

Visions Olympics

2012 VISIONS-OLYMPICS COMPETITION

The next generation products and procedures for Vessels and Floating Structures

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RA1 – Offshore installations ☐

RA2 – Alternative products for the Marine Industry ☒

Project Title:

The Future of Urban Ferry Services – The Electric Ferry



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1 Introduction

Due to recent increases in fuel prices and the ever-increasing set of rules and regulations governing the pollution produced by marine systems, the ferry industry is facing challenging times. Ferry services have been serving local communities living in cities which are surrounded by water ways, basins and lakes for centuries. Many European countries including Sweden, Finland, Croatia and Greece have been using ferries of different sizes as the only means of transport between islands and other parts of the country that are divided by water. Major cities like New York, Honk Kong and Sydney still use ferries which support the local public transportation while in the same time serving as tourist attractions. In the past decades, advances in technology have brought about the introduction of faster means of transportation to overcome the water barrier such as underground trains, larger bridges and cheaper automobiles reducing the dependency and need of inland water ways travel by means of ferries. Added to the aforementioned reasons, the ferry is no longer considered as an essential inner-city transport method.

The concept of our project is to introduce a new generation of ferry system that would be more appealing to the communities where ferries are still in use, but are held back due to the effects of their emissions. The concept of an electric ferry is as much as an innovation as it is a flashback from turn of the 20th century technologies. Our concept looks into applying old, proven technologies to new designs. The proposed idea is to build or modify existing vessels that will run on shore power. The vessels, depending on their application, can be adapted to use on-board electric motors for propulsion, receiving the power from shore. The vessels would receive the required power from specially adapted power transmission systems that would vary for each application.

The technologies of interest for this concept are:

- Overhead power cables that would power the vessel much like trains today.
- Cables laid and retrieved by the vessel similar to cable laying technologies.
- Magnetic levitation technology modified and applied for underwater use.
- Underwater live cable feeding the vessels on-board busbar.

The power required for this concept would be produced by cleaner, more efficient electricity production plants, surplus energy from already established power units or even better renewable sources that could be available or implemented for such use. This project hopes to motivate the market leaders into considering a change from fuel powered engines to the proposed electrical system in order to operate at a more efficient level, limit our dependency on depleting fossil fuels and minimise our emissions.

2 Problem Definition

The following section of this report is going to focus on the main problems with which the ferry industry is being faced. The challenges were narrowed down to three main problems being:

- The rising cost of crude oil
- The stringent MARPOL regulations being imposed on the industry
- Decreasing profits of ferry operators

The aims of this project are to:

- Achieve a zero emission system
- Eliminate the fuel costs
- Facilitate the maintenance of machinery
- Create a sustainable means of ferry transport
- Revive the ferry industry

2.1 Rising Cost of Crude Oil

Fuel is a scarce resource that has seen a drastic rise in cost in the past decades. This has resulted in higher operational costs throughout these years, considering that marine fuel represents 60-70% of the ship's operating cost [1]. Dated Brent, an oil trading company priced a barrel of oil at \$79.50 in 2010, an increase of 29% from the previous year, nearly \$18 per barrel below the 2008 record level. Other benchmark crude's registered similar increases. High consumption growth and continuing OPEC production restraint helped to push prices higher late in the year, with prices reaching a peak of almost \$94 at the end of the year. Global oil consumption grew by 2.7 million barrels per day (b/d), or 3.1%, to reach a record level of 87.4 million b/d after falling for two consecutive years. This was the largest percentage increase since 2004 yet still the weakest global growth rate among fossil fuels [2]. The graph below illustrates an overall increase in fuel consumption throughout the years. [1]

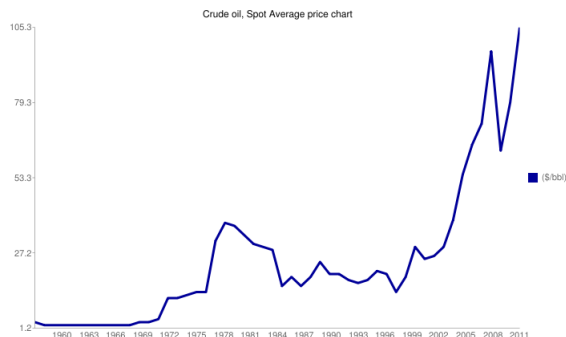


Figure 1: The cost of crude oil from 1960 to 2011 [2]

In order to reduce operational costs, marine engines have been designed to achieve the least fuel consumption possible. Ocean going ships are usually designed to run on residual fuel, which is a low grade fuel being sold at the lowest price. This is not always possible for ferry services operating in coastal areas due to the emission regulations imposed by IMO and the flag states. Out of all the two-stroke, low-speed engines, 95% use HFO and 5% are powered by MDO.[3] Fuel consumed by 70% of the four-stroke, medium-speed engines is HFO, with the remainder burning either MDO or MGO. Four-stroke, high-speed engines operate on MDO or MGO. The remaining engine types are small, high-speed diesel engines operating on MDO or MGO, steam turbines powered by HFO fueled boilers, or gas turbines powered by MGO [3]. Due to the increase in oil price, ferry services such as; SeaStreak, High-speed Hawaii Superferry, Washington State Ferries, and British Colombia Ferries have had to overcome this issue through implementing a number operational strategies such as operating at a slower speed (usually one or two knots below cruising speed), improving hull and propeller designs and various others. [4]

Emission restrictions have been imposed to reduce the environmental damage done by ships, forcing ferry operators to use higher grade fuel which is much higher in price. This has lead to a decrease in the profit margin thus ferry service usually opt for a more efficient design to attract more customers in

order to increase their revenue. A more popular decision taken by the operators is often to increase the ferry toll. It is safe to say that such solutions are only practicable in the short term, as fuel prices are going to soar when resources are scarce and emission regulations are going to become more stringent over time.

It has been estimated by the Government/Industry Scientific Group of Experts that in 2007 global merchant marine fuel oil consumption was around 369 million tonnes, and that in 2020 it would increase to 486 million tonnes. [5] According to archeologists with the current proved reserves there are 43 years of oil, 148 years of coal and 61 years of natural gas production left on the planet. We can therefore acknowledge the fact that fuel is not an infinite source of energy, thus an alternative energy has to be found.

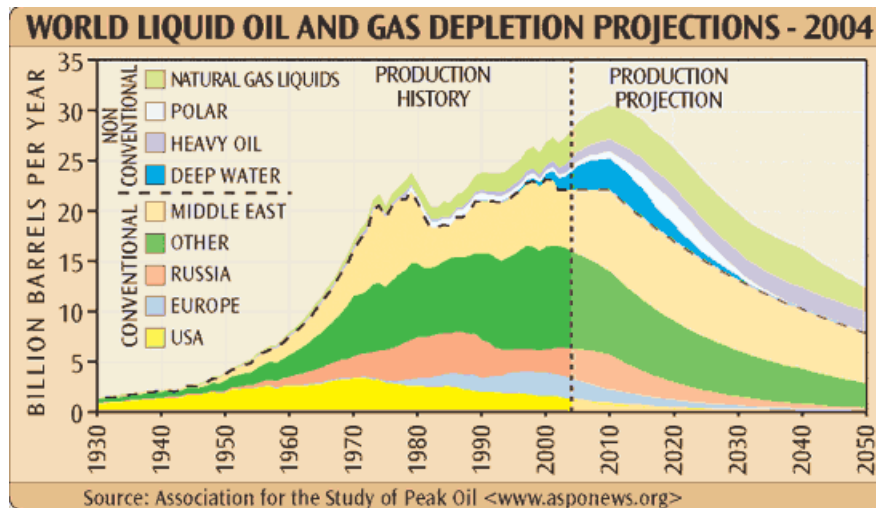


Figure 2: The world liquid oil and gas depletion projections [6]

2.2 Pollution Legislation

As seen in the previous section, the trend of fuel consumption has been on the rise for a long time reaching record levels in recent years. This has brought about problems other than scarcity of fuel and rising prices, in the form of emission, which pose a serious threat to the environment. The main set of rules governing the ship emissions were introduced by the IMO in an international conference in Geneva in 1948; the International Convention on the Prevention of Pollution from Ships, commonly known as MARPOL 73/78. The IMO (International Maritime Organization) is the United Nations' governing body for the maritime industry and was established to promote maritime safety and preserve the environment. On 27 September 1997, the 1997 Protocol was amended to include Annex VI titled "Regulations for the Prevention of Air Pollution from Ships". MARPOL Annex VI limits the amount of NO_x and SO_x emissions from the ship's exhaust, and prohibits deliberate emissions of ozone depleting substances. The emission standards are usually referred as Tier I, II, III standards.

There are two sets of emission and fuel quality requirements defined by Annex VI; the first being global requirements which apply to all vessels and the second being the more stringent requirements applicable to ships operating in Emission Control Areas (ECA). An Emission Control Area can be designated for SO_x and PM, or NO_x, or all three types of emissions from ships, subject to a proposal from a Party to Annex VI [7]. The following are areas that have emission control: Baltic Sea, North Sea, North America including most of US and Canadian coast, US Caribbean including Puerto Rico and the US Virgin Islands.

In 2011, IMO introduced mandatory measures to reduce emissions of greenhouse gases (GHG) found in Chapter 4 of Annex VI on "Regulations on energy efficiency for ships"[7]. Depending on the engine maximum operating speed (n, rpm), NO_x emission limits are set for diesel engines. As shown in Figure 1.3

and 1.4. Tier I and Tier II limits are global, while the Tier III standards apply only in NOx Emission Control Areas [7]. The following table illustrates the MARPOL Annex VI NOx Emission Limits:

Tier	Date	NOx Limit, g/kWh		
		$n < 130$	$130 \leq n < 2000$	$n \geq 2000$
Tier I	2000	17.0	$45 \cdot n^{-0.2}$	9.8
Tier II	2011	14.4	$44 \cdot n^{-0.23}$	7.7
Tier III	2016†	3.4	$9 \cdot n^{-0.2}$	1.96

† In NOx Emission Control Areas (Tier II standards apply outside ECAs).

Figure 3: MARPOL Annex VI NOx Emission Limits [7]

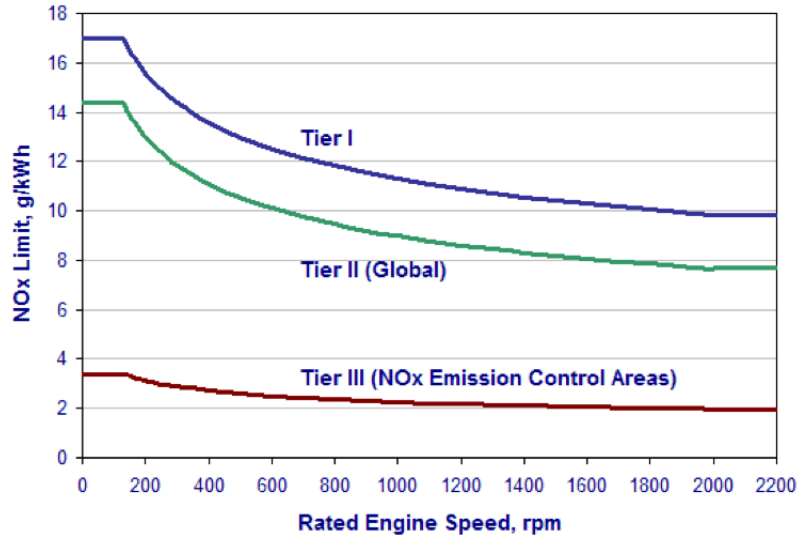


Figure 4: MARPOL Annex VI NOx Emission Limits [7]

The sulfur content in fuel oil is included in Annex VI in order to control SOx emissions and indirectly restricting PM emissions. There are special fuel quality provisions for SOx Emission Control Areas (SOx ECA or SECA) [7]. The sulfur limits and implementation dates are illustrated in Figure 1.5 and Figure 1.6 [7]:

Ferry companies such as P&O Ferries, Stena Line and Brittany Ferries are facing great difficulties to comply with these regulations. The above mentioned ferry companies stated that the changes will nearly double their fuel costs, which may lead the ferry services to bankruptcy. The only technical alternative to the ultra-low sulphur fuel emission control areas in 2015 (0.1% sulphur in the burnt fuel oil rather than the 1% imposed at present) is to fit ships with sulphur scrubbing abatement technology. This technology is a promising solution but is still being developed and up till now, it has not been an economically feasible solution. Other sources of energy are also being considered namely liquefied natural gas (LNG). Using LNG also faces some challenges, as there is no supply chain in most ports. This system still has to be developed and needs a lot of infrastructural investment which will most likely be viable in 2020 but is still a costly solution. Ferry companies will be helpless if they don't find a new feasible source of energy or hope for an ease in the current regulations which is highly unlikely to happen. If they continue on this trajectory, they cannot escape the risk of financial insolvency which will create a shift of freight from sea back to roads and threaten the jobs of seafarers and shipping support services in ports around emission control areas.

Date	Sulfur Limit in Fuel (% m/m)	
	SOx ECA	Global
2000	1.5%	4.5%
2010.07	1.0%	
2012	0.1%	3.5%
2015		0.5%
2020a		
a – alternative date is 2025, to be decided by a review in 2018		

Figure 5: MARPOL Annex VI Fuel Sulfur Limits [7]

2.3 Economics of short distance ferry services

This is an important issue that is the determining factor in the going concern of many ferry operators in urban waterways. If the operator is not profitable it is extremely difficult to continue trading unless it has some form of government subsidy that ensures that it remains in service. Ferry services seem to excel when there can be a direct connection made between two terminals or that some other means of transport will require heavy investment in infrastructure [8]. There are a number of factors affecting revenue generated by ferry operators as whole, both in short and long distance services. This project however presents more of a focus on the short distance services in an urban environment. [8]

Safety is an important factor in influencing the costs experienced by the operators. With these short distance services, journeys are frequent with in some situations significant volumes of passengers using the service. This presents the issue of having safe, well equipped vessels that can safely manage the large numbers of customers boarding and disembarking in short periods of time. This will lead to an increase in capital investment in the ship and in turn take longer for the revenue generated to cover this cost.

Maximizing efficiency is essential for ships of this nature, however this is something that is difficult to achieve. Short turnaround times and quick increases and decreases in speed means that the engine may have to be part loaded at times, reducing its efficiency. In addition to this, high and medium speed diesel engines are those which are common on these types of vessels due to the size and space available in the engine room. Such engines are not as efficient as their slow speed counterpart. Therefore, efficiency is again compromised meaning that there is a greater fuel requirement for the same delivered power and so the operational costs rise.

Coupled with the previous point regarding efficiency, fuel cost itself is a

key consideration. It has been previously mentioned that crude oil price rises has had, and will continue to have a major impact on the profitability of the shipping industry as a whole. Ferry operators may be one of the hardest hit in this regard due to the low profit margins that they currently experience, the reduced efficiency of the ship and the fact that with the use of medium and high speed diesel engines they will have to use a higher grade of diesel, adding to the cost. This is also the case for such ferries as they will have to meet MARPOL and local regulations governing the emissions of the vessel. This again leads to the requirement of a higher grade, more expensive fuel.

The vessel must be aesthetically pleasing as well as functional. There are a number of different reasons for the use of ferry services in an urban environment. They may be used as part of a city tourist attraction or just for transferring a large number of people across a waterway to a different part of the city. For tourist attractions, aesthetics is particularly important however it is important that even for transport purposes the ship is attractive as it may be the determining factor in whether or not the customer chooses to use the ferry instead of some other public service. This will mean that the ships built will need greater capital investment, which as discussed before leads to a longer payback period and take more time for the company to see profit.

Ferry services have a relatively elastic price elasticity of demand. This means that an increase in price will have a direct impact on the number of passengers using the service. It is not just as simple to increase prices for this type of service as in most cases there will be some form of substitute service that the customer could take as an alternative [8]. Therefore, the ferry service needs to be financially appealing to the customer and so the operator can't simply set a high price to gain high profits. In many cases this is the difficulty facing the ferry operators as the inability to raise prices in response to operational costs inevitably lead to the operator not being able to break even and so the ferry service becomes redundant.

3 Technological Solutions

The idea behind this project is to develop a design which would make the ferry industry less dependent on marine fuel energy and thus more environmentally sensitive. The best alternative to marine fuel is to provide electrical power onshore and transfer it to the ferry, thus the ferry would not be burning any fuel, resulting in zero emission. This solution would satisfy two out of three of our main aims, leaving feasibility to be examined later in the project when we are aware of what this project takes to implement.

The idea of a zero emission ferry traveling without burning fuel sounds very pleasing but also poses a lot of challenges ahead, the most obvious one being; how is the moving ferry going to be powered by an onshore supply. To answer this question, this project is going to present four different ideas, mainly technologies which have already been developed for other purposes, which can fit our cause and help in transferring the required power. These four technologies are:

- Overhead Cable Technology
- Underwater Cable Technology
- Underwater Magnetic Levitation Technology
- Cable Laying Technology

3.1 Overhead Cable Technology

The concept of overhead power cables used to provide electric power to moving vehicles is not a novice technique. This technology has been used since the beginning of the 19th century to power buses, trams and other forms of public transportation systems throughout the developed world.

Europe and the U.S at the beginning of the 19th century, used to transport good from port to the mainland by means of transport along inland water ways or canals. The canals where shallow trenches filled with water and were often

narrow, disabling the use of larger vessels to navigate. This called for the use of barges that were built specifically for these canals. Canal boats or barges had a shallow draft and were powered by steam engines propelling either paddle wheels or screws. These also offered a solution for larger canals. In smaller, more rudimentary canals, these barges were also inconvenient. Due to the crude nature of these canals which lacked reinforced banks, the wake and wash produced by self-propelled boats caused a rapid deterioration of the water ways and required the depth to be sufficient for the propellers or paddle wheels. This pushed the need for an alternative method of propelling the barges. An obvious solution at the time was to use animals to pull the barges along the canals. This proved impractical due to the low weight capacity and the low towing speeds provided by the mules. Engineers in the U.S and Europe (namely France and Germany) combined the already established technology of electric vehicles and applied it to the barges used in the canals. At the beginning, towing barges were using electric motors powered by overhead cables which would use a towing chain or rope to pull the cargo barges. Other engineers devised systems with overhead cables powering electric trolleys replacing the mule which in turn towed the barges.

At the turn of the 20th century, this technology inspired and led to many prototypes and ideas that sadly did not were not adopted. One such idea was the trolley boat which modified the concept used to power trolleybuses on land. A cable above the boat would provide the electricity to the on-board electric motors and propel the boat. After some experiments, this system proved to be impractical because it did not provide sufficient maneuverability and did not address the problem concerning the wash and wake. Another attempt made was to implement this technology on the Erie Canal (U.S) so it could power a passenger ferry crossing the canal using overhead cables. This system was also abandoned due to the need to deepen and reinforce the canal.

Due to the great advances in technology and the drive to find a more eco-

friendly and efficient systems, this has paved a way for the revival of such system. Technical problems that were deal breakers for the implementation of this technology can be solved today using the extensive knowledge gained in the field. A major problem that baffled engineers in those days was to change in speed of the electrical propulsion system. This problem has been solved already offering various solutions such as the fitting of a controllable pitch propeller or the installation of an azimuthing device.

The power requirements of a ship depend greatly on its type and size. The power requirements for a typical ferry are the propulsion needs and the hotel services, which play a major role in the passenger business. These power demands can prove to be a challenge for power transmission purposes. The equivalent systems that use overhead power cables range from urban transportation systems such as trolley buses, trams and metro, to larger systems such as trains, cranes and other. All of the aforementioned systems have overhead power cables and power collection systems specifically adapted for each. There are various differences in the application of each system, the primary difference being the different environment they operate in. Power collection systems that could be used for an “electric” ferry could either be a trolley system which is permanently attached to the overhead cables and follows the motion and direction of the vehicle using rollers and bearings or a pantograph system similar to the systems used by high speed trains. These systems would require modifications and alterations in order to be adapted to the sea motion experienced by seaborne vehicles. This is due to the added complexity of the motions experienced by a sea going vessels in the terms of the six degrees of freedom which are not experienced in such an extent by any other land-based systems.

3.2 Underwater Cable Technology

The idea behind this technology is having a live cable connected to an onshore power source, lying on the seabed, running along the distance of the chosen

route. The ship would have a wire which runs freely along the live wire transferring power from the cable to the ship's busbar.

The challenge posed by this system is that it is not possible having a current carrying conductor exposed to sea water, mainly due to the fact that sea water is a conductor and thus current will be dissipated to the water, making the system inefficient and hazardous.

The solution proposed for this system is derived from the wet diving bell concept. A diving bell is a rigid chamber used to transport divers to depth in the ocean. It is shaped like a bell having an open bottom and a place where the divers sit and stand inside. As it is lowered into the water, the air is trapped inside the structure such that the pressure of the air keeps the water outside. Due to the buoyancy created by the trapped volume, the diving bell is heavily ballasted so it can go down deep.

This concept is applied to the problem at hand to create a semicircular structure in the form of an open pipe cut in half which is heavily ballasted to lie at a given depth. The dry air is trapped inside the structure and a live wire runs through it. The structure would also be connected to a structure which is bolted to the seabed to provide the structure with strength and stability needed to overcome the environmental elements. An insulated cable connects the ship to this live wire thus providing the ferry with suitable electrical power without exposing the conductor to sea water as the exposed parts of the connection would be trapped in dry air.

An air gap has to be present between the exposed wire and the sea in order to prevent current conducting through moist air which rises from the sea. This air gap might be in the range of meters due to the high conductivity of moist air and the high voltage being carried by the conductor.

The system would be connected by a three phase arrangement due to the high power requirements needed to propel and maintain a fully electrically driven ship. This would involve three live wires and a neutral cable connected to the onshore supply and the ship. The neutral cable would be exposed to the sea water to provide an earthing system to this powering arrangement. The neutral can be earthed to the sea since the live wire is not in contact with the sea, so a circuit is not created between the live and the neutral.

This powering system has been ruled out of selection due to its various mechanical complications, maintenance difficulties and economic factors. These include the cost of the structure which has to have good mechanical strength to overcome the opposing buoyancy, and the large air gap between the exposed wire and the sea which further increases the size of the structure and thus pushing the cost up. Due to the position of the structure being immersed deep in the water, maintenance works would be very expensive and difficult to complete. In case of water ingress to the system, the powering system ceases to work and restarting the system would mean pumping the water outside the structure which proves to be a difficult mechanical task.

Given all these problems, this system would no longer be considered as a potential powering arrangement but it is still worth presenting as it has its merits since it does not restrict any sea traffic. This might develop into a viable solution in the distant future.

3.3 Underwater Magnetic Levitation Technology

Magnetic levitation is a technology that makes use of powerful electro-magnets to create a transportation system. The idea of magnetic trains was established by engineers around the world as early as 1902, where the first patent was filed in the United States. It is a relatively new technology developed in the 1950's and 70's as an alternative solution for mass public transportation systems. Magnetic trains are suspended, guided and propelled by magnetic fields.

The first public magnetic levitation train was opened in 1984 in Birmingham, England but it was a small slow speed shuttle that operated between Birmingham International Airport and Birmingham International railway station. In 1995, this system was closed due to reliability issues and cost.

This technology has evolved across the years and faster more complex systems were developed. The Japanese MLX01 concept can achieve speeds of 350mph, so can the German Transrapid concept traveling at a speed of 281mph. These systems share the advantage of having no engines aboard used to propel the vehicles, at the same having no wheel contact resulting in limited noise, vibrations and friction. Other concepts were also developed for underwater magnetic levitation trains proving that this system can be adapted to the marine environment.

These concepts are promising futuristic solutions but share inherent disadvantages of high costs of installation and excessive maintenance requirements. The power requirements for such system are extremely high. The cost of developing and building such system on land is in the range of billions of pounds and the cost is estimated to be even greater for an underwater track guiding a ship. For the aforementioned reasons this technology is considered unfeasibly and economically unfeasible for the applications considered in this project.

3.4 Cable Laying Technology

This idea uses the concept of the cable laying vessel where you have a large cable sheaves which is winded with cable and it is uncurled as the vessel moves. In this case, the cable would be connected to an onshore supply and winded and unwinded from the shore. As the vessel travels along its route, the cable is unwound and lies on the seabed. The other end of the cable is connected to the busbar in order to transform the transmitted power into propulsion and other electrically driven auxiliaries.

The ship ferry would be connected with 3 phase power as the requirements to power a ship are quite high. The cable would hold in it 3 live wires and a neutral wire to balance the system. The cable would be fully insulated so the current carrying conductors would be isolated from the sea water. The material of the cable casing has to be strong enough to withstand corrosion and forces imposed by the natural elements and the sea.

One of the challenges posed by this technology is that the vessel has to be big enough to carry its payload; in this case the passengers whilst at the same time not compromising speed and efficiency of operations. One has to keep in mind that the space saved from a lack of on-board machinery will mean higher passenger carrying ability. Another challenge comes up when the ship has to do the return journey. The cable has to be drawn back and winded which calls for a machine which develops the force to pull the cable back with the ship.

There has to be a means to clean the cable as it is drawn from the seabed as it might pick up undesired object from the seabed, most commonly mud and sand which would damage the sheaving mechanism.

Due to sea traffic, the cable has to be kept slack and has to be heavy enough to lie on the sea bed as the ferry moves apart. This problem is partly solved by making the onshore connection deep in the water so the cable is naturally drawn downwards as the ferry departs.

On the other hand, this concept has the advantage of being already used in cable laying and thus the system has been tested and proved to work to a certain extent. It is also relatively simple to install as there is no need for new infrastructure to accommodate the system. The cable and sheaving system might be expensive but when compared to the cost of installing a new diesel engine, the argument might turn into an advantage. The maintenance work involved in such system is not too demanding as the only added components are the sheave which is a rugged component and the cable which would be inspected periodically as it is highly undesirable for cracks to propagate which leads to water entering the electrical system.

4 Ferry Services

This section of the project presents the research done on ferry services currently operating around the globe. This study was done with the intention of learning the types of problems ferry services are encountering and also with the aim of finding a location which would suit our needs to implement our idea of a ferry service.

The ideal target location was a short ferry crossing situated in a metropolis area where the ferry service is a popular choice of transport and thus new investment in the system would be considered. A metropolis area located in a developed country was our main target as the current trend of developed countries is to cut emissions, and the aim of this project fits that description; that is, decrease pollution to a target of no emissions. Such areas would be ready to be ready to go the extra mile in the sense of a financial investment, in order to implement a clean means of transportation in the heart of the city. A short ferry crossing in sheltered waters is preferred as it eases the implementation of this innovative idea. If such an idea works, the same technology can be adapted to face new challenges posed by a longer route and maybe rougher seas.

The table below shows details of various popular ferry services selected from different continents and then we narrowed our choice to four candidates which can fit our cause.

The search was narrowed down to four options namely Victoria Harbour, Hong Kong; Istanbul, Turkey; Auckland, New Zealand; Vancouver harbour, Canada. A deeper study was done on these locations to enable an informed decision to be taken concerning which port is the best for applying such technology. The criteria governing the research were; weather conditions, water conditions, sea traffic, physical barriers and wind speed. These factors could help in deciding which technological system, from the above mentioned, would be most suitable to implement.

ASIA						
	Route	Distance (APPROX)	Total Travel Time (APPROX)	Passenger/Day (APPROX)	Passenger/Year (APPROX)	Number of Trip/Day or Week
CHINA	Victoria Harbour to Hong Kong Island	3 km	9.1 min	20,000	26 million/year	147
	Tsim Sha Tsui to Wan Chai Ferry Pier	1.60 km	6 min	30,000	N/A	N/A
	Hong Kong Ferry Pier to North Point Ferry Pier	1.30 km	6 min	35,000	N/A	N/A
MALAYSIA	Sultan Abdul Halim to Raja Tan Uda	13.5 km	25 min	10,847	3.9 million/year	N/A
	Erusakum to Willingham Island	1.34 km	6 min	10,000	N/A	N/A
	Erusakum to Bulgatty	3.1 km	10 min	8,000	N/A	N/A
INDIA	Willingham Island to Bulgatty	2.23 km	7 min	10,000	N/A	N/A
	Edinburgh to Old Boat Jetty	0.97 km	4 min	N/A	N/A	N/A
	Bangkok and Hanoi	Different Distance between each Pier	6 to 10 min	6,000	N/A	N/A
PHILIPPINES	Cebu to Mactan Island	4.47 km	15 min	7,000	N/A	N/A
AUSTRALIA & NEW ZEALAND						
AUSTRALIA	Bay Islands Transit	10 km	N/A	N/A	N/A	40
	Darwin (North Strandbrook Island) to Cleveland	13 km	N/A	N/A	N/A	16
	Circular Quay (Sydney) - Neutral Bay	3 km	N/A	12,000 - 15,000	N/A	30
	Circular Quay (Sydney) - Taronga Zoo	3 km	N/A	13,800 - 25,000	N/A	25
	Queensdill - Sorrento (Melbourne)	5 km	N/A	N/A	N/A	14
	Barack St Jetty - Merews St Jetty (Perth)	2 km	N/A	N/A	N/A	40
	Kangaroo Island Seafork	20 km	N/A	Up to 10,000	N/A	4
	Foster Island Ferry	6 km	N/A	N/A	600,000	6
	Auckland - Stanley Bay	2 km	N/A	100/ one trip	N/A	11
	Auckland - Northcote Point	3 km	N/A	N/A	N/A	20
NEW ZEALAND	Auckland - Hukeruaud	5 km	N/A	N/A	N/A	20
	Auckland - Devonport	3 km	N/A	N/A	N/A	35 - 40
EUROPE						
SWEDEN	Färösund to Breda	1.3 km	N/A	N/A	N/A	15-20
	Sweden to Denmark	4.3 km	N/A	N/A	N/A	15-25
FINLAND	Moskova (Northwade) to Njorki (Helsinki)	0.940 km	N/A	N/A	N/A	50
	Bergö (Helsinki) to Brändö (Brändö)	1.75 km	N/A	N/A	N/A	50
	Juonoo (Juonoo) to Aava (Grands)	2 km	N/A	N/A	N/A	20
ITALY	Carloforte (San Pietro) to Calasetta (Sardinia)	6.85 km	N/A	N/A	N/A	7
	Sorrento to Capri	15.6 km	N/A	N/A	N/A	4
	Portofino (Sardinia) to Carloforte (San Pietro)	9.57 km	N/A	N/A	N/A	13-17
	Tripoli (Sardinia) to Fregene	19.4 km	N/A	N/A	N/A	5 to 13
	Portofino (Sardinia) to Portofino	30 km	N/A	N/A	N/A	11 to 20
	Messina (Sardinia) to Villa San Giovanni	8 km	N/A	N/A	N/A	25
	Carallole to Ecosat	5.22 km	N/A	N/A	N/A	21
	Topofar to Ecosat	8.4 km	N/A	N/A	N/A	30
	Gelbdu to Lupta	6.42 km	N/A	N/A	N/A	40
	Pavali to Yalova	24.47 km	N/A	N/A	N/A	11 to 13
MALTA	Migam (Gozo) to Għolwewa (Malta)	6.08 km	N/A	N/A	N/A	26
CROATIA	Ilkon (Parsani) to Biograd	2.58 km	N/A	N/A	N/A	8 to 13
	Portofino, Cres to Brestova	6 km	N/A	N/A	N/A	8 to 14
SPAIN	La Savina (Formentera) to Eivissa (Ibiza)	20 km	N/A	N/A	N/A	6 to 20
AMERICA						
Hudson River, NY	Manhattan to Staten Island	8.36 km	25 min	20,000	N/A	104
	Manhattan Liberty Island - Ellis Island	2.57 km	15 min	9,000	N/A	18
	Manhattan Sandy Hook		60 min	5,200	N/A	13
California	W.C. Paulsen Hook		7 min	N/A	N/A	117
	San Francisco Sausalito		25 min	N/A	N/A	9
	San Francisco Alameda Oakland		25 min	4,656	N/A	12
	San Francisco Alcatraz Island	1.207 km	15 min	215	N/A	16
	Ilbuan Angel Island		10 min	1368	N/A	4
	Seattle - Bremerton	24.94 km	60 min	37,500	N/A	15
Washington, WA	Seattle - Bainbridge Island	13.64 km	35 min	57,300	N/A	23
	Edmonds - Kingston		30 min	22,000	N/A	26
	Point Delance - Tahlequah	2.73 km	15 min	10,920	N/A	20
Vancouver, Canada	Horseshoe Bay Bowen Island	1.93 km	20 min	6930	N/A	15
	Vancouver - North Vancouver	3.23 km	12 min	19,250	N/A	50

Figure 6: List of Potential Locations

4.1 Victoria harbour, Hong Kong

Victoria harbour is one of Hong Kong's busiest ports, it caters for a lot of sea traffic whilst still serving as a tourist attraction. The harbour is situated between Hong Kong Island and the Kowloon Peninsula and the area is catered by Star Ferry service, a very popular operator, placing high with the top ferry services around the world.

Victoria harbour sees all kind of international sea traffic passing by the Star Ferry Service Terminal, namely bulk carriers, passenger vessels, tankers, yachts and container vessels. This can restrict some of the technology described in the previous section. For example passing an overhead cable would not be feasible for such a location as it would restrict large vessels from passing underneath. The area is however sheltered which would be favourable for our applications. The speed of wind is usually between 5 to 9 knots, which is considered to be relatively low and thus should not disturb any of the technological systems discussed. The busy nature of the port also promotes the cable laying option as this would minimise restriction of sea traffic across the waterway.

Pollutant	Contribution of Maritime Emissions to Total Territory-wide Emissions			
	Ocean-going Vessels	River-trade Vessels	Domestic Vessels	Total
RSP	21%	4%	5%	31%
SO ₂	19%	3%	2%	23%
NO _x	12%	6%	8%	27%

Figure 7: Marine Emission Statistics in Hong Kong [9]

According to the research carried out by the government of Hong Kong, OGVs run on residual oil, which is a low grade fuel with Sulphur content as high as 4.5%, having an average of 2.8% sulphur content. River-trade vessels (RTVs) and domestic vessels (DVs) working between Hong Kong and neighbouring cities use light diesel oil which has a nominal sulphur content of 0.5%. These sulphur contents are 2,800 times and 500 times higher than the sulphur content in fuel used by motor vehicle (0.001%) respectively. [9] Hence, emissions from vessels are a significant source of air pollution in this area. In 2008, the contribution of maritime emissions to Hong Kong's total territory-wide emission was as seen in Figure 7:

4.2 Istanbul, Turkey

The second location considered was Turkey, Istanbul. The depth of Bosphorus varies from 36 to 124 m in midstream having an average depth of 65 m. The deepest location is between Kandilli and Bebek at 110 m. The shallowest locations are off Kadıköy İnciburnu, situated on the northward route with 18 m and off Aşiyan Point, found on the southward route with 13 m depth. The passage from the Black Sea to the Aegean Sea is carried out in 164 nautical miles by the Istanbul strait, the Marmara Sea, and the Çanakkale strait. These straits are very sinuous, often narrow, and effected by strong and complex currents. The strait of Istanbul is subjected to strong northerly winds, rain and dense fogs particularly during spring and autumn. The weather conditions can change so quickly that a ship entering the strait by cloudy sky can be suddenly in a thick fog, with no visibility. The wind speeds are between 5 to 20 knots or more than that sometimes. Although Istanbul is a metropolis area, the weather and sea conditions are not favourable for implementing the technological projects. [10] [12]

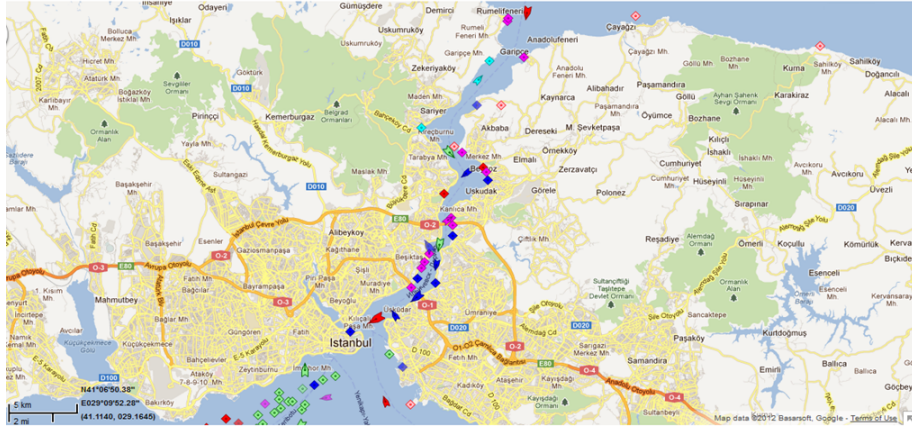


Figure 8: Istanbul, Turkey [11]

4.3 Auckland, New Zealand

The main ferry terminal in Auckland is positioned between a large marina and a port where a number of merchant vessels regularly berth. The port of Auckland caters for over 1400 ships from 176 international ports coming from 69 different countries every year. Some conflict may arise between the routes that could currently be adopted for the use of the electric technology, in particular yachts with large masts that will determine the height that an overhead cable will have to be set at. [13]

The marina caters for commercial vessels, pleasure craft and super-yachts with 150 marina berths ranging in size up to 60 metres. In addition to this, occasionally large merchant vessels can moor in the deep waters of Waitemata harbour presenting another factor to be considered in the determination of which technology is best to apply. Cruise ships also berth at the port of Auckland, with a ships arriving approximately 20 times per month and staying for one day. Well-known cruise ships to call at the Port include Queen Mary 2, one of the largest passenger ships ever built. The cruises berth at Princes Wharf which is just east of the main ferry terminal. This means that the cruise ships will need to pass directly through the routes that the proposed new ferry would operate on. [14]

Taking the Queen Mary 2 as our example, as it is probably one of the largest ships operating in the area, it is 72m in height from the keel to the top of its funnel, meaning that with a draft of 10m it sits 62m above the water. This effectively removes the ability to use overhead cables due as it would not be feasible to have the cables that far above the ferry.

The only physical barrier other than sea traffic is the Auckland harbour Bridge that would cut across the routes from the main ferry terminal to the ferry terminals at Birkenhead and Northcote Point. The bridge rises 43.27m above the water to allow ships to pass beneath it that need to access the Chelsea Sugar Refinery. [15]

The average wind strength in Auckland on a monthly basis is between 9 and 13 knots, a relatively manageable strength. In addition to this, the wind usually comes from the south west, making most of the routes in question fairly sheltered and meaning that sea conditions should not present a problem. Due to Waitemata harbour being an enclosed bay with the entrance between Westhaven and Northcote Point, strong tidal flow may prove to be a difficulty in implementing the different forms of technology such as the cable laying technology. There is an average water height increase of 3 to 3.5m as the tide floods and ebbs. [15]

4.4 Vancouver harbour, Canada

Vancouver harbour is a sheltered port having only one opening to the Salish Sea on the west. This opening is known as the Burrard Inlet and is only 1 mile in width at its narrowest point.

According to Port Metro Vancouver, which is the company in charge of the port, the port of Vancouver is a very busy port making it Canada's biggest and busiest ports and placing 4th in Northern America for the largest port by tonnage. The Port of Vancouver trades around \$75 billion worth of goods annually. The port has virtually no draught restrictions due to its deep sea terminals which makes it a popular destination for big merchant vessels. The port caters for four different types of business namely ro-ro ferries carrying automobiles, break-bulk carriers, bulk containers and cruise liners. [16]

The only physical barrier to marine traffic is a limit on the height of the ships passing. This is because of the Lions Gate Bridge which connects the city of Vancouver to the North Shore. The bridge lies on the narrowest point of Burrard Inlet which is the only way in the harbour. It has a ship clearance of 61m which is more than enough for merchant ships and will only restrict large cruise liners from passing.

A study conducted by James. L Galloway of the Canadian Hydrographic Service states that: "Water depths ranged from near drying line to 60 meters and included all wharf and jetty areas". The winds across the Vancouver region consist of westerly winds from the Strait of Georgia (which is the area just outside the Burrard Inlet) outflow and easterly winds from Howe Sound and the Fraser Valley, and southerly winds from the Juan de Fuca Strait and Puget Sound. The easterly winds occur most frequently, but some of the strongest winds are from the west. The wind speeds in this area are between 5 to 15 knots which is relatively calm. [17]

Vancouver was chosen to be the best location at which the project could be implemented for a number of reasons discussed below. At first thought, Vancouver looked like a busy port but this did not affect the already present ferry crossing as it was located inwards in the port area where only few vessels cross. The deep seaways which are frequently dredged also provided an opportunity for the cable laying project. The report by Galloway also pointed out that the seabed is smooth mainly made up of sand, silt, pebbles and gravel, which further pointed us towards the cable laying technology. [17] The final decision was to choose between overhead and cable laying technology and the overhead was eliminated from the race as it would restrict the waterways, create a potential eyesore, and also needed heavy infrastructural investment.

Vancouver further proved to be the ideal location as the local community is always striving for a cleaner environment. This was evident by various decisions taken by the port authority namely the voluntarily call to the IMO to become a Emission Control Area, in 2009. This became reality in 2010, when Vancouver became an ECA under MARPOL. The port has also implemented a 'Clean Air Strategy' which is a scheme which rewards ocean going vessels given that they minimise their emission while in port. [18]

The port of Vancouver strongly encourages vessels to use cold ironing. This means that a vessel switches off the on-board engines and draws power from the cold ironing facility situated on land. This also offered an opportunity for our project. Since the port already offers cold ironing facilities, boasting a maximum power output of 28MW, it should be fairly easy for our vessel to be powered by the same source. This should not disrupt the system as the ferry to be discussed later on only consumes 1.5MW. [19]

The port authority also goes out of its way to promote the use of clean fuel by offering financial incentives which reach \$4,400, to berthing vessels in the form of discounted harbour dues. This clearly shows the desire of the port authority to create a cleaner environment in their port. A presentation given by Port Metro Vancouver also encourages the private sector to invest in green technology by offering financial help for acceptable projects proposed.

The project target is to apply our technology to the already functioning ferry service, connecting the City of Vancouver to North Vancouver. The ferry service is operated by Translink, which is a governmental subsidiary company operating all the transport services in Vancouver. This further encouraged engagement in this project, as it would be possible to convince one ferry operator to invest in a new system which promises a zero emission rate, knowing that the company is not private but state owned. The ferry service covers 50 crossings daily, carrying a maximum of 19,250 passengers per day over a distance of two miles.

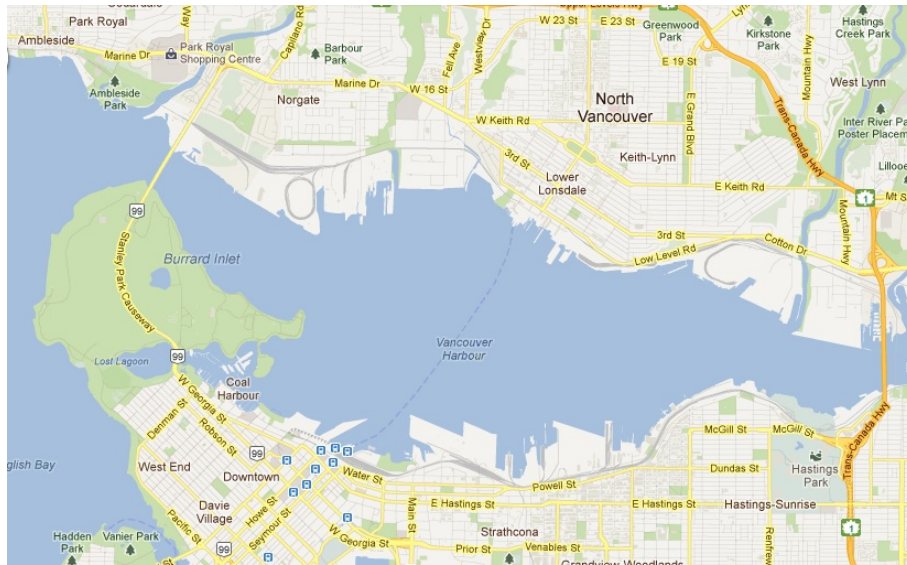


Figure 9: Vancouver harbour [21]

5 System Design

5.1 Electrical Power Transmission

This part of the report focuses on different options in which power can be transmitted from an onshore supply to the ferry. As it has already been discussed, the location of this project is going to focus on the port of Vancouver due to its various advantages which make it easier for the system to be implemented. The Port of Vancouver offers the facility of cold ironing to visiting cruise ships. The facility can cater for two ships at once offering up to 14MW of power, which should be more than enough for this system as it will draw less than 2MW. The power from the shore can be transferred either at 6.6kV or at 11kV. [19] Transferring at higher voltage means lower currents are drawn, thus less energy losses are dissipated since $P_{Lost} = I^2 R$. Despite this fact, it was decided that the power would be transferred at 6.6kV as this would reduce the size and cost of the transformer on board. Also, the power is going to be transferred over 4km which is a relatively short distance which would not cause a big power loss. The section below shows the different options for electrical distribution once the power is transferred on-board the ferry.

5.1.1 Option A

The power is transferred to the vessel at 6.6kV. It is divided between Distribution Board (DB) 1 and 2, catering for the propulsion and hotel services respectively. The power is transferred to two transformers connected in parallel, which drop the voltage from 6.6kV to 440V. This parallel arrangement provides redundancy to the whole system in case of a fault occurring in one of the transformer. DB1 feeds four propulsion branches, from the transformers which provide power at 440V. This power goes into the inverter drive which implements a Pulse Width Modulator (PWM) scheme to set the frequency and the magnitude of the voltage input to the induction motors which power the fixed pitch propeller. The frequency is changed by the PWM, in order to provide a different speed to the motor which is reflected in the speed of the propeller. DB2 is connected to the same set of transformers which supply power at 440V to the hotel services and other auxiliaries. [21]

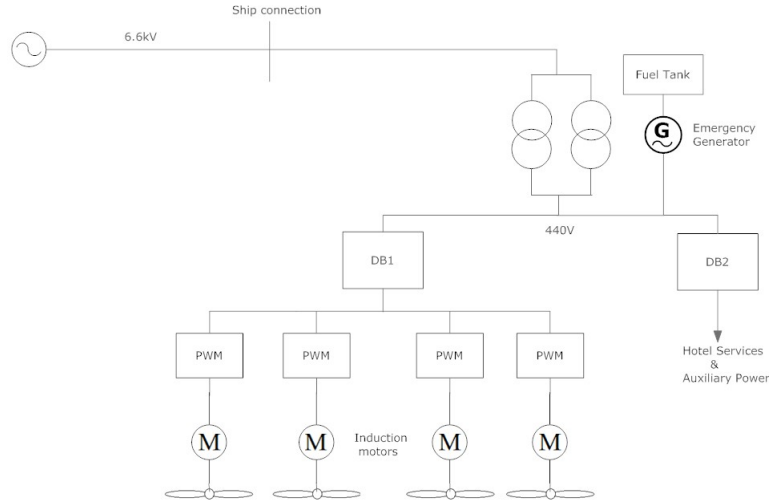


Figure 10: Electrical Arrangement A

5.1.2 Option B

In this system, the power is also transferred at 6.6kV to DB1 and DB2 which provide for propulsion and hotel services respectively. DB1 is connected to a set of delta-star transformers connected in parallel again to provide redundancy to the propulsion system. These transformers drop the voltage from 6.6kV to 440V. The current at 440V is used to run synchronous machines which then turn the propellers. Starter motors are also needed to support the synchronous machines as synchronous machines are not self-starting. For this kind of arrangement, controllable pitch propellers had to be fitted in order to change the speed since the synchronous motors only run at synchronous speed as opposed to the induction motors which are able to vary the rate of rotation. The advantage of this system is that the transformer system is much smaller, simpler and thus cheaper compared to the PWM systems used in Option A. The downside is that the ferry has to be fitted with controllable pitch propellers which increase the cost of implementation. DB2 works on the same principle as in Option A. It is connected to a transformer which drops the voltage to 440V, providing the hotel services and auxiliary with 3 phase AC power. [21]

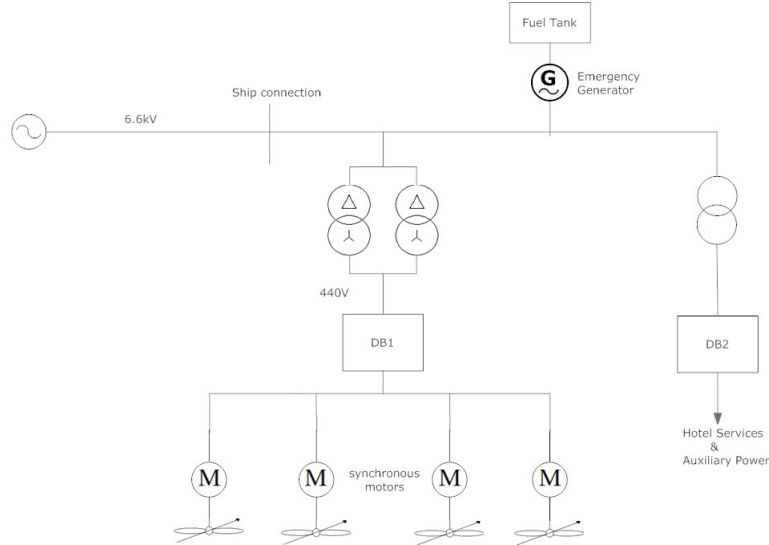


Figure 11: Electrical Arrangement B

5.1.3 Option C

This third option looks at the possibility of DC transmission. The power taken from shore is AC power at 6.6kV, which is rectified into AC using a rectifier situated onshore. The MVDC power is transmitted to the ship into DB1 and DB2. As seen in the other systems, DB1 feeds four branches for propulsion power and DB2 caters for the auxiliaries and hotel services. DB1 transfers the power to an inverter at each motor which converts the power back to AC, drops the voltage to 440V and sets the frequency needed by the motor. The 440V AC power is fed to an induction motor which runs a fixed pitch propeller. The speed of the fixed pitch propeller is governed by the variable frequency provided by the inverter which provides variable speed to the induction motor. [21]

DB2 is also connected to an inverter which turns the rest of the power back to AC and drops the voltage to an operation level of 440V which is fed to the hotel and auxiliary machinery. The advantage of transmitting DC power is that more power can be transferred at the same voltage and current ratings since $P_{DC} = \sqrt{3}P_{AC}$ thus a smaller, two core cable can be used which would reduce the cost of the cable when compared to the three core cable used in Options A and B. The drawback of using such a system comes when converting MVDC back to AC which requires costly and bulky convertor equipment on-board. [21]

The system chosen to be implemented on the Vancouver ferry system is the one discussed in Option A. Option B was dropped due to the need to fit four new controllable pitch propellers. The idea is to keep the design loyal to the original one as to reduce the cost, which is why Options A and C are preferred since they would use the existing fixed pitch propeller. Option C was later discarded due to the high cost of the inverters to be fitted on-board the vessel which outweighed the reduction in cost of having a two core wire instead of three needed to transmit AC. These inverters are needed to convert HVDC back to AC since the motors run on alternating current. Option A prevailed since it is a viable system and comes at the cheapest cost compared to the other options discussed.

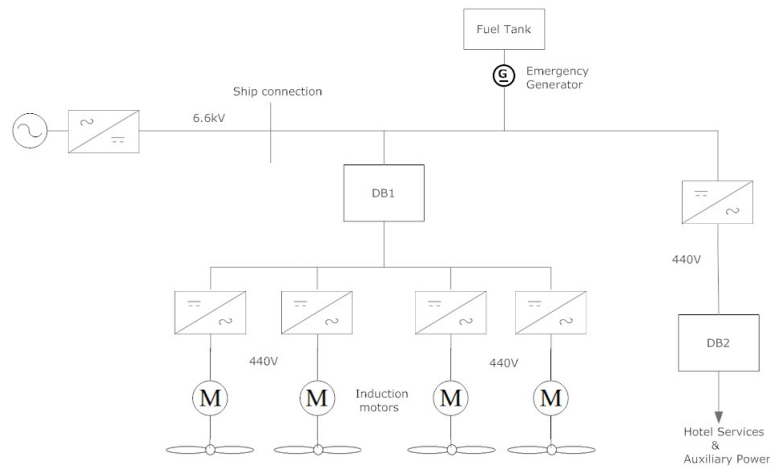


Figure 12: Electrical Arrangement C

5.2 Cable Technology

One of the key considerations when designing the system was devising a way to minimize the amount of additional technology that was required on the vessel. The reason for this is that more on-board equipment requires more space and hence effectively reduces the additional passenger carrying capacity the ship has generated through the removal of the main engines. This in turn reduces profits made by the ferry operators, countering one of the basic objectives this project intends to achieve. As outlined in the previous section, a system loosely based on cable laying technology was devised as a method to provide the vessel with the electric power required from an on shore source.

The key difference of the system that this project intends to implement is that the cable reel will not be operated from on-board the ship, but from a shore mounted reel of similar design to those widely used in the cold ironing process in ports. The advantage of this is not only the space saving as outlined above, but there will be improved ease of maintenance, ability for a much more robust method of cleaning the cable and the availability of the on shore power supply to drive the motor required for the reel operation. Naturally, this form of the system will also come with its disadvantages. This will primarily be the restricted ability to effectively lay the cable on the seabed on the outward journey. With a cable laying vessel, the speed of the ship and in turn the rotation of the cable drum will effectively determine the rate at which cable is laid on the seabed. With these industrial vessels, speed is not as important as the ability to lay the cable accurately and securely on the seabed. This however will not be the primary objective for the ferry, as passengers need to be transported across the city quickly and efficiently to ensure repeat business. [22]

The figure below offers a brief schematic of the basic operation of the system. The cable reel will be secured onshore with cable being run from it down the quay to the seabed. Initially it was thought that this would be secured only to the bottom of the quay, however it was identified that there may be an issue with tension in the cable creating a shallow plane of cable across the harbour and not fully sinking to the bottom. This would cause an obstruction to sea traffic operating in the harbour with large draughts. Therefore as a solution to this it was determined that by fastening the cable to a point on the seabed at a greater depth, the angle created by the cable would be much steeper, allowing other vessels to pass much closer to the ferry. [22]

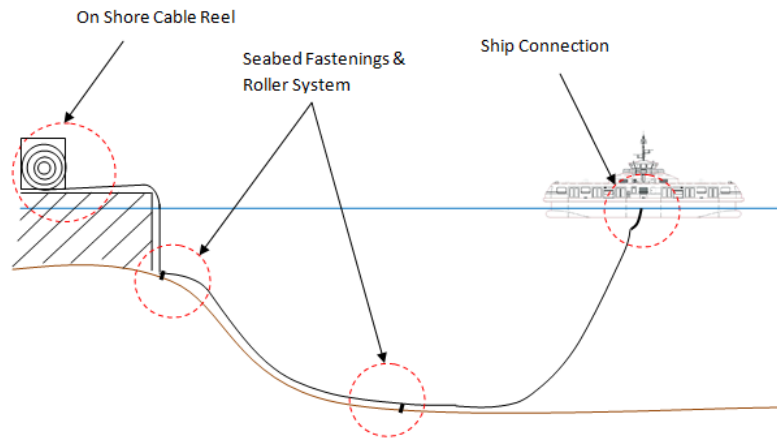


Figure 13: Basic Cable Schematic

The following section will focus on the analysis of the different off ship components required to enable the system to operate effectively. This will not be as detailed as the design of the electrical system itself, but will offer a number of solutions to the varying issues that have been identified. Much of this will be based on existing technologies or a proposed adaption of these.

5.2.1 Ship Connection

This is a vitally important aspect of the design as failure of the main connection will mean that the ship will have to run on its redundancy generators. Therefore a secure, reliable connection with a degree of flexibility must be designed to be able to withstand any scenario that arises with the ship. There were a number of design constraints that were required to be considered when designing this component:

- Avoidance of ships propellers – Ensuring that the cable is connected well clear of the four propellers and a depth to ensure trailing cable cannot drift onto the propellers.
- Avoidance of other sea traffic – Creating a great enough laying depth to allow large draught ships to pass easily.
- Tension control of the cable – Prevention of large tension forces in the cable as the ship motion creates unexpected surges.
- Ease of replacement – Minimizing heavy fixings to ensure that maintenance or replacement can be easily implemented.

Taking these factors into consideration allowed the development of a potential design that ensures that both the safety and operational aspects are met and the ship connection will be able to perform its function with the greatest efficiency.

5.2.2 Distribution Board Connection

For ease of maintenance, it was decided that the most effective way to connect the cable end would be using the same method as is used in the cold ironing process, through a socket connection. The reason for this is that it allows for the potential of numerous onshore cable reels to be installed onshore and then used as required. This would mean when one cable needs routine maintenance or unexpected repairs, another could be quickly and easily fitted to the vessel

to minimize the downtime incurred and hence the loss of profits. To ensure the connection remains in place, a section of the cable will be clamped in place.

A typical connection that could be used would be the Cavotec AMP (Alternative Marine Power) high voltage power connector. These are commonly found connectors in many cold ironing setups. The connectors are available in either 7.2kV or 12kV connections. As this system is based on a 6.6kV onshore power supply infrastructure currently available at the Port of Vancouver, the 7.2kV connector would be the most suitable connector to use. A designer drawing of the connector is shown below:

Although Cavotec have designed the connector to ensure that it will not disconnect under load conditions, as an additional safety measure the cable itself will be securely fastened to the ship's hull. See Appendix A for a more detailed specification on the socket connection. [23]

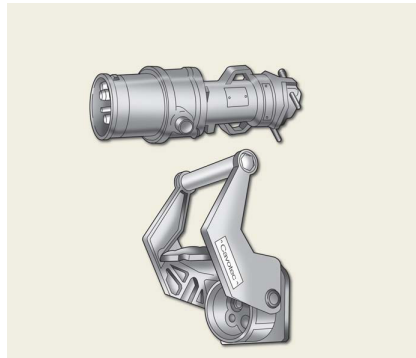


Figure 14: Cavotec AMP high voltage power connector [23]

5.2.3 Tension Control

Another important part of the ship connection is the tension control system in place to cope with any unexpected movements on the ship. Naturally due to the setup of the system, the ship will impart some force on the cable to drag it along on the outward journey. This is one of the main disadvantages of not having the cable laying equipment on-board the vessel. This however can be easily managed by ensuring there is adequate cable to be pulled through maintaining good control of the onshore cable reel. In addition to this, the vessel itself will have a small reel that will effectively act as a suspension unit. This will contain a small amount of cable, approximately 20m in length to ensure that if a situation arises when there is a sudden movement of the ship, the reel will be able to maintain slack in the cable and then retrieve this as the vessel returns to its normal condition.

5.2.4 External Cable Housing

To solve the issue of cable contact with the ships propellers and the trailing cable impeding large draught vessels, some form of extension from the ship's hull will be required to house the cable and ensure it is sufficiently submerged at an adequate depth. This will essentially be a small, curved sheath that will extend from the middle of the ship to a depth of approximately 5 meters below the waterline of the vessel. As the vessel is a catamaran there will be no need for this to be watertight as sheath will penetrate the main body of the hull sitting above the waterline. It will be important for this to be designed in as hydrodynamic as possible to minimise the additional drag that will be created by this sort of structure.

5.2.5 Seabed Fastening and Roller System

As outlined earlier, this is a key consideration that will allow for unrestricted, effective operation of the vessel when using a shore based cable reel. It is important that this is selected to be implemented at the correct depth and distance from the shore to ensure that the restricted distances that ship's may pass behind the ferry is minimised and does not cause issue for the majority of the sea traffic in the area. In addition to this, there must be a system in place that will feed the cable onto the seabed at a sufficient rate that will exceed the speed of the vessel and ensure that no tension is caused to restrict its operation.

5.2.6 Final Fastening Position

It is known from section 4.4 of the report that the seabed in Vancouver harbour has a maximum depth of 60m with a width of 3.3km where the ferry operates. Assuming the final fastening is at the maximum depth, at a distance of 500m from the terminal where the cable reel will be housed, the available draught can be calculated from simple trigonometry. Under these conditions, the worst case scenario for ships passing behind the ferry will occur when the ferry has just completed its crossing.

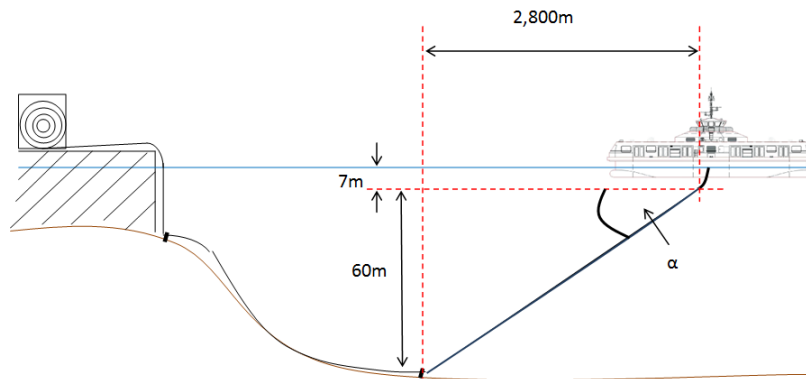


Figure 15: Trigonometric calculation of ship distance

Sheath Depth	7	M
Fastening Depth	60	M
Distance Travelled	2800	M
Angle of Cable	0.0189	°

Distance Aft of Ship (m)	50	100	150	200	250	300	350	400
Clearance of Cable (m)	7.95	8.89	9.84	10.79	11.73	12.68	13.63	14.57

Figure 16: Aft Clearance of Cable at Max Distance across Channel

Sheath Depth	7	M
Fastening Depth	60	m
Distance Travelled	1150	m
Angle of Cable	0.0461	°

Distance Aft of Ship (m)	50	100	150	200	250	300	350	400
Clearance of Cable (m)	9.30	11.61	13.91	16.22	18.52	20.83	23.13	25.43

Figure 17: Aft Clearance of Cable at Mid-point of Channel

From the above tables it will be possible to provide the worst case condition of the cable restricting sea traffic to the port authorities to ensure that vessels operating in the channel are adequately warned of the distances behind the ferry that their draft will be unable to safely manage. In reality, the rate at which the cable is fed out of the roller system will be greater than the speed of the ship and therefore the weight of the cable should allow for an amount of slack in the cable that will increase its depth below the water surface.

5.2.7 Feeder and Fastening System

There were a number of possibilities for the feeder/fastening system used underwater to distribute the cable. Initially it was proposed that it be modelled on the linear cable system used on board ships which consists of a motor driving a number of ‘rubber tires’ that grip the cable and are able force it out and subsequently retrieve it. This however would require additional power for the motor and also came with a number of complications of installing such a piece of equipment underwater and the cost and maintenance implications of this. To overcome this issue it was decided that the same piece of equipment would be installed on land and feed the cable into a casing that contains a large amount of free moving, ball bearing rollers that will minimise the resistance of the cable passing through the casing. The casing itself would then be fastened at a number of points on the dock and the seabed, with the casing extending the 500 metres to the final fastening depth of 60m.

5.3 On Shore System

There are numerous components required to make up the on shore system. Due to much of the cable technology required for the system being positioned on land for ease of maintenance and operation, the system can be modelled on that of a cold ironing setup as opposed to that of a cable laying vessel. As with the previous areas of concern, the system will be split into the individual components deemed to be required for operation.

5.3.1 Cable Reel and Motor

Commonly on cable laying vessels, cable drums or turntables are used to house the vast quantities of cable that are required to be laid over long distances (for example transatlantic cables spanning from the UK to North America). The total distance of the crossing between the two Vancouver ferry terminals is only 3.3km, a significantly lower amount of cable is required by the ferry. Considering a safety factor and the setup of the seabed fastenings it was estimated that 4km of cable would be needed to allow for slight variations in the ship course and other unforeseen events. To manage this, a magnetic drive motor driven cable reel could be used which will include all the components required to operate the reel accordingly. The modular components used for this are:

- Electric motor
- Magnetic coupler
- Main gearbox
- Secondary gearbox
- Additional gearbox
- Slip rings and rotary joints
- Cable spools (with the option for dual spools)

This is based on the specification of some alternative maritime power supplies from a company called Conductix and their ‘Mag Drive Technology’. This is currently used worldwide however primarily for cold ironing or on land industrial uses. The application is generally for a lower cable length and slower distribution/retrieval rate, however as for the purpose of this project, since the technology is land based there is no size or weight restriction on any of the components so technology should be capable of being scaled up to a suitable size for the purpose required. It will be important to make the components more robust to deal with the harsh environment and frequent operation of the reel. See Appendix B for a more detailed specification of the Conductix cable reel

technology. Cavotec also supply alternative marine power technology of this nature, however the same issues apply regarding size and durability. [24]



Figure 18: Conductix Mag Drive Motor Cable Reel [24]

5.3.2 Cleaning Equipment

Due to large lengths of the cable frequently being submerged and then retrieved from the seawater of Vancouver Bay, it is important that the cable is thoroughly cleaned when it is removed from the water. This is important to remove the sand, brine and associated organisms that may have attached to the cable when it is being reeled in.

The cleaning equipment will be a simple setup consisting of motorised rotating brushes that will be constantly fed with freshwater to clean the cable and remove the impurities. This should keep the cable in good condition and prevent deterioration of the insulation and casing. This will also avoid damaging any of the cable reel components outlined above.

5.4 Electrical System Components

Power Requirements

For the sake of simplicity, this project is going to keep the same vessel used by the TransLink Seabus and just replace the diesel engine arrangement with the electrical design proposed as Option A. Since the hull and propellers are unchanged, the vessel is going to experience the same level of resistance and thus needs the same amount of power to run at the design speed. The power for the Seabus was provided by a total of four diesel engines, producing 300kW for each propeller and two auxiliary generators accounting for the hotel services and auxiliaries, producing 99kW a piece. [25] This accounts to a total of 1.4MW.

Make and model:	MTU/Detroit Diesel Series 60
Power:	Maximum continuous rating (MCR), 300kW
R.P.M:	At maximum continuous rating, 1800
Fuel:	No. 2 diesel (also suitable for Biodiesel)
Fuel consumption:	At maximum continuous rating, 215 gallons/kW hour maximum
Emission certification:	US EPA Tier II or better
Dry Weight:	1,700kg maximum

Figure 19: Properties for MTU/Detroit Diesel Series 60 Main Engine [25]

Make and model:	Northern Lights M99C2 series
Generator rating (prime power):	99 kW minimum
Prime mover rating (continuous):	To suit generator
Speed:	1,800 rpm
Ignition cycle:	4 stroke
Fuel:	No. 2 diesel (also suitable for Biodiesel)
Fuel consumption at maximum continuous rating:	45 litres/hour max
Emissions certification:	US EPA Tier II or better
Dry weight including sub base:	1,500 kg maximum

Figure 20: Properties for Northern Lights M99C2 Series Auxiliary Generators [26]

5.4.1 Cable Design

The cable chosen for the transfer of electrical power from shore to the vessel is an Armoured Medium Voltage Power Cable MV-FHFX/A (FE4H1OAM1) 6/10 (12) kV. This cable is produced by Prysmian, an Italian based company specialising in cable manufacturing for energy transmission and telecommunications. The ferry covers a distance of 3.24km and since the cable needs to lie on the sea bed and be kept slack, 4km of cable will be delivered.

Design Criteria

Prysmian offer a selection of different sizes of cables making up the Armoured Medium Voltage Power Range. This section discusses the criteria by which the cable was selected backed by calculations that determine the current at which the power is transferred whilst taking into account the power lost along the cable.

Size (n x mm ²)	Conductor Diameter approx. (mm)	Core Diameter approx. (mm)	Inner Cover Thickness approx. (mm)	Braid Diameter approx. (mm)	Diameter approx. (mm)	Cable Weight approx. (kg/km)
3x35	7,5	17,0	1,2	41,0	46,0	3460
3x50	8,7	18,5	1,2	44,5	50,0	4010
3x70	10,3	20,0	1,2	47,5	53,0	4930
3x95	12,1	21,5	1,2	51,0	57,0	6060
3x120	13,6	23,0	1,2	54,0	60,0	7050

Size (n x mm ²)	Current rating at +45 °C ambient 1) (A)	Conductor Resistance R _{dc} (Ω/km)			Inductance L (mH/km)	Capacitance C (µF/km)
		at +20 °C	at +45 °C	at +85 °C		
3x35	104	0,524	0,575	0,658	0,357	0,221
3x50	130	0,387	0,425	0,486	0,341	0,242
3x70	160	0,268	0,294	0,337	0,321	0,277
3x95	194	0,193	0,212	0,242	0,307	0,309
3x120	225	0,153	0,168	0,192	0,296	0,340

Figure 21: Properties of Armoured Medium Voltage Power Cable MV-FHFX/A (FE4H1OAM1) 6/10 (12) kV [27]

Power required on board = 1.4MW Voltage transfer = 6.6kV

The minimum current transfer is 122.5A

$$P = \sqrt{3} \times I \times V$$

$$1.4 \times 10^6 = \sqrt{3} \times 6.6 \times 10^3 \times I$$

$$I = 122.5A$$

In order to have a power supply of 1.4MW, the current has to be at a minimum of 122.5A, given that it is transferred across 6.6kV. Due to the power dissipated across the stretch of cable, the current has to be more than the minimum value in order to account for these losses. Due to this factor a cable able of carrying a maximum of 130A was chosen.

Size (n x mm ²)	Conductor Diameter approx. (mm)	Core Diameter approx. (mm)	Inner Cover Thickness approx. (mm)	Braid Diameter approx. (mm)	Diameter approx. (mm)	Cable Weight approx. (kg/km)
3x35	7,5	17,0	1,2	41,0	46,0	3460
3x50	8,7	18,5	1,2	44,5	50,0	4010
3x70	10,3	20,0	1,2	47,5	53,0	4930
3x95	12,1	21,5	1,2	51,0	57,0	6060
3x120	13,6	23,0	1,2	54,0	60,0	7050

Size (n x mm ²)	Current rating at +45 °C ambient 1) (A)	Conductor Resistance R _{dc} (Ω/km) at +45 °C			Inductance L (mH/km)	Capacitance C (μF/km)
		at +20 °C		at +85 °C		
3x35	104	0,524	0,575	0,658	0,357	0,221
3x50	130	0,387	0,425	0,486	0,341	0,242
3x70	160	0,268	0,294	0,337	0,321	0,277
3x95	194	0,193	0,212	0,242	0,307	0,309
3x120	225	0,153	0,168	0,192	0,296	0,340

Figure 22: Properties of Armoured Medium Voltage Power Cable MV-FHFX/A (FE4H1OAM1) 6/10 (12) kV highlighting the chosen model

$$P_{lost} = I^2 \times R$$

$$P_{lost} = 122.5^2 A \times 0.387 ohm/km \times 4km$$

$$P_{lost} = 23.2kW$$

This value is the maximum power lost by the cable when transferring power at 122.5A as it is safe to assume that the temperature of the seawater in Vancouver never exceeds 20 degrees Celsius.

If the power is transferred at the calculated 122.5A, implies that the vessel will actually receive $1.4\text{MW} - 23.2\text{kW} = 1.38\text{MW}$, which is not enough for the vessel to operate at the design conditions. To correct the actual power available on the vessel, the current will have to be increased. The following calculations demonstrates the new current required to supply a net power of 1.4MW:

$$P_{gross} = \sqrt{3} \times I \times V$$

$$P_{net} + P_{lost} = \sqrt{3} \times I \times V$$

$$1.4\text{MW} + I^2 \times (0.387 \times 4) = \sqrt{3} \times 6.6 \times 10^3 \times I$$

This turns into a quadratic equation:

$$I^2 - 7260.13I + 904393 = 0$$

$$I_1 = 124.6A \quad I_2 = 7260.13A$$

The relevant solution given by the quadratic solution is 124.6A, which is enough to transfer a net amount power of 1.4MW. This also proves that the prysman cable of choice is suitable for this application as its limit is a maximum current transfer of 130A.

$$Weight.of.cable = 4010\text{kg/km} \times 4\text{km}$$

$$Weight.of.cable = 16040\text{kg}$$

5.4.2 Emergency Generator

One of the main aims of this project was to reduce the dependency of the ferry service on fossil fuels. Although the solution seems plausible it is not infallible as any fault in supplying the power onshore or transferring it to the vessel would result in the ferry being left powerless and helpless which is unacceptable. In the previous design there was no need for an emergency generator as the system had a high redundancy factor as it was powered by four different main engines and two separate generators. On the other hand, the new design lacks redundancy thus an emergency generator has to be included. The capacity of this generator is governed by SOLAS Regulation 42 and the class rules; for this project LR Main and Auxiliary Machinery - Propulsion and Steering Machinery Redundancy - Machinery arrangements Section 3 was used. Extracts of the regulations used can be found in the Appendix. [28]

Most of the regulations for passenger vessels found in SOLAS does not distinguish between ocean going cruise liners and the ferry in question which is a small coastal ferry operating in sheltered water. Thus most of the regulations seem too harsh and sometimes unreasonable such as the requirement to have 36 hours emergency lighting where the crossing being discussed only takes 20 minutes in normal operation. [29] In such cases, exemptions are given by the IMO where the regulations are altered to the applied scenario. In this case, an assumption was made that the emergency provisions are going to cater for 5 hours.

The emergency generator will supply the full load for hotel services and auxiliaries since customer satisfaction is paramount in the passenger ferry industry. On the other hand, the propulsion capability is going to be reduced to half the load of two propellers which is still in line with Lloyd's Rules, and should only delay the trip by a couple of minutes until the ferry is in the pier and maintenance work can take place.

$$\text{Emergency Generator Capacity} = \text{Hotel \& Auxiliary Services} + \text{Propulsion Load}$$

$$\text{Hotel \& Auxiliary Services} = 99kW \times 2$$

$$\text{Hotel \& Auxiliary Services} = 198kW$$

$$\text{Propulsion Load} = 50\% \times 2\text{motors} \times 300kW$$

$$\text{Propulsion Load} = 300kW$$

$$\text{Emergency Generator Capacity} = 198kW + 300kW = 498kW$$

The generator used to provide the 498kW in the case of an emergency, are two Volvo Penta D9 MG marine genset engine (D9 MG/HCM434E). The generator complies with the level of emissions of EPA Tier 3. This generator has lower fuel consumption relative to other ones making it more feasible for the operation of the ferry in the long run. Added to these advantages it has a reduction in noise level which makes it ideal for the passenger industry. [30]

At 50% of power requirement; the fuel consumption is 218gr/kWh. Therefore for 5 hours continuous running the generator will require:

$$218gr/kWh \times 5hr = 272.5litres$$

KEEL COOLED GENSETS				
ENGINE	50 Hz 1500 rpm		60 Hz 1800 rpm	
	kVA*	kWe*	kVA*	kWe*
D9 MG/UCM274H	-	-	213	170
D9 MG/HCM434C	210	168	245	196
D9 MG/HCM434D	230	184	270	216
D9 MG/HCM434E	275	220	312	250
D9 MG/HCM434F	282	225	-	-

Figure 23: D9 MG/HCM434E genset specification [30]

5.4.3 Motor Selection

The SeaBus ferry which operates in Vancouver uses four marine diesel engines for main propulsion. For the concept of this project, the main propulsion engines, crank mechanism and the shaft, which all together provide the propulsion power will be replaced by electric motors. On the other hand, the diesel generators which cater for hotel services and auxiliaries will be removed and provided for by direct power delivery from the onshore connection. Each main engine produces 300kW maximum continuous rating (MCR) at speeds of 1800 rpm and weighs approximately 1700 kg. [31]

The electric motors that will replace the engines will have equivalent power characteristics, similar dimensions and preferably the similar weight in order to keep the vessel stable. The electric motors suitable for this application are induction motors due their operational capabilities. Induction motors have variable speed control which is compatible with fixed pitch propeller, in the same way diesel engines produce variable speed at different throttle positions. Added to this, induction machines are more robust and can cope with the demands of a marine operational environment as compared to equivalent synchronous machines. The motors will be attached to the existing propulsion units currently installed on the SeaBus ferry. The units are steerable right angle drive systems driving fixed pitched propellers. The motor torque characteristics also matches the torque produced by the current engines. The diesel engines produce 1591.54Nm of torque.

The motor chosen for this application is the ABB M2CA-355LA. This motor is rated at 362kW at 1786 rpm, producing a torque of 1936Nm and weighs 1550kg. This motor was chosen due to its low voltage requirements and performance characteristics (93.6% efficiency).

1800 r/min = 4 poles			440 V 60 Hz			Basic design							
88	M2CA	280 SA	1780	95.0	0.86	144	6.2	472	2.0	2.4	1.15	445	
105	M2CA	280 SMA	1780	95.3	0.87	167	6.7	563	2.3	2.6	1.4	490	
125	M2CA	315 SA	1785	95.1	0.87	200	6.5	668	1.8	2.5	2	675	
150	M2CA	315 SMA	1784	95.6	0.87	238	6.4	803	1.9	2.4	2.3	730	
185	M2CA	315 MB	1785	95.8	0.87	290	6.8	990	2.0	2.6	2.9	850	
230	M2CA	315 LA	1784	96.1	0.87	362	6.8	1230	2.2	2.6	3.5	970	
230	M2CA	355 SA	1788	95.8	0.87	362	6.6	1228	1.7	2.3	4.8	1200	
285	M2CA	355 MA	1787	96.1	0.87	445	6.9	1523	1.8	2.3	5.7	1320	
362	M2CA	355 LA	1786	96.3	0.87	570	6.7	1936	1.9	2.5	6.9	1550	
400	M2CA	355 LB	1788	96.5	0.88	618	7.0	2136	2.0	2.4	6.9	1550	
450	M2CA	355 LKD	1788	96.4	0.88	692	7.4	2403	2.2	2.5	8.4	1900	
500	M2CA	400 MLA	1790	96.3	0.88	773	6.9	2667	1.6	2.4	12	2300	
550	M2CA	400 MLB	1791	96.5	0.87	855	7.6	2933	1.8	2.6	13	2400	
630	M2CA	400 LKA	1790	96.7	0.86	992	7.0	3361	2.1	2.7	15	2700	
710	M2CA	400 LKB	1790	96.7	0.88	1090	7.2	3787	1.8	2.6	16	2800	

Figure 24: ABB M2CA-355LA Induction Motor [31]

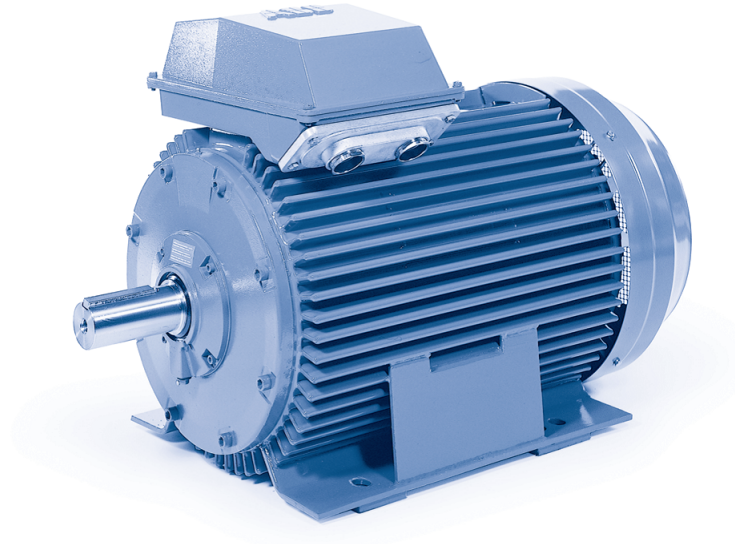


Figure 25: ABB M2CA-355LA Induction Motor [31]

5.4.4 Transformer Selection

The ferry is going to receive power from the onshore supply through the cable discussed in the previous sections, at 6.6kV and a current of 124.6A. All the systems on the vessel are rated at 440V, thus the voltage needs to be stepped down using transformers. The transformer has to be suitable for marine use and also approved by a classification society. Due to the high power requirement it might be better to design a transformer for this particular system but for the sake of this project, an off the shelf transformer was chosen.

HV [kV]		Uk [%]	Power [kVA]	NLL [W]	LL (75°C) [W]	losses comb.	L appr. [mm]	W appr. [mm]	H appr. [mm]	oil weight appr. [kg]	total weight appr. [kg]	LWA [dB(A)]
160												
10		4	160	460	2350	A-A'	1060	690	1140	180	840	62
20		4	160	300	3100	B-C'	960	740	1140	180	805	52
			160	300	2350	A-C'	1060	690	1140	180	840	52
			160	300	2000	C-C'	1060	690	1140	180	865	52
			160	460	2350	A-A'	1020	715	1215	205	880	62
			160	300	3100	B-C'	1060	690	1215	180	825	52
			160	300	2350	A-C'	1020	715	1215	205	880	52
			160	300	2000	C-C'	1020	715	1215	205	905	52
Wheelbase (D):				520mm		Wheel diameter:			(E):	125mm	Wheel	width: 40mm

Figure 26: ABB, Liquid filled transformers IEC standard small and medium, rated power <2500 kVA, HV ≤ 36 kV [32]

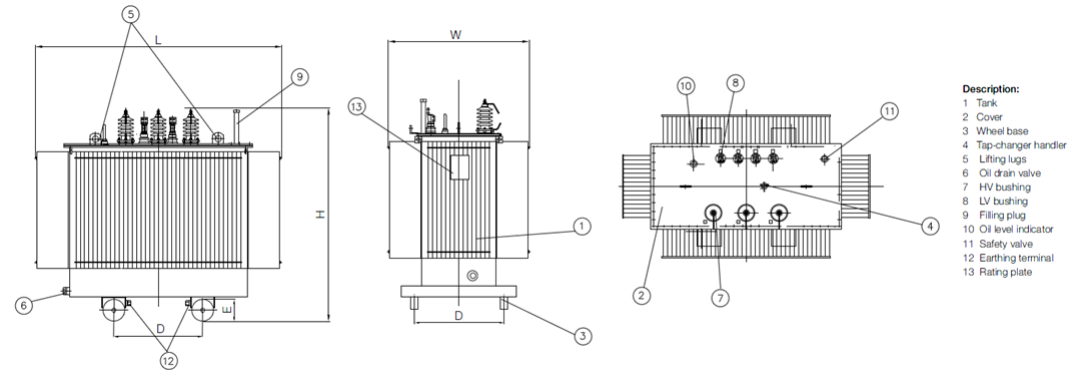


Figure 27: ABB Transformer Schematics [32]

The chosen model is rated at 1.6MW, capable of handling voltage up to 10kV which should cover the maximum load on board of 1.4MW at 6.6kV. [32]

5.4.5 Pulse-Width Modulation Scheme

The PWM scheme comprises of an inverter drive connected to a rectifying end by means of a DC capacitor. The aim of this scheme is to regulate the frequency and voltage magnitude of the incoming power in order to fit the compatibility of the induction motors. The power is fed into the rectifying end, where it comes out as DC, goes through a capacitor and is inverted back to AC. This process is essential when the system is connected to induction motors which power fixed pitch propellers, as changing the frequency of the power is the only way to change the speed of rotation.

The PWM system chosen is produced by ABB and comes in the form of a free standing drive which is relatively compact and should not pose a space problem. This model is rated at 355KW and can handle up to 840A. These should be suitable for the system as each propulsion branch is carrying 300kW of power at a maximum current of 681.8A. [33]

Nominal ratings		No-overload use	Light-overload use		Heavy-duty use		Noise level
$I_{\text{cont. max}}$ A	I_{max} A	$P_{\text{cont. max}}$ kW	I_N A	P_N kW	I_{hd} A	P_{hd} kW	dBA
$U_N = 500 \text{ V}$ (Ranges 380 to 500 V). The power ratings are valid at nominal voltage 500 V.							
196	326	132	192	132	162	110	71
245	384	160	240	160	192	132	71
289	432	200	284	200	224	160	71
440	588	250	435	250	340	200	72
515	588	315	510	315	370	250	72
550	840	355	545	355	490	315	72
602	840	400	590	400	515 ²⁾	355	72
684	1017	450	670	450	590 ²⁾	400	72
718	1017	500	704	500	632 ³⁾	450	72

Nominal ratings		Heat dissipation	Air flow	Type designation	Frame size
$I_{\text{cont. max}}$ A	I_{max} A	W	m ³ /h		
$U_N = 500 \text{ V}$ (Ranges 380 to 500 V). The power ratings are valid at nominal voltage 500 V.					
196	326	3000	540	ACS800-02-0170-5	R7
245	384	3800	540	ACS800-02-0210-5	R7
289	432	4500	540	ACS800-02-0260-5	R7
440	588	6850	1220	ACS800-02-0320-5	R8
515	588	7800	1220	ACS800-02-0400-5	R8
550	840	7600	1220	ACS800-02-0440-5	R8
602	840	8100	1220	ACS800-02-0490-5	R8
684	1017	9100	1220	ACS800-02-0550-5	R8
718	1017	9700	1220	ACS800-02-0610-5	R8

Figure 28: Free Standing ABB ACS800-02 PWM Scheme [33]

6 Stability Study

This project aims keep the same ferries used in Vancouver, making them more eco-friendly and financially efficient by installing the electrical arrangement discussed in the previous section. The various changes in components are surely going to change the stability of the ferry and so, it is of paramount importance to see that the vessel with the installed system is still stable and sea-worthy. This section contains simple calculations which will assure the stability of the improved ferry.

6.1 Preliminary Stability Calculation

Seabus Particulars [25]

- Length overall : 34.29 meters
- Length at the waterline : 31.50 meters

- Beam (moulded) : 11.89 meters
- Beam (extreme) : 12.64 meters
- Depth : 3.525 meters
- Design draft : 2.00 meters
- Passenger capacity : 395
- Crew : 4
- Fuel Capacity (95%): 8675 litres
- Speed (trials): 13.5 knots
- Gross tonnage (approx.) : 438 tonnes

Fully loaded, the vessel can carry up to 29.92 tonnes of passengers, 0.30 tonnes of crew and effects, 7.56 tonnes of fuel, considering all tanks and operational systems carrying liquids as being pressed full. For this project the main engines, generators and other auxiliaries will be replaced with the required components to convert this vessel to a fully electric system.

The following table shows a comparison between the components making up the two different systems. The new design appears to be 138kg lighter than the original design. This change in weight is not going to affect the over all stability of the vessel as it is a relatively small change. Nevertheless, once the project's proposal is through and it is decided that it will be implemented, more detailed calculation would be required to prove that the vessel is stable, taking into account the exact weights and position of every component. [26]

Current Component	Location	Weight	New Component	Location	Weight
4 x MTU/ Detroit Diesel Series 60 (Main Engines)	Engine Room in catamaran pontoons 2 x port 2 x starboard	4 x 1700kg = 6800 kg	4 x ABB M2CA-355LA Marine Steel motors	Engine Room in catamaran pontoons 2 x port 2 x starboard	4 x 1550kg = 6200kg
2 x Northern Lights M99C2 series (Aux. Generators)	Engine Room in Catamaran pontoons 1 x port 1 x starboard	2 x 1500kg = 3000kg	2 x Volvo Penta D9 MG/HCM434E (Emergency Generators)	Engine Room in Catamaran pontoons 1 x port 1 x starboard	2 x 2655kg = 5310kg
2 x Fuel tanks	1 x port 1 x starboard	2 x 3780kg = 7560kg capacity	4 x ABB Driver ACS800-37-0870-5	Engine Room in Catamaran pontoons 2 x port 2 x starboard	4 x 2055kg = 8220kg
2 x Dirty bilge tanks	1 x port 1 x starboard	2 x 1880kg = 3760kg	2 Smaller fuel tanks for Emergency Generator	1 x port 1 x starboard	1 x 500kg + 1 x 500kg = 1000kg
			Power transmission cable	Centreline connection	From C to seabed, 252 kg
		21120kg			20982kg

Figure 29: Stability comparison for the two systems

6.2 The effect of the cable

The cable laid on the seabed will create friction and a resistive force acting on the vessel as it goes along its route. Resistance calculations can be performed to estimate this resistive force and determine whether this force can be overcome by the vessel's propulsion system. The largest amount of resistive force would be encountered at the end of the route where the longest amount of cable would lie on the seabed. This calculation is taking into consideration the topology of the seabed in Vancouver harbour as being soft and sandy, as previously discussed

in section 4.4. The surface friction of the seabed can be determined through seabed stiffness values that range from low to high depending on the topology. For a sandy seabed the stiffness can be approximated to be the mean value of low and medium stiffness. The following calculations can determine an approximate resistive force of the cable.

Seabed Stiffness		Average value
Low	779.2	1948
Medium	3116.8	

Figure 30: Seabed Stiffness

The following equation is used to calculate the drag force between two surfaces:

$$F - \mu R = m.a$$

Where F is the resistive force, μR is the drag coefficient depending on the objects, m is the mass of the cable and a is the acceleration which the vessel travels at.

$$\mu R = \frac{\text{Seabed Stiffness}}{\text{Length of Cable} \times \text{Area of Cable in contact with seabed}}$$

The area of cable being in contact with the seabed is estimated to be 3% of the area of the whole cable, thus:

$$A = 3\% \times 2\pi R$$

$$A = 0.03 \times 2\pi \times 0.05$$

$$A = 0.00942m^2$$

$$\therefore \mu R = \frac{1948 \times 10^3}{3.3 \times 10^3 \times 0.00942} = 62664.87N$$

The maximum resistive force is experienced at the end of the voyage when all the cable is unwound, that is 3.3km of cable. The Prysmian cable chosen in Section 5.3.1 weighs 13.233tonnes and is going to be dragged at the vessel's design speed of 13.2knots, thus:

$$V = 13.2knots = 13.2 \times 0.5144 = 6.79m/s$$

Assuming the vessel takes 2 minutes to accelerate to cruising speed:

$$a = \frac{dV}{dt} = \frac{6.79}{2 \times 60} = 0.0566m/s^2$$

$$F - \mu R = m.a$$

$$F = m.a + \mu R$$

$$F = 13.233 \times 10^3 \times 0.0566 + 62664.87$$

$$\therefore F = 63413.86N$$

The force exerted by the seabed on the cable is 63.414KN. This is a relatively small force, when compared to the propulsion power of the vessel thus in conclusion it can be said that the vessel will experience a small loss of speed but it would not affect greatly the general performance of the ferry.

7 Economic Evaluation

In any potential venture it is important that the economic aspects of the project are analysed to get a more comprehensive idea of its viability. Although the primary objective of this project might be to reduce emissions associated with ferry operations in Emission Control Areas, it is also important to ensure that the financial benefits are realised from the project. These ideally will arise from the annual savings in fuel costs that the ferry operator will obtain from the use of bulk, shore based, hydro-power.

In the short term, while the cost of diesel is still relatively low, these annual savings may not be substantial enough to quickly cover the high initial cost of investment that will be required to implement the described system. Diesel engines are a tried and tested technology that is reasonably priced with well established systems in place, that are durable and experienced in performing the required function. As the system described above is a new design which has numerous theoretical components, the investment cost of implementing the system could be extremely high.

Figure 30 shows a Net Present Value calculation that compares the savings that the ship should theoretically generate through the implementation of the electric system with the approximate investment cost of the project. The fuel calculations in Table 1 are based on the engines running continuously for 19 hours a day (the ferry operates between 6 am and 1am with 5 hours of no operation) at the engines MCR. It was also assumed that the ferry operates for 350 days a year, taking into account holiday periods and additional downtime. The fuel price is based on the bunker price of No.2 Diesel Fuel for the month of February. Naturally this fluctuates considerably over the course of even a year so it is important to bear this in consideration when reviewing the later NPV calculation. The electrical costs have been considered using the same operation time and power demands. [27]

Approximate Fuel Costs	
Engine	
215 g/kWh	19 hours/day
0.215 kg/kWh	1200 kW
258 kg/h	3.470 \$ per gallon
4902 kg/day	916.7 \$ per m3
5.51 m3/day	0.89 g/cm3
5049.06 \$/day	890 kg/m3
	350 operating days
1767171 \$ p.a.	
Diesel Generators	
- g/kWh	19 hours/day
- kg/kWh	200 kW
45 litres/h	3.470 \$ per gallon
855 litres/day	916.7 \$ per m3
0.855 m3/day	0.87 g/cm3
783.78 \$/day	870 kg/m3
	350 operating days
274322.5 \$ p.a.	
Total	
2041493 \$ p.a.	

Approximate Electrical Costs	
0.0885 \$/kWh (Canadian) ^[1]	+15% on BC Hydro Rates ^[2]
0.0891 \$/kWh (US)	
0.1025 \$/kWh (US)	
1090607 \$ p.a.	
950886.5 \$ p.a.	Annual Fuel Savings

Figure 31: Fuel Calculations

Realistically fuel costs will be significantly lower than this as the vessel will not operate at full power capacity for this length of time. In reality only two propellers will be under load on each journey and the other two engines will be idling, reducing the power output and therefore fuel consumption. Also time spent loading and unloading passengers will only require the engine to be idling, therefore burning less fuel. Without any reliable data it is difficult to estimate what percentage of maximum power output is the real output.

Looking at the overall picture, the economic viability of the project can be estimated using a simple NPV calculation. It must be stressed that a considerable amount of this is based on estimation and numerous factors have not been considered to try and offer simplicity. In reality, the NPV of the real project may be considerably different. Below is the NPV calculation:

NPV Evaluation of Fuel Savings											
	Year										
	0	1	2	3	4	5	6	7	8	9	10
	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$	\$
Annual Fuel Savings		950886.5	950886.5	950886.5	950886.5	950886.5	950886.5	950886.5	950886.5	950886.5	950886.5
Vessel re-fit	-3000000										
Motor & Drivers x 4	-498773										
Additional Electrical Equipment Cost	-63632										
Backup Generators	-100000										
Cable (Main & Reserve)	-400000										
Cable Drum	-100000										
Cleaning Equipment	-31816										
Roller Sheath	-100000										
Additional Crew Required		-30000	-30000	-30000	-30000	-30000	-30000	-30000	-30000	-30000	-30000
Total	-4294221	-3373335	-2145812	-852413	280469	1112447	1611605	1830637	1860370	1788749	1679495
Discount Factor (10%)	1	0.9091	0.8264	0.7513	0.683	0.6209	0.5645	0.5132	0.4665	0.4241	0.3855
NPV	-4294221	-3066698	-1773299	-640418	191560.3	690718.2	909750.9	939483.1	867862.4	758608.4	647445.3

Figure 32: NPV Calculation

It can be seen from the table above that the project has the potential to offer a positive return after a short period in service. This comparison looks at the initial investment in plant and machinery required for operation of the electric cable laying vessel compared with the fuel saving that are achievable on the use of shore power as opposed to marine diesel fuel. The advantage of this prediction is that trends show the ever rising price of fuel. The likelihood therefore is that over the course of 10 years the fuel savings will increase rather than remain constant as shown in the NPV calculation. This means that the return will be greater as the advantage of having an on shore supply becomes more prominent in the later years of the project's life. There may however be higher dry-docking and other maintenance costs associated with the laying and retrieving of the cable which have not been considered in the analysis.

Although this NPV shows that there is a quick positive return on the investment, as mentioned in reality it has a number of limitations. Some of the investment costs include new technologies where industry quotes are not obtainable meaning that a best guess has had to be made at a cost figure. In addition to this refit cost has been estimated based on an existing vessel having this technology installed on-board. Realistically however for this design to be effectively implemented, a new vessel specifically tailored to the requirements of cable laying will need to be designed and built. This will take significant investment that will reduce the NPV of the project and create a significantly longer payback period of the project.

8 Conclusion

The ever-increasing price of fuel and the rising awareness of environmental impacts have brought about new regulations in the marine industry. This is even more evident in Emission Control Areas as outlined by the International Convention for the Prevention of Pollution from Ships; MARPOL 73/78. In addition to this, other public transportation systems which might be faster and cheaper have pushed the ferry industry into a competitive market. The need to comply with these regulations and compete with other means of transport has led to the development of more efficient ships and the use of more expensive higher grade, driving the ferry industry to the edge of bankruptcy. Nevertheless, ferries still have the potential for high demand in metropolis areas both from daily commuters and tourists alike.

The main concept behind this project is to replace the main engines on-board the ferry with an onshore power supply providing green and efficient power. The power delivered to this system would be from surplus hydroelectric power produced by the local energy authority providing an emission free, inexpensive power. In addition to this, the removal of on-board machinery can create greater passenger capacity further contributing to a better return of revenue.

This was achieved through the implementation of a modification to cable laying technology. This involved an onshore cable reel supplying sufficient cable to allow the vessel to cross the waterway. Basing all technology on land would minimise the on-board maintenance costs and effectively make the vessel emission free. Under SOLAS regulations, there would be a requirement for a redundancy generator on the vessel however this would only be used in emergency situations.

This project focused on one ferry crossing, located in Vancouver, Canada. It was determined that this was an ideal location to implement the technology as it offered a short crossing, weather protected water with a high passenger usage of the ferry. A study was conducted to see how costly it would be to re-fit the current ferry with the proposed technology. It was determined that although the initial capital cost for establishing such a system for a similar application would be significantly greater than adopting a conventional system. The savings in annual running costs and especially fuel costs would amount to a reasonable payback period and introduce profit for the operator.

Challenges and further work

The main criteria for this concept was to utilise an onshore power supply which introduced a major setback. The challenge of this condition was to determine a viable way to transmit the power from the supply to the vessel. Due to the fact that an underwater cable was selected despite never being used for this kind of application, limits on available data required the use of a number of assumptions. This project is a concept that combines new and old technologies to fulfill the initial aim of this project. As with any new concept limiting factors such as time and funds have restricted the possibility of further research.

Further work could be carried out for this project and advances in technologies could aid in determining and introducing a market ready solution. Like any other new technology, a lot of milestones need to be overcome in order to introduce this system to the industry. New cable technologies, power management systems and even propulsion systems that would be more cost effective could contribute to the realisation of this concept.

References

- [1] BP Statistical Review of World Energy, 2011
- [2] U.S. Energy: Overview and Key Statistics, 2012
- [3] James J. Corbett; Horst W. Koehler : Updated emissions from ocean ship-ping, 2003
- [4] The Impacts of Globalisation on International Maritime Transport Activity, 2008
- [5] IMO : Revision of MARPOL Annex VI and the NOx Technical Code, 2007
- [6] World Energy Supply; URL: <http://www.theglobaleducationproject.org/earth/energy-supply.php>
- [7] IMO Marine Engine Regulations; URL: <http://www.dieselnets.com/standards/inter/imo.php>
- [8] DNV, Fuel Saving Guideline measure on bulk carrier
URL: <http://www.dnv.com/industry/maritime/publicationsanddownloads/publications/updates/bulk/2011/2.2011/Fuelsavingguidelinemeasuresonbulkcarriers.asp>
- [9] Legislative Council Panel On Environmental Affairs, 2011
- [10] The Turkish Straits Vessel Traffic Service
- [11] URL: <http://www.marinetraffic.com/ais/>
- [12] VİTSAN, MINISTRY OF TRANSPORTATION, MARITIME AFFAIRS AND COMMUNICATIONS, 2011
- [13] Ports of Auckland; URL: <http://www.poal.co.nz/>
- [14] Viaduct harbour, Auckland, New Zealand; URL: <http://www.viaduct.co.nz/>
- [15] Wind Finder; URL: http://www.windfinder.com/windstats/windstatistic_auckland.htm
- [16] Port Metro Vancouver; URL: <http://www.portmetrovancover.com/en/about.aspx>
- [17] William T. Collins; James. L Galloway, Secure Ports and Harbors: Seabed Classification and Multibeam Bathymetry, 2002
- [18] Port Metro Vancouver; Port of Seattle; Port of Tacoma, USA; Northwest Ports Clean Air Strategy: 2010 Implementation Report, 2010
- [19] Port Metro Vancouver: Electrifying the Port – Switching to clean, green electricity, 2010
- [20] Google Maps; URL: <http://maps.google.co.uk/>

- [21] Hughes, Electrical and Electronics Technology, 10th Edition, 2008
- [22] Axelsson, T, Submarine Cable Laying and Installation Services For the Off-shore Alternative Energy Industry, (2008)
- [23] Cavotec Ports and Maritime,
URL: http://www.cavotec.com/en/ports-maritime/alternative-maritime-power-amp_45/
- [24] Conductix: MOTOR DRIVEN REEL TECHNOLOGY,
URL: <http://www.conductix.us/literature/literature-download/?mediaID=74>
- [25] Translink, Seabus Information: South Coast British Colombia Transportation Authority, 2011
- [26] Northern Lights: M99C2 Series Auxiliary Generators,
URL: http://www.northern-lights.com/PDFs/brochure_pdfs/c-series.pdf
- [27] Prysmian, URL: http://www.prysmian.fi/export/sites/prysmian-fiFI/attach/pdf/Marine/MV-FHFX_6_10.pdf
- [28] Lloyd's Register Class Rules: LR Main and Auxiliary Machinery - Propulsion and Steering Machinery Redundancy - Machinery arrangements Section 3
- [29] SOLAS: Regulation 42 - Emergency source of electrical power in passenger ships
- [30] Volvo Penta,
URL: <http://senyltd.com/uploads/userfiles/file/Volvo%20Penta/mARINE%20DIESEL%20GENERATORS/D9%20MG.pdf>
- [31] ABB, Motors Catalogue 2011,
URL: [http://www05.abb.com/global/scot/scot285.nsf/veritydisplay/3600a1875a4fb8d5c125784c004ffc79/\\$file/drives%20and%20motors%20catalogue%202011.pdf](http://www05.abb.com/global/scot/scot285.nsf/veritydisplay/3600a1875a4fb8d5c125784c004ffc79/$file/drives%20and%20motors%20catalogue%202011.pdf)
- [32] ABB, Liquid filled transformers IEC standard small and medium, rated power < 2500 kVA, HV ≤ 36 kV Brochure 2010.
URL: [http://www05.abb.com/global/scot/scot252.nsf/veritydisplay/e74fd653d2eea766c125771a0038659b/\\$file/abb%20pptr_2451pl024-w2-en_04-2010.pdf](http://www05.abb.com/global/scot/scot252.nsf/veritydisplay/e74fd653d2eea766c125771a0038659b/$file/abb%20pptr_2451pl024-w2-en_04-2010.pdf)
- [33] ABB, industrial drives ACS800, single drives 0.55 to 5600 kW Catalogue
URL: <http://www05.abb.com/global/scot/scot239.nsf/>

veritydisplay/411ac81f6a476367852574630063b4d2/\$file/acs800-phtc01u-en.pdf

[26] K.J.Rawson and E.C.Tupper, Basic Ship Theory, Fifth edition, Volume 1 and 2, 2001

[27] Hackney, T. (2010). BC Hydro's Large General Service Rate Design (LGSRD) application.

URL: <http://www.bcsea.org/solutions/government/policy/bc-hydro%E2%80%99s-large-general-service-rate-design-lgsrd-application>.