Translating Shuttle Foil

The translating shuttle foil (TSF) is a technology developed by inventors at Da Vinci Energy Inc., British Columbia. The TSF works similarly to a reaction ferry. There is a cable that is attached to the TSF frame. This cable is a replacement for the overhead cable and the ferry cables. However, this cable will move with the frame. In a TSF, there are foils which acts like the oar boards of a reaction ferry. Like the oar boards, they also redirect the water current to use as propulsion. As you can see in Figure 6, when the foils are slanted to the left, the TSF will propelled in the right direction. When the foils are slanted to the right, the TSF will be propelled in the left direction. These foils have a motor on top that changes the orientation of the foils. But unlike the reaction ferries, the front of the base of the TSF will remain parallel to the attached cable the whole time. In summary, the two key differences between the TSF and the reaction ferry are how the cables are connected and how the foils are being orientated.

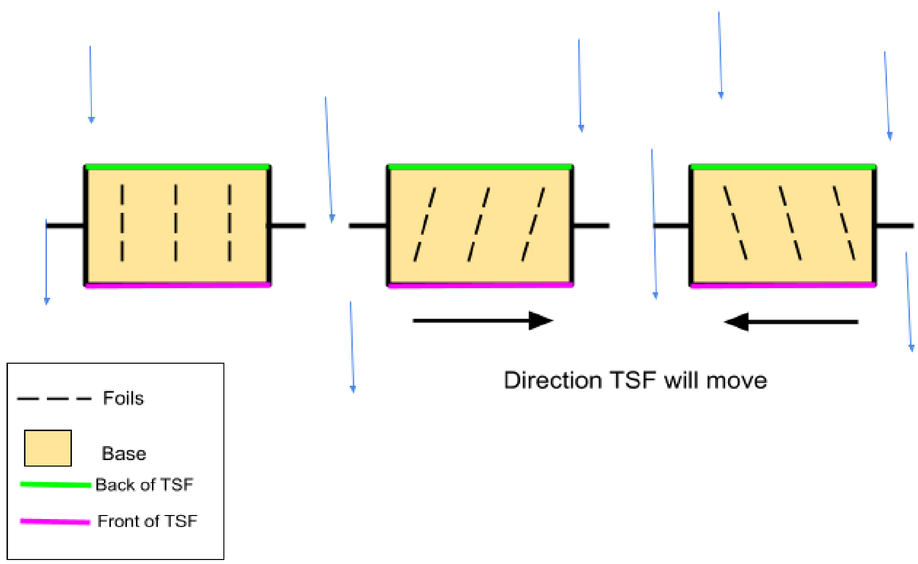

Figure 6: Diagram showing how the TSF moves. Drawing created by author (Tan, 2022).

For clarity, in this report, when I used the term “TSF system”, it refers to the TSF and the generators that it is connected to. In the TSF system, each end of the cable attached to the TSF will be hooked to the shaft of a generator. When the TSF moves back and forth, the cable will spin the shaft of the generators allowing it to produce electricity using Faraday's Law of Electromagnetic Induction.

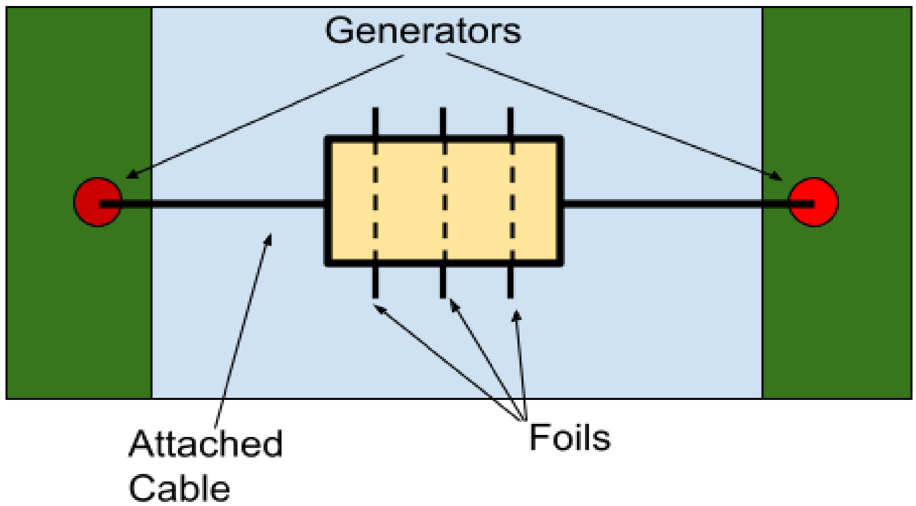

Figure 7: Top view of TSF system. Drawing created by author (Tan, 2022).

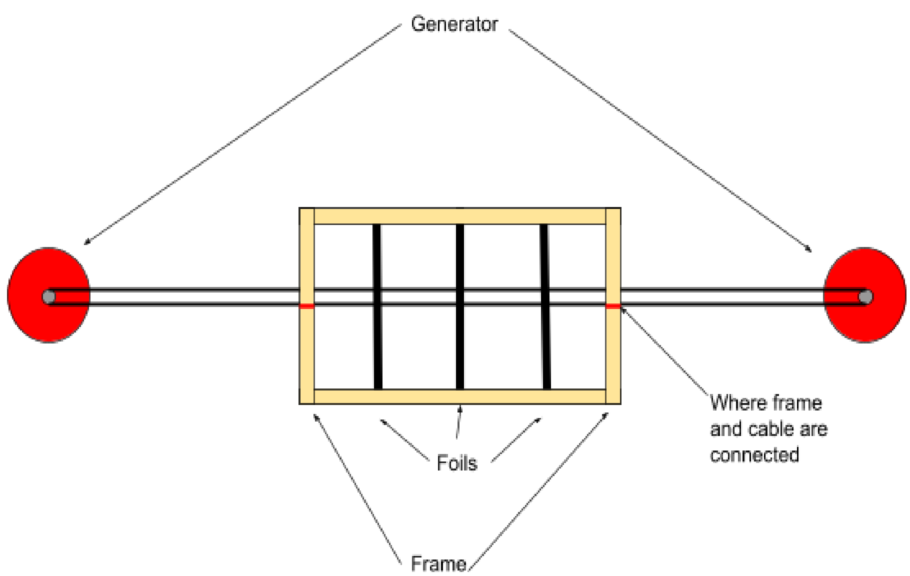

Figure 8: Front view of TSF system. Drawing created by author (Tan, 2022).

After an extensive search on the internet, I was not able to find the dimensions of the reaction ferry. So, I used a photo of the Lytton Reaction Ferry to estimate the size of the foil area. In the figure below, a truck is loading onto the ferry. The width of a regular Ford F-150 truck is about 2 m (Dimensions.com, n.d.). From that, I estimated that the width of the loading platform is around 3 m wide. Since the orange pontoons are about 4 times the width of the loading platform, I inferred that it is 12 m. If we assume that the oar boards can stretch over the full length under the pontoons and are about 1 m deep, then the area of the oar boards on each side is 12 m^2. That makes the total area of the oar boards 24 m^2. I assume that the foil area of a TSF will be similar, but for simplicity, assumed it is about 25 m^2.

Figure 9: Picture of a truck boarding the Lytton Reaction Ferry (Mike, 2013) Dimensions estimated by Tan (2022).

There was no research on how to estimate the maximum output power of a TSF. Data from Da Vinci Energy (n.d.), showed that a wind-based TSF with "One square meter of foil area, placed in a 12 m/s wind, will generate the equivalent of three quarters (3/4) of a horsepower". When I used it to extrapolate what $25m^2$ of foil would generate in water, I arrived at 11400 kW after taking into consideration that the density of water is greater than air. With the help of the industry subject matter experts, I realised that this number was unrealistic for a river situation.

One technology that also works like a TSF system is a run-of-the-river hydropower plant. Both use the kinetic energy in the movement of the water to generate electricity. For this report, after consulting with Mr. O'Gorman, I assumed that the maximum power of the TSF can be estimated using the same formula for the run-of-the-river hydropower plant. The maximum output power of a TSF was estimated using the formula below.

$$P_{max} = \frac{1}{2} \times \eta \times \rho \times A \times v^3$$

Where

P_{max} = maximum output power

η = efficiency of system

ρ = density of water

A = area of foils

v = velocity of water

The speed of a river is between 0 m/s to 3.1 m/s (Gaballa, 2006). Although the average efficiency for a hydropower system is 90% to 95% (Electropaedia, n.d.), I used an estimate of 20% for the TSF system. This took into consideration that it has yet to be deployed in an actual environment and the advice of Dr. Nowicki. We also know that the density of water is around 1000 kg/m^3 (Water Science School, 2018c). By using this information, a foil area of 25 m^2 will be able to generate up to 74 kW of electric power. Here is how I calculated this number.

$$P_{max} = \frac{1}{2} \times \eta \times \rho \times A \times v^3$$

$$P_{max} = \frac{1}{2} \times 20\% \times 1000\ kg/m^3 \times 25\ m^2 \times (3.1\ m/s)^3$$

$$P_{max} = 74477\ W$$

$$P_{max} = 74.477\ kW$$

Model of TSF

I built a miniature model of the TSF system. The frame and the foils of the TSF were built out of cardboard. Instead of metal cables, I used some yarn that I had. I looped this around a small direct current motor so that the yarn would spin the shaft of the motor turning it into a generator. Finally, I connected a multimeter to the motor / generator. When the TSF moved back and forth, it was able to generate around 0.1 volts of electricity with no load connected to the generator. Since the model was not able to work in water, I simulated the movement of the TSF manually with my hand.

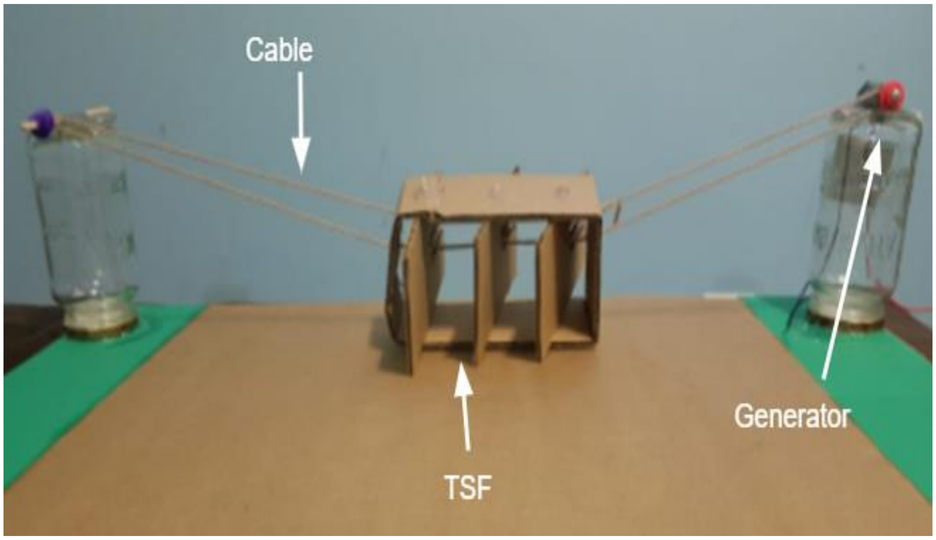

Figure 10: Front view of the model of TSF system. Picture provided by author (Tan, 2022).

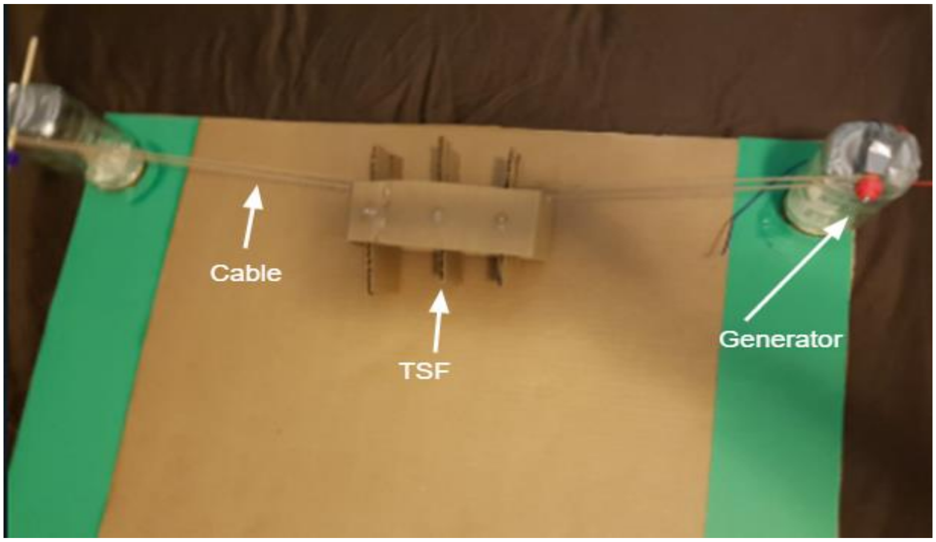

Figure 11: Top view of TSF system model. Picture provided by author (Tan, 2022).

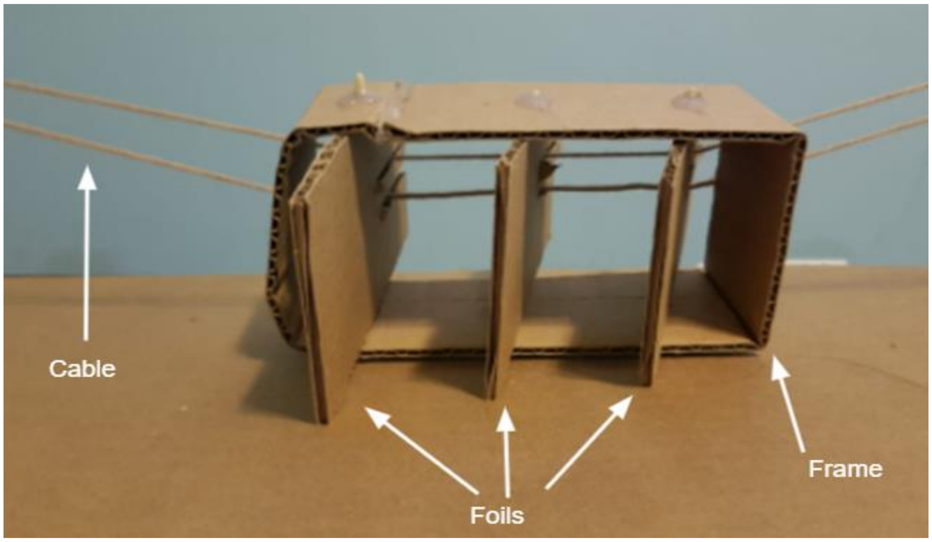

Figure 12: Close-up view of TSF model. Picture provided by author (Tan, 2022).

Comparison of TSF System with Other Hydropower Systems

Now, how will the translating shuttle foil system in water compare with the two most common types of hydroelectric power technologies today: run-of-the-river hydropower plants and hydropower dams. I considered four different factors: fish friendliness, cost, electricity production, and the availability of production facilities.

Compared to the other types of hydropower technologies, the translating shuttle foil system should not affect the fishes in the water as much. In hydropower dams, the ecosystem of the waterway is significantly impacted. Fish migration paths are affected as the dam blocks off the natural flow of the water (Succi, 2019). In the run-of-the-river hydropower plants, the turbine in the water will often suck in the fishes swimming by and kill them (Pynn, 2012). The TSF system disrupts the flow of the water relatively minimally as the TSF moves across the river quite slowly. This should not interrupt the fishes in the river.

The estimated cost of the TSF system is expected to be lower than the other types of hydropower. Da Vinci Energy estimates that “The TSF will produce electricity at a cost of less than one cent per kWh.” Currently, hydropower costs around 4 to 10 cents per kilowatt-hour (Government of Canada, n.d.).

Based on my calculations above, the TSF system will generate around 74 kW. Comparing this to the bigger hydroelectric dams (22,500 MW) (Water Science School, 2018b) and bigger run-of-the-river hydroelectricity power plants (3750 MW) (Mitsui, 2013) the TSF produces a lot less power. This result is to be expected since my 25 m^2 TSF is much smaller than these large hydro systems. However, the TSF could be ideal for areas that do not have a high electrical requirement since electricity is expensive to store.

Unlike the other two types of hydropower, the TSF system has never been fully tested in an actual river yet. This lack of actual production facilities allows me to only speculate on whether the lab results of the TSF system can be replicated in the real world.

	Fish Friendliness	Cost	Electricity Production	Production Facilities
Translating Shuttle Foil	✔	✔	✔	✘
Run-of-the-river	✘	✘	✔	✔
Hydropower dams	✘	✘	✔	✔

Figure 13: Chart comparing different types of hydropower power plants. Chart created by author (Tan, 2022).

Conclusion and Discussion (Tab: Conclusion)

Conclusion

I hypothesized that the translating shuttle foil system can be used in water to generate electricity and the results of my research support my hypothesis. The TSF in water uses the same principles as reaction ferries which have been operating in many rivers globally for many years. Da Vinci Energy has also demonstrated a working prototype of the TSF system in water in the lab. All evidence indicates that a TSF system in water can successfully generate electricity.

However, this technology is still not proven. Since there is no actual production facility, it is not possible to figure out if this technology will be commercially viable under real world conditions. I am still sceptical about the claim that this technology will be able to generate electricity at less than a cent per kilowatt-hour (Da Vinci Energy, n.d.).

Significance of Research

The TSF is useful because it does not interfere with fish migration paths. The fish can swim and reproduce normally without being affected by the foils. This technology would be placed in waterways that have lots of migrating fish.

The TSF system just needs constantly flowing water so that it can move back and forth along the waterway and generate electricity. There are about 940 million people who do not have access to electricity (Ritchie & Roser, 2020). Since most communities are built near waterways, this could be a possible solution for them. They could also set up multiple TSF systems in these waterways if they need more electricity.

The same report by Ritchie and Roser (2020) found that many people do not have access to energy because they are in low-income households. Electricity from TSF systems might reduce costs by almost four to ten times. With a cheaper method to generate electricity, more low-income communities can get access to electricity.

The lower maximum power output for the TSF system makes it ideal for smaller, isolated communities that are not connected to a main power grid. The storage of electricity is still relatively expensive. By utilizing the TSF system, it reduces the need for these electricity storage facilities. This could add resiliency by acting as a backup power generator for these remote communities too.

My Learnings

During this project, I discovered many things. I learned about reaction ferries and how they use the kinetic energy in the water to move and transport people and cargo. By researching the information that the creators of the TSF (Da Vinci Energy) had to offer, I was able to have a more in-depth understanding of the workings of the translating shuttle foil technology.

I was also exposed to Faraday’s Law of Electromagnetic Induction which helped me learn how generators work. Along with this law, I learned about magnetic flux. With this knowledge in hand, I was able to learn how the TSF can be combined with a generator to generate electricity.

In addition to the TSF, I learned about two other types of hydropower and compared them.

Future Research / Next Steps

For future research, I suggest comparing the wind-based TSF system to wind turbines. It would be interesting to see whether the TSF system that works in the air is able to outperform wind turbines in electricity production.

One last thing I would suggest doing is to find the optimal efficiency of the water-based TSF system. One way to do this is by using computational fluid dynamic analysis (CFD analysis). By increasing the efficiency of the TSF from 20% to 30%, we could increase the amount of electricity generated by over 50%

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