ISLAMIC UNIVERSITY OF TECHNOLOGY (IUT)

MICRO-HYDRO POWERPLANT DESIGN BY HARNESSING WAVE ENERGY WITH ‘SEARASER’- A CASE STUDY FOR SAINT MARTIN’S ISLAND

B.Sc. Engineering (Mechanical) THESIS

BY

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Candidate's Declaration

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Abstract

Electricity, the most suitable and convenient form of energy for transmission and usage purpose is the key to the development for a country. The demand of electricity in an underdeveloped country like Bangladesh is increasing exponentially day by day while the supply increases in a linear fashion. On the other note the economy of Bangladesh largely depends on tourism. St Martin's Island is one of the most notable tourist spots here, the only coral Island of Bangladesh in Bay of Bengal. But due to the lack of electricity supply and uncontrolled tourism policy, this beautiful Island becoming inhabitable to the tourists and losing its tourism potential. Because of location, St Martin's Island is isolated from the national grid. Currently the basic electrical power requirements of the Tourist Resorts there are being supplied by standalone diesel generators. The electricity supply by generators is discontinuous and they are operated at some specific hours when the tourists most likely to in need of electricity. On average, the generators remain turned on for 8 to 9 hours daily within two shifts of operation namely: 'Day-shift' and 'Evening-shift'. The sole purpose of this work is to present a preliminary theoretical outline for supplying necessary electrical energy requirements within those specific periods when the generators are usually put into operation, by renewable wave powered hydro-electricity and replace the diesel generators, thereby constructing a wave powered micro-hydro power plant with an isolated grid system to facilitate the supply of renewable electrical energy to the resorts. For harnessing the energy available in the waves near shore area of the Island, the use of a novel wave energy converter named ***'Searaser'*** *has been suggested in this study along with logical reasoning about its application in the area of interest. While, renewable energy supply is the major concern, the issue of sustainable tourism is also placed at the base of every major decision.*

Chapter 1 Introduction

There is a worldwide rapidly growing trend of demand for the production of electricity from natural and renewable sources. The race for cleaner and greener forms of energy has pushed governments and research organizations all around the world to investigate into the largely untapped renewable sector, mainly to combat the fiercely increasing rate of greenhouse gasses (GHG's) that have accumulated in the earth's atmosphere. As the global warming threat reaches its peak, it comes as no surprise that several countries are investing in renewable energy technologies (RET).

Bangladesh though, lags significantly behind other developing countries in the field of application of renewable energy. This thesis however, explores the possibility of generating electricity from renewable energy especially from oceanic wave energy here in Bangladesh using a wave energy converter (WEC) called the ***Searaser***. The location chosen for our study is Saint Martin island located in the Bay of Bengal about 9 km south of the tip of the Cox's Bazar-Teknaf peninsula, and forming the southernmost part of Bangladesh.

1.1 Prospective Aspects of Wave Energy

Wave energy has immense power generation potential worldwide. Based on a research conducted by the International Energy Agency (IEA), the total energy potential of the oceans has been estimated to be around 93,100 TWh per year [1]. The utilization of wave energy worldwide has been cemented by the numerous proven useful attributes of wave energy. As a potential renewable energy source, some competitive advantages of wave energy over other resources include:

1. The highest energy density amongst all renewable energy sources [2].

2. A significantly lower environmental impact, as compared to other sources [3].

3. Wave energy is highly predictable [4].

4. The energy from the waves can be harnessed almost throughout the day (depending on the Wave Energy Converter technology) with a maximum extraction percentage of 90 percent, as opposed to significant lower numbers for solar and wind energy (30% and 20% respectively) [3].

1.2 Environmental Aspects of Wave Energy

The increasing levels of greenhouse gases in the earth's atmosphere has played a vital role behind the global incentive to push towards a more renewable energy orientated world. According to the Kyoto protocol, there is a plan to reduce the global greenhouse gas emission by 50 %, before the year 2050 [1]. Keeping this in consideration, it comes as no surprise behind the global research in wave envy converters and renewable energy technologies. This section outlines a few advantages of wave energy and also comments about some of the disadvantages associated with wave energy.

The first advantage of wave energy is the obvious reduction in the emission of GHG's. Significant levels of carbon dioxide and methane are produced during the combustion of fossil fuels, like coal, oil, gas etc. According to a study, 300 kg of CO2 could be avoided for each Mwah generated via ocean energy [1] . Another key advantage of wave energy is its impact on tourism. By the application of wave energy, key tourist spots can be protected by the government, along with its ecosystem and historical monuments/ landmarks. Thus, establishment of wave energy in islands would have a positive impact on its tourism industry [5] .

Despite of the numerous other advantages, wave energy does in fact have some disadvantages as well. It has been observed that some WEC's such as Oyster, generate noise pollution, as a result disturb aquatic life. However, this noise is often neutralized by the sound of the waves and the wind [1]. Constructing large wind farms can cause damage to shore lines or coast line areas [6]. Frid et al. [7] discussed a few similar negative impacts of wave farms. One of them being changing the fish population due to transportation of larvae.

1.3 Wave Energy Converters

Making use of the tremendous reservoir of wave energy is challenging to say the least, not to mention the expense that can that needs to be covered in such projects. Nevertheless, there is a worldwide demand for cleaner and greener sources of energy, with several countries investing heavily in these projects, due to ever rising carbon dioxide and greenhouse gas emissions [3].

Wave energy can be harnessed by the application of special types of devices called wave energy converters (WEC). New concepts of WECs are being developed worldwide, with the bulk of the research and techniques been done in Japan, North America and Europe [3]. However, in Bangladesh, research in the field of WEC technology is still in the beginning phase though the Bay of Bengal has sufficient wave energy potential which can be utilized reasonably with the application of appropriate WEC technology. Wave energy converters (WEC) are capable of harnessing power or energy from the oscillatory motion of the waves to supply necessary electrical energy requirements. At present, over 200 different types of WEC's exist, with several still undergoing the testing phase [8]. A significant portion of work in the field of WEC's has been conducted in North America, Europe and Japan, along with several patents [3].

There are a wide variety of WEC's and several classifications [9]. M. Fadaeenejad et al. [4] classified the various types WEC's all over the world, based on location, working principle and wave direction. The classification is shown in Figure 1.1.

1.3.1 Brief description of the common types of converters

Shore line WECs: These are located entirely on the shore. Shore line WEC's are easy to install and maintain. Furthermore, these devices do not require deep-water moorings and long underwater electrical cables [10]. Shore line WEC's are in close proximity to the power grid, however, these devices have the disadvantage of generating low power in shallow waters. Two renowned examples of shore line WEC's include: SDE Sea Wave and Oscillating Water Column (OWC). SDE Sea Wave is one of the new onshore converters that produce proper range of power.

As shown in the Figure 1.2, the construction of the ***SDE converter*** is fairly simple, buoys are placed on a breakwater and they move up and down based on the frequency of sea waves. Buoys push a hydraulic liquid for conversion of energy to circular system. Finally, the generator will be operated.

In contrast the ***OWC*** has a more complex approach. As illustrated in Figure 1.3, in these systems, waves are trapped in a reservoir and the rise and fall of the water moves a column of air to drives a turbine named wells turbine [1].

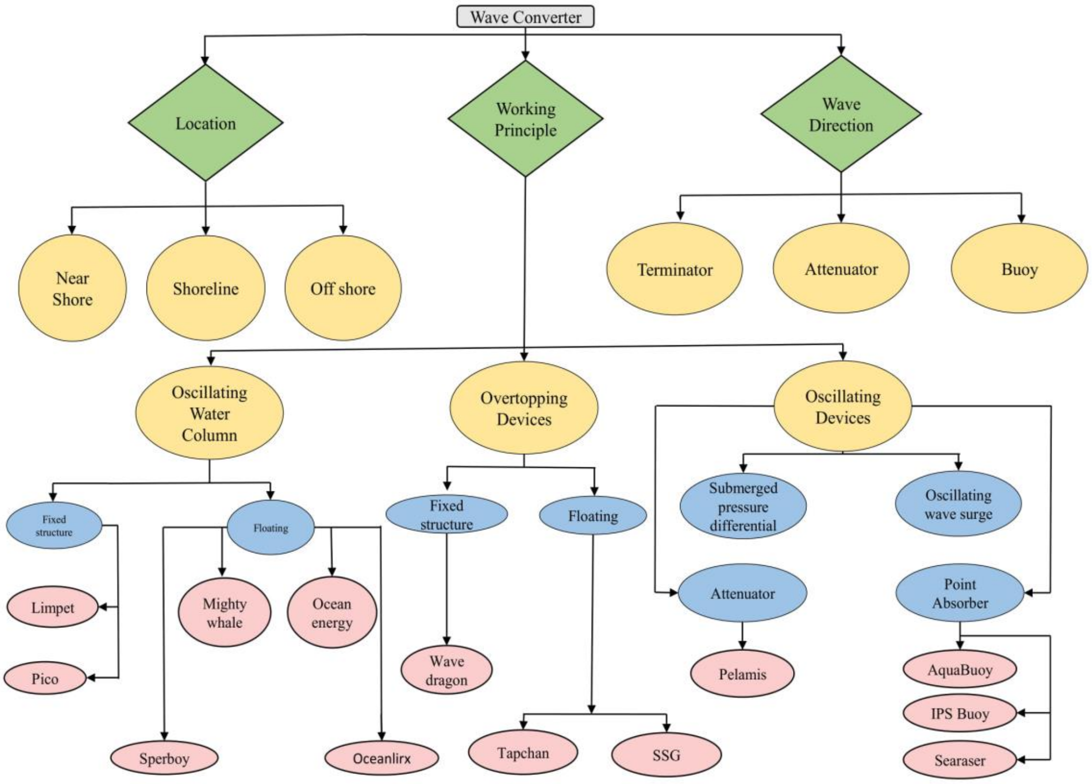


Figure 1.1: Wave Energy Converter classification [1]

Figure 1.2: SDE Sea Wave Energy Converter [1]

This system has a maximum output of 500 KW. It is ideal for locations where there is strong wave energy, such as breakwaters, coastal defenses, land reclamation schemes and harbor walls. This form of energy generation is suitable for producing power for small islands with high level of wave energy [10].

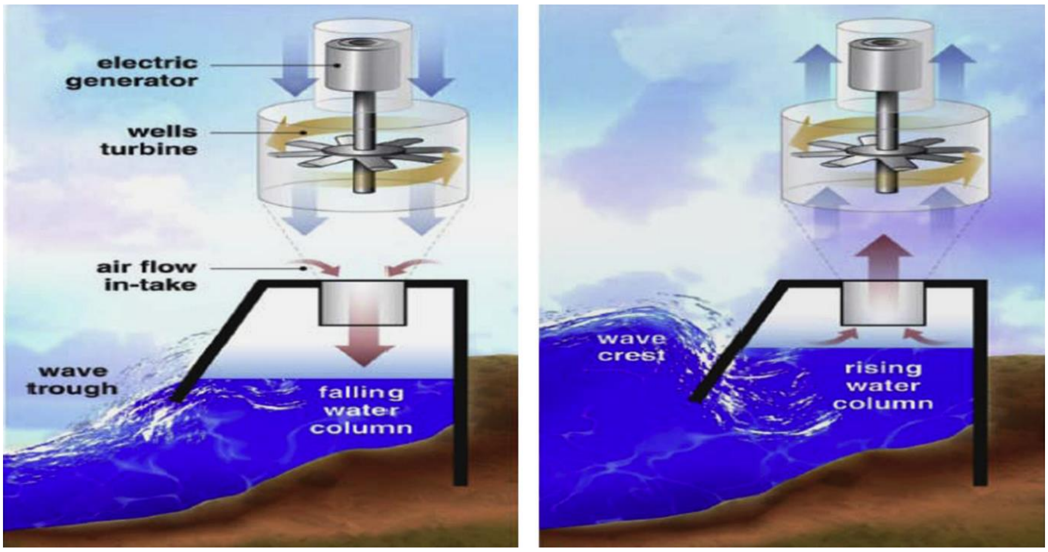


Figure 1.3: Illustration of an Oscillating Water Column

<u>Near shore WECs:</u> Near shore devices capture wave energy in the nearshore and convert it into electricity in an onshore facility. These devices are often attached to the seabed, which provides a suitable situation for oscillating body to work [11]. Oyster, Archimedes Wave Swing (AWS), ***Searaser*** etc. are some example of such devices, proposed in 2005, 2003 and 2007 respectively.

Oyster captures energy in nearshore waves and converts it into clean electricity [1]. Oyster is a wave powered pump which pushes high pressure water to drive an onshore hydro-electric turbine [10]. Oyster is shown in Figure 1.4.

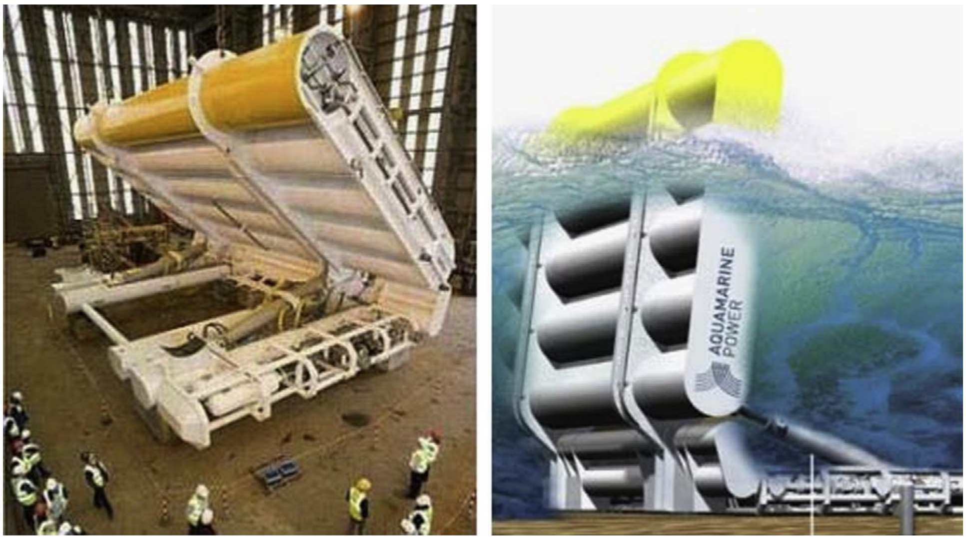


Figure 1.4: Size and operation of Oyster converter [12]

The Archimedes Wave Swing (AWS) is a point absorber type WEC. Point absorber is defined as a latest technology for wave extraction and works based on a floating body with a linear generator [13]. AWS as a point absorber converter uses the pressure difference above the device between wave crests and troughs. AWS consist of a sea bed fixed air-filled cylindrical chamber and a moveable cylinder. When a crest passes over the converter, the upper cylinder will go down due to water pressures and air within the cylinder. As a trough passes over, the water pressure on the device will be reduced and the upper cylinder rises. A key advantage of this device is that it’s fully submerged and no slamming forces are experienced.

Searaser is a wave-driven high-pressure water pump for generating hydro-electric power. The oscillatory motion of this device pumps seawater to an elevated reservoir situated in main land, form where the reserved sea-water can be released back downhill through a hydro-electric turbine to produce hydro-electricity, before finally returning back to sea.

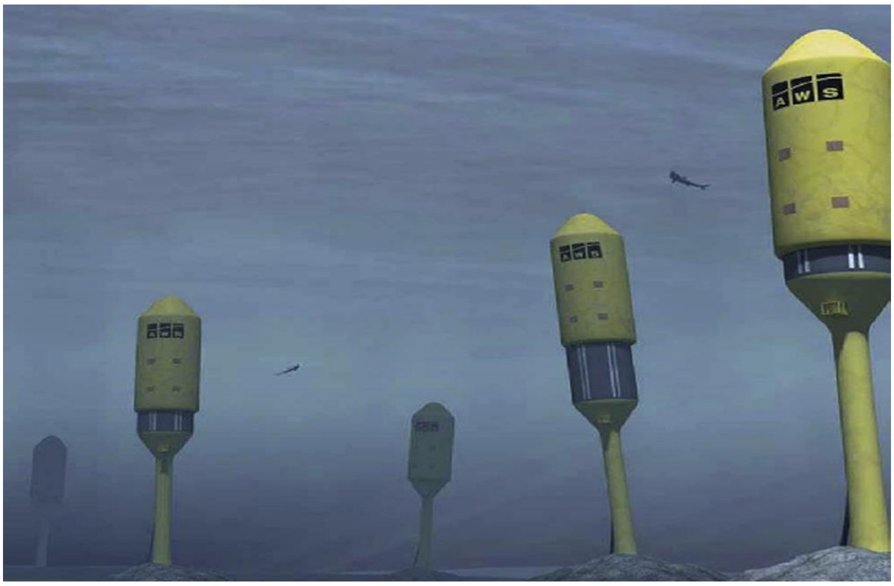


Figure 1.5: Archimedes Wave Swing, AWS

Figure 1.6: ***Searaser*** Wave Energy Converter

<u>**Offshore WECs:**</u> Offshore energy converters are deployed in deep waters without an onshore installation (Between 30 m and 100 m). These tools, which sometimes classified as third generation devices are classified under oscillating bodies. Offshore wave energy converters are in general more complex due to problem associated with mooring point, maintenance and underwater electrical cables. However, in recent years some effective

offshore systems have built [10]. Wave Dragon, AWS-iii and Pelamis etc. are this type of wave energy converters with high power and are applied widely.

The AWS-III technology consists of a multi-cell array of flexible absorbers, which convert wave power to pneumatic power through compression of air within cells that are inter-connected. Turbine-generator sets are provided to convert the pneumatic power to electricity [1].

The Wave Dragon is an offshore floating device uses a pair of curved wave reflectors to force ocean waves for flowing over a ramp and into a reservoir. The water is let out through a number of turbines. Wave Dragon is designed to overtopping water into the reservoir for high power production [1]. The main body or platform consists of one large floating reservoir. The wave dragon is large and heavy to reduce rolling and keep the platform stable.

Figure 1.7: Applied model of AWS-III in Loch Ness.

The total steel weight of the main body plus the ramp is 150 tons, thus 87 tons of water must be added to achieve the 237 tons total weight for stable operation [10].

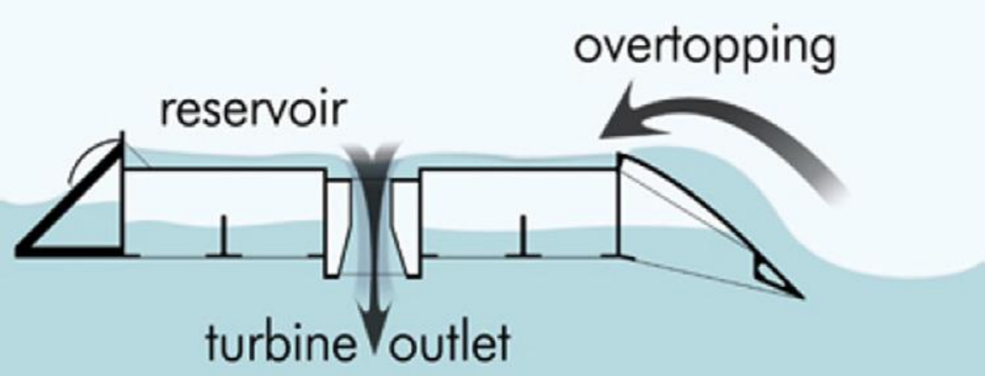


Figure 1.8: Operating diagram of wave dragon

The Pelamis is an offshore, floating, slack-moored wave energy converter consisting of a set of semi-submerged cylinders linked by hinged joints. Ocean waves perform work on the Pelamis by moving adjacent cylindrical sections relative to each other across two degree of freedom joints. The two axes that comprise each joint are inclined to the horizontal to allow a net inclined response to be induced by the power take-off system (PTO), which resists and reacts against the relative angular motion of the joints. It is this motion which is used to generate electricity.

Figure 1.9: Pelamis Wave Energy Converter

1.4 Brief description of the WEC used in this study

1.4.1 Introduction to the *Searaser*; a breakthrough innovation

Searaser is a fascinating new British invention by **Alvin Smith** in collaboration with **Ecotricity** Ltd. and registered as a patent in 2013 [14]. It can be used as a wave-driven water pump for generating hydro-electric power. It is designed to float at sea as a wave energy converter to provide clean renewable energy on demand. The device works by bobbing up and down in the sea working on a piston.

1.4.2 Construction and working principle of *Searaser*

The modified model of ***Searaser*** (Alvin Smith's second scheme) is shown schematically in Figure 1.10.

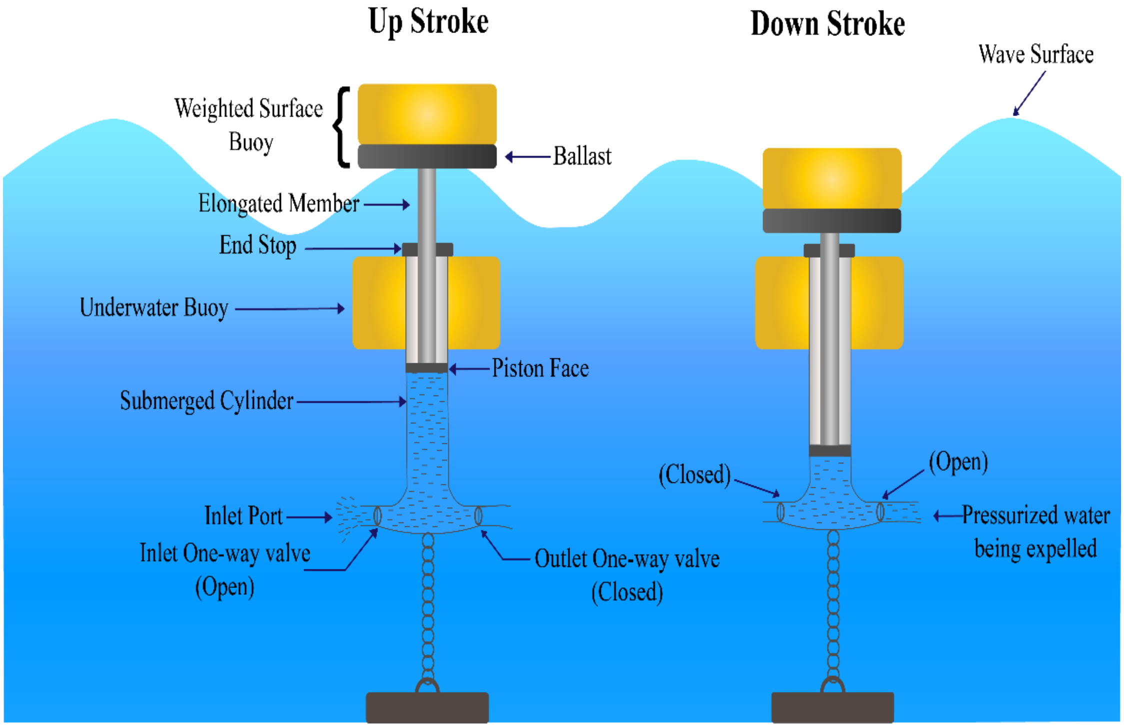


Figure 1.10: Different components and working cycle of a ***Searaser***

As it can be seen the ***Searaser*** mainly consists of two buoys, one held at a fixed depth called the underwater buoy, and the other one floating up and down on the swells called the surface buoy. An elongated member having a piston face or simply a piston is attached to the surface buoy. The piston is guided through the bore of a submerged cylinder anchored to the sea-bed. The underwater buoy is a hollow tank filled with air which urges the cylinder into an upright orientation in the water by buoyancy. The surface buoy has a buoyant portion and a ballast portion. The buoyant portion may be air filled. The ballast portion may include a tank, which may be filled with concrete, aggregate, heavy metal, sand or water as a ballast. If water is used, the amount of water in the tank may be controlled dynamically to vary the ballast if required. The body of this device is made of some specific corrosion resistive composite materials. At the lower end of the cylinder, two ports named inlet and outlet port having one-way valve inside are provided.

The working cycle of ***Searaser*** is based on two actions: i) **Up stroke or suction stroke**, ii) **Down stoke or working stroke**. During the **Suction stroke**, the weighted surface buoy along with the piston moves upward due to forces applied on it by waves when a wave crest reaches the vicinity of ***Searaser***. As a result, a high vacuum is created inside the cylindrical chamber or pumping chamber and surrounding water enters into it through the inlet port because of pressure gradient. During the Working stroke, the surface buoy moves downward due to its gravity pressurizing the water in the pumping chamber when the wave passes or it meets a wave trough. The highly pressurized water then flows through the outlet port to a higher ground, where it can be stored in a holding tank/reservoir. From the holding tank / or reservoir the accumulated sea-water can be released back downhill through a hydro-electric turbine to produce renewable electricity, before finally returning back to sea. Here it appears as obvious that the stroke length or the length of pumping chamber may vary with different sea-condition.

1.4.3 Beneficial aspects of the *Searaser*

Searaser is a simple device with cheaper components in comparison with other types of WECs because the components that produce electricity (turbine and generator) are separated from ***Searaser*** and it is also really beneficial because generating electricity in offshore area is so hard due to corrosion problems. Another important benefit of ***Searaser*** is that during the process of producing electricity there is no gas emission so it is completely green [15].

1.4.4 Efficiency and ongoing research with *Searaser*

When it comes to generating electricity by WEC's, the question about efficiency of that systems always come first. One of the ways for improving the efficiency of ***Searaser*** is to use numerous ***Searasers*** simultaneously. Increasing the number of ***Searasers*** not only increases the electricity production but also can help producing more stable electricity. A common reason for using multiple devices is to have stable **outlet flow rate**. Stabilizing the outlet flow rate causes to produce uniform electricity and reduce fluctuation in electricity production and it is of high importance when the electricity is produced and used at the same time. The best way of stabilizing the outlet flow rate is to synchronize **the maximum volume flow rate (VFR) of one device with the minimum VFR of another device**. The maximum VFR of first device is synchronized with the minimum VFR of another device when the devices are at an optimum distance from each other [16].

Babajani et. al [16] conducted a study in the Caspian-Sea (Iran) to investigate **Searaser's** function at 3 different distances: 10, 15 and 20m between two **Searasers**. For the three mentioned distances, they measured the outlet flow rate and the buoys movement. The task was done numerically by solving momentum and continuity equations at unsteady conditions by using the FLOW 3D software. In their result they found when the devices are in 15 m distance from each other, the difference of outlet flow rate for two devices is negligible in comparison with distances 10 and 20 m.

1.5 Layout of the Proposed Powerplant

The cycle of generating electricity by **Searasers** along with the layout of the proposed power plant is shown in Figure 1.11. As it can be seen from the figure that, the **Wave Energy Converter (WEC) 'Searaser'** will harness the energy stored within the striking waves and by its principle of operation. It will pump sea-water to a '**Mega Reservoir**' mounted on an elevated 'Artificial Ramp-structure' constructed onshore.

The artificial ramp structure provides support for the reservoir. Different generating units each having a set of 'Hydraulic Turbine-Generator' will be connected to the reservoir. Water flow rate required to the turbines will be provided and controlled from the 'Mega-reservoir'. The reservoir will have separate chambers with certain water storage capacity for each unit. The size/capacity of the **'water chambers'** within the reservoir, water flow required from the water chambers to the turbines will be largely upon the ‘Water Head available from the action of ***Searaser***’, ‘Power rating’ and ‘Running time’ of their respective units.

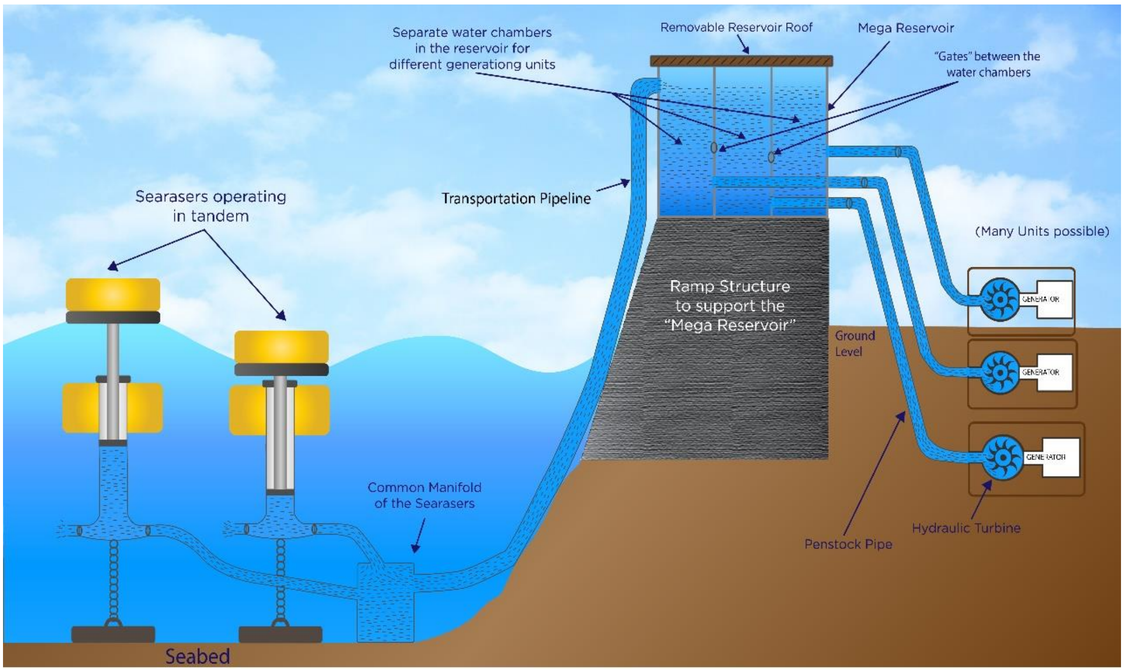


Figure 1.11: Layout out proposed hydro-electric power plant operated by ***Searaser***

The water chambers will have interconnected gates/ways among them, this is provided so that in case of emergency water might be needed to be transferred to the water chamber of the unit where shortage of water was observed from the water chamber/s of the standby unit or the units that are yet to come into operation. The size of water chambers can be increased easily if required to facilitate the future expansion in the unit’s size.

In addition, a removeable roof may be provided to take advantage of storing **rain-water**. A filtering net should be incorporated with removeable roof in order to catch debris and prevent the reservoir from getting clogged with sediments. In this layout of power production, the generation of electricity depends solely upon the supply of water from the ‘Mega reservoir’ or the availability of wave power. However, wave power level in a near shore region doesn’t remain steady because the wave energy tends to be higher during high-tide and tends to be lower during low-tide periods. Often wave power level in low-tide condition may be too small to be absorbed by the near shore WECs like ***Searaser*** and as a result continuous electricity supply may not be possible. In those cases, only the wave energy during high-tide periods is absorbed and utilized to supply electricity demand at some peak hours.

1.6 Background of this study

Saint Martin’s Island is one of the most beautiful and important tourist spots here in Bangladesh. But due to inadequate transportation facility and location, Saint Martin’s Island is isolated from the national power supply grid and as a result lack of proper supply of electricity has been a crying issue among the tourists. So, because of this reason the Island is about to lose its tourist attraction potential, which could put a huge negative impact on the economy of Bangladesh. At presents the basic electrical power requirements of the Tourist Resorts in the Island are being provided by standalone diesel generators.

The generators are only operated at some specific hours when the tourists most likely to in need of electricity. On average, the generators remain in operation for 8 to 9 hours daily. But the operation of those generators is not environment friendly and moreover their running cost is exorbitantly high. However, the electricity at those peak demand hours could easily be supplied with environment friendly process if the potential renewable energy resources available in the Island such as wave energy could be utilized. Some prominent authors such as **Ahmed, Al-Amin, Hasanuzzaman** et al. [17] [18] gave positive feedback about the wave power potential in some specific regions of

Bangladesh such as Kuakata, Sandwip and **St. Martin's Island.** Unfortunately, because of some technical and economic difficulties, Bangladesh still lags far behind other nations in the field of wave energy utilization. This is the scenario where the necessity of this present work becomes essential.

All around the world, using wave energy converters to mitigate the energy demands in remote islands has been a topic of interest from the past few decades. The rising prices of fossil fuels and the costs associated with fuel transportation to these remote islands have sparked a growing interest to replace fossil fuels with renewable energy, particularly wave energy.

However, with the prospect of the novel WEC technology called ***Searaser,*** this study investigated that the wave energy utilization status quo of Bangladesh will change for the better and many more crucial coastal spots such as Saint Martin's Island could be benefited. The ***Searaser*** was invented and patented by British inventor Alvin Smith in 2013. Since then, it has garnered international attention nationally and internationally, being tested in some areas as well [16] .

The simplistic design and concept of the ***Searaser***, coupled with its environmentally friendly features (not having any rotating parts in the water or fish trapping areas) makes it an ideal WEC for low budget situations and to be implementable in many remote islands. The Searaser's performance has also been extensively tested in the Caspian Sea in Iran by Babajani et al. [18]. They investigated the optimum distance between a pair of ***Searasers*** for maximum power generation in the Caspian Sea. With the proper installation of ***Searaser***, harnessing wave energy to supply necessary electricity demand in the tourist resorts of Saint Martin’s island, which is a peak tourist spot here in Bangladesh, can become a reality from a possibility within a span of a few years.

1.7 Objective with specific aims:

Present work aims to design a micro hydroelectric powerplant for the island of Saint Martin’s which will mainly supply the integral electricity demand in the tourist resorts by replacing the standalone diesel generators. The powerplant will derive its driving power from the reasonable amount of wave energy available in the coastal regions of Bay of Bengal near the Island. The wave energy will be utilized and harnessed by using the novel wave energy conversion device ***Searaser***. Since wave energy is completely renewable, the energy conversion system will involve no generation of harmful greenhouse gasses and it is hoped that a completely environmentally friendly power generation system will be achieved.

The research work has following objectives:

1. To analyse the wave power potential in the coastal regions of Saint Martin’s Island.
2. To measure the performance and feasibility of using ***Searaser*** in the case study by analytical **Hydrodynamics** and **Water Wave Mechanics.**
3. To design and specify the dimensions of ***Searaser’s*** power take-off (PTO) system considering the technical and economic aspects of wave power absorption.
4. To estimate the electricity demand curve of the resorts by field survey.

5. To interlink energy supply with **sustainable tourism policy** and take decision based on that.
6. To design the proposed micro-hydro powerplant (MHHP) and simulate the cost of its different components by using some generic cost functions.

1.8 Organization of this thesis

This thesis comprises of five chapters. Chapter 1 gives a brief overview of the background and concept of this study. Finally, significance of the research and the objectives of this study are summarized. This chapter also outlines the organization of this dissertation.

A comprehensive literature review is given in the Chapter 2, which categorized into seven sections. First section gives a brief overview of the current energy scenario in Bangladesh, along with relevant supporting data. In the second section, ongoing work and research in the field of micro hydropower plants is discussed, including the ongoing research conducted by various authors in this particular field. Section three discusses the other forms of renewable energy sources (other than wave energy) that exist in Bangladesh, along with their prospects and scope. Section four gives an insight into the analysis of wave energy converters, various methods of analysis are highlighted in this section, along with key data and how the respective authors carried out the analysis. Section five is all about the ***Searaser***, along with its benefits and experimental details regarding past experiments that some researchers have conducted using it. Section six is regarding the past studies that have been conducted in Saint Martin Island, compiled by various distinguished authors in this field. The necessity of this particular study is also highlighted. Finally, the last section gives a brief summary, summing up all the information and key points discussed throughout the literature review.

Chapter 3 describes the methodology of the study. Some underlying assumptions that have been adopted in the entire design process, are also stated there.

Chapter 4 describes the findings and end results of the overall design process explained in section 3.

The conclusions and summary of the contributions are presented in chapter 5. In addition, some directions for future work related to this study are also presented. Chapter 6 lists the literature cited in this work.

Chapter 2 Literature Review

Nowadays widespread concern about global climate change, increasing rate of green-house gas emissions, fast depletion of ozone layer, various environmental hazards, limited storage and rising prices of fossil fuels have made people/researchers to shift their interest on cleaner renewable energy resources.

At present, among many more renewable energy sources, hydroelectric projects are the cheapest and the most efficient source; but oceanic wave energy could be a good competitive source to mitigate the increasing needs for cleaner energy.

Oceanic wave energy has great potential in supplying the worldwide increasing demand for power. After the oil crisis in 1970s, wave energy attracts great attention but few people have heard of the capabilities of ocean wave energy. Because of its high potential to generate electricity, different types of wave energy converters have been being introduced by the researchers starting from the past 18th century. Following the trend, many efficient and effective modern design of WECs were patented in the past few years. Some of them are now operational and supplying electricity commercially. ***Searaser*** is one of the modern wave energy converters. It has very simple construction and efficient design compared with other WECs. **Bangladesh** can utilize this type of wave energy converters to harness the energy of the waves in the Bay-of-Bengal. The Saint Martin’s, the only coral Island of Bangladesh in the Bay-of-Bengal, being one of the popular tourist destinations, adequate supply of electricity is vital to this area. The reasonable amount of wave power potential in the Island has accelerated this work to focus on the utilization of this potential by a simple, cost effective WEC such as

Searaser in order to provide a lion’s share of electricity requirements of the Saint Martin’s Island.

2.1 Current Energy Scenario in Bangladesh

Rapid growth of population, urbanization and industrialization triggered energy consumption phenomenally in the country. Primary energy consumption was 12.7 Mtoe in 2000 and reached 24.3 Mtoe in 2011 [19]. From 1992 to 2011, final energy consumption has increased over 200%. However, per capita primary energy consumption was 0.152 Mtoe in 2011. But total primary energy consumption increased by 2.59% annually from year 1980 to 2010 [20]. Expected power demand will rise by 185% by the year 2020 [21]. Primary energy demand is still increasing drastically, which is currently being generated by depleting fossil fuel (nonrenewable energy) sources such as natural gas, coal, oil and petroleum products [22].

However, Biomass’ share in the total primary energy supply is considerable. Around 65% of the population of the country resides at rural areas and 44% are living under the poverty line for whom biomass energy is being used as primary energy source [23]. Among the local primary energy sources in Bangladesh, natural gas is widely used in power plants, fertilizer factories, industrial entities, and most recently in transport sector as compressed natural gas (CNG).

As a primary energy source, natural gas accounts for 73% of the total energy consumption [20]. At annual GDP growth of 7%, it is estimated that, by 2021, electricity demand will rise up to 18,838 MW, and by 2030, it will be 33,708 MW [24]. By 2021, GOB (Government of Bangladesh) envisioned providing uninterrupted electricity supply to all citizens as per mentioned in the power system master plan (PSMP) 2010. Total generation capacity will be 20,000 MW with a per capita consumption of 600 kWh, by 2021. By then, natural gas will account for 3115 MW of electricity generation, which reflects mono fuel dependency. In an overall energy demand scenario by all sectors, 5.6 BCF of natural gas will be required by 2025 [20]. Present reserve of natural gas is 11.77 trillion cubic feet (TCF) which is supposed to be diminished by 2019 [25]. With this present consumption rate of fossil fuel, it is expected that Bangladesh will face serious energy crisis within next few decades.

2.1.1 Fossil Fuel Energy Mix in Bangladesh

Natural Gas: Natural gas is the most valuable indigenous natural resources of Bangladesh, and playing a pivotal role in the growth of the economy. It shares 75% of the primary commercial energy supply and 79.15% of power generation [20]. Until 2012, 24 gas fields have been discovered with proven reserve of 37.680 TCF, out of which 26.877 TCF is recoverable. Currently, 20 gas fields are in full operation, and as of June2012, total 10.514 TCF of natural gas has been produced.

Among different sectors, power plants have the largest share of natural gas consumption, which is 41%, followed by industry – 17%, captive power sector – 16%, domestic sector – 12% and fertilizer factories – 8% [20]. In 1992, natural gas demand in power sector was 88.1 BCF that reached 304.3 BCF in 2012, which is a net 200% increase. In fiscal year2010–2011, approximately 38.54BCFwas consumed by CNG sector, which is 6% of the total natural gas consumption, and it is expected to increase 120.9 BCF by 2015. From 1991 to 2012, demand for natural gas increased by 300% [20]. Mono fuel dependency on natural gas is seen in all over the industry which might pose threat to future long-range energy sector planning and sustainable development of the country.

Oil: Bangladesh has no significant oil reserve except the Haripur oil reserve which was discovered in1989 at northwest of Sylhet district [26]. Estimated reserve is 1.4 Mtoe, out of which 0.84 Mtoe was supposed to be recovered as of year 2004 but the exploitation was abandoned due to poor oil quality and presence of water in the oil zone [10]. Bangladesh heavily depends on imported crude and refined petroleum products for transportation, industrial heating and small-scale power generation.

At present, demand for refined oil in the country is 4.87 million metric tonne (MT) at an annual growth rate of 5%. A large amount of revenue budget is spent every year for purchasing imported petroleum. Developing countries like Bangladesh require affordable energy and electricity supply which Must be meet with available energy sources, rather imported energy sources. Economic viability and environmental concerns should be addressed with present energy demand, and in such circumstances, finding out alternative energy sources and its utilization has to be ensured.

Coal: Coal is the most abundant and economical energy sources not only in Bangladesh but also, all over the world [26]. At present, coal as primary commercial energy accounts for 39.8% of the world's electricity generation. In Bangladesh, coal shares 3.25% of the actual generation of electricity. National coal policy is under process, and it is expected that realistic planning and allocation of national budget could provide meaningful development in the sector which was previously, long halted due to administrative and technological barrier [20]. So far, five coal deposits have been discovered at the north-west part of Bangladesh. Current estimated reserve is approximately 3300 million MT which is equivalent to 45–50 TCF of natural gas [20]. Barapukuria has a daily production capacity of approximately 2500–3000MT, and as of June 2012, total 4.55 million MT of coal has been produced. Thermal power plant located at Barapukuria with an installed capacity of 250MW, requires 2000MTof coal per day [27]. At present,39.8% of the world's electricity is generated from coal. Coal deposits found in Bangladesh consist of bituminous type of coal, and among the deposits, Barapukuria coal has the calorific value ranges from 5546 to7202 kilo calorie per kilogram (kcal/kg) [28].

2.1.2 Renewable Energy Resources and Their Prospects

Global energy consumption will increase by 36% with an annual growth of 1.6% from year 2011 to 2030, comprising 88% fossil fuel share. Bangladesh being a developing country in the Southeast Asia, which is one of the lowest per capital energy consuming nation [20]. Due to severe power crisis, the economic growth of the country is becoming severely restricted and thus is not up to the mark. In these crucial times, an alternative is needed urgently, other sources of renewable energy could be the answer to this problem. Sources like wind, solar, geothermal and biomass are studied in this section along with their respective prospects from a Bangladeshi perspective.

2.1.2.1 Biomass

Biomass is extensively used as alternative energy sources in developing countries for the purpose of cooking, heating and other necessary household activities. Generally, biomass refers to rice husk, crop residue, jute stick, wood, animal waste, municipal waste etc. It is the fourth largest source of energy [20]. At present, biomass accounts for 8.5% of the global final energy consumption [29]. It can contribute to the overall environment quality by reducing emission, and as a promising source of electricity generation. Global biomass energy share will be 50% by 2050, in terms of consumption [30]. Like other developing countries in Asian continent, biomass accounts for 48% of the total energy consumption in Bangladesh [29]. In Bangladesh, traditional biomass as energy supply source such agricultural residues, wood wastes and animal dung, represents 46%, 34% and 20%, respectively [32]. Bangladesh is endowed with rich biomass energy with a potential electricity generation capacity of 160.93 TWh from agricultural crop residues, followed by 121.768 TWh from recoverable waste, and 29.91 TWh from fuel wood, saw dust and tree residues [27]. Lately, Infrastructure Development Company Limited (IDCOL) financed 238.65 million Bangladesh Taka (BDT) in biomass-based technologies including biomass power plant, biomass gasification plant and biogas-based electricity generation plant.

2.1.2.2 Biogas

Biogas is a very promising renewable energy resource derived from various residues, mainly from animal and municipal wastes. Technology dissemination in this particular renewable energy source is very poor all over the country [33] . IDCOL financed a 250 kW biomass based power plant at Kapasia, Gazipur, in which local agricultural residues such as rice husk is used [34] Municipal solid waste could also be an important source of biogas production [33].

2.1.2.3 Biofuel

Biomass utilization is categorized by bio-product, bio-energy and bio-power [35]. So far, Bangladesh is in early stage developing bio-fuel from biomass energy. Biofuel is produced from transesterification of oil derived from various energy crops. Both developed and developing countries are putting effort to commercialize biofuels at large scale. For instance, government of Malaysia, lately introduced fuel diversification policy where it was emphasized on use of biodiesel as biofuel both in transportation and industrial operations [36]. In Bangladesh, there is currently, no energy crops being produced for biofuels at commercial scale however, on experimental basis, NITOL Motors, Bangladesh has started working with two Singaporean firms to produce bio-fuel from ethanol molasses [32]. The bio-fuel will be used as gasohol in the transportation vehicle, and the price will be reduced by 20–30% compared to other transport fuel [36]. Bangladesh can also utilize Jatropha curcas as energy crop which is a non-edible plant containing 50–60% vegetable oil. It is comparatively cheap feedstock for biodiesel production, generally grows on degraded soils with less fertility and moisture [38].

2.1.2.4 Solar Energy

Solar energy is today considered to be one of the most promising renewable energy sources worldwide. It has the highest energy potential, as compared to other renewable resources [20] .Approximate annual solar radiation on the earth surface is about 3,400,000 exajoule (EJ). Theoretically, available solar energy insolation could generate 1700 TW of electric power, and it is estimated that 1% of this energy can resolve world's present power demand [39]. It is also estimated that solar energy could deliver 450 EJ energy, equivalent to 7500 times higher of the world's energy consumption if the full potential is utilized [40]. Generally, solar energy is being utilized in lighting, heating, and most importantly; in power generation. Geographical location of Bangladesh is considered to be an ideal place for solar energy utilization. [41]. Annual solar radiation available is over 1900 kWh/m2 [42]. Theoretically, Bangladesh receives approximately 69,751 TWh/yr equivalent of solar energy which is 3000 times higher than the electricity generated as of year 2006 in the country [43]. It is found that 94% of the land area in Bangladesh have such radiation which is sufficient for appropriate utilization based on available technology [43]. Maximum radiation begins from March to April, and minimum – December to January. The highest solar radiation is found at Rajshahi district showing an immense potential of solar energy utilization [20].

2.1.2.5 Wind Energy

Wind energy is one of the fastest growing renewable energy sectors of present time [44]. Wind energy currently accounts for 38.1% of total electricity generation in Germany. On the other hand, the US and China represents world's wind power installed capacity [45]of 61.1 GW. Wind energy potential is not encouraging except in some coastal areas of Bangladesh. Bangladesh has a costal belt of around 724 km along the Bay of Bengal consists of several islands. However, commercial power generation from wind turbine requires adequate techno-economic evaluation which is not readily available. On the other hand, a well-constructed wind map and ground data is essential for assessment harnessing wind energy potential. Approximately, from March to September wind blows at an average speed of 3–6 m/s over Bangladesh [46]. Global wind data and research shows that wind speed not more than 7 m/s is not viable for large scale grid connected electricity production within wind parks [20]. Up to present, several studies conducted by Bangladesh Center for Advance Studies (BCAS), BMD and Local Government Engineering Department (LGED) revealed that wind speed varies from 2.96 to 4.54 m/s at a height of 25 m and 50 m in different parts of the country [32]. From literature, it is found that total wind turbine installed capacity in Bangladesh, varies from 20 kW to 50 kW [45]. Global wind energy is growing at an expanding rate due to ecofriendliness and bulk power generation capabilities. Bangladesh is on its footstep to harness wind energy potential. At present, wind mapping and necessary ground data should be acquired to assess the full potential of wind energy. More research and development in the area should be conducted with comprehensive analysis, based on geographical context of Bangladesh.

2.2 Ongoing Work in the Field of Micro Hydro Power Plants

J.L. Ma´rquez has presented a novel control approach of a three-phase grid connected MHPP (micro hydro power plant) incorporating dynamic active power generation jointly with reactive power compensation of distribution systems in his paper [44] . He proposed an advanced structure of a micro-hydro power plant (MHPP) based on a smaller, lighter, more robust and more efficient higher-speed turbine.

The suggested design was much simpler and eliminated all mechanical adjustments through a novel electronic power conditioning system for connection to the electric grid. It allows obtaining higher reliability and lower cost of the power plant. A full detailed model of the MHPP was derived and a new three-level control scheme was designed in his research. Simulation studies and experimental results was demonstrated by him. The effectiveness of the proposed multi-level control approaches in the reference frame and the detailed models were presented.

M. Hanmandlu proposed an electric servomotor as a governor for a micro hydro power plant especially those plants that are operated in isolated mode [45]. An advanced controller was developed combining four control schemes for the control of the governor following the concept that the control action could be split up into linear and non-linear parts. The linear part of this controller contains an adaptive fast transversal filter (FTF) algorithm and normalized LMS (nLMS) algorithm. The non-linear part of the controller incorporates a neural network. The concept behind splitting the control action is reasoned out and the conditions for stability of the controller are proved. The maintenance of desired power generation and frequency of micro hydro power plants using flow control is the main theme of his research. The proposed scheme consists of dividing the controller action into two parts: Linear and Non-linear.

C.P. Ion stated that Autonomous micro hydro power plants (MHPP) are a reliable solution for supplying small power consumers in areas located far from the distribution grid. [46]When an induction generator (IG) is used in such a power plant, voltage and frequency needed to be stabilized. He presented a single control structure that ensures both the voltage and frequency regulation of an isolated induction generator (IG). He described the application of an isolated induction generator in a micro hydro power-plant.

Nasir has illustrated the feasibility of micro hydro systems in a suitable site [47]. The only requirements for micro-hydro power are water sources, turbines, generators, proper design and installation, which not only helps each individual person but also helps the world and environment as a whole. He has shown that the choice of turbine will depend mainly on the pressure head available and the water flow rate. There are two basic models of operation for hydro power turbines: Impulse and reaction. Impulse turbines are driven by a jet of water and they are suitable for high heads and low flow rates. Reaction turbines run filled with water and use both angular and linear momentum of the flowing water to run the rotor and they are used for medium and low heads and high flow rate. Regulated turbines can move their inlet guide vanes or runner blades in order to increase or reduce the amount of flow they draw. Cross-flow turbines are considered best for micro-hydro projects with a head of (5) meters or less and water flow rate (1.0) *m3/s* or less. Micro-hydro power installations are usually run-of-river systems, which do not require a dam, and are installed on the water flow available on a year round basis. An intake structure with trash rack channel.

B. Ogayar has analyzed the cost of electro mechanical equipment's of a small hydro power plant [48]. The cost of the electro-mechanical equipment (turbine, alternator and regulator) means a high percentage of a small hydropower plant budget (around 30% and 40% of the total sum). It stems from this the importance of the determination of that cost, which could directly influence the project feasibility. For the determination of the cost of the electro-mechanical equipment, there are graphs which can approximately calculate those costs. But these graphs refer to a distant time period, since they use to be at least 10 years old. Besides, manufacturers of turbines and alternators do not supply any information about cost, since every installation is different and complex. An example of these graphs are those developed by the Institute for Energy Diversification and Saving [Instituto para la Diversificacio ´n y Ahorro de la Energı´a, IDAE, Spain], with which it is possible to determinate the cost of a turbine depending on its power and net head.

Maurice Pigaht described the early results of a project in Rwanda that has successfully mobilized been attempted through a wide range of approaches [49]. The project was the community-owned approach that still dominates development aid projects, with few notable exceptions. Although there is not sufficient information to allow a comparison of different approaches in the experience of the authors community-owned projects have generally disappointed in impact, self-replication potential and sustainability. The PSP Hydro project was conceived to pilot a new private-sector oriented approach to micro-hydro power development, with a view to significantly increase local equity and debt, impact and local equity and debt capital for micro-hydro projects with local distribution grids.

2.3 Works on Wave Energy Converter

A. Babarit investigated semi-analytically the latching control applied to a mechanical oscillator; and numerically three strategies of latching control for a point absorber wave energy converter oscillating in the heave mode only. [50] By solving the equation of motion of a mechanical damped oscillator, He has shown that latching control can magnify the amplitude of the motion whatever the frequency of the excitation force, and how it can improve the efficiency of the system, in term of absorbed energy, for excitation frequencies apart from the natural frequency. Assuming that the excitation force is known in the close future and that the body is locked in position at the current time step, equations of motion of the body are solved numerically in the time domain for different initial conditions (i.e. latching durations). For all these simulations, three criteria one for each strategy were tested and the latching time leading to the best result was selected. Time domain simulation results were presented for a heaving buoy in small-amplitude regular and random waves. In regular waves, the same results as for the case of a mechanical oscillator are recovered for the wave energy converter. In random sea, results show that for all the three proposed strategies, efficiency of the wave energy converter is considerably improved in terms of absorbed energy. Numerical study of the period of the controlled system shows that the delay of prediction of the excitation force in the future seems to be bounded by the natural period of the system.

A.H. Clement described two methods which can be used to estimate the gain that latching control can bring to wave energy - Time domain simulation of the SEAREV device in irregular waves; absolute latching/weak latching. Converters[51]. The main interest of these methods was that they can be used whatever the wave energy converter, provided their equation of motion can be written under a state equation form. In this study, this was achieved by using Prony's method in order to replace the convolution integrals of radiation force memory terms by additional state variables, and solutions of additional differential equations. Applying the first analytical method to a heaving buoy, he had shown that latching control should preferably be used with opposite ending ramps condition; while the other possibility (equal ending ramps condition) was efficient only in a limited range of the considered frequency spectrum. Comparison of the results of this method in a regular wave with the optimal command method based on Pontryagin's principle showed that the optimal command theory may slightly under predict the absorbed power, due to numerical constraints. In this approach, the quality of the prediction was strongly related to the latching coefficient G, the larger it is, and the better is the result. Anyway, application of the optimal command method in a random sea leads to the same results on the improvement of the efficiency as in other studies.

L. Margheritini discussed a Wave Energy Converter (WEC) of the overtopping type. The overtopping water of incoming waves was stored in different basins depending on the wave height. [52] Turbines played an important and delicate role on the power takeoff of the device.They had to work with very low head values (water levels in the reservoirs) and wide variations in a marine aggressive environment. The concept of the innovative Multi-Stage Turbine (MST) was presented as integrant part of the SSG concept. The Company “wave energy” as found in Stavanger Norway, was developing the device (patented in 2003) since 2004 when the pilot project had been partially funded by the European Commission FP6-2004-Energy (WAVESSG project) and it could now benefit of 2.7 MV, the majority of which were from private investors. Partners from different countries in Europe collaborate for the realization of the pilot project. The installation of the structure was foreseen for summer 2008 in the island of Kvitsøy, Norway. The main strength of the device consisted on robustness, low cost and the possibility of being incorporated in breakwaters (layout of different modules installed side by side) or other coastal structures allowing sharing of costs and improving their performance while reducing reflection due to efficient absorption of energy.

R. Carballo has done wave resource assessment to determine the power performance that can be obtained at a location of interest with a certain WEC technology [53]. In this work a comprehensive procedure for this purpose was developed and illustrated with a case study, an Oscillating Water Column WEC projected to be constructed in A Guarda (NW Spain). First, a characterization of the offshore wave climate was performed based on energy bins - trivariate intervals of significant wave height, energy period, and mean wave direction. For the characterization of the offshore wave resource to be accurate, three basic requirements were identified: (i) a large proportion of the offshore wave resource should be covered; (ii) the fundamental wave parameters (wave heights, periods, and directions) should be characterized with a high resolution; and (iii) the intra-annual variability of the resource should be taken into account. A procedure complying with these requirements was developed and applied to the case study. 95% of the total energy was covered; energy bins with interval sizes of 0.5 m of significant wave height, 1 s of energy period, and 22.5 of mean wave direction were adopted; and the intra-annual variability was accounted for by performing the analysis on a monthly basis, considering an average year (the average of 13 years of data).

M. Fadaeenejad reviewed the recent works about extraction of electricity from wave energy and to evaluate the new applied converters for electrification of small islands. [54] Although there are many research articles about wave power energy but a few of them have considered a suitable wave energy converter (WEC) as a power system for remote islands.

J.P. Deane an investigated the impacts of including 500 MW of wave power into Ireland’s electricity generation portfolio in the year 2020 [55]. One year of detailed market simulations were undertaken to determine the impact on wholesale electricity prices, system operation costs and CO2 emissions with and without this installed wave power under a number carbon prices assumptions. In both scenarios (with and without wave energy), Ireland’s installed renewable capacity is fixed such that 40% of Ireland’s electricity in 2020 is from renewable source.

Anto´nio F addressed the characterization of the wave energy resource; theoretical background, with especial relevance to hydrodynamics of wave energy absorption and control; how a large range of devices kept being proposed and studied, and how such devices could be organized into classes; the conception, design, model-testing, construction and deployment into real sea of prototypes; and the development of specific equipment (air and water turbines, high-pressure hydraulics, linear electrical generators) and mooring systems [56].

Chris Retzler described an experimental investigation of the slow-drift excitation and damping [56]. The Pelamis wave energy converter (WEC) was moored with a clump-assisted wire catenary of high compliance that, coupled with the displacement mass of Pelamis, had a resonant frequency an order of magnitude lower than the wave frequencies. The mooring was thus decoupled from first-order wave excitation, and is excited by second-order slowly varying drift forces, which were mainly due to the wave momentum transferred to the device as wave power is absorbed. The slow drift motion is damped by a combination of drag and wave-drift damping.

2.4 Works on Searaser

The Searaser was invented and patented by British inventor Alvin Smith in 2013. Since then, it has garnered international attention nationally and internationally, being tested in some areas as well [16]. The simplistic design and concept of the Searaser, coupled with its environmentally friendly features (not having any rotating parts in the water or fish trapping areas) makes it an ideal WEC for low budget situations and to be implementable in many remote islands. The Searaser’s performance has also been extensively tested in the Caspian Sea in Iran by Babajani et al. [16] They investigated the optimum distance between a pair of Searasers for maximum power generation in the Caspian Sea. In the present study, attempts have been made to simulate the Searaser performance in the wave tank by solving Navier–Stokes equations. A commercial CFD code (Flow-3D) which is suitable for modeling of WEC had been used by Babajani to solve the governing equations. In order to validate the hydrodynamic results, firstly the hydrodynamic performance of a point absorber was investigated via this software in which the difference of numerical and experimental data was negligible. In their research, two Searasers were simulated numerically in different distances to find an optimum distance between these two devices where they can produce more electrical energy.

David Dunnett discussed the performance of three different types of wave energy converters (WECs) which were evaluated at hundreds of Canadian locations using wave activity data made available by the Marine Environmental Data Service of Canada [58]. Two Atlantic and three Pacific locations are found where at least one of these devices operates with a capacity factor of greater than 20%, while also being located close to urban/industrial centers. The economics of a nominal 25 GWh wave power plant are investigated at these five locations and compared among the three WEC types using two indicators: the 25-year life-cycle cost, and the required price of electricity for a 10-year simple payback period. The lowest required electricity price for a 10-year payback is $0.089/kWh, and occurred at a location near the Hibernia Oil Platform using the Aqua Buoy WEC. The highest annual capacity factor is 32.1%, which occurred near the Hibernia Oil Platform when using the Wave Dragon WEC.

2.5 Previous work on Saint Martin Island

A.K.M. Sadrul Islam has investigated about establishing PV –wind diesel battery hybrid energy systems in his research [59] .This study simulates a PV-wind diesel-battery hybrid energy system in St. Martin Island. A system with 8 kW PV array along with a 15-kW diesel generator and 25 numbers of batteries (nominal capacity 800 Ah, nominal voltage 2V each) gave the most economically feasible solution. In Bangladesh the price of diesel fuel is increasing very rapidly. So using only diesel generators will not be feasible in near future. Therefore, he proposed to establish PV –wind diesel battery hybrid energy systems in Saint Martin Island.

Ferdous Ahmed studied Present energy scenario, alternative energy resources and future prospect in Bangladesh [60]. His work compiles latest literatures in terms of thesis, journal articles, conference proceedings, web materials, reports, books, handbooks on energy and renewable energy resources in Bangladesh. Deficiency in the energy sector is a major problem in Bangladesh, which hinders the smooth economic development workflows. Being the eighth most populated country in the world, Bangladesh is one of the most electricity deprived nations with a total electricity generation of only 5000 MW. Thus, Bangladesh is facing difficulty to achieve an overall sustained progress in the economy due to the lack of a sound energy security. In this context, he emphasized on using alternatives of conventional energy sources, renewable energy resources to be the solution for the energy security. This study discovered the factors that are useful to lessen the existing power supply crisis and summarized the current energy scenario, lack of infrastructure and conventional energy sources to promote the renewable energy sources to fulfill the power demand in Bangladesh.

2.6 Summary

Micro hydro power plants can be designed to harness electricity from wave energy from the Bay of Bengal. In this regard, *Searaser*, a noble wave energy converter invented by Alvin Smith has great potential and flexibility to harness energy in Bay of Bengal. The island of Saint Martin in the Bay of Bengal may be an appropriate location for constructing this wave energy converter. Past literatures have established the efficiency of the *Searaser*, along with valid tests and simulations. As Bangladesh continues to depend on fossil fuels, the transition to renewable wave energy could be a huge leap forward for a developing, over populated country. This will also result in the preservation of the natural environment and help sustain the local population by fulfilling their energy demands.

Chapter 3 Methodology and Design

3.1 Introduction

Designing of hydro powerplant requires a lot of key factors and scenarios to be considered. As per the aim of the study, since the ***Searaser*** WEC will be supplying the necessary energy input required by the plant in order to meet specific electricity demand, its design and performance study becomes very crucial at the initial stage of design process. In order to visualize the entire design process, the study flow chart is given in Figure 3.1.

Here at first the methodology of hindcasting Wave Characteristics at the nearshore regions of St Martin’s Island from Wind Speed Measurement has been discussed since the record of wave characteristics in regions near the Island was not available. Net water head that will be available from the interaction between striking waves and ***Searaser*** is calculated by applying the knowledge of analytical water wave mechanics and hydrodynamics. After that the entire resorts of the Saint Martin’s Island were classified into different categories based on the information gained from the field survey that was conducted on several resorts. The total accommodation capacity of all resorts is modelled such that it remains below the Effective Carrying Capacity (ECC) of the Island. Then the load curve of the resorts is constructed from the survey findings and the proposed wave-powered micro hydro powerplant (MHPP) is designed accordingly.

Finally, cost simulation of major components of the proposed hydro powerplant is done by the application of some generic cost functions available from literature.

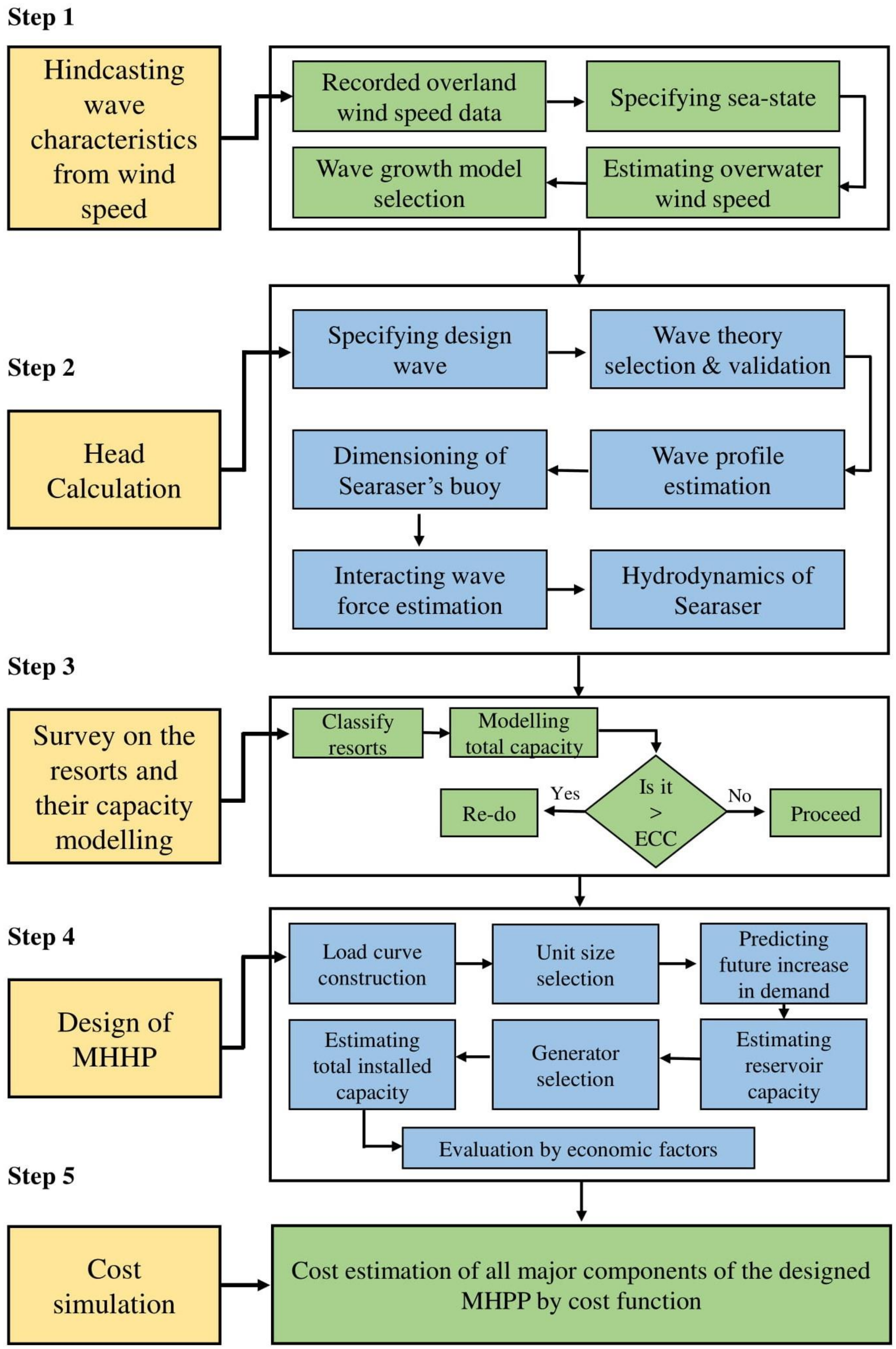


Figure 3.1: Entire Design Process

3.2 Hindcasting Wave Characteristics from Wind Speed Measurement

3.2.1 Wave characteristics and use of historical wind data

Real ocean waves are very complex in nature, therefore to study about them some idealizations are required to be made. Considering the energy spectrum of the wave field, a significant height and significant period (H_m & T_m) are defined such that they would represent the characteristics of the real sea in the form of monochromatic waves. The representation of a wave field by spectrally based significant height and period has the advantage of retaining much of the insight gained from theoretical studies [19].

The performance of ***Searaser*** or in other words 'The Water Head' that will be obtained by its action is governed by the characteristics of wave at the desired location. Therefore, before coming to the design stage of the proposed wave-powered powerplant for 'St Martin's Island', it is crucial to know the wave characteristics of 'Bay-of-Bengal' at a specific water depth (yet to be defined) in a certain location near the Island where the ***Searaser*** will be put under service.

Finding the wave characteristics by field measurement is beyond the scope of this study. Moreover, there hadn't been any direct study conducted to find the wave characteristics in the St Martin's Island. But in the past, several studies had been conducted in the island to collect the wind speed data over there. The R&D sector (IFRD) of BCSIR (Bangladesh Council for Scientific and Industrial Research) had conducted a study in the St Martin Island to find the wind speed and collected data for 3 consecutive years (1999-2001) at 30m above ground level. Kaiser et al. [20] synthesized those monthly averaged wind speed data from BCSIR along with the information about the height of measurement location from ground level =30m, elevation of ground level from sea-level =3m, surface roughness of ground =0.01m. They used HOMER for synthesizing purpose to generated a pattern of hourly wind speed data for a year (Figure 3) based on the parameters such as Weibull factor, K=1.8, Auto correlation factor (measures randomness in wind speed) =0.9, Diurnal pattern strength (measures wind speed variation over a day) =0.25, hour of peak wind speed = 22 (10pm). NASA satellite values of wind speed for the same location at 10m height for terrain similar to airport are also available. These records are tabulated in Table 1.

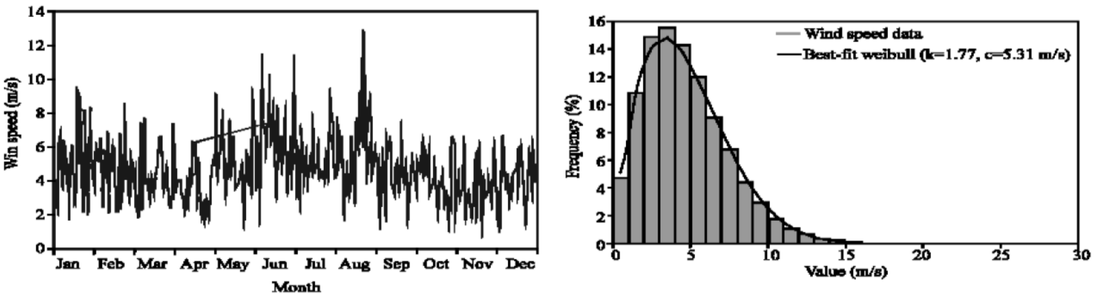
However, it is possible to predict the wave characteristics at a certain location of the sea provided the wind information at that location is known, this is because of the reason that wind is mainly responsible for the generation of most common types of waves seen in the seas. Many studies on this issue have shown that wave characteristics (wave height and period) are closely related to wind speed. Therefore, it should be possible to reconstruct a wave climate at a site from historical, measured wind records. Such a computation is known as wave hindcasting.

In this work, a ‘Simplified Wave Prediction Model’ discussed in the literature has been applied to hindcast wave characteristics at the desired location from the wind speed data over the St. Martin’s island available from the record of BCSIR and the information used by Kaiser et al. [20] to synthesize them.

Though now-a-days computer-based wave estimation tools are available, however, there are often cases where neither the time available nor the cost justifies ‘the estimation with complex numerical models used in computers. In these cases, a simplified theoretical method may be justified. Therefore, the simplified theoretical methods for hindcasting wave characteristics from the wind field information have been used in this present case study for quick, low-cost estimates.

Table 3.1: ‘Monthly Averaged Wind speed’ data at St Martin’s Island

Month	NASA (at 10m height) [21]	Measured by BCSIR from ‘1999-2001’ (at 30m height) [22]
	$V_{av}\,(ms^{-1})$	$V_{av}\,(ms^{-1})$
January	3.27	**5.03**
February	3.39	**4.7**
March	3.57	**4.24**
April	3.67	**3.79**
May	3.89	**5.07**
June	6.27	**6.17**
July	6.35	**5.56**
August	5.64	**5.78**
September	4.05	**4.47**
October	3.27	**4.11**
November	3.24	**3.53**
December	3.10	**4.11**
Annual average	4.14	**4.71**



(a) (b)

Figure 3.2: Wind speed probability density function, (b) Daily wind speed for St Martin [20]

3.2.2 Mechanism of wave generation

The most common type of waves observed in Sea are **‘Gravity Waves’**. Gravity waves are generation by wind. Wind is the exciting force in this case and gravity is the restoring force. Hence, the wave is developed as a vertically oscillating component influenced by the gravity, g, because of which, the wind generated waves are called gravity waves. When wind blows, disturbances of ocean surface take place due to the action of tangential and normal stresses of wind (Figure 3.3) induced on sea surface and hence waves are generated. Initially ripples, short period or high frequency waves are generated. Gradually the transfer of energy towards the lower frequency wave takes place. The energy is continuously transferred from waves of high frequency to those of low frequency until the phase velocity or the celerity of the wave, C is equal to the wind velocity V i.e., C=V; in more general terms the group celerity C_G =V is considered. When C_G >V, the transfer of energy from the wind doesn’t contribute anymore to the growth of the waves. That means wave reaches equilibrium with wind at a certain point. This equilibrated sea state is called ‘Fully Developed Sea (FDS)’. The wind wave development and generation thus depend significantly on the ratio of C and V, which is termed as wave age. Before reaching FDS, wave age may range from 0.1 to 2.0.

Prior to the waves attaining their equilibrium, if the wind stops blowing, the sea state is under-developed compared to its potential. This sea state is called duration-limited. On the other hand, if there is a constraint in the space for the wave propagation or for them to grow, the sea state is called fetch-limited sea [23]. Here, Fetch is defined as an area of ocean surface over which the wind blows in an essentially constant direction, thus generating waves.

So, based on the condition of wind-generated waves, sea states can be classified as:

- Fully Developed Sea (FDS), wave growth is a function of windspeed only i.e., *f (V, g)*.
- Duration-limited sea, wave growth is a function of windspeed and time i.e., *f (V, t, g)*.
- Fetch-limited sea, wave growth is a function of both windspeed and fetch length i.e., *f (V, F, g)*.

Once the sea state condition for a particular wind climate is known, it is obvious to seek a solution to arrive at the wave characteristics such as significant wave height and the significant wave period wave period reasonably well directly through several of the wave growth models in existence. [23]

In this study, a fetch limited condition of wind for wave generation in the coastal regions of the island has been assumed since this is the most frequent case in real scenario.

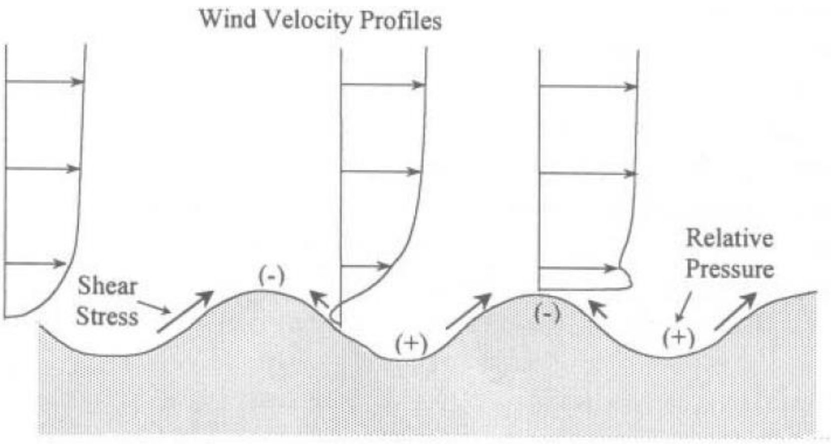


Figure 3.3: Wind Energy Transfer [24]

3.2.3 Determination of overwater wind speed from the measured overland wind speed

The wind speed in a wave hindcast computation must be wind speed over the water. Normally we only know wind speeds from nearby land measurement, and we must realize that winds over water are usually greater than winds over land because of the smaller friction over the water [24].

However, the frictional effect for overwater wind is not negligible. If the wind is considered to be driven by large-scale pressure gradients in the atmosphere that have been in a near-steady state, the boundary layer of winds above the wave field, then, can be considered as a profile as shown in Figure 3.4. The simple wave hindcasting methods usually deals with air within the height limit of 10m-100m in the boundary layer [19].

In generally, overwater winds for wave prediction are obtained either by [19]:

I. Direct observations over the fetch.
II. Projection of wind speed values over the fetch from observations over land.
III. Estimates based on weather maps.

All of these methods are based on the key assumption that wind fields are well-organized and can be adequately represented as an average wind speed and direction over the entire fetch. Option-(II) turned out as most suitable for our study since the overland wind speed values in the St. Martin’s are available from the record of BCSIR.

There are several criterions & correction factors that are needed to be considered while projecting overland wind into overwater wind. These are described below:

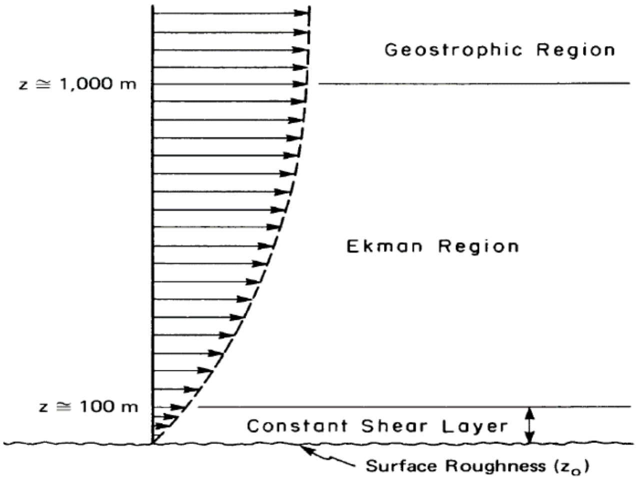


Figure 3.4: Atmospheric boundary layer over waves [19]

(i) Conversion of observed wind speed to a 'Reference Height Level'

Wind speed varies with distance above the surface. The standard reference height used in wave hindcasting is 10m. Any wind speed measurement taken above or beneath this standard height must be converted into '10m level'. For wind records taken at a different height above the ground/water surface a logarithmic velocity profile (similar to Figure 3.4) is usually assumed [24]. So, for the wind measurement taken overland:

$$U_{L,10} = U_{L,Z}\left(\frac{10}{Z}\right)^{\frac{1}{7}} \qquad 3.1$$

Where, Z = height (in meter) from the ground surface where anemometer is placed for measuring wind speed, $U_{L,Z}$ = wind speed measured at height 'Z' from the ground surface, $U_{L,10}$ = equivalent wind speed of measured data at '10 m reference height level'.

This is also called $\left(\frac{1}{7}\right)^{\text{th}}$ power law of velocity profile. But this simple approximation can be used only if *'Z'* is less than 20 meters [19]. The values given by this formula tend to deviate from the real observation for higher height level. Therefore, the "1/7" rule should not be used as a general method for transforming wind speeds from one level to another in marine areas. The ACES software package (Leenhnecht, Szuwalski, and Sherlock 1992) contains algorithms, based on planetary boundary layer physics, which compute the values shown in Figure 3.5 [25]

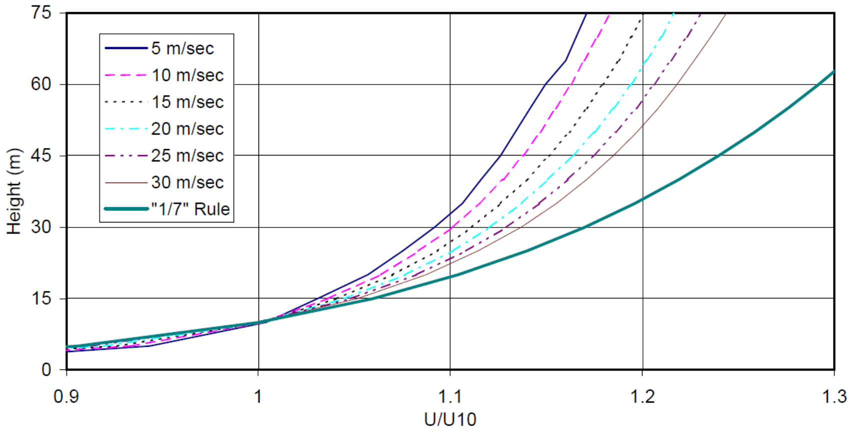


Figure 3.5: Ratio of wind speed at any height to the wind speed at the 10-m height as a function of measurement height for air-sea temperature difference, $\Delta T = 0^{\circ}\mathrm{C}$. [25]

(ii) Adjustment for location effects

Often overwater wind data are not available, but data from nearby land sites are. It is possible to translate overland winds to overwater winds if they are the result of the same pressure gradient and the only major difference is the surface roughness. When the observation was collected overland and a 'Fetch limited' sea state is assumed such that the fetch is long enough for full development of a marine boundary layer (longer than about 16 km or 10 miles), the observed wind speed can be adjusted to an overwater wind speed using Figure 3.6. In this figure, overland windspeed U_L is given as $U_{L,10}$, that means it is adjusted to the 'Reference Height Level'. U_W is the overwater wind speed at the 'Reference Height Level'.

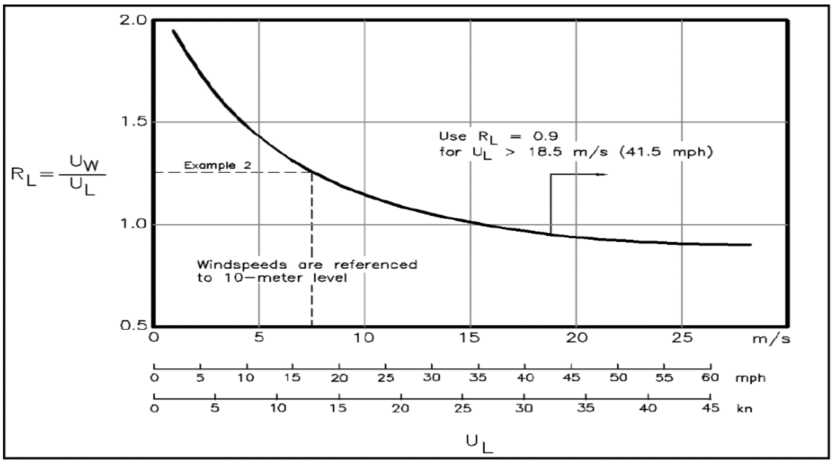


Figure 3.6: Ratio R_L; of windspeed overwater U_W to windspeed overland U_L as a function of windspeed overland U_L (After Resio and Vincent (1977)) [25]

(iii) Adjustment for stability effects

The stability conditions for Atmospheric air boundary layer over waves depends solely upon the air-sea temperature difference, $\Delta T = T_a - T_s$. Based on this factor the boundary layer conditions can be categorized as [19]:

Stable - when the air is warmer than the water i.e., $\Delta T > 0$, the water cools air just above it and decreases mixing in the air column.

Neutral - when the air and water have the same temperature i.e., $\Delta T = 0$, the water temperature does not affect mixing in the air column.

Unstable - when the air is colder than the water, the water warms the air i.e., $\Delta T < 0$, causing air near the water surface to rise, increasing mixing in the air column.

For fetches longer than 16 km, an adjustment for stability of the boundary layer is also needed. The factor that includes this adjustment is represented by 'R_T'. If the air-sea temperature difference (ΔT) is known, Figure 3.7 can be used to estimate R_T.

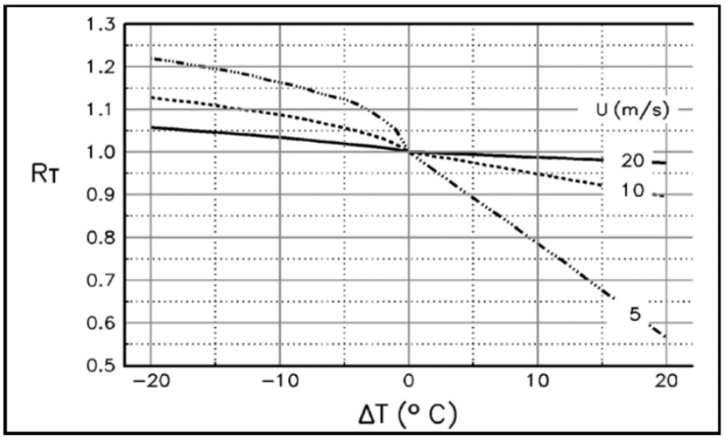
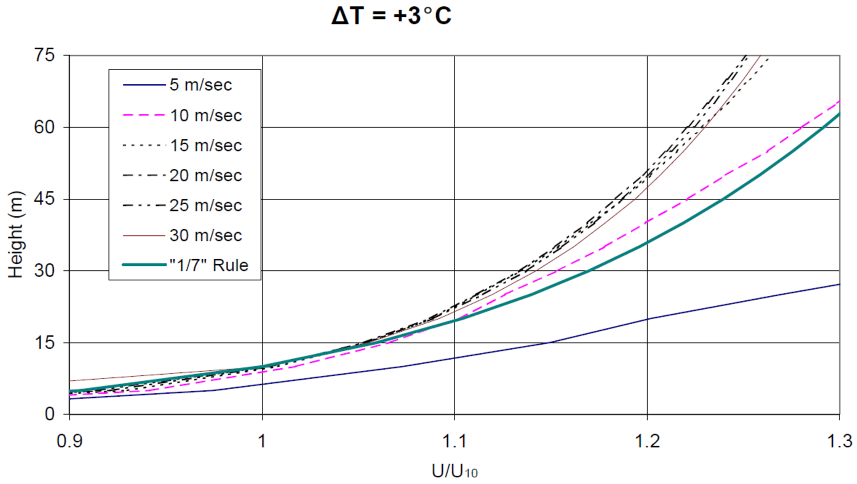


Figure 3.7: R_T ;ratio of 'wind speed accounting for effects of air-sea temperature difference' to 'wind speed over water without temperature effects' [25]

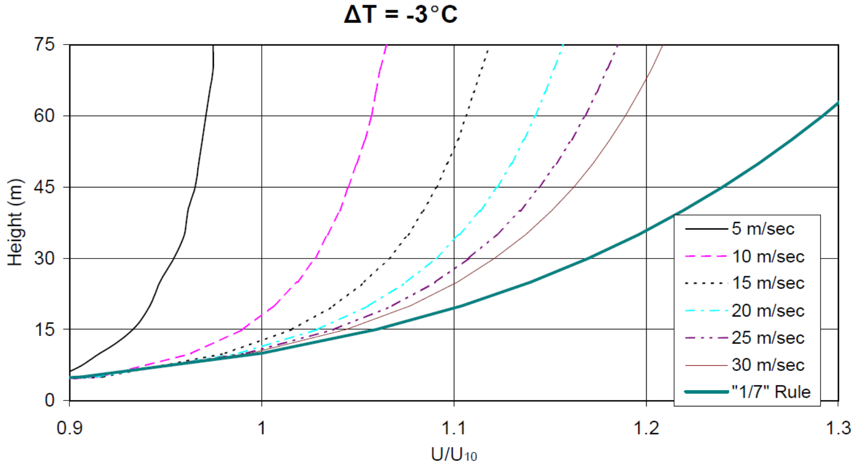
In Figure 3.7, 'U' represents 'wind speed over water without temperature effects'. If the air-sea temperature difference ΔT is desired to be $\pm 3^0\mathrm{C}$ which is the most often cases in real scenario, a convenient way of including both the effect of 'Reference Height Level' as well as 'Stability effects' is to use the graphs shown in Figure 3.8.

So, the overall relation for transforming overland wind into overwater wind can be written as,

$$U_W = U_{L,10} R_T R_L \tag{3.2}$$



(a)



(b)

Figure 3.8: Ratio of wind speed at any height to the wind speed at the 10-m height as a function of measurement height for selected values of air-sea temperature Difference and wind speed, (a) $\Delta T = +3^0\text{C}$, (b) $\Delta T = -3^0\text{C}$ [25]

Where, U_W = Overwater wind speed (in m/s), $U_{L,10}$ = Adjusted speed of measured wind speed data at ‘10 m reference height level’ (can be calculated from Figure 3.5), R_T = Stability effects adjustment factor (can be calculated from Figure 3.7), R_L = Location effect adjustment factor (can be calculated from Figure 3.6).

The combined value of '$U_{L,10}R_T$' can be found directly for some specific air-sea temperature difference from Figure 3.8.

The average overwater wind speed value calculated from Equation 3.2 often provide biased results. Therefore, some adjustment is made to the calculated 'U_W (in m/s)' value by the following expression:

$$U_A = 0.71\,(U_{\mathrm{W}})^{1.23} \qquad 3.3$$

'U_A' is termed as 'Wind stress factor' or 'Adjusted overwater wind speed'. It represents a fairly constant value over the entire fetch [19]. This adjusted windspeed value is used in wave hindcasting models. For this study on the St Martin's Island, the 'Adjusted overwater wind speed' can be calculated from the 'measurement of overland wind by BCSIR' using Equations 3.2 & 3.3. BCSIR published the monthly averaged wind speed info in the St Martin Island for period '1999-2001'. The data were collected at a height of 30 m above the ground level and 33 m above the sea-level [20].

While applying those equations, the following cases were realized:

- Since the overland wind data available from the BCSIR are monthly average data of three (1999-2001) consecutive years, it is obvious that the effect of extreme winds/storms in the data is negligible. Therefore, no adjustment is done in the windspeed data for extreme winds.
- Though the specific values shown in the Figures 3.5 to 3.8 are from a study of winds in the Great Lakes [25], they can be applied in oceanic environment for quick, low-cost estimates without a great loss in accuracy.

3.2.4 Wave growth models: For Simple Wave Hindcasting

After the estimation of overwater wind speed is completed, the hindcasting of wave characteristics from the wind data can be done by using suitable wave growth model. There are in generally two types of wave growth model:

- Shallow Water Wave Growth Model
- Deep Water Wave Growth Model

Some parametric models for predicting 'Shallow Water Wave Growth' as well as 'Deep Water Wave Growth' was discussed in 'Shore Protection Manual,1984 (SPM)' [19]. The Parametric models of wave growth determine wave height and period from fetch length (*F*), uniform wind speed over fetch (U_A), duration of wind (*t*) and depth of water in the generating area (*d*) [24].

For a fetch limited condition (assumed earlier) of generating wind, information about duration (t) is not required. Moreover, wave growth in deep water is independent of the depth (d). Therefore 'Deep Water Wave Growth Models' do not require the information about depth. On the contrary, water depth affects wave generation in shallow water [19]. So, 'Shallow Water Wave Growth Models' do require the 'depth (*d*)' value to be specified for wave prediction.

'Shallow Water Wave Growth Model' is of particular interest for this study, because we are interested to know the wave characteristics at a specific water depth where the ***Searaser*** will be put under operation. This is because the energy output from ***Searaser*** (Head) depends primarily on the wave condition under which it is operating. Since ***Searaser*** is a nearshore type WEC and needs to be moored rigidly to the sea-bed, we cannot set this up in deep water while considering economic viability, although the wave energy density is much in deep water. Therefore, it turns out that for using 'Shallow Water Wave Growth Model' three input parameters are to be given.

They are Fetch length (*F*), uniform wind speed over fetch (U_A), and depth of water in the desired location (*d*).

3.2.4.1 Shallow Water Wave Growth Model

Water depth affects wave generation in shallow water. For a given set of wind and fetch conditions, wave heights will be smaller and wave periods shorter if generation takes place in transitional or shallow water rather than in deep water. This is because of the effect of bottom friction and percolation in the permeable sea bottom [19].

'Shore Protection Manual (SPM)' (1984) [20] discusses wave generation in finite depth developed by Bretschneider (1958) from Bretschneider and Reid (1953). The expressions were further developed by Young and Verhagen (1996). The model proposed by them is based on successive approximations in which wave energy is added due to wind stress and subtracted due to bottom friction and percolation.

In this case study, the expressions proposed by Young and Verhagen [27] for wave prediction in shallow water has been used. The expressions are given below:

$$\begin{cases} H_m{}^* = 0.24\left[A_1 \tanh\left\{\dfrac{0.0031\left(F^*\right)^{0.57}}{A_1}\right\}\right]^{0.87} \\ A_1 = \tanh\left\{0.49\left(d^*\right)^{0.75}\right\} \end{cases} \qquad 3.4$$

$$\begin{cases} T_m{}^* = 7.54\left[A_2 \tanh\left\{\dfrac{0.00052\left(F^*\right)^{0.73}}{A_2}\right\}\right]^{0.37} \\ A_2 = \tanh\left\{0.33\left(d^*\right)\right\} \end{cases} \tag{3.5}$$

And,

$$F^* = \frac{gF}{U_A{}^2},\ d^* = \frac{gd}{U_A{}^2},\ H_m{}^* = \frac{gH_m}{U_A{}^2},\ T_m{}^* = \frac{gT_m}{U_A} \tag{3.6}$$

Where,

F = Fetch length (m),
d = Depth of water (m),
H_m = Spectrally based significant wave height (m),
T_m = The period of peak wave spectrum (s),
U_A = Wind stress factor/Adjusted overwater wind speed (m/s),
F^* = Non-dimensional fetch,
$H_m{}^*$ = Non-dimensional significant spectral wave height,
$T_m{}^*$ = Non-dimensional peak wave period,
d^* = Non-dimensional depth

3.3 Calculation of 'Water Head' Achievable from the Action of *Searaser*

3.3.1 Specifying the design wave

Often such situation arises where 'Wave-Structure Interaction' or 'Wave forces on the offshore structures' are to be estimated for specific case studies. It requires the solution of sea-state using an idealization of wave surface profile and the wave kinematics by wave theory because from an engineering point of view, obviously it is neither practicable nor meaningful to deal individually with each and every wave [28].

The usual practice in such cases is to specify a 'Design Wave' which is roughly the statistical averages of the observed waves. Design wave is usually specified in terms of "Height (*H*), Period (*T*) and Depth (*d*)" because they are usually the easiest to measure or estimate from observations [28]. It roughly represents the entire dataset without significant loss in accuracy.

Similarly, for this study, to calculate the 'Head' of water achievable from the 'Searaser' by utilizing the wave energy, it is not convenient to estimate and analyze for each set of hindcasted $H_m \& T_m$ value. So, a design wave must be specified. The hindcasted values for wave characteristics ($H_m \& T_m$) from section 3.2, will definitely vary from month to month (Jan-Dec). So, the wave height and period for the 'Design Wave' ($\overline{H_m}$ & $\overline{T_m}$) can be calculated simply by taking the 'Weighted average of monthly $H_m \& T_m$ values'. So, mathematically, for the design wave,

$$\overline{H_m} = \frac{\sum_{i=1}^{12} n_i H_{mi}}{\sum_{i=1}^{12} n_i} \tag{3.7}$$

$$\overline{T_m} = \frac{\sum_{i=1}^{12} n_i T_{mi}}{\sum_{i=1}^{12} n_i} \tag{3.8}$$

Where, n_i = total number of days in the ith month. (*i* =1 for January …………..*i* =12 for December), H_{mi} = hindcasted wave height (from section 3.2) for ith month, T_{mi} =

hindcasted wave period (from section 3.2) for i^{th} month, $\sum_{i=1}^{12} n_i$ = total number of days in a year = 365 days. The depth (*d*) of the design wave was assumed as **25 m** for this study.

3.3.2 Selection of appropriate wave theory and its validation

After the ‘Design Wave’ has been specified, an appropriate ‘Wave Theory’ must be selected to get a better estimate of wave breaking, wave forcing, etc. on the WEC for reliable design and performance analysis [29]. That means for our study, the realistic calculation of ‘Water Head’ from the action of ***Searaser*** depends mostly on the selection of appropriate wave theory.

In general, actual ocean-wave phenomena are complex and difficult to describe mathematically because of nonlinearities, three-dimensional characteristics, and apparent random behavior. Studies on waves over the years have shown that no wave theory performs sufficiently well. In other words, there is neither a ‘perfect’ wave theory nor a perfect sea [28]. However, for the preliminary stage of design of a case study like ours, the simplified theories can be used to get some insight about wave interactions with the WEC.

There are two types of theories available in literature in order to model ‘Water Waves/Ocean Waves’ depending upon the situation of application [20]. These are:

i) Small Amplitude Wave (SAW) Theory / Linear Wave Theory

The most elementary wave theory, referred to as small-amplitude or linear wave theory, was developed by Airy (1845), also known as Stokes’s 1st order theory. The waves that can be modeled by this theory also referred as Airy Waves. This wave theory is of fundamental importance since it is not only easy to apply, but also reliable over a large segment of the whole wave regime. Mathematically, the Airy theory can be considered a first approximation of a complete theoretical description of wave behavior [20]. This theory is based on some simplified assumptions such as:

- Wave profile is perfectly sinusoidal. That means the wave profile is symmetrical about the Sea Water Level (SWL).
- The wave height is small compared to its length or depth of water column (Small amplitude wave). That means the wave motions are sufficiently small to allow the free surface boundary condition to be linearized, i.e., the terms involving wave amplitude to the second and higher orders are considerably negligible [24].

However, the shape and the spectrum of the waves cannot be represented by the linear wave theory when the waves are too steep or the water depths are too shallow [28]. For those situations, waves are better described by higher order theories, which are usually referred to as finite-amplitude theories [20].

ii) <u>Finite Amplitude Wave (FAW) Theory</u> / <u>Higher Order Wave Theory</u>

Some of the main characteristics of ‘The Finite Amplitude Wave Theory’ are that:

- Wave height cannot be considered as small in comparison with either the wavelength or depth of water column (Finite Amplitude Wave) as it was in Small Amplitude Wave Theory.
- The Wave profile is not sinusoidal. As the ratio *H/L* (Wave height to Wave length) increases, the wave crest becomes sharper and trough becomes flatter than the ‘Airy Wave’ or ‘Small Amplitude Wave’ (Figure 3.9).

- FAW theory retains additional higher order terms that were neglected in the SAW theory to obtain an accurate representation of wave motion. Higher order wave profiles are unsymmetrical about SWL.

There are a number of ‘Finite Amplitude Wave Theory’ that have been developed over the past years, decades. There is no unique FAW theory that is applicable to all depth regions from deep to very shallow water; while on the other hand, for small amplitude waves, a single wave theory (Airy’s theory) is applicable over the entire water depth region [29] . Some of the most famous FAW theories are:

- Stokes’ 2nd order theory
- Stokes’ 3rd order theory
- Stokes’ 4th order theory
- Stokes’ 5th order theory

Stoke’s Wave

- Cnoidal wave theory
- Solitary wave theory
- Dean’s stream function theory.

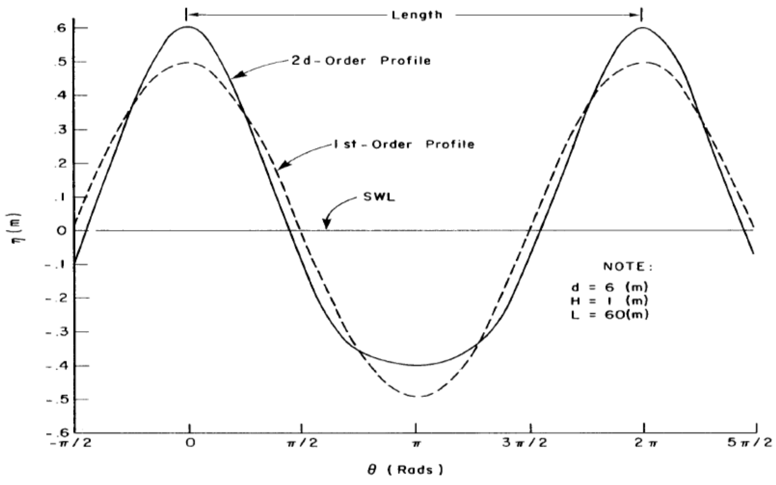


Figure 3.9: Comparison of higher order (2nd) wave profile with linear profile [19]

For Stokes' wave the higher the order of the wave theory, higher will be the limiting wave height for which it would be valid. The relative complicacy of the of the Stokes' wave increases with their order due to the relative importance of the additional parameters namely *H/d* (Wave height/water depth) and *H/L* (Wave height/wave length) [23].

'Cnoidal Wave Theory' is mostly suitable for shallow water wave. It is applicable over the range $"\frac{1}{50} < \frac{d}{L} < \frac{1}{10}"$ [23]. This theory gives good results when $\frac{H}{d} \cong 0.4$ [29].

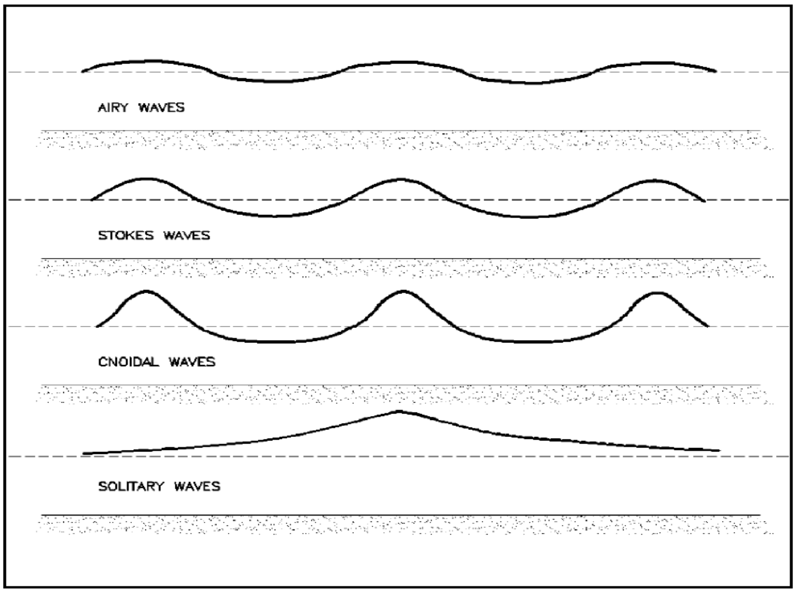


Figure 3.10: Wave profile shape of different progressive gravity waves (Small Amplitude Waves & Finite Amplitude Waves) [25]

Unlike all other wave profiles, Solitary wave profile is not periodic and has no definite wave length (Figure 3.10). To model solitary waves 'Solitary Wave Theory' was developed. It is a special case of 'Cnoidal Wave Theory'. 'Solitary Wave Theory' is applicable for very shallow water depth. As the water depth becomes very shallow and wavelength $L \to \infty$, the 'Cnoidal Wave Theory' approaches 'solitary wave theory' [23].

Selecting the most suitable wave theory for a defined 'Design wave' (given *'H'*, *'T'* and *'d'*) is rather difficult. Any comparison between the theories must be considered only in relation to the prevailing environmental characteristics and the particular location [27]. Some graphs available in literature such as Figure 3.11 indicating 'Regions of Applicability of Different Wave Theories' have been used to select an appropriate wave theory for this study.

Figure 3.11 has been used by replacing *H&T* with the design wave parameters $\overline{H_m}$ **&** $\overline{T_m}$ specified for this study. If the co-ordinate $\left(\frac{d}{g\left(\overline{T_m}\right)^2}, \frac{\overline{H_m}}{g\left(\overline{T_m}\right)^2}\right)$ falls within the region of linear wave theory or Stokes' 2nd order theory, then the wavelength *'L'* of the design wave can be computed from the Equation 3.9.

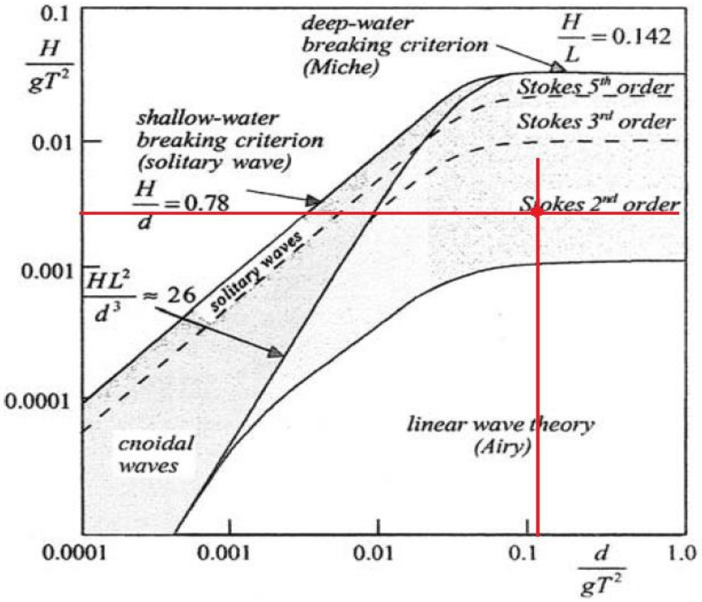


Figure 3.11: The approximate regions of applicability of the various wave theories (after LeM´ehaut´e 1976; Kamphuis 2000; and SPM 1973) [27]

*red lines refer to the result section

$$L = \frac{g\left(\overline{T_m}\right)^2}{2\pi}\tanh\left(\frac{2\pi d}{L}\right) \text{ [23]} \qquad 3.9$$

However, this Equation is implicit in terms of *'L'*. The explicit expression developed by Fenton and Mckee (1990) [30] [23] is:

$$kd = \frac{\sigma^2 d}{g}\left[\coth\left\{\left(\sigma\sqrt{d/g}\right)^{\frac{3}{2}}\right\}\right]^{\frac{2}{3}} \qquad 3.10$$

Where, $\sigma = 2\pi/\overline{T_m}$ and $k = 2\pi/L$, known as wave number, $g = 9.81\,\mathrm{ms}^{-2}$.

After selecting appropriate wave theory from the Figure 3.11, the selection can be further validated by using a dimensionless parameter called 'Ursell's Number'. For the design wave, it is defined as [29]:

$$\text{Ursell Number, } U_R = \frac{L^2\overline{H_m}}{d^3}$$
$$= \frac{\overline{H_m}/d}{(d/L)^2} = \frac{\text{"Non-linearity" (measure of wave steepness)}}{\text{"Shallowness" (measure of relative water depth)}}$$

For Stokes' wave '$U_R < 26$' and for Cnoidal wave '$U_R > 26$'.

3.3.3 Estimation of wave profile

After both the design wave and the appropriate wave theory that best describes the design wave have been specified, the measure of wave profile i.e., measure of wave crest or wave trough amplitude can be obtained by using some analytical expressions corresponding to the wave theory. For each and every wave theory, the equation of wave profile is available in literature.

From linear wave theory / Stokes' 1st order theory, the profile equation for the design wave is:

$$\eta_1 = \frac{\overline{H_m}}{2}\cos\theta \qquad 3.11$$

Where, η_1 = position of wave particle at any instant from linear / 1st order theory, and

$\theta =$ Phase angle $= \left(\frac{2\pi x}{L} - \frac{2\pi t}{\overline{T_m}}\right)$.

Also, the profile equation for the design wave from Stokes' 2nd order theory,

$$\eta_2 = \frac{\overline{H_m}}{2}\cos\theta + \frac{\pi \overline{H_m}^2}{8L}\frac{\cosh(2\pi d/L)}{\sinh^3(2\pi d/L)}\left[2+\cosh\left(\frac{4\pi d}{L}\right)\right]\cos\ 2\theta \qquad 3.12$$

Comparison between the Equations 3.11 and 3.12 reveals that as the order of wave theory increases, the profile equations get much more complicated because of non-linear effects and increasing dominance of *'d/L'* ratio. That's why the stokes 3rd, 4th and 5th order theories become quite tedious and troublesome in hand calculations for simple design processes. Since the 'Cnoidal' and 'Solitary' wave theories are applicable to very shallow water depth, it can also be said from intuition that they may not be the appropriate wave theories to describe the wave interactions with nearshore WECs such as ***Searaser***.

However, for wave profile of any order (Figure 3.9): The wave crest, η_c occurs when $\theta = 0^{o}$ $\therefore \cos\theta = 1,\ \cos 2\theta = 1$.

So, from the linear wave theory,

Wave crest amplitude, $A_{c,1} = \eta_{c,1} = \dfrac{\overline{H_m}}{2}$ 3.13

and from Stokes' 2nd order theory,

$$A_{c,2} = \eta_{c,2} = \frac{\overline{H_m}}{2} + \frac{\pi \overline{H_m}^2}{8L} \frac{\cosh(2\pi d / L)}{\sinh^3(2\pi d / L)} \left[2 + \cosh\left(\frac{4\pi d}{L} \right) \right] \tag{3.14}$$

Similarly, the wave trough, η_t occurs when θ = 180° $\therefore$ $\cos\theta$ = -1, $\cos 2\theta$ =1.

So, from the linear wave theory, Wave trough amplitude,

$$A_{t,1} = \eta_{t,1} = -\frac{\overline{H_m}}{2} \tag{3.15}$$

and from 2nd order wave theory,

$$A_{t,2} = \eta_{t,2} = -\frac{\overline{H_m}}{2} + \frac{\pi \overline{H_m}^2}{8L} \frac{\cosh(2\pi d / L)}{\sinh^3(2\pi d / L)} \left[2 + \cosh\left(\frac{4\pi d}{L} \right) \right] \tag{3.16}$$

3.3.4 Dimensioning of *Searasers* 'Power Take-Off System (PTO)'

The mechanism by which energy is transferred between the waves and the WEC, and subsequently or directly into useful form, is generally known as the power take-off (PTO) [31]. In case of a ***Searaser***, the major component of the PTO system is the 'Weighted Surface Buoy' which provides pressurized sea-water purely through the action of the wave. This highly pressurized water is then transported to an elevated reservoir subjected under atmospheric pressure and thus 'Water Head' is gained. So, the 'Weighted Surface Buoy' of a ***Searaser*** should be of such dimensions that it provides desired output without violating the economic aspects of power absorption from the waves. After the dimensions have been specified, interacting forces between 'Waves' and 'Surface Buoy' can be estimated.

Depending upon relative diameter to incident wavelength ratio, offshore members/structures (such as buoy) can be classified as:

- Small-sized members/structures
- Large-sized members/structures

Force analysis on 'Small-sized members' is relatively easy because such members don't influence the wave field by diffraction and reflection considerably. However, for large-sized members, the analysis is more complex because for them it is necessary to take into consideration the scattering or radiation of incident wave energy from the member.

The dimensionless parameter that can differentiate between these two types is called 'Diffraction Parameter' (D_p). It is defined as:

$D_p = \frac{\pi D}{L}$; Where D = Diameter of the member, L = Wavelength.

The diffraction parameter indicates if the scattering of waves from the member surface is an important consideration or not. For large-sized members, the waves in the vicinity of the member are diffracted causing a significant effect on the forces experienced by the member from waves. As a rule of thumb, if $D_p < 0.5$ for an offshore member, it can be considered as 'Small-sized' and diffraction effect of waves is insignificant. The opposite is true for 'Large-sized' members [32].

In order to keep the analysis in our study simple, we considered the following scenarios:

- The diameter D (or Radius R) of the 'Surface Buoy' of the ***Searaser*** is chosen such that it can be considered as a 'Small-sized member' to avoid difficulties regarding wave diffraction.
- The Buoys of the ***Searaser*** are axisymmetric.
- The device is restricted to a single degree of freedom (heave). That means, power absorption from the waves by 'Surface Buoy' takes place during 'Heave' mode of oscillation only, although in reality an axisymmetric buoy subjected under wave motion may have six (6) degrees of freedom.

Now, for the design wave,

$$J = \frac{\rho g^2 D(kd)}{4\omega} A_c^2 \quad [33] \qquad 3.17$$

Where,

J = Incident wave energy transport per unit wave front / wave power level (W/m), $\omega = 2\pi / \overline{T_m}$, k = wave number = $2\pi / L$, $D(kd)$ = Depth function , $\rho =$ Sea-water density = 1030 kgm^{-3}, $A_c =$ Wave crest amplitude.

Depth function incorporates the effect of change in wave celerity (wave front velocity) with water depth. Several expressions for depth function are available in the literature in terms of *'water depth, d'* and *'wave number, k'*.

$$D(kd) = \left[1 + \frac{2kd}{\sinh\left(2kd\right)}\right]\tanh\left(kd\right) \quad [33] \qquad 3.18$$

Substituting the specified values for design wave in Equation 3.18 and 3.17, J value can be obtained. This value indicates the 'wave power level' in the area of interest where the ***Searaser*** will be put under operation.

Now, theoretically maximum wave power that can be absorbed by the surface buoy of the ***Searaser*** oscillating in 'Heave' mode of motion only,

$$P_{theoretical,\max} = \frac{LJ}{2\pi} \quad [33] \qquad 3.19$$

However, in practice, as stated by Falnes [33], efficiency of a WEC more than 50% is not achievable. So, in real scenario the maximum wave power that can be absorbed by a WEC oscillating only in the 'Heave' mode of motion,

$$P_{\max} = 50\% \times P_{theoretical,\max} \qquad 3.20$$

Absorption ability of the oscillating body is limited. Although the energy stored and transported in the sea is large, only a fraction of it can be extracted by the oscillating body. Most of the wave power remains unutilized in the sea. This situation may, from an economic point of view, be desirable for a wave-energy converter. Because wave power in the ocean is free, whereas the realization of a large body-velocity amplitude requires economical expenditure. What should be maximized is the ratio between the energy produced and the total cost including investment, maintenance and operation.

However, it is very difficult to find the solution of this problem. A much simpler problem is to consider the ratio between the produced power and the volume of the wave-absorbing body [33]. So, for small-sized buoy of a WEC oscillating in one mode of motion (heave) only, considering the economic aspects of power absorption; the following inequality relating absorbed power and volume of the buoy $\mathrm{V}_{\mathrm{buoy}}$ must be satisfied.

$$\frac{P_{\max}}{V_{buoy}} < \frac{\pi \rho g A_c}{2\overline{T}_m} \quad [33] \qquad 3.21$$

From the Equations 3.19-3.21, the decision about the volume of the buoy or the height $\boldsymbol{h}\left(=\frac{V_{buoy}}{\pi R^2}\right)$ for a specified radius $\boldsymbol{R}$, can be taken.

3.3.5 Interaction between Waves and Surface Buoy

'Weighted Surface Buoy' of the ***Searasers*** 'PTO' system having single degree of freedom (heave) basically incorporates two types of forces:

i. Weight of the Buoy itself (W_F)

ii. Wave applied exciting force in heave on the buoy (F_f) (Figure 3.12).

Weight of the buoy should be such that it floats on the water surface, that means it must be buoyant.

So, for the 'Surface Buoy' to be buoyant, Weight of the buoy, W_F = *mg* = 'Weight of the displaced water by the buoy' or buoyancy force = $\rho g \pi R^2 D_r$.

$$\therefore W_F = mg = \rho g \pi R^2 D_r \qquad 3.22$$

Where, *m* = Assigned mass on the buoy, D_r = Draft for floating buoy/submergence depth (portion of the buoy length which is submerged underwater).

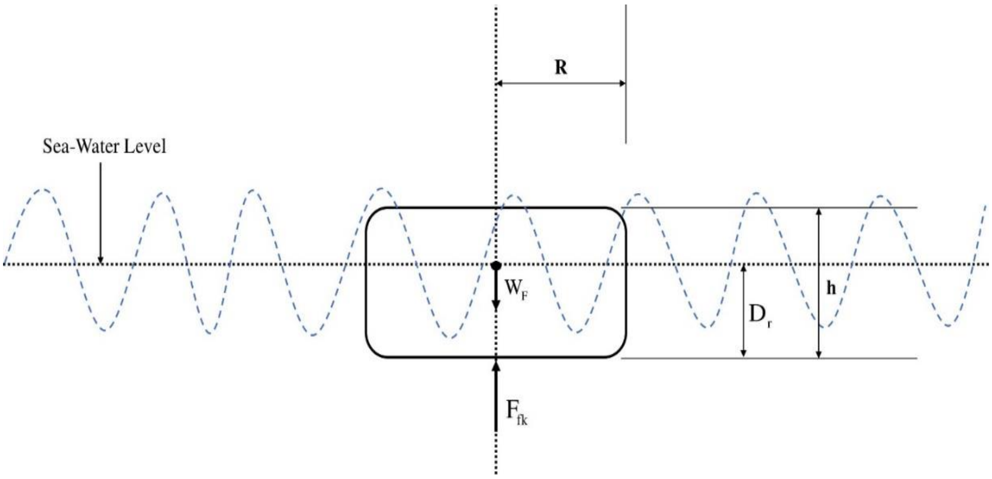


Figure 3.12: Forces acting on the ‘Weighted Surface Buoy’

On the other hand, the total wave applied exciting force in heave on a submerged buoy can be expressed as:

$$\hat{F}_f = \hat{F}_{fk} + \hat{F}_d \qquad 3.23$$

Where, $\hat{F}_f =$ Total wave applied exciting force in heave, $\hat{F}_{fk} =$ Froude-Krylov force component in heave and $\hat{F}_d =$ Diffraction force component in heave. However, considering only the magnitudes of those forces Korde et al. [34] showed that for a ‘Small-sized’ buoy,

$$F_f \approx F_{fk} = \rho g A_c \pi R^2 e^{-kD_r} \qquad 3.24$$

Where, kD_r = Wave number × Buoy draft = Force transfer co-efficient between wave and the buoy.

During the Suction stroke, suction of water through the inlet port will occur when the wave applied Froud-Krylov force component in heave is greater than the assigned weight of the ‘Surface Buoy’. That means $F_{fk} > W_F$. So, the suction force will be =

$F_{fk} - W_F$. The working force during the Working stroke is simply the weight (W_F) of the ‘Surface Buoy’.

3.3.6 Hydrodynamics of *Searaser* and associated system

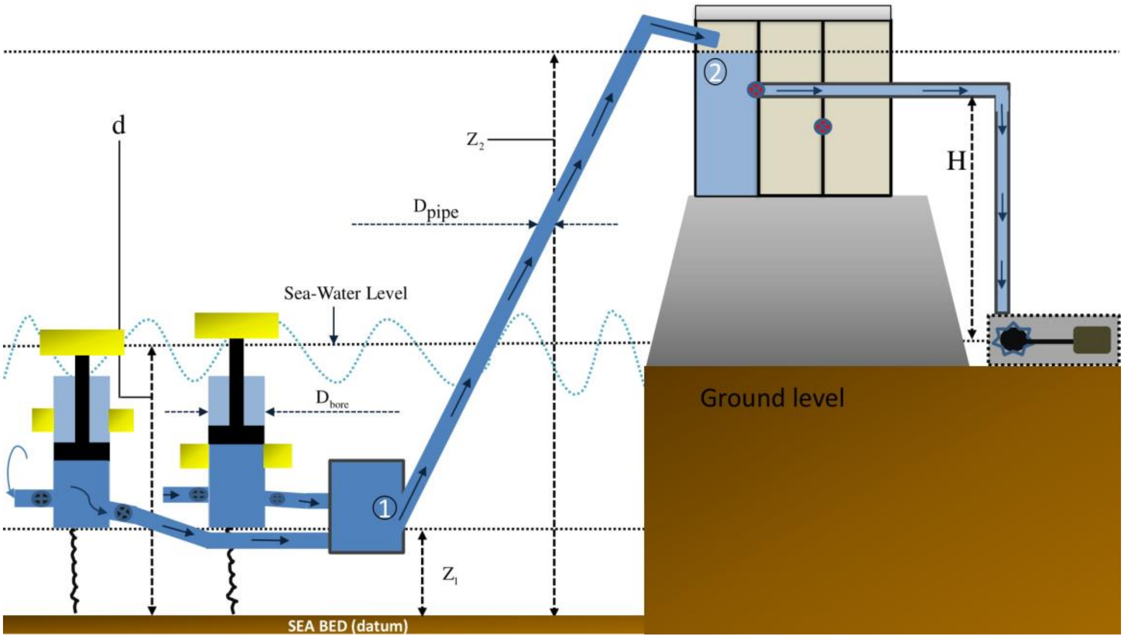


Figure 3.13: Schematic for head calculation

Suction pressure (during suction stroke) that would be created inside the pumping chamber of ***Searaser***,

$$= \frac{\text{Suction force}}{\text{Area of the cylindrical bore}} = \frac{F_{fk} - W_F}{\frac{\pi}{4}\left(D_{bore}\right)^2} \qquad 3.25$$

And, the pressure to which sea-water would be raised (during compression stroke) or the Working pressure can be calculated from,

$$= \frac{\text{'Working force' or 'Weight of the buoy'}}{\text{Area of the cylindrical bore}} = \frac{W_F}{\frac{\pi}{4}\left(D_{bore}\right)^2} \qquad 3.26$$

The water head that could be achieved from the energy of the pressurized sea-water supplied by ***Searaser*** during working stroke, might be estimated in a very simplistic manner by using Steady form of 'Bernoulli Equation' without sacrificing a significant amount of accuracy. While applying the 'Bernoulli Equation', the following assumptions were adopted:

- Unchanged sea condition (design wave characteristics are constant over time).
- Minor losses in the pipe components are negligible.
- ***Searaser*** is operating under steady state.

Now, Applying Bernoulli's equation between the exit of manifold/inlet of transportation pipeline and top surface of the 'Mega' reservoir which is open to atmosphere (indicated by point 1 & 2 as shown in Figure 3.13),

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+Z_1=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}+Z_2+h_L \qquad 3.27$$

Where,

P_1 = Absolute pressure at the exit of the common manifold = Working pressure = $\frac{W_F}{\frac{\pi}{4}\left(D_{bore}\right)^2}$,

P_2 = Absolute pressure at the top surface of the 'Mega' reservoir = approximately 1 atm = 101.325 kPa, V_1 = Velocity of pressurized sea-water at the exit of the manifold, V_2 =Velocity of water at the top surface of the 'Mega' reservoir, ρ = Sea-water density = 1030 kg/m^3, g = gravitational acceleration = 9.81 m/s^2, Z_1 = elevation head of point 1 from the sea-bed (datum line), Z_2 = elevation head of point 2 from the datum, h_L = major head loss due to friction in the transportation pipeline.

Here, Z_2 can be replaced by $(d+H)$ where *'d'* is the depth of mean sea-water level from the datum and *'H'* is the effective water head that is available at the turbine entrance of the generation unit (Figure 3.13). Therefore, from Equation 3.27,

$$\Rightarrow \frac{P_1}{\rho g}+\frac{V_1^2}{2g}+Z_1=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}+(d+H)+h_L$$

$$\Rightarrow H=\underbrace{\frac{P_1-P_2}{\rho g}}_{\text{Pressure}}+\underbrace{\frac{V_1^2-V_2^2}{2g}}_{\text{Velocity}}-\underbrace{\left(d-Z_1\right)}_{\text{Elevation loss due to}}-h_L \qquad 3.28$$

The velocities at the two points $(V_1 \& V_2)$ can be found in the following way:

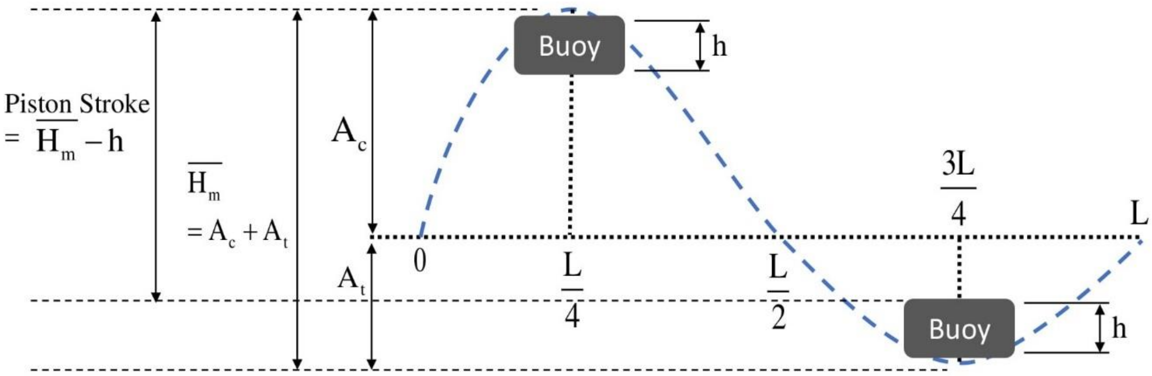


Figure 3.14: Idealized work cycle of a ***Searaser's*** piston stroke (after El-Wakil) [35]

A complete stroke during the work cycle of ***Searaser*** occurs when a wave crest followed by a successive wave trough pass over the buoy. As depicted in Figure 3.14, the length of the piston's stroke can be obtained usually by subtracting buoy height, *'h'* from the wave height, $\overline{H_m}$ [35]. So, Stroke length of the piston $= \overline{H_m} - h$. Distance between successive crest & trough = *(3L/4 - L/4) = L/2.*

Now by definition, within the time period $\overline{T_m}$, a distance L is passed by the design wave which is the wavelength. Similarly, *L/2* distance will be passed within a time period $T_{L/2}$ (say). The $T_{L/2}$ value can be calculated from the Equation 3.9 by replacing L with *L/2* and $\overline{T_m}$ by $T_{L/2}$. Then the Equation 3.9 becomes:

$$T_{L/2} = \sqrt{\frac{\pi L}{g}\frac{1}{\tanh\left(2kd\right)}} \tag{3.29}$$

$T_{L/2}$, is the time required to complete each stroke. Now, Total mass of water inside the cylinder at the end of suction stroke:

$$m_w = \text{Sea-water density} \times \text{Area of the cylindrical bore} \times \text{Stroke length}$$

$$= \rho \times \frac{\pi}{4}\left(D_{bore}\right)^2 \times (\overline{H_m} - h) = \frac{1}{4}\pi\rho(\overline{H_m} - h)\left(D_{bore}\right)^2$$

$\therefore$ Mass flow rate of water through the transportation pipe, $\dot{m}_w = m_w / T_{L/2}$

Volume flow rate, $Q = \dfrac{\dot{m}_w}{\rho} = \dfrac{m_w}{\rho T_{L/2}} = \dfrac{\pi(\overline{H_m} - h)\left(D_{bore}\right)^2}{4T_{L/2}}$

Let’s consider the diameter of the transportation pipe, $D_{pipe} = (1/n) \times D_{bore}$, where *‘n’* is a constant and maybe be termed as reduction factor. Now, the velocity of water at the manifold exit or the inlet of transportation pipe (point 1) can be calculated as:

$V_1 = \dfrac{\text{Volume flow rate}}{\text{Cross-sectional area of the pipe}} = \dfrac{Q}{\frac{\pi}{4}\left(D_{pipe}\right)^2} = \dfrac{n^2(\overline{H_m} - h)}{T_{L/2}}$. The velocity of water at the top surface of the ‘Mega’ reservoir can be approximated as $V_2 \approx 0$ since the cross-sectional area of the reservoir is very large compared to that of the pipe.

$$\therefore \text{Velocity head } = \frac{V_1^2 - V_2^2}{2g} = \frac{V_1^2}{2g} = \frac{n^4\left(\overline{H_m} - h\right)^2}{2g\ (T_{L/2})^2} \qquad 3.30$$

Head loss in the transportation pipe due to friction, $h_L = f\,\frac{l}{D_{pipe}}\,\frac{V_1^2}{2g} = f\,\frac{nl}{D_{bore}}\,\frac{V_1^2}{2g}$

Where, f = friction factor, l = length of the transportation pipeline. Substituting the expression of velocity head from Equation (30),

$$h_L = f\,\frac{nl}{D_{bore}}\,\frac{n^4\left(\overline{H_m} - h\right)^2}{2g\ \left(T_{L/2}\right)^2} \qquad 3.31$$

Friction factor 'f' can be calculated from Haaland's equation:

$$\frac{1}{\sqrt{f}} = -1.8\ \log\left\{\frac{6.9}{\text{Re}} + \left(\frac{n\varepsilon / D_{bore}}{3.7}\right)^{1.11}\right\}\ [36] \qquad 3.32$$

Where,

Re = Reynolds number = $\rho V_1 D_{pipe} / \mu$,

μ = dynamic viscosity of sea-water $= 1.08 \times 10^{-3}$ Pa.s

(at 35 g kg^{-1} salinity, atmospheric pressure and 20^{0}C temperature), ε = Surface roughness of the pipe surface. For smooth pipes made of plastic, (ε = 0 mm).

Now Substituting all the expression developed here to the Equation 3.28, final equation of effective 'Head' appears as,

$$H \;=\; \frac{P_1 - P_2}{\rho g} + \frac{\left(\overline{H_m} - h\right)^2 n^4}{2g\left(T_{L/2}\right)^2}\left(1 - \frac{fnl}{D_{bore}}\right) - \left(d - Z_1\right) \qquad 3.33$$

3.4 Surveying on resorts and their capacity modelling

In this study, a field survey was conducted on the resorts of St martins Island in order to find out total electrical power requirements in the resorts. Based on accommodation capacity and variety of electrical appliances, the resorts in the St. Martin’s Island can be classified into mainly of 3 categories:

i) High Capacity Average Standard (HCAS) Resorts.
ii) Medium Capacity Average Standard (MCAS) Resorts.
iii) Medium Capacity High Standard (MCHS) Resorts.

HCAS resorts typically have large tourist accommodation capacity, higher number of rooms; but they contain only necessary electrical appliances (for example Light, Fan etc.). MCAS resort are also equipped with only necessary appliances but they have decreased number of rooms and moderate accommodation capacity unlike HCAS resorts. Similarly, MCHS resorts have moderate accommodation capacity but they incorporate some luxury appliances such as CRT/LED TV, heater etc. together with the necessary appliances. However, each type of resort incorporates some electric motor driven water pumps to provide necessary water for the tourists. It was found in the survey that around 71% resorts are MCAS resorts, 10% are HCAS and rest 19% are MCHS resorts. Table 3.2 & 3.3 list out typical examples of HCAS, MCAS and MCHS resorts with their average accommodation capacity, types of rooms, the electrical appliances they contain and their ratings etc.

Currently the number of tourists visiting this Island per day has exceeded the Real Carrying Capacity (RCC) of the Island and obviously the Effective Carrying Capacity

(ECC) which is the optimum number of tourists to be allowed to the St Martin's Island. Hasan et al. (2014) [37] conducted a study on the carrying capacity of St Martin's Island and they found the Real Carrying Capacity of the Island is about 2913 tourists/day. They also evaluated the Effective Carrying Capacity (ECC) for 63% management capacity is about 1835 tourist/day. The RCC and ECC are related by the following relation:

$$ECC = RCC \times MC \quad [37] \qquad 3.34$$

Figure 3.15 depicts the trend of yearly increase in average number of tourists visiting this Island per day over the past few years. It was constructed with the available data from www.parjatan.gov.bd [38] and 'The Daily Star Newspaper [39]' about total number of tourists visited St. Martin's Island yearly and then averaging this data over the peak tourist season ("Oct-Mar" =182 days total). It is clear from the figure that the average number of tourists visiting the Island/day exceeded its Effective and Real Carrying Capacity by around 2010. Currently the Island is overloaded with tourists well beyond the carrying capacity. To make room for these rapidly increasing number of tourists, many resorts have been built there.

But power generation & supply in this Island should not be desired by keeping its ecological and tourism potential at risk. Therefore, the concept of sustainable tourism policy has been taken under major consideration in this study to model the effective accommodation capacity of the resorts or alternately to figure out the approximate electrical energy requirements in resorts of the St Martins Island.

For the convenience of this study we have assumed the present ECC of the Island is similar to that found by Hasan et al. [37] in 2014 .The accommodation capacity in all three types of resorts mentioned earlier was modeled such that the number remains under "Effective Carrying Capacity (ECC)" of the Island in a particular time (year). For this study we have considered total 21 resorts; out of which two (2) HCAS, fifteen (15) MCAS and four (4) MCHS resorts have been selected to maintain compatibility with survey result.

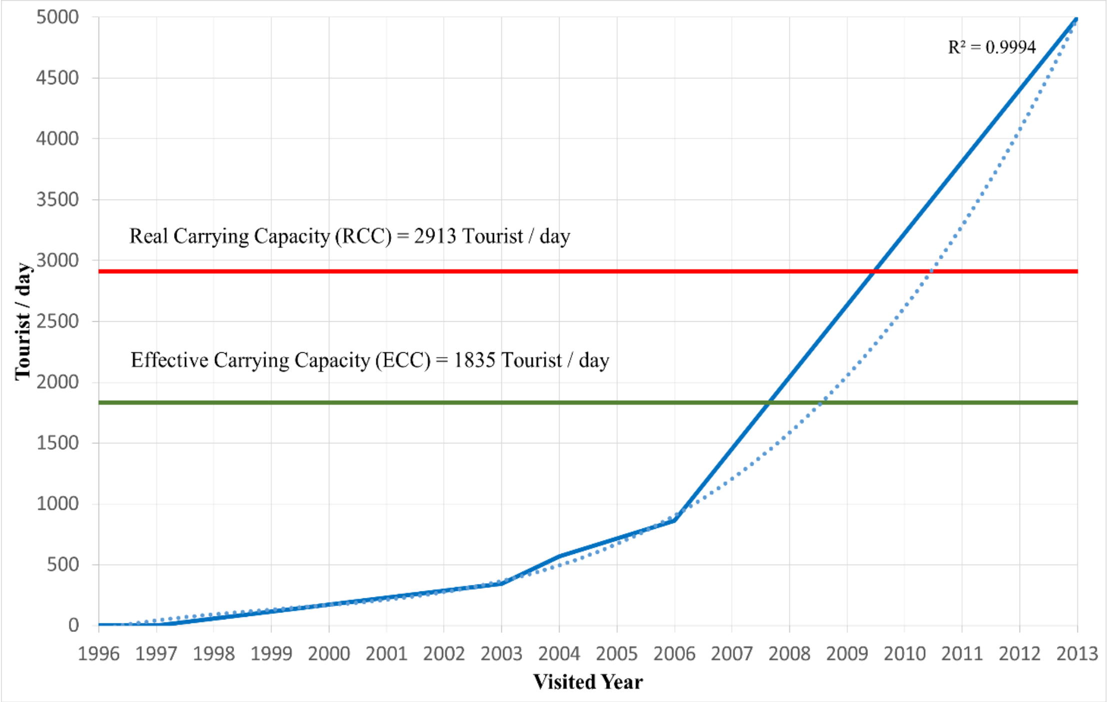


Figure 3.15: Yearly change in Average number of 'tourist/day' visited Saint Martin's Island

Total 21 resorts were picked due to the fact that their total average accommodation capacity which is 1748 tourists, remains somewhat below the 'Effective Carrying Capacity (ECC)' 1835 tourists daily. The electricity demand profile constructed from field survey data for these 21 modelled resorts has been demonstrated in the next section.

Table 3.2: Typical categories of resorts in the Saint Martin’s Island

Resort type	Number of such type of resorts modeled in this study	Examples	Total average no. of rooms in each resort	Types of rooms in each resort	Quantity of rooms	Electrical appliances per room
HCAS	2	Nil Diganta.	44	4 bedded room	40	1 Light 1 Fan
				6 bedded room	4	2 Light 2 Fan
MCAS	15	Somudra Kuthir.	20	Couple room	2	2 lights 1 Fan
				4 bedded room	18	2 Lights 1 Fan
MCHS	4	Hotel Blue Marine, Hotel Prince Heaven, CTB Resorts.	25	Couple room	5	2 Light 1 Fan 1 LED TV (21 inch)
				Triple bedded room	10	2 Light 1 Fan 1 LED TV (21 inch)
				4 bedded room	10	2 Lights 2 Fan 1 CRT TV (21 inch)

Table 3.3: Types of loads and their total ratings in the modelled number of resorts

Resort type	Electrical Appliance	Total Quantity in all modelled resorts	Rating of each appliance (W)	Total Rating (kW)
HCAS (2)	Light	96	15	1.44
	Fan	96	40	3.84
	Water pump	8	1000	8
MCAS (15)	Light	600	15	9
	Fan	300	40	12
	Water Pump	30	1000	30
MCHS (4)	Light	200	15	3
	Fan	140	40	5.6
	CRT TV (21 inch)	40	60	2.4
	LED TV (21 inch)	60	40	2.4
	Water Pump	8	1000	8
Total **'Connected Load'** in all **21** modeled Resorts =				85.68

3.5 Design of the proposed power plant

3.5.1 'Load Curve' Construction and the selection of unit size

Any energy system design requires an approximate evaluation of electricity demands and load profile of the area of interest at the initial stage. So as per the aim of this study, a realistic estimation of total connected electrical loads in the resorts, their daily consumption profiles and prediction about expected increase in load demand within a defined study period becomes essential to take decision about the installed capacity of the power plant to be proposed and the operating schedules of its different generating units.

Although every resort in St martin Island has isolated stand-alone generators of their own as source of main power supply, in this study we assumed that all the 21 modeled resorts are connected to a central power supply system or in other words connected to a grid. Their individual load demand will be fulfilled integrally by the proposed power plant.

The generator of a typical resort is only operated at some specific hours when the tourists are most likely to in need of electricity. Those periods can be termed as **'Peak Demand Hours (PDHs)'** which is on average 8 to 9 hours/day for any resort. PDHs may vary from day to day and resort to resort though. However, from the survey it has been observed that the overall 'PDHs' of all resorts as a whole, are in total of around **11 hours/day** and can be divided into two shifts:

- **'Day-Shift', 10am-3pm** (In case of a single resort, within these 5 hours period the PDHs is around 2 to 3 hours when the necessary water required for tourists are pumped to the water tank by a water pump. So, Generator of that resort remains ON for a couple of hours mainly to this purpose).
- **'Evening-Shift', 6pm-12am** (Majority of the tourists return to the resorts within this time. Generators remain ON almost over the entire period).

However, in almost every resorts of the St Martin's Island **the generators remain off from around 12am to 10am**. The prime objective of this work is to provide an outline to mitigate the electricity requirements in both 'Day-shift' and 'Evening-shift' of PDHs of the resorts by renewable wave powered hydro-electricity as an alternative of using the diesel generators. Here continuous supply of electricity from the proposed hydro-electric power plant may not be realized because of seemingly very low wave power level in the near shore regions of St. Martin's Island during low-tide periods.

So, there will be two types of load curves on the proposed power plant in a typical day:

- Load curve for the 'Day-shift' of PDHs, which spans over a period of 5 hours.
- Load curve for the 'Evening-shift' of PDHs, which spans over a period of 6 hours.

To generate load curves during the PDHs, survey on each type of resorts (HCAS, MCAS & MCHS) was done for 3 consecutive days. Load data at a particular hour for all three days was averaged to get more realistic load profile with minimized error. The Load curves for both shifts for all the modelled number of HCAS, MCAS and MCHS resorts had been constructed with data collected from field survey. The load curves of all three types of resorts during each shift of PDHs then aggregated to find a single load curve representing the overall electricity demand in all the resorts in a typical day of Peak-tourist season.

From these load curves the decision about the installed capacity of the power plant to be constructed, size of generating units in each shift, their startup & shutdown time, operating periods and total running time were made. Constructing a load duration curve from the load curve maybe more useful in this decision-making purpose which is simply the re-arrangements of all the load elements of chronological load curve in the order of descending magnitude [40].

From the constructed load curves and load duration curves for both 'Day-shift' and 'Evening-shift' of PDHs, the selection of the size of generating units was done according to the following constraints and requirements:

1. The aim while selecting the unit size should be to have generating units of different capacities which will suitably fit into the load curve/load duration curve so that most of the generating sets when in use can be operated at nearly full load [41].
2. In a power station neither there should be only one generating unit nor should there be a large number of small sets of different sizes [42].
3. It is economical to use a few generating units of larger size than using number of small sized generating units for the same total capacity [41].
4. The unit size mustn't exceed 20%-25% of the total generating capacity of the plant [43].
5. 'Day-shift' and 'Evening-shift' should have as much same sized unit as possible. That's because to minimize the installation cost of the plant [44].
6. One unit of the largest size should be kept as a spare generating unit/standby unit so that repairs and overhauling of the working units can be carried out [44].

The load curves for the two mentioned shifts will obviously have different peak and average demand/load than each other. So, the overall peak load and overall average load on the plant will be formulated by the following equations:

$$OAL = \frac{5}{11} AL_{day} + \frac{6}{11} AL_{evening} \tag{3.35}$$

$$OPL = \frac{5}{11} PL_{day} + \frac{6}{11} PL_{evening} \tag{3.36}$$

Where,

OAL = Overall average load on the plant, OPL = Overall peak load on the plant, AL_{day} = Average load during the day-shift = $\dfrac{\text{Area under load curve (kWh)}}{\text{5 (h)}}$,

PL_{day} = Peak load during the day-shift, $PL_{evening}$ = Peak load during the evening-shift & $AL_{evening}$ = Average load during the evening-shift = $\dfrac{\text{Area under load curve (kWh)}}{\text{6 (h)}}$.

3.5.2 Predicting future increase in demand

When a power station is to be installed in a particular area it is desirable that together with maximum current power demand in that area, ‘the future demand needs’ within a defined study period should also be known. Since the hydro-electric projects have a gestation time of about 10 years from conception to realization, they should be able to cater to the demands at least 10-15 years in future from the planning stage [45]. The economical installation of a power plant calls for the correct prediction of load [46]. The future load requirements are predicted by taking into account the various factors like population growth, standard of living of the people, climate of the regions and industrial development [46].

For this study, to predict the future power demand, a short-term study period of 4 years has been considered. There are many techniques and mathematical formulae available for forecasting the load demand. One of the most commonly used such formulae is the **‘Scheer Formula’** [45] for estimating power generation requirements. It deploys simple extrapolation technique from past records, to using complex correlations. The formula can be expressed as:

$$\log_{10} G = c - 0.15 \log_{10} U \qquad 3.37$$

Where G = Annual growth in generation in % (with respect to previous year), *‘c’* a constant = 0.02*(Population Growth Rate) +1.33, U = per capita generation.

In the present study this very formula has been used to predict future increase in electricity demands in the resorts of St. Martin’s Island within the defined study period by replacing the **‘Population Growth Rate’** with **‘ECC** (Effective Carrying Capacity) **Growth Rate’**. Here it is to be noted that if the RCC remains constant over time and MC (Management Capacity) increases by some percentage annually, by Equation 3.34 ECC of the Island will also increase. Therefore, some more resorts could be included in the study which would result in a net annual increase in electricity demand. Finding experimental results of **‘ECC Growth Rate’** in the St Martin’s Island are beyond the scope of this study. Therefore, it has been assumed that the ‘Management Capacity’ increases by 1% annually from a present value of 63% over the study period while RCC remains essentially the same. Hence as depicted by Equation 3.34, ECC will also increase by some rate which is the ‘**ECC Growth Rate**’.

3.5.3 Total Installed Capacity of the Proposed Plant

‘Total capacity to be installed’ for a power plant under planning is the summation of installed capacity to fulfill the immediate demand and the anticipated growth in demand within the defined study period.

3.5.4 Generator/Alternator Selection for the Selected Unit Sizes

One of the most important elements of any generating unit of a small/micro hydro-power plant is the electromechanical equipment (turbine-Generator/alternator). The turbines used in this type of power plant are hydraulic turbines (either ‘Reaction’ or ‘Impulse’ turbine). They work as prime movers of the generators connected the them. Selection of suitable turbine type and appropriate rating depends mainly upon the ‘HEAD’ of water available in the site under study. On the other hand, generators are the output terminal of generation units, that means, power is indirectly supplied to the consumers by generators according to the demand. Selecting suitable generator rating for a unit is mainly guided by ‘power to be supplied’ by that unit and power factor (PF).

$$\begin{cases}\text{Power Output to be Supplied by the Unit } \left(kW\right) \div \text{ Power Factor} \\ = \text{ Generator Rating } \left(kVA\right)\end{cases} \qquad 3.38$$

International standards rate generators as having a power factor of 0.8. Considering a power factor of 0.8 for the previously selected unit sizes, appropriate generating ratings for the selected units have been picked. Selection has been done by using Equation 3.38 and the obtained *‘kVA’* rating rounded to next standard value.

3.5.5 Estimating required capacity of ‘Water Chambers’ for selected units

As mentioned earlier, the capacity of the **‘water chamber’** associated with each unit or water flow required from the water chamber to the turbine largely depends upon the water head available, power rating and running time of the respective generation unit. For any unit the required water flowrate to the hydraulic turbine can be estimated from the following expression:

$$Q_t = \frac{3.6\times 10^6 P_u}{\rho g \eta H} \qquad 3.39$$

Where, Q_t = flowrate in cubic meter/hour, P_u = Power rating of the unit in watts *(kW)*, $\rho = 1030\ kg/m^3$, g = $9.81\ m/s^2$, η = Efficiency of turbine-generator assembly typically 0.9, H = achievable water head in meters *(m)*.

Capacity of water chamber for any unit can be calculated using Equation 3.40,

$$WC = Q_t \times RT \qquad 3.40$$

Where, *WC* = Capacity of water chamber (cubic meter), Q_t = flowrate in cubic meter/hour, *RT*= running time of the unit (hours).

3.5.6 Economic Factors of the Proposed Plant

When a power plant is being installed or after the power plant has been installed, its economic operation and maintenance is always desired from an engineering perspective. There are some ‘Economic Factors’ that governs the economic aspects of a power plant. Some of such factors are:

- Demand Factor (DF)
- Load Factor (LF)
- Diversity Factor (DF)
- Plant Capacity Factor (PCF)

High values of these factors are always desired for economic operation of a power plant and to produce energy at a cheaper rate [43]. From the calculated numerical values of these factors for the proposed power plant, an economic outline for the operation of the plant can be figured out.

Demand Factor (DF) = $\frac{\text{Maximum Demand}}{\text{Connected Load}}$ [44].

$$\therefore \text{Overall Demand Factor } (ODF) = \frac{5}{11} DF_{day} + \frac{6}{11} DF_{evening} \qquad 3.41$$

Load Factor (LF) = $\frac{\text{Average Load}}{\text{Maximum Demand}}$ [44].

$$\therefore \text{ Overall Load Factor } (OLF) = \frac{5}{11} LF_{day} + \frac{6}{11} LF_{evening} \qquad 3.42$$

Here the subscripts 'day' and 'evening' indicate the corresponding values during the 'Day-shift' of Peak Demand Hours (PDHs) and the 'Evening-shift' of PDHs respectively.

In this study, we have three (3) types of consumers. These are HCAS resorts, MCAS resorts and MCHS resorts. Their individual maximum demand in both shifts was found from their respective load profiles constructed by data collected from 'Field-Survey'. Simultaneous maximum demand of all consumers or the peak load for both shifts is available from the corresponding load curves.

The ratio of the sum of individual maximum demands of different consumers to the simultaneous maximum demand on power station is known as diversity factor i.e.,

$$\text{Diversity Factor (DivF)} = \frac{\text{Sum of individual Max. demands}}{\text{Max. demand on power station}} \text{ [44].}$$

Similarly,

$$\text{Overall Diversity Factor } (ODivF) = \frac{5}{11} DivF_{day} + \frac{6}{11} DivF_{evening} \qquad 3.43$$

$$\text{Plant Capacity Factor (PCF)} = \frac{\text{Average Demand}}{\text{Plant Capacity}} \text{ [44].}$$

$$\therefore \text{ Overall Plant Capacity Factor } (OPCF) = \frac{5}{11} PCF_{day} + \frac{6}{11} PCF_{evening} \qquad 3.44$$

There are also two more factors named,

$$\text{Plant Use Factor (PUF)} = \frac{\text{Peak Load}}{\text{Plant Capacity}} \text{ [43].}$$

$$\therefore \text{ Overall Plant Use Factor } (OPUF) = \frac{5}{11} PUF_{day} + \frac{6}{11} PUF_{evening} \qquad 3.45$$

and,

$$\text{Reserve Factor} = \frac{\text{Load Factor}}{\text{Plant Capacity Factor}} = \frac{\text{Plant Capacity}}{\text{Peak Load}} \text{ [43].}$$

Reserve factor shows the extent by which plant capacity is greater than the peak demand.

$$\therefore \text{Overall Reserve Factor } (ORF) = \frac{\text{Overall Load Factor } (OLF)}{\text{Overall Plant Capacity Factor } (OPCF)} \qquad 3.46$$

3.6 Cost estimation of major components of the proposed powerplant

At the preliminary stage of designing any power plant, it is essential to make a rough cost estimation of all the major components to get an insight about the economic viability of the project. Various cost simulation methods have been adopted in literature for estimating the cost of the various components of a small/micro hydro powerplant. Some authors developed a computer program for performing a preliminary evaluation of small/micro hydroelectric (SHE) system installations [47].

In this study, some cost functions available from literature have been used to simulate the costs of major components of the proposed hydro powerplant. Cost functions are empirical equations relating the cost of a specific component to the head and power rating of the plant. These cost functions strongly depend upon the geography of the country and many other managerial and economic factors. Deduction of cost function for any region requires extensive field study on the powerplants of that region. Voros et. al [48] established and used such cost functions for hydroelectric power plants in Greece. Comparisons between cost functions were also made between countries like India and Brazil by other authors [49].

Since Bangladesh at the moment does not have enough hydroelectric power plants to enable deductions of cost functions, cost functions developed for India have been used in this study considering the fact that the geographical and economic standings of Bangladesh is somewhat similar to that of India. The cost functions for India were deduced by Mishra et. al [50] after studying over a hundred hydro power plants all across the country. This approach was verified by other authors as well [51].

Application of those cost functions in this study may provide a reasonable estimate of the costs needed to establish major components of the powerplant. The Indian cost functions for various component of an MHPP are listed in the Table 3.4.

Table 3.4: Cost functions for different components of a hydro power plant [50]

Components	**For single unit (Rs/kW)**
Water Intake System (C1)	$14382 \times P^{-0.2368} \times H^{-0.0596}$
Penstock (C2)	$4906 \times P^{-0.3722} \times H^{-0.3866}$
Power house building (C3)	$62246 \times P^{-0.2354} \times H^{-0.0587}$
Tail race channel (C4)	$28164 \times P^{-0.376} \times H^{-0.624}$
Turbine with governing system (C5)	$39485 \times P^{-0.1902} \times H^{-0.2167}$
Generator with excitation system (C6)	$48568 \times P^{-0.1867} \times H^{-0.2090}$
Mechanical and electrical auxiliaries (C7)	$31712 \times P^{-0.1900} \times H^{-0.2122}$
Main transformer and switchyard equipment (C8)	$14062 \times P^{-0.1817} \times H^{-0.2028}$

Now,

Cost per kW for civil work, *Cc (Rs.)* $= C1 + C2 + C3 + C4$ 3.47

Cost per kW for electro-mechanical equipment,

$Cem\ (Rs.) = C5 + C6 + C7 + C8$ 3.48

Total cost per kW (Rs.) = $1.13 \times (Cc + Cem)$ 3.49

The cost functions listed here give the cost in Indian Rupees. So, the costs have been converted to BDT. As of July 2018, 1 Indian Rupee =1.25 Bangladeshi Taka [52].

Chapter 4 Results and Major Findings

4.1 Hindcasted wave characteristics

In this study, a fetch limited condition of wind for wave generation in the coastal regions of the St Martin's Island and Air-sea temperature difference of $-3^0\mathrm{C}$ have been considered since these are the most frequent cases in real scenario. The fetch lengths of the overland wind data measured by BCSIR (Table 3.1) are not known. Also, measurement of fetch length by weather/synoptic charts is beyond the scope of the study. So, a typical range of 42 km-100 km has been assumed. Fetch length of the wind has been considered to vary within this range.

Now, using Figure 3.5 the given overland wind speed at 33 m height from sea-level has been converted to 10 m reference height level ($U_{L,10}$). Using this converted speed, Figure 3.6 is utilized to find the correction factor for location effects (R_L). The combined correction factor '$U_{L,10}R_T$' of overland wind for both '10 m reference height' criteria and 'temperature effects' has been calculated directly using Figure 3.8 (b).

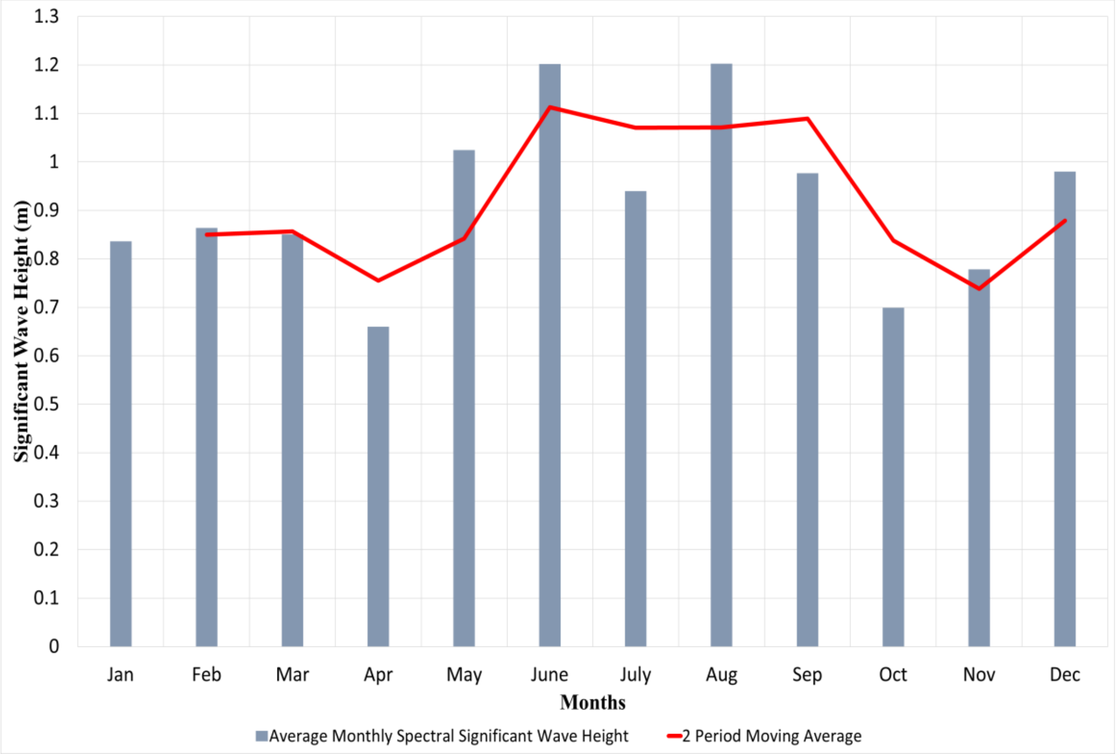
The adjusted overwater windspeeds (U_A) for wave prediction have been calculated by using the values of correction factors found from the figures and Equations 3.2 & 3.3 and overland windspeed data from Table 3.1. The results are tabulated in Table 4.1. The average significant wave characteristics $H_m \,\&\, T_m$ for every months of a year has been estimated using the Equations 3.4-3.6 of 'Shallow Water Wave Growth Model' along with the calculated U_A data from Table 4.1.

Table 4.1: Calculation of overwater wind speed for wave prediction from measured overland wind speed by BCSIR in St Martin's Island

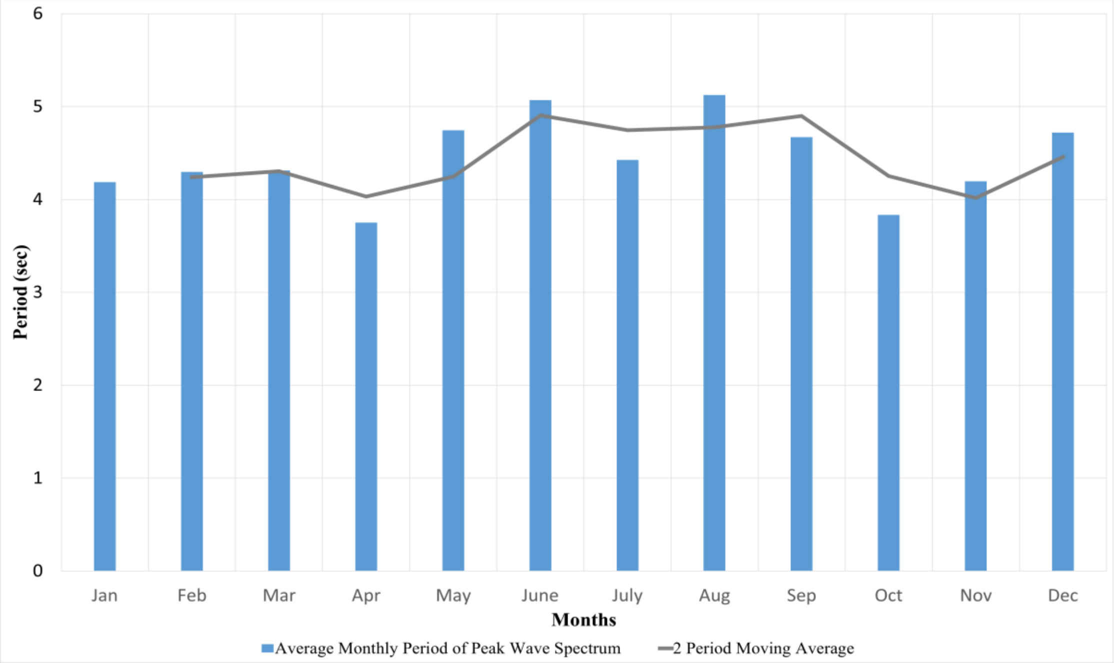
Month	**'Overland wind speed'** value at St. Martin Island measured by BCSIR, **33** m above Sea-level, $U_{L,33}$ (m/s)	$U_{L,10}R_T$ **(m/s)**	R_L	**'Wind stress factor'** or **'Adjusted overwater wind speed'** U_A **(m/s)**
January	**5.03**	**5.24**	**1.46**	**8.67**
February	**4.7**	**4.95**	**1.50**	**8.36**
March	**4.24**	**4.58**	**1.53**	**7.79**
April	**3.79**	**4.15**	**1.59**	**7.23**
May	**5.07**	**5.27**	**1.44**	**8.59**
June	**6.17**	**6.3**	**1.375**	**10.11**
July	**5.56**	**5.73**	**1.43**	**9.44**
August	**5.78**	**5.87**	**1.41**	**9.55**
September	**4.47**	**4.76**	**1.51**	**8.03**
October	**4.11**	**4.47**	**1.563**	**7.76**
November	**3.53**	**3.9**	**1.625**	**6.88**
December	**4.11**	**4.47**	**1.563**	**7.76**

Table 4.2: Hindcasted Wave Characteristics

Month	**Number of days**	U_A **(m/s)**	d^*	**Fetch length, *F*(km)**	F^*	H_m^*	T_m^*	H_m **(m)**	T_m **(s)**
January	**31**	**8.67**	**3.26**	**46**	**5998.56**	**0.11**	**4.74**	**0.837**	**4.19**
February	**28**	**8.36**	**3.51**	**55**	**7718.46**	**0.12**	**5.04**	**0.864**	**4.30**
March	**31**	**7.79**	**4.05**	**65**	**10519.51**	**0.14**	**5.44**	**0.850**	**4.31**
April	**30**	**7.23**	**4.69**	**42**	**7880.73**	**0.13**	**5.09**	**0.660**	**3.75**
May	**31**	**8.59**	**3.33**	**80**	**10641.83**	**0.14**	**5.42**	**1.025**	**4.74**
June	**30**	**10.11**	**2.40**	**76**	**7300.68**	**0.12**	**4.92**	**1.202**	**5.07**
July	**31**	**9.44**	**2.75**	**49**	**5397.11**	**0.10**	**4.60**	**0.94**	**4.43**
August	**31**	**9.55**	**2.69**	**90**	**9670.88**	**0.13**	**5.26**	**1.203**	**5.13**
September	**30**	**8.03**	**3.8**	**87**	**13227.42**	**0.15**	**5.7**	**0.977**	**4.67**
October	**31**	**7.76**	**4.08**	**40**	**6521.04**	**0.11**	**4.85**	**0.699**	**3.83**
November	**30**	**6.88**	**5.18**	**77**	**15956.03**	**0.16**	**5.98**	**0.778**	**4.2**
December	**31**	**7.76**	**4.08**	**100**	**16302.59**	**0.16**	**5.97**	**0.98**	**4.72**



(a)



(b)

Figure 4.1: (a) Hindcasted significant spectral wave height, (b) Hindcasted period of peak wave spectrum

In those equations, the fetch length *(F)* of the generating wind has been considered to vary randomly month to month within the assumed 42 km-100 km range**.** This random variation of fetch length has been allowed in the hindcasting calculation just to get an intuition about realistic values of wave characteristics since the wave characteristics are not very sensitive to absolute variation in fetch length for large fetches [25]. The water depth *(d)* where ***Searasers*** will be put under operation is assumed to be **25 m.**

The hindcasted wave characteristics are tabulated and shown in Table 4.2 and Figure 4.1 respectively.

4.2 Estimation of design wave parameters and its validation

As shown in Figure 4.1, the estimated values for wave characteristics ($H_m \& T_m$) vary from month to month (Jan-Dec). But to calculate water head that will be obtained from the operation of ***Searaser***, a design wave must be specified and its different parameters also need to be calculated. The wave height and period for the 'Design Wave' **(**$\overline{H_m}$ & $\overline{T_m}$ **)** has been calculated by using Equations 3.7-3.8 and data from Table 4.2. The result gives: $\overline{H_m}$ = 0.918 m and $\overline{T_m}$ = 4.446 s. The depth of the design wave d = 25 m (assumed). Using these values in Figure 3.11 it is seen that the design wave is best described by Stokes' 2nd order theory.

So, Equation 3.10 has been used to calculate the wavelength *'L'* of the design wave which gives L = 31.066 *m*. The Ursell's number in this case, $U_R = \frac{L^2\overline{H_m}}{d^3}$ = 0.057 which is <<26. This further confirms that the selection of Stokes' 2nd order theory for the design wave is valid. Since the wave theory has been specified, the crest amplitude

($A_{c,2}$) and trough amplitude ($A_{t,2}$) of the design wave are computed directly from Equations 3.14 and 3.16. The results are:

Wave crest amplitude, $A_c = A_{c,2} = 0.4803\ m$.

Wave trough amplitude, $A_t = A_{t,2} = -0.4377\ m$ (below the sea-water level).

4.3 Dimensions of *Searaser's* PTO system

As described in Section 3.3.4, the 'Weighted Surface Buoy' of ***Searaser*** which pressurizes sea-water and supply it to the elevated reservoir. Thus, its dimensioning is a matter of prime importance before the calculations regarding wave forcing with ***Searaser*** are done. The surface buoy should be of such dimensions that it extracts as much wave energy as possible keeping the losses to a minimum and at the same time being not-bulky and cost effective.

For the simplicity of analysis, the buoy has been considered as a Small-sized member in order to neglect the wave diffraction effects.

In such case, diffraction parameter $D_p = \frac{\pi D}{L} < \mathbf{0.5}$

Let's take $\mathrm{D_p} = 0.4$, $\therefore$ Buoy diameter, $D = 3.96\ m \approx 4\ m$ or Radius, $R = 2\ m$ (Figure 3.12).

Substituting the estimated values of $\overline{T_m}$, L, d and A_c in Equations 3.18 and 3.17, J = 4047.94 *W/m* is obtained. This value indicates the 'wave power level' in the area of interest where the ***Searasers*** will be put under operation. The maximum wave power that can be absorbed by the surface buoy of ***Searaser***, $\mathrm{P}_{\max}$ has been found to be 10 *kW* by using Equations 3.19 and 3.20 respectively.

Now, solving the power to volume inequality [Equation 3.21], it appears that the volume of the buoy, V_{buoy} should be $>$ 5.85 m^3 for economic wave power absorption. However, in order to avoid bulky size a value of $V_{buoy} = 7.5\ m^3$ is taken. So, the height of the buoy, $h = \dfrac{V_{buoy}}{\pi R^2}$ becomes $\approx 0.6\ m$ (Figure 3.12).

4.4 Head calculation

From Equations 3.22 and 3.24, it is understood that both suction force ($F_{fk} - W_F$) and working force (W_F) varies with draft length, D_r of the surface buoy. For the **specified buoy radius and design wave parameters** as estimated in Sections 4.2 and 4.3, the variation of suction force and working force with draft length of the buoy has been plotted and shown in Figure 4.2. As described in 3.3.5, a **negative value of suction force** is not acceptable. Therefore, for this case study a draft length of **0.4 m** is chosen from the plot to have an optimum value of suction force and working force simultaneously.

Now the design wave parameters, buoy dimensions and its draft length being known, the working force during compression stroke (W_F) and the wave applied Froud-Krylov force component in heave (F_{fk}) can be calculated by using Equations 3.22 and 3.24. The calculation results in W_F = 50.79 *kN*, F_{fk} = 56.25 *kN* and **suction force** $F_{fk} - W_F$ = 5.46 *kN*.

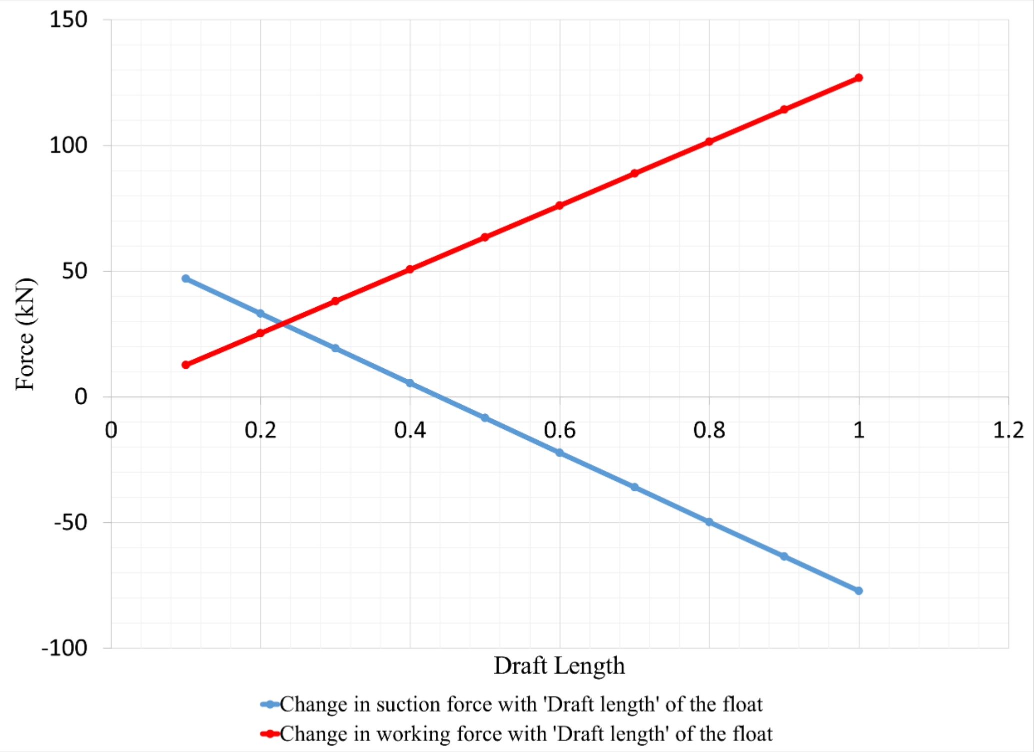


Figure 4.2: Variation of suction force and working force with draft length

As in the working stroke the buoy should push the water accumulated during suction stroke, so in order to have a working force value of W_F = 50.79 *kN*, the mass assigned to it should be approximately **5200kg**. Babajani et. al [16] assigned a buoy mass of **9000kg** in their model to investigate the distance effect between two *Searasers* for hydrodynamic performance.

Once the diameter of the cylindrical bore (D_{bore}) of the Searaser is known, the suction pressure and working pressure (P_1) can be calculated by using the Equations 3.25 and 3.26. In this study D_{bore} = **350 *mm* = 0.35 *m*** has been assumed. So, P_1 = 5.21 *atm* is obtained. P_2 =1 *atm* = 101.325 *kPa* (Section 3.3.6).

Now the time required to complete each stroke of *Searaser's* piston, $T_{L/2}$ has been calculated for the design wave parameters specified in Section 4.2 by using Equation 3.29, which gives $T_{L/2}$ = 3.15 *s*.

The material of the transportation pipe that carries pressurized sea-water to the reservoir is assumed to be made of smooth plastic. So, the relative roughness parameter, ε =0 *mm*. As described in Section 3.3.6, the diameter of the transportation pipe may be defined by, $D_{pipe} = (1/n) \times D_{bore}$, where '*n*' is a reduction factor. For specified buoy dimension and design wave condition, the velocity head and frictional head loss in transportation pipe depends greatly on the reduction factor '*n*'. Their variations with '*n*' have been shown in Figure 4.3.

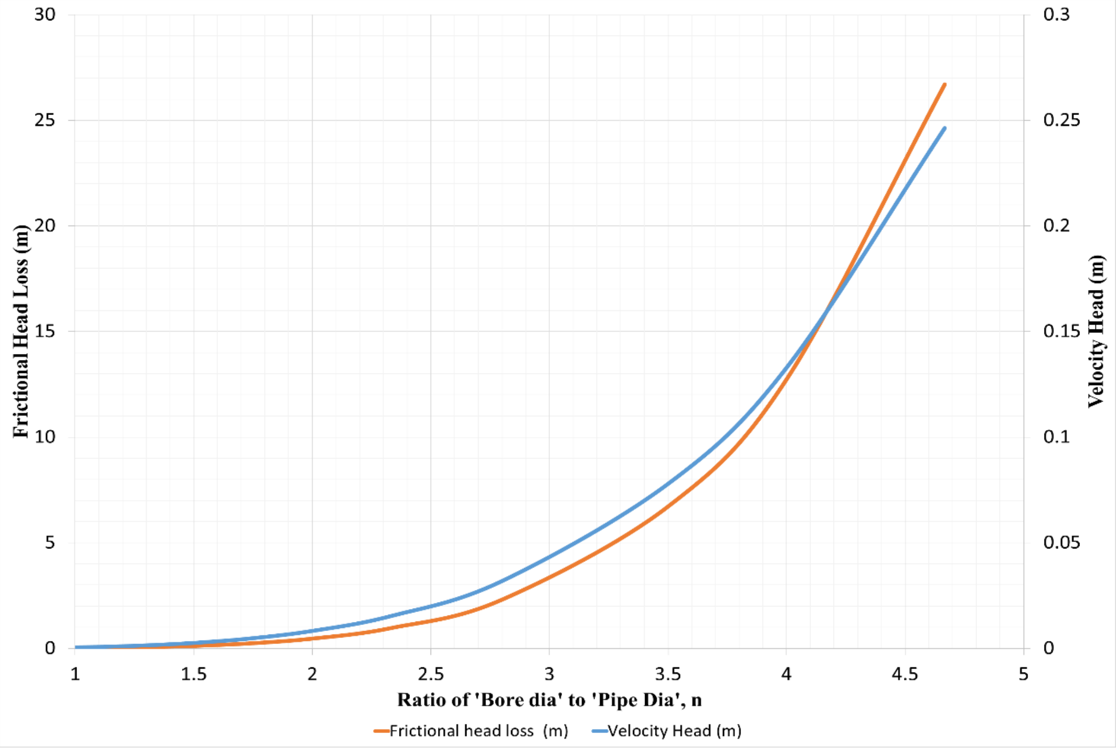


Figure 4.3: Effect of *'n'* on frictional head loss and velocity head

By analyzing this figure, $n = 2.8$ is chosen because beyond this value frictional head loss keeps on increasing while net gain in velocity head is quite negligible. Also, it is not economical to use pipe of larger diameter although the head loss would be minute in that case. This $n = 2.8$ value can be considered as optimum considering both economic and head loss constraints. With this ratio, the **chosen transportation pipe diameter is 125 *mm*.**

The value of friction factor 'f' can be determined from the expression of V_1, Reynolds number (Re) and Equation 3.32. The result in this case is f = **0.018**.

As described in Section 3.3.6 and indicated in Figure 3.13, $Z_1 = 20\ m$, $d = 25\ m$ have been assumed in this study. The length of the transportation pipeline, $l = 500\,m$ can be assumed safely since it is visible from the Equation 3.33 that this value will not have any significant effect on the equation output. Now plugging in all these findings in the effective 'Head' expression [Equation 3.33] we obtain,

$$\boldsymbol{H = 34.95\ m \approx 35\ m.}$$

This is the net head that we can get by the action of *Searaser* utilizing the wave power potential in coastal regions of St Martin's Island at 25 *m* water depth. This estimated head plays a major role in designing the MHPP and estimating its cost.

4.5 Design of the MHHP

4.5.1 Load curve and load duration curve of the resorts during PDHs

The variation of electrical load demand with time during each shift of the peak demand hours (PDHs) has been shown in Figure 4.4 and Figure 4.5. As stated earlier, the generators of a resort are turned on during the Day-shift (10 am - 3 pm) only for a couple of hours for pumping water to the water reservoir tank for supplying necessary water for the tourists. So, along with the electric motors, other appliances such as lights, fans are also used by the tourists in this period. This particular time period may vary from day to day, resort to resort depending upon situation. That’s why in Figure 4.4, the overall load curve of the resorts in ‘Day-shift’ of operation exhibits a rapid change with time. According to Figure 4.4, 11 am - 12 am turned out as prominent hours in the ‘Day-shift’ when the demand at its peak (nearly 61 *kW*). This is because usually within this period majority of the tourists prepare themselves to go out to the beach and use all the appliances in the room. In the other periods of ‘Day-shift’ demand falls because at those periods either the tourists are out to the beach or not using the appliances while the supply is on yet.

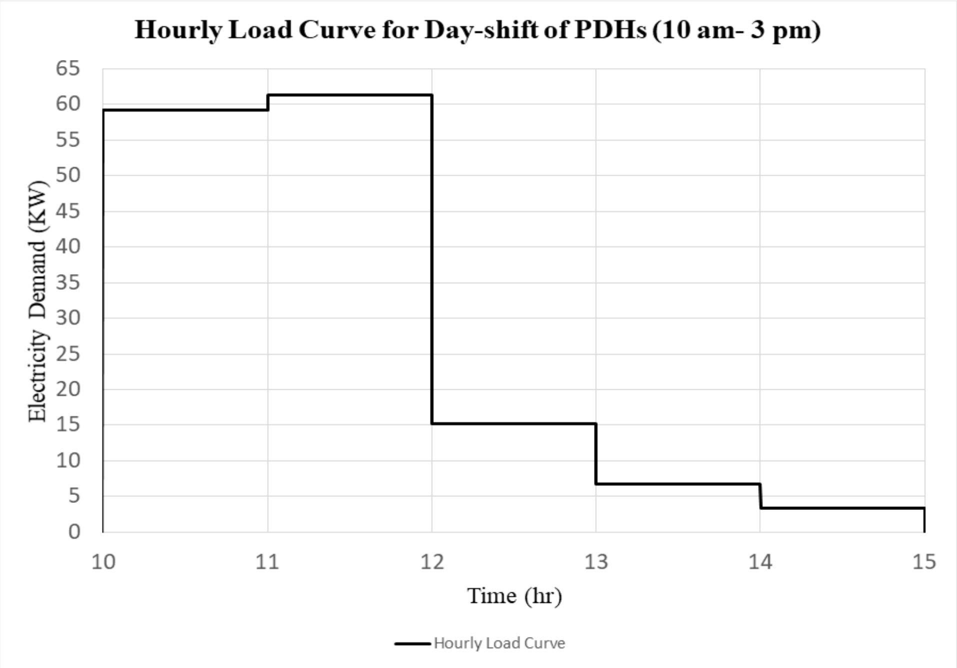


Figure 4.4: Load variation in a typical day of peak tourist season during Day-shift of peak demand hours (PDHs)

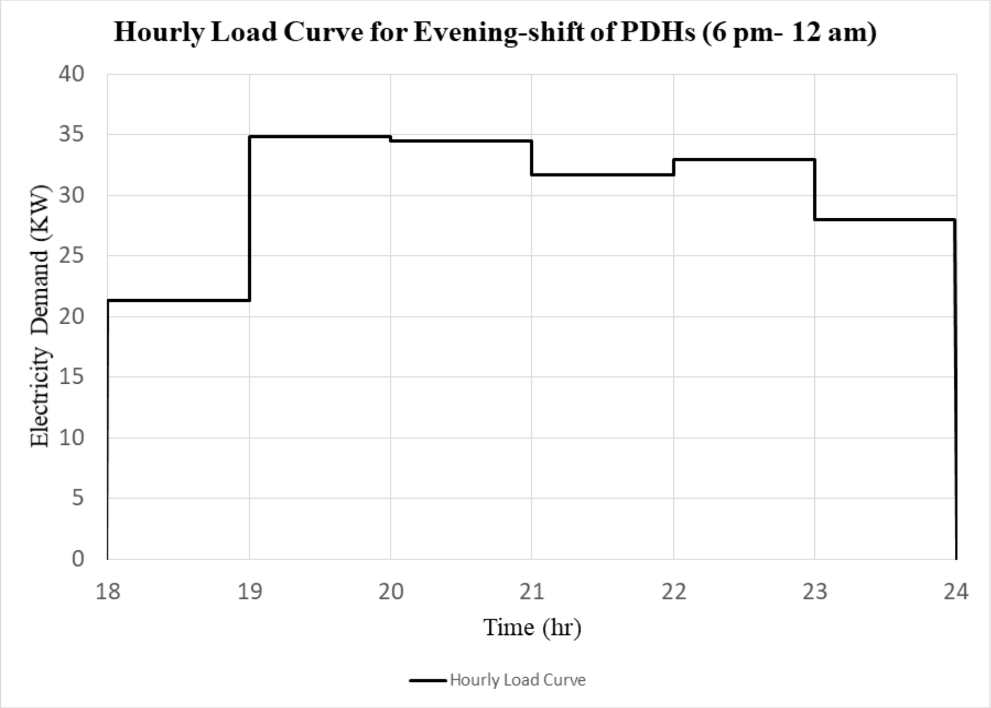


Figure 4.5: Load variation in a typical day of peak tourist season during Evening-shift of peak demand hours (PDHs)

On the other hand, in the 'Evening-shift' of peak demand hours (Figure 4.5), generators remain heavily loaded almost over the entire period. The reason is majority of the tourists return to resorts by evening and use almost all of the appliances available in rooms. That's why the demand curve in this shift doesn't seem to be fluctuating a lot, rather it remains quite steady and consistent. The peak demand in this shift is nearly 35 *kW*.

The load duration curves for both Day-shift and Evening-shift have been shown in Figure 4.6 and 4.7.

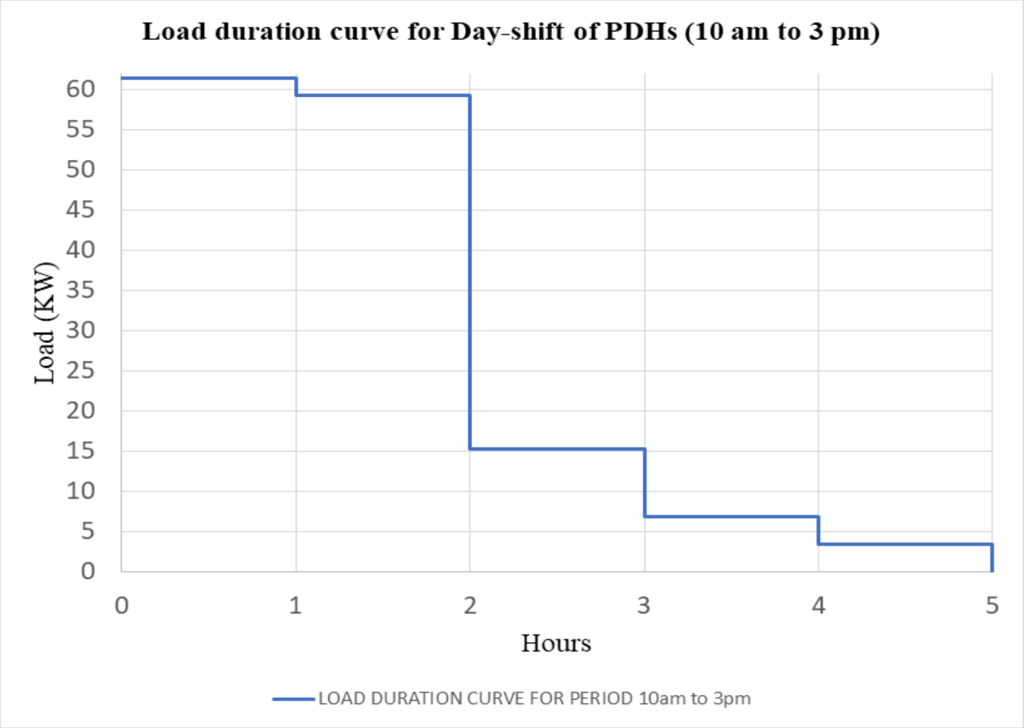


Figure 4.6: Load duration curve for 'Day-shift' of peak demand hours

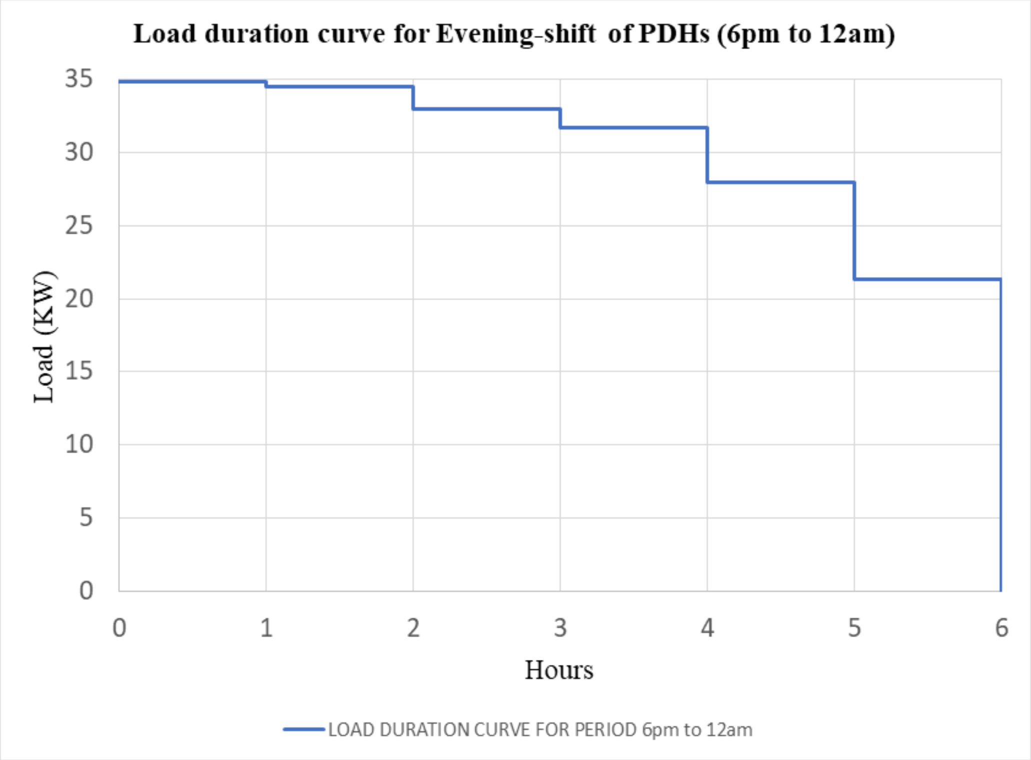


Figure 4.7: Load duration curve for 'Evening-shift' of peak demand hours

4.5.2 Determining installed capacity of the proposed powerplant

Considering the constraints and requirements for the selection of unit size from load curves/load duration curve as discussed in Section 3.5.1, the size of the generating units of the proposed powerplant for both 'Day-shift' and 'Evening-shift' has been selected according to their respective load curves, load duration curves and tabulated in Table 4.3 and Table 4.4.

Table 4.3: Selected size of generating units for 'Day-shift' of PDHs (10 am - 3 pm)

Unit Size (kW)	Portion of load to be supplied by the unit	Running Time (hours)	Operational Schedule	Loading Condition (Rounded % value)
8	Base Load	5	10 am-3 pm	43% Loaded for 1 hour. 84% Loaded for 4 hours.
8	Intermediate Load	3	10 am-1pm	90% Loaded over its entire running period.
46	Peak Load	2	10 am-12 pm	99% Loaded over its entire running period.

Here it is to be kept in mind that since the generation of electricity depends upon the supply of water from the reservoir or the availability of wave, we cannot use a generating unit employed for the 'Day-shift' in the 'Evening-shift' although they have **same size; or vice-versa**. All the 'water chambers' within the reservoir associated with the generating units should be filled before their scheduled time of operation. That's why, while calculating the installed capacity of the proposed powerplant for the immediate demand, all generating units selected for both shifts have to be taken under consideration **regardless of their common size.**

Among all the selected units, the largest 46 *kW* unit is kept as Standby unit.

Table 4.4: Size of generating units for 'Evening-shift' of PDHs (6 pm - 12 am)

Unit Size (kW)	Portion of load to be supplied by the unit	Running Time (hours)	Operational Schedule	Loading Condition (Rounded % value)
22	Base Load	6	6 pm-12 am	97% Loaded over the entire running period.
6	Intermediate Load	5	7 pm-12 am	99% Loaded over the entire running period.
8	Peak Load	4	7 pm-11 pm	46% loaded for 1 hour.
				62% loaded for 1 hour.
				81% loaded for 1 hour.
				85% loaded for 1 hour.

For the immediate demand, the installed capacity for the proposed wave powered hydro-electric power plant is the summation of all seven selected units including the Standby unit. That is **144 *kW*.** The overall average load (*OAL*) and overall peak load (*OPL*) on the proposed plant have been calculated using the Equations 3.35 and 3.36 and the load curves of Figures 4.4 & 4.5. The result is *OAL* = **29.92 *kW*** and *OPL* = **46.87 *kW***.

Table 4.5: Prediction of generation requirements by 'Scheer Formula' within a study period of 4 years (for Management Capacity, MC=1% increase annually, at year 0 MC is 63%)

Study period (year)	RCC (tourist/ day)	MC (%)	ECC (tourist/ day)	ECC Growth Rate (%)	'c'	Energy Generated/ annum (kWh) *	Overall Peak Demand (kW)	Per Capita Generation / annum, M (kWh/tourist)	G (%)
0	**2913**	**63**	**1835.2**	**-**	**-**	188183.1	**46.9**	102.54	**--**
1	2913	64	1864.3	1.59	1.36	209794.9	52.3	112.53	11.5
2	2913	65	1893.5	1.56	1.36	233527.9	58.2	123.33	11.3
3	2913	66	1922.6	1.54	1.36	259556.2	64.7	135	11.2
4	2913	67	1951.7	1.52	1.36	288065.2	71.8	147.60	11
Growth in overall peak demand within the study period =							**24.88**		

* Energy generated/annum was calculated by assuming an **'Annual Plant Load Factor' of 1** and considering **11 hours of plant operation time daily** as per the load curve

In actual scenario when the total capacity of a proposed powerplant is to be determined, anticipated growth in demand within a defined study period is also considered along with the immediate calculated demand. In Table 4.5, year-by-year increase in demand within a study period of 4 years calculated by using ‘Scheer Formula’ (Equation 3.37) [84] has been listed.

Now the ‘Total capacity to be installed’ for the proposed powerplant is simply the summation of installed capacity to fulfill the immediate demand and the anticipated growth in demand within the defined study period. For this study the total installed capacity for the desired power station turned out as **144 kW + 24.88 kW = 169 kW approximately.**

4.5.3 Generator selection

Based on the discussion of Section 3.5.4, suitable generator sizes have been picked using the Equation 3.38 for the selected unit sizes. The results are tabulated in Table 4.6.

Table 4.6: Selected Generator Ratings

Power Output to be Supplied by the Unit (kW)	Power Factor	Generator Rating (kVA)	Quantity
6	0.8	7.5	1
8	0.8	10	3
22	0.8	27.5	1
46	0.8	58	2 (1 standby unit)

4.5.4 Estimation of water chamber capacity

The capacity of ‘water chamber’ inside the mega reservoir associated with each unit has been computed and tabulated in Table 4.7 by using Equations 3.39-3.40 and data about running time of the units from Table 4.3-4.4. The net head achievable from wave power,

$H = 35\ m$ as estimated in Section 4.4 is used in Equation 3.39 to calculate water flowrate required. Here it is to be mentioned that, since the standby unit will seldom come in operation, the water chamber of this unit should have connection with the chambers of other six units so that necessary water can be transferred to them in case of emergency.

Table 4.7: Capacity of water chambers

Unit size, P_u (kW)	Shift of operation	Flowrate, $Q_t\,(m^3/h)$	Running time, RT (h)	Water chamber capacity, WC (m^3)
6	Evening	67.86	5	339.30
8	Evening	90.48	4	361.92
8	Day	90.48	5	452.40
8	Day	90.48	3	271.44
22	Evening	248.83	6	1492.98
46	Day	520.29	2	1040.58
46	Standby	---	---	1040.58

4.5.5 Estimation of economic factors and comment on them

From Table 3.3, total connected load in the modelled number of resorts = 85.68 *kW*. From Section 4.5.2, plant capacity = 169 *kW* Also, from the Figures 4.4-4.5, Peak load/maximum demand during day shift = 61.35 *kW* and peak load during evening-shift = 34.81 *kW*, average load during day-shift = 29.19 *kW* and average load during evening-shift = 30.52 *kW*. Using these values and expressions & equations developed in Section 3.5.6, Overall Demand Factor (*ODF*), Overall Load Factor (*OLF*), Overall Plant Capacity Factor (*OPCF*), Overall Plant Use Factor (*OPUF*) and Overall Reserve Factor (*ORF*) have been estimated.

In order to calculate Overall Diversity Factor (*ODivF*), load profiles of each type of consumer such HCAS resorts, MCAS resorts and MCHS resorts need to be known. However, this information was available from the field survey done for this study.

In Table 4.8, calculation of *ODivF* is shown and in Table 4.9 all the calculated factors are listed and also comment on their magnitude from economic aspects has been stated.

Table 4.8: Calculation of overall diversity factor

Shift of PDHs	**Time Span**	**Consumer Type**	**Individual Max. Demand (kW)**	**Simultaneous Max. Demand/Peak Load (kW)**	**Diversity Factor (DF)**	**Overall Diversity Factor**
Day-shift (10am-3pm)	5 hours	HCAS resorts	11.85	61.35	1.22	1.12
		MCAS resorts	48.53			
		MCHS resorts	14.4			
Evening-shift (6pm-12am)	6 hours	HCAS resorts	4.81	34.81	1.069	
		MCAS resorts	21			
		MCHS resorts	11.4			

Table 4.9: Summary of all factors

Factor	Value	Comment	Decision to Improve the Factors
Overall Demand Factor	0.55	Acceptable	--
Overall Load Factor	0.69	Acceptable	During the day-shift, Water pumps (most power consuming appliances) should be switched on during off-peak periods i.e., from 12pm-3pm. Tourism board should make rules regarding this. By doing so, the peak load will be spread over off-peak periods. As a result, load curve will flatten out. Hence peak load on the station will decrease and the average load will increase. Thus, values of load factor, diversity factor, plant capacity factor will also increase.
Overall Diversity Factor	1.12	Not satisfactory	
Overall Plant Capacity Factor	0.18	Acceptable	
Overall Plant Use Factor	0.28	Acceptable	--
Reserve Factor	3.83	Acceptable	--

4.6 Cost estimation

Based on the discussion of section 3.6, The price of equipment for all selected generating units are tabulated below:

Table 4.10: Estimated Cost

Component	**Size of Generating Units (kW)**	**Number of Units**	**Simulated Cost /Generating Unit (Tk/kW)**	**Total (Tk)**
Water Intake System (C1)	6	1	11873.96	11873.96

Water Intake System (C1)	8	3	11092.64	33277.92
	22	1	8731.50	8731.50
	46	2	7333.27	14666.53
Penstock (C2)	6	1	1287.16	1287.16
	8	3	1153.67	3461.00
	22	1	785.00	785.00
	46	2	592.86	1185.72
Powerhouse building (C3)	6	1	61704.95	61704.95
	8	3	57669.60	173008.79
	22	1	45463.18	45463.18
	46	2	38225.13	76450.26
Tail race channel (C4)	6	1	1952.19	1952.19
	8	3	1752.04	5256.12

	22	1	1197.72	1197.72
	46	2	907.63	1815.26
Turbine and GS (C5)	6	1	25984.01	25984.01
	8	3	24592.65	73777.95
	22	1	20265.67	20265.67
	46	2	17598.71	35197.42
Generator with excitation system (C6)	6	1	33543.80	33543.80
	8	3	31800.65	95401.96
	22	1	26359.66	26359.66
	46	2	22988.87	45977.75
ME auxiliaries (C7)	6	1	17137.54	17137.54
	8	3	16229.69	48689.06
	22	1	13402.58	13402.58

	46	2	11656.84	23313.69
Main transformer and SE (C8)	6	1	8108.89	8108.89
	8	3	7699.02	23097.05
	22	1	6415.40	6415.40
	46	2	5616.52	11233.03
Cost per kW of civil work (Cc) = (C1 + C2 + C3 + C4)	6	1	76818.25	76818.25
	8	3	71667.94	215003.83
	22	1	56177.40	56177.40
	46	2	47058.89	94117.78
Cost per kW of electro-mechanical equipment (Cem) = (C5 + C6 + C7 + C8)	6	1	84774.24	84774.24
	8	3	80322.01	240966.02
	22	1	66443.31	66443.31
	46	2	57860.96	115721.89
Total cost per kW = 1.13*(Cc + Cem)	**1,900,045.43 Tk**			

Chapter 5 Conclusions and Future Plan

5.1 Conclusion

Energy crisis is becoming a crying issue day by day. As a result, developed countries are constantly searching for reliable renewable energy alternatives such as oceanic wave energy and utilizing them in fields wherever possible. However, following this recent trend many authors gave positive opinion on the wave power potential in the Saint Martin’s Island, one of the most significant tourist spots of Bangladesh. In this study, a micro hydro powerplant (MHPP) has been designed along with feasibility analysis to mitigate the part time electricity demand in the tourist resorts of that Island. Power will be generated by harnessing the wave power potential by means of a renowned wave energy converter named ***‘Searaser’*** invented by an inventor named Alvin Smith.

The major uniqueness and findings of this work are:

- The determination of the maximum possible head achievable by the action of *Searaser*.
- Applying hydrodynamics and wave mechanics it is seen that *Searaser* is capable of producing around **35 *m*** of water head by utilizing the wave power potential in the Island of Saint Martin.
- A second major conclusion of our study was finding the capacity of the installed power plant. Our calculations pointed to a value of 169 kW.

5.2 Future Plan

The next phase of our work will involve the construction and testing of a ***Searaser*** prototype. Our project will include, firstly building a special tank called ‘Wave Tank’ to simulate waves like in the Bay of Bengal (near St Martin’s Island). In the ‘Wave Tank’ we will generate waves of smaller parameters with some scaling applied to the observed wave parameters in the coastal regions of St Martin’s Island. Our prototype of the *Searaser* will be submerged in the ‘Wave Tank’, waves will be generated in the tank by a mechanical ‘Wave Maker’ attached to it. The oscillation of the waves will in turn force the *Searaser’s* weighted float to move up and down.

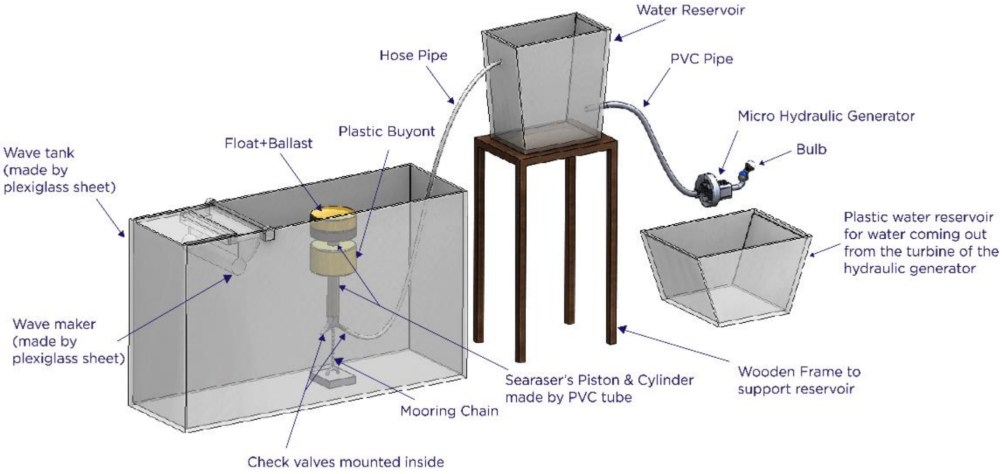


Figure 5.1: Layout of the project

The weighted float is connected to a piston cylinder arrangement to pump water from the tank into an overhead reservoir. The reservoir outlet is controlled via valves that can be adjusted to release water when needed. Once water is released from the reservoir, it falls a certain height and impacts a turbine assembly that is pre-connected to an alternator. The turbine will run the alternator thus a voltage will be generated. The power produced can further be used to light an ‘LED’ or light bulb as an indication of electricity generation.

Chapter 6 Bibliography

[1] M. Fadaeenejad, “New approaches in harnessing wave energy: With special attention,” *Renewable and Sustainable Energy Reviews,* p. 345–354, 2013.

[2] Z. F, “Review of marine renewable energies: case study of Iran.,” *Renewable and Sustainable Energy Reviews,* p. 2461–74., 2011.

[3] B. Drew, “A review of wave energy converter technology,” *Power and Energy,* vol. 223, pp. 887-900, 2009.

[4] A.-D. A, “Methods and tools to evaluate the availability of renewable energy sources,” *Renewable and Sustainable Energy Reviews,* p. 1182–200, 2011.

[5] L. H-Y, “An assessment on the planning and construction of an island renewable energy system—a case study of Kinmen Island,” *Renewable Energy,* p. 2723–31., 2010.

[6] H. A. F. P. Margheritini L, “A method for EIA scoping of wave energy converters—based on classification of the used technology,” *Environmental Impact Assessment Review,* p. 33–44, 2012.

[7] F. C, “The environmental interactions of tidal and wave energy generation devices.,” *Environmental Impact Assessment Review,* p. 133–9., 2012.

[8] J. Hayward, “Economic modelling of the potential of wave energy,” *Renewable energy,* pp. 1-27, 2011.

[9] J. Falnes, “A review of wave-energy extraction,” *Marine Structures,* pp. 185-201, 2007.

[10] A. n. F. d. O. Falca˜o, “Wave energy utilization: A review of the technologies,” *Renewable and Sustainable Energy Review,* p. 899–918, 2010.

[11] G. Iglesias, “WAVE ENERGY CONVERTERS,” in *Encyclopedia of Life Support Systems,* Uniiversity of Santiago de Compostela.

[12] “Oyster - the world's largest working hydro-electric wave energy device,” 2009. [Online]. Available: https://newatlas.com/oyster-hydro-electric-wave-energy-device/13461/#gallery. [Accessed 2018].

[13] M. RPG, “Wave energy potential in Portugal assessment based on probabilistic description of ocean waves parameters,” *Renewable Energy* , p. 1–8., 2012.

[14] A. Smith and Devon (GB), “PUMPING DEVICE”. United States of America Patent US 2013 0052042A1, 28 February 2013.

[15] A. A. Babajani, “Numerical investigation of distance effect between,” pp. 2257-2268, 2016.

[16] A. A. Babajani, M. Jafari and P. H. Sefat, "Numerical investigation of distance effect between two Searasers for hydrodynamic performance," *Alexandria Engineering Journal,* vol. 55, no. 2016, pp. 2257-2268, 2016.

[17] F. Ahmed, A. Q. Al Amin, M. Hasanuzzaman and R. Saidur, "Alternative energy resources in Bangladesh and future prospect," *Renewable and Sustainable Energy Reviews,* no. 25, p. 698–707, 2013.

[18] UNDP, "Human development index and electricity use in Asia and the Pacific, 1995 and 2002," 2006.

[19] "BP.Statistical review of world energy 2012," BP, 2012. [Online]. Available: http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/statistical_review_of_world_energy_full_report_2012.pdf. [Accessed 2018].

[20] M. T. Islam, "Current energy scenario and future prospect of renewable energy," *Renewable and Sustainable Energy Reviews,* p. 1074–1088, 2014.

[21] "AkbarMS.EnergyandnuclearpowerplanninginBangladesh.Nuclearenergy," 2012. [Online]. Available: http://www.iaea.org/INPRO/activities/Joint_SE/2._Bangladesh_-_Shawkat_Akbar.pdf. [Accessed 2018].

[22] A. F, "Alternative energy resources in Bangladesh and future prospect.," *RenewSustainEnergyRev,* p. 698–707., 2013.

[23] B. KM, "Prospect and trend o frenewable energy and its technology towards climate change mitigation and sustainable development inBangladesh," *IntJAdvRenewEnergyRes,* p. 14–25., 2012.

[24] BPDB., "Demandforecast.," [Online]. Available: http://www.bpdb.gov.bd/bpdb/index.php?option=com_content&view=article&id=12&Itemid=126.

[25] GOBPC, "Outline perspective plan o f Bangladesh 2010–2021.Making vision 2021 a reality.Dhaka:Planning Commission,Government of Bangladesh," 2010. [Online]. Available: http://www.plancomm.gov.bd/Final_Draft_OPP_June_2010.pdf.

[26] M. S. Podder J, "A study on thermal and electrical characterization of Barapukuria coal of north western Bangladesh," *ThermochimActa,* p. 113–8., 2001.

[27] B. Hossain AK, "Prospects of renewable energy utilisation for electricity generation in Bangladesh," *Renew Sustain Energy Rev:,* p. 1617–49, 2007.

[28] I. MR, "Geology and coal bed methane resource potential of the Gondwana Barapukuria Coal Basin,Dinajpur,Bangladesh," *Int J Coal Geol,* p. 127–43, 2008.

[29] REN21, "Renewables 2012 global status report.REN21," 2012. [Online]. Available: http://www.map.ren21.net/GSR/GSR2012.pdf. [Accessed 2018].

[30] D. Mondal MAH, “Assessment o frenewable energy resources potential for electricity generation in Bangladesh,” *Renew Sustain Energy Rev,* p. 2401–13, 2014.

[31] A. M, “Greenhouse gas emission and renewable energy sources for sustainable development in Bangladesh,” *RenewSustainEnergy,* p. 4659–66., 2011.

[32] C.-S.-Y. M. M. Islam A, “Energy security in Bangladesh perspective – An assessment and implication,” *Renew Sustain Energy Rev,* p. 154–71., 2014.

[33] M. Huda A, “Biomass energy in Bangladesh:Current status and prospects,” *RenewSustainEnergyRev,* p. 504–17., 2014.

[34] D. BiswasMM, “Prospects of renewable energy and energy storage systems in Bangladesh and developing economics,” *Glob JResEng(GJRE),* p. 23–31, 2011.

[35] C. Sumathi S, “Utilization of oil palm as a source of renewable energy in Malaysia,” *RenewSustainEnergyRev,* p. 2404–21, 2008.

[36] T. Ang GT, “Recent development and economic analysis of glycerol-free processes via supercritical fluid transesterification for bio diesel production,” *RenewSustainEnergyRev,* p. 61–70, 2014.

[37] R. I. A. B. Rofiqul IslamM, “Renewable energy resources and technologies practice in Bangladesh.,” *Renew Sustain Energy Rev,* p. 299–343, 2008.

[38] H. M. Nabi MN, “Karanja(Pongamia pinnata) biodiesel produc-tion in Bangladesh,characterization of karanja biodiesel and its effect on diesel emissions,” *Fuel Process Technol .,* p. 1080–6, 2009.

[39] J. MZ, “Review of solutions to global warming,air pollution,and energy security.,” *Energy Environ Sci,* p. 148–73, 2009.

[40] K. K. N. S. S. Kumar A, “Renewable energy in India Current status and future potentials.,” *Renew Sustain Energy Rev,* p. 2434–2442, 2010.

[41] K. L. N. Mondal MAH, “Drivers,barriers,and strategies for implementation of renewable energy technologies in rural areas in Bangladesh – An innovation system analysis.,” *Energy Policy,* p. 4626–34., 2010.

[42] M. NoorN, “Concentrating Solar Power(CSP) and its prospect in Bangladesh.,” *In:Proceedings of the 1st IEEE International Conference on the Developments in Renewable Energy Technology(ICDRET),* 2009.

[43] D. M. Mondal MAH, “Assessment of renewable energy resources potential for electricity generation in Bangladesh,” *RenewSustainEnergyRev,* p. 2401–13., 2010.

[44] J. Jacobsson S, “The diffusion of renewable energy technology: an analytical framework and key issues for research.,” *EnergyPolicy,* 2000.

[45] I. AKM, “Effective renewable energy activities in Bangladesh,” . *RenewEnergy,* p. 677–88, 2006.

[46] IslamS, “Appropriate low head micro hydro systems for Bangladesh,” *In:Proceedings of the Second International Conference on Electrical and Computer Engineering,* 2002.

[47] *. M. M. b. J. P. c. J.L. Ma ´rquez a, “Dynamic modeling, simulation and control design of an advanced micro-hydro power plant for distributed,” *Science direct,* vol. 35, pp. 5772-5777, 2010.

[48] H. G. M. Hanmandlu *, “Proposing a new advanced control technique,” *Scince Direct,* vol. 30, pp. 272-282, 2008.

[49] C. M. C.P. Ion*, “Autonomous micro hydro power plant with induction generator,” *Renewable Energy,* vol. 36, pp. 2259-2267, 2011.

[50] Nasir, “Design Considerations of Micro Hydro Electric Power-plant,” *Science-Direct,* vol. 50, pp. 19-29, 2014.

[51] P. V. B. Ogayar*, “Cost determination of the electro-mechanical equipment,” *Renewable Energy,* vol. 34, pp. 6-13, 2009.

[52] R. J. v. d. P. Maurice Pigaht, “Innovative private micro-hydro power development in Rwanda,” *Energy Policy,* vol. 37, pp. 4753-4760, 2009.

[53] G. D. A. C. ´. A. Babarit, “Comparison of latching control strategies for a heaving wave energy,” *Applied Ocean Research,* vol. 26, pp. 227-238, 2004.

[54] A. C. A. Babarit, “Optimal latching control of a wave energy device in regular and,” *Science Direct,* vol. 28, pp. 77-91, 2006.

[55] D. V. b. P. F. a. L. Margheritini a, “SSG wave energy converter: Design, reliability and hydraulic performance of an innovative overtopping device,” *Renewable Energy,* vol. 34, p. 1371–1380, 2009.

[56] G. I. R. Carballo, “A methodology to determine the power performance of wave energy converters,” *Energy Conversion and Management,* vol. 61, pp. 8-18, 2012.

[57] M. Fadaeenejad, “New approaches in harnessing wave energy: With special attention,” *Renewable and Sustainable Energy Reviews,* vol. 29, pp. 345-354, 2014.

[58] J. Deane, “Modelling the economic impacts of 500MW of wave power in Ireland,” *Energy Policy,* vol. 45, pp. 614-627, 2012.

[59] A. F. d. O. Falca˜o, “Wave energy utilization: A review of the technologies,” *Renewable and Sustainable Energy Reviews,* vol. 14, p. 899=918, 2010.

[60] C. Retzler, “Measurements of the slow drift dynamics of a model,” *Renewable Energy,* vol. 31, pp. 257-269, 2006.

[61] D. Dunnett, “Electricity generation from wave power in Canada,” *Renewable Energy,* vol. 35, p. 179=195, 2009.

[62] M. M. R. M. H. M. F. A. A.K.M. Sadrul Islama, “Hybrid energy system for St. Martin Island, Bangladesh: An optimized,” *Sciverse Science direct,* vol. 49, pp. 179-188, 2012.

[63] A. Q. A. A. b. M. H. c. R. S. d. Ferdous Ahmed a, “Alternative energy resources in Bangladesh and future prospect,” *Renewable and Sustainable Energy Reviews,* vol. 25, pp. 698-707, 2013.

[64] U.S. Army Corps of Engineers, SPM (SHORE PROTECTION MANUAL), vol. I, Vicksburg: Coastal Engineering Research Center, 1984.

[65] M. S. Kaiser, “Energy Efficient System for St Martin’s Island,” *Journal of Engineering and Applied Sciences,* vol. 1(2), pp. 93-97, 2006.

[66] “NASA surface meteorology and solar energy, released 5.1,” [Online]. Available: http://eosweb.larc.nasa.gov..

[67] “Sustainable Rural Energy,” Local Government Engineering Department, [Online]. Available: http://www.lged.org/sre.

[68] V. Sundar, Ocean Wave Mechanics (Applications in Marine Structures), Chichester, West Sussex: John Wiley & Sons Ltd, 2016.

[69] J. W. Kamphuis, Introduction to Coastal Engineering and Management, Singapore 912805: World Scientific Publishing Co. Pte. Ltd., 2000.

[70] CEM (Coastal Engineering Manual), 2006.

[71] I. R. Young and L. Verhagen, “The growth of fetch limited waves in water of finite depth. Part 1. Total energy and peak frequency,” *Coastal Engineering,* vol. 29, no. 1996, pp. 47-78, 1996.

[72] T. “. Sarpkaya, WAVE FORCES ON OFFSHORE STRUCTURES, New York: Cambridge University Press, 2010.

[73] K. K. Varma, “Finite Amplitude Ocean Waves,” RESONANCE, India, 2014.

[74] J. D. Fenton, *Nonlinear Wave Theories,* NEW YORK: Wiley, 1990.

[75] J. D. Fenton and W. D. Mckee, “On calculating the lengths of water waves,” *Elsevier,* Vols. Coastal Engineering, 14, pp. 499-513, 1990.

[76] R. Henderson, “Design, simulation, and testing of a novel hydraulic power take-off system for the Pelamis wave energy converter,” *Renewable Energy,* vol. 31, no. 2006, p. 271–283, 2005.

[77] S. K. CHAKRABARTI, HANDBOOK OF OFFSHORE ENGINEERING, vol. I, Illinois: ELSEVIER, 2005.

[78] J. Falnes, OCEAN WAVES AND OSCILLATING SYSTEMS, Cambridge, United Kingdom: Cambridge University Press, 2004.

[79] U. A. Korde and R. C. Ertekin, “Wave energy conversion by controlled floating and submerged cylindrical buoys,” *Journal of Ocean Engineering and Maine Energy,* vol. I, pp. 255-272, 2015.

[80] M. M. El-Wakil, POWERPLANT TECHNOLOGY, New Delhi: Tata McGraw-Hill, 2010.

[81] Y. A. Çengel and J. M. Cimbala, Fluid Mechanics Fundamentals and Applications, New York: McGraw-Hill, 2014.

[82] D. S. R. Hasan, "Tourist-Group Consideration in Tourism Carrying Capacity Assesment: a New Approach for the Saint Martin's Island, Bangladesh," *Journal of Economics and Sustainable Development,* pp. 155-158, 2014.

[83] Khan, "www.parjatan.gov.bd," 2015. [Online].

[84] R. Khan, "St. Martin's in peril," 01 December 2013. [Online]. Available: http://www.thedailystar.net/nature-quest/st-martin-s-in-peril-4386.

[85] G. R. Nagpal, "Load Duration Curve," in *Power Plant Engineering,* Delhi-110 006 (India), Khanna Publishers, 2006, p. 61.

[86] G. R. Nagpal, "Choice of Power Station," in *Power Plant Engineering,* Delhi-110 006 (India), Khanna Publishers, 2006, pp. 80-81.

[87] G. R. Nagpal, "Economics in Plant Selection," in *Power Plant Engineering,* Delhi-110 006 (India), Khanna Publishers, 2006, pp. 72-74.

[88] P. K. Nag, "Load-Duration Curves," in *Power Plant Engineering,* New Delhi, Tata McGraw-Hill Education Private Limited, 2008, pp. 2-6.

[89] V. K. Mehta and R. Mehta, Principles of Power System, 4th ed., New Delhi: S. Chand & Company Ltd., 2008, pp. 45-61.

[90] M. M. Dandekar, "Prediction of load," in *Water Power Engineering,* New Delhi-110014. India, VIKAS® PUBLISHING HOUSE PVT LTD, 2013, pp. 114-115.

[91] G. R. Nagpal, "Prediction of Future Loads, Terms and Definition," in *Power Plant Engineering,* Delhi- 110 006 (India), Khanna Publishers, 2006, pp. 56-58.

[92] P. D. Karlis AD, "A systematic assessment of the technical feasibility and economic viability of small hydroelectric system installations," *Renewable Energy* , pp. 253-262.

[93] N. Voros, "Short-cut design of small hydroelectric plants," *Renewable Energy,* pp. 545-563, 2000.

[94] G. L. T. Filho, "Cost estimate of small hydroelectric power plants based on the aspect factor," *Renewable and Sustainable Energy Reviews,* pp. 229-238, 2017.

[95] S. Mishra, "Optimal installation of small hydropower plant—A review," *Renewable and Sustainable Energy Reviews,* pp. 3862-3869, 2011.

[96] S. K. Singal, "Optimization of low-head, dam-toe, small hydropower," *JOURNAL OF RENEWABLE AND SUSTAINABLE ENERGY,* pp. 1-11, 2010.

[97] "XE Currency Converter," June 2018. [Online]. Available: https://www.xe.com/currencyconverter/convert/?Amount=1&From=INR&To=BDT.

Appendix A: Flowcharts and Survey Sheets

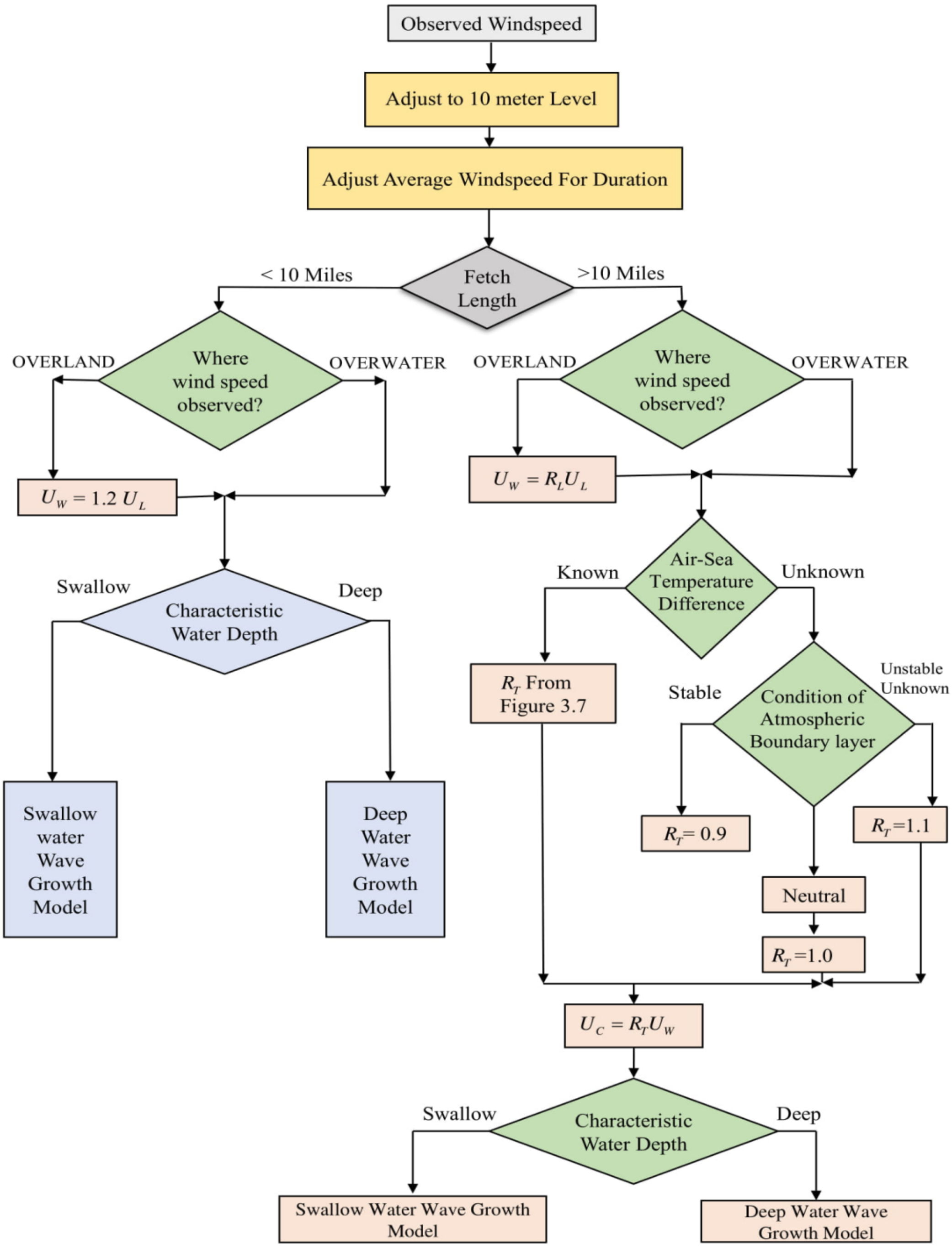


Fig A.1: Wind Hindcasting Flowchart

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Resort Name: Neel Diganta	Resort Type: Medium
Total no. of rooms:	Total Accommodation Capacity (Including stuffs):
Dates of surveying: From:	To:
Survey Room No. : Nipobon 6, 8. Tosnuchaya Udayehal 3, 4, 5. 2, 3, 4.	Room Capacity:

Table 1: Electric Appliances Details

Name (Short Form)	Rating(Watt)
1.	
2.	
3.	
4.	
5.	

Table 2: Electric Appliances Usage Data

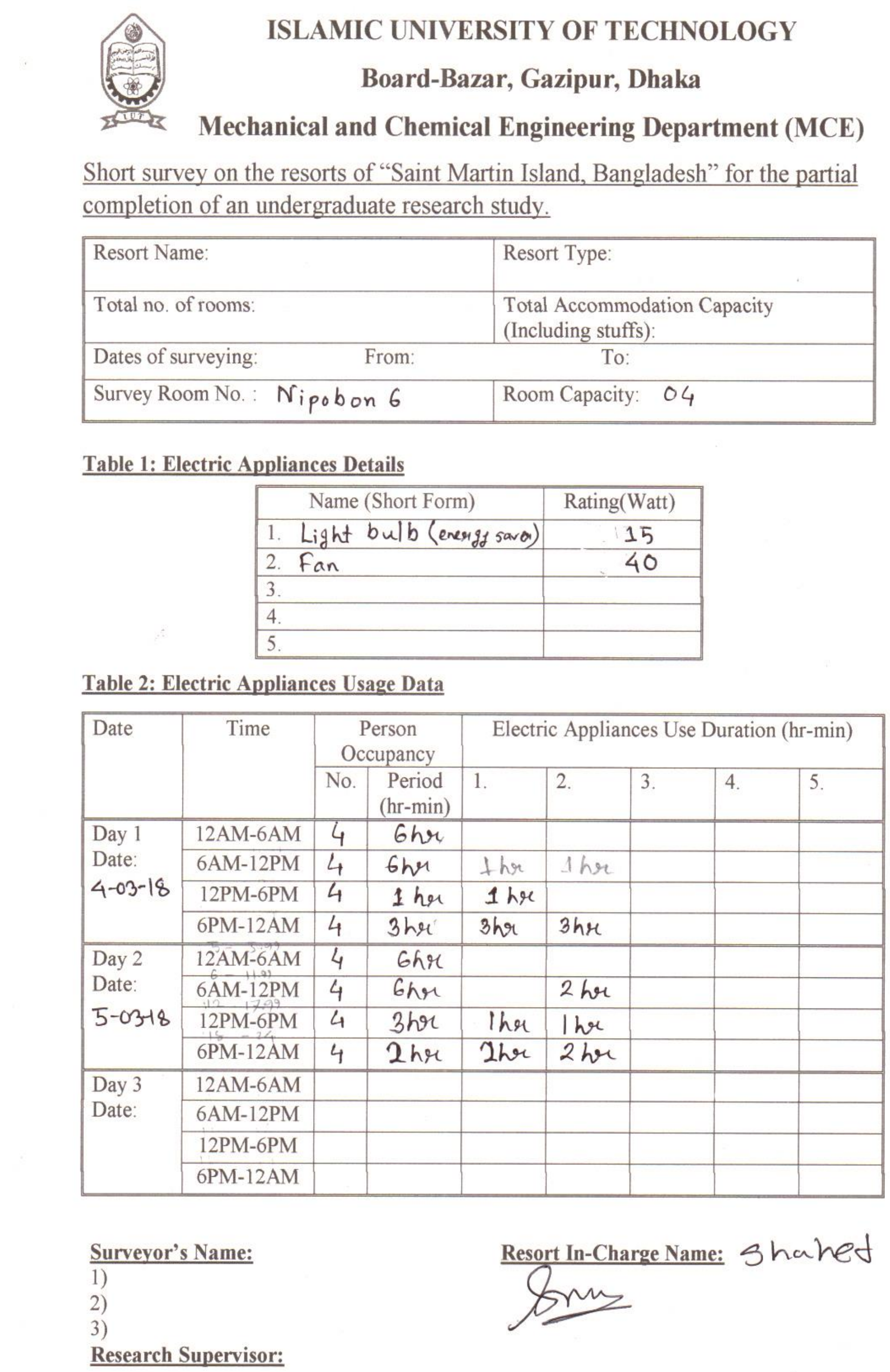
Date	Time	Person Occupancy		Electric Appliances Use Duration (hr-min)				
		No.	Period (hr-min)	1.	2.	3.	4.	5.
Day 1 Date:	12AM-6AM							
	6AM-12PM							
	12PM-6PM							
	6PM-12AM							
Day 2 Date:	12AM-6AM							
	6AM-12PM							
	12PM-6PM							
	6PM-12AM							
Day 3 Date:	12AM-6AM							
	6AM-12PM							
	12PM-6PM							
	6PM-12AM							

Surveyor's Name:

1)
2)
3)

Resort In-Charge Name:

Research Supervisor:



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Board-Bazar, Gazipur, Dhaka

Mechanical and Chemical Engineering Department (MCE)

Short survey on the resorts of "Saint Martin Island, Bangladesh" for the partial completion of an undergraduate research study.

Resort Name:	Resort Type:
Total no. of rooms:	Total Accommodation Capacity (Including stuffs):
Dates of surveying: From:	To:
Survey Room No. : Nipobon 6	Room Capacity: 04

Table 1: Electric Appliances Details

Name (Short Form)	Rating(Watt)
1. Light bulb (energy saver)	15
2. Fan	40
3.	
4.	
5.	

Table 2: Electric Appliances Usage Data

Date	Time	Person Occupancy		Electric Appliances Use Duration (hr-min)				
		No.	Period (hr-min)	1.	2.	3.	4.	5.
Day 1 Date: 4-03-18	12AM-6AM	4	6hr					
	6AM-12PM	4	6hr	1 hr	1 hr			
	12PM-6PM	4	1 hr	1 hr				
	6PM-12AM	4	3hr	3hr	3hr			
Day 2 Date: 5-0318	12AM-6AM	4	6hr					
	6AM-12PM	4	6hr		2 hr			
	12PM-6PM	4	3hr	1hr	1 hr			
	6PM-12AM	4	2 hr	2hr	2 hr			
Day 3 Date:	12AM-6AM							
	6AM-12PM							
	12PM-6PM							
	6PM-12AM							

Surveyor's Name:
1)
2)
3)

Research Supervisor:

Resort In-Charge Name: Shahed

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Board-Bazar, Gazipur, Dhaka

Mechanical and Chemical Engineering Department (MCE)

Short survey on the resorts of "Saint Martin Island, Bangladesh" for the partial completion of an undergraduate research study.

Resort Name:	Resort Type:
Total no. of rooms:	Total Accommodation Capacity (Including stuffs):
Dates of surveying: From:	To:
Survey Room No. : Nipobon 8	Room Capacity: 04

Table 1: Electric Appliances Details

Name (Short Form)	Rating(Watt)
1. Light bulb (energy saver)	15
2. Fan	40
3.	
4.	
5.	

Table 2: Electric Appliances Usage Data

Date	Time	Person Occupancy		Electric Appliances Use Duration (hr-min)				
		No.	Period (hr-min)	1.	2.	3.	4.	5.
Day 1 Date: 4-03-18	12AM-6AM	4	6hr					
	6AM-12PM	4	6hr	1hr	1hr			
	12PM-6PM	4	3hr	1hr	1hr			
	6PM-12AM	4	4hr	2hr	2hr			
Day 2 Date: 5-03-18	0-5.99 12AM-6AM	4	6hr					
	6-11.99 6AM-12PM	4	6 hr		2hr			
	12-17.99 12PM-6PM	4	3hr	2hr	2hr			
	18-24 6PM-12AM	4	3hr	3hr	3hr			
Day 3 Date:	12AM-6AM							
	6AM-12PM							
	12PM-6PM							
	6PM-12AM							

Surveyor's Name:

1)

2)

3)

Research Supervisor:

Resort In-Charge Name: Shahet

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Mechanical and Chemical Engineering Department (MCE)

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Resort Name:	Resort Type:
Total no. of rooms:	Total Accommodation Capacity (Including stuffs):
Dates of surveying: From:	To:
Survey Room No. : Torunchaya 02	Room Capacity: 4

Table 1: Electric Appliances Details

Name (Short Form)	Rating(Watt)
1. Light bulb (energy saver)	15
2. Fan	40
3.	
4.	
5.	

Table 2: Electric Appliances Usage Data

Date	Time	Person Occupancy		Electric Appliances Use Duration (hr-min)				
		No.	Period (hr-min)	1.	2.	3.	4.	5.
Day 1 Date: 4-03-18	12AM-6AM	4	6hr					
	6AM-12PM	4	6hr	1hr	1hr			
	12PM-6PM	4	3hr	3hr	3hr			
	6PM-12AM	4	4hr	4hr	4hr			
Day 2 Date: 5-03-18	0 - 5.99 12AM-6AM	4	6hr					
	6 - 11.99 6AM-12PM	4	6hr	1hr	2hr			
	12 - 17.99 12PM-6PM	4	2hr	2hr	2hr			
	18 - 24 6PM-12AM	4	3hr	3hr	3hr			
Day 3 Date:	12AM-6AM							
	6AM-12PM							
	12PM-6PM							
	6PM-12AM							

Surveyor's Name:

1)

2)

3)

Research Supervisor:

Resort In-Charge Name: Shahed

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Mechanical and Chemical Engineering Department (MCE)

Short survey on the resorts of “Saint Martin Island, Bangladesh” for the partial completion of an undergraduate research study.

Resort Name:	Resort Type:
Total no. of rooms:	Total Accommodation Capacity (Including stuffs):
Dates of surveying: From:	To:
Survey Room No. : Toruchaja 03	Room Capacity: 04

Table 1: Electric Appliances Details

Name (Short Form)	Rating(Watt)
1. Light bulb (energy saver)	15
2. Fan	40
3.	
4.	
5.	

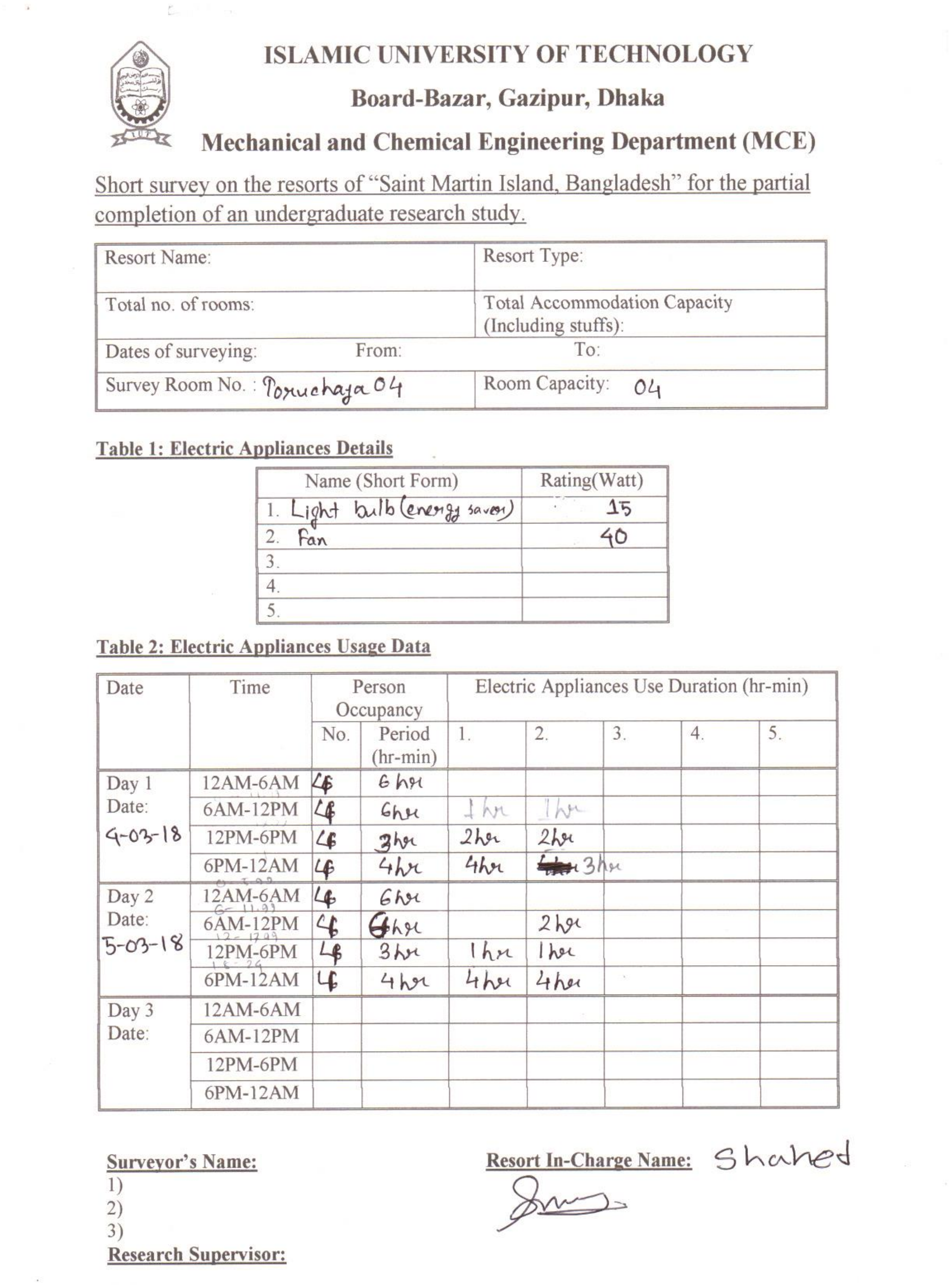
Table 2: Electric Appliances Usage Data

Date	Time	Person Occupancy		Electric Appliances Use Duration (hr-min)				
		No.	Period (hr-min)	1.	2.	3.	4.	5.
Day 1 Date: 4-03-18	12AM-6AM	4	6hr					
	6AM-12PM	4	6hr	1hr	1hr			
	12PM-6PM	4	1hr	1hr	1hr			
	6PM-12AM	4	3hr	3hr	3hr			
Day 2 Date: 5-03-18	0-5.59 12AM-6AM	4	6hr					
	6-11.59 6AM-12PM	4	6hr		2hr			
	12-17.59 12PM-6PM	4	4hr	1hr	1hr			
	18-24 6PM-12AM	4	2hr	2hr	2hr			
Day 3 Date:	12AM-6AM							
	6AM-12PM							
	12PM-6PM							
	6PM-12AM							

Surveyor’s Name:
1)
2)
3)

Research Supervisor:

Resort In-Charge Name: Shahed



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Resort Name:	Resort Type:
Total no. of rooms:	Total Accommodation Capacity (Including stuffs):
Dates of surveying: From:	To:
Survey Room No. : Toruchaya 04	Room Capacity: 04

Table 1: Electric Appliances Details

Name (Short Form)	Rating(Watt)
1. Light bulb (energy saver)	15
2. Fan	40
3.	
4.	
5.	

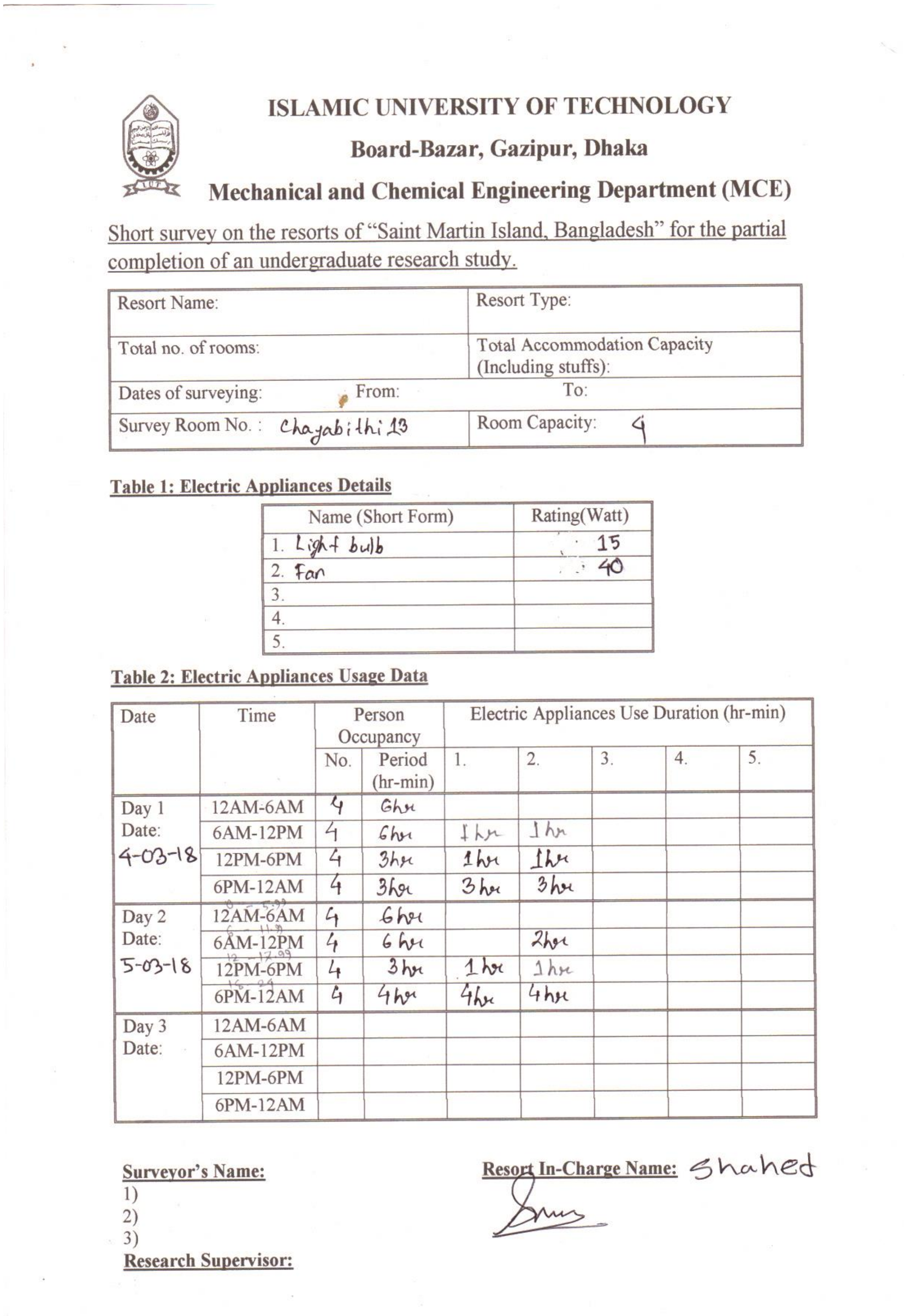
Table 2: Electric Appliances Usage Data

Date	Time	Person Occupancy		Electric Appliances Use Duration (hr-min)				
		No.	Period (hr-min)	1.	2.	3.	4.	5.
Day 1 Date: 4-03-18	12AM-6AM	4	6 hr					
	6AM-12PM	4	6hr	1 hr	1 hr			
	12PM-6PM	4	3hr	2hr	2hr			
	6PM-12AM	4	4hr	4hr	3hr			
Day 2 Date: 5-03-18	12AM-6AM	4	6hr					
	6AM-12PM	4	6hr		2hr			
	12PM-6PM	4	3hr	1hr	1hr			
	6PM-12AM	4	4hr	4hr	4hr			
Day 3 Date:	12AM-6AM							
	6AM-12PM							
	12PM-6PM							
	6PM-12AM							

Surveyor's Name:
1)
2)
3)

Resort In-Charge Name: Shahed

Research Supervisor:



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Short survey on the resorts of "Saint Martin Island, Bangladesh" for the partial completion of an undergraduate research study.

Resort Name:	Resort Type:
Total no. of rooms:	Total Accommodation Capacity (Including stuffs):
Dates of surveying: From:	To:
Survey Room No. : Chayabithi 13	Room Capacity: 4

Table 1: Electric Appliances Details

Name (Short Form)	Rating(Watt)
1. Light bulb	15
2. Fan	40
3.	
4.	
5.	

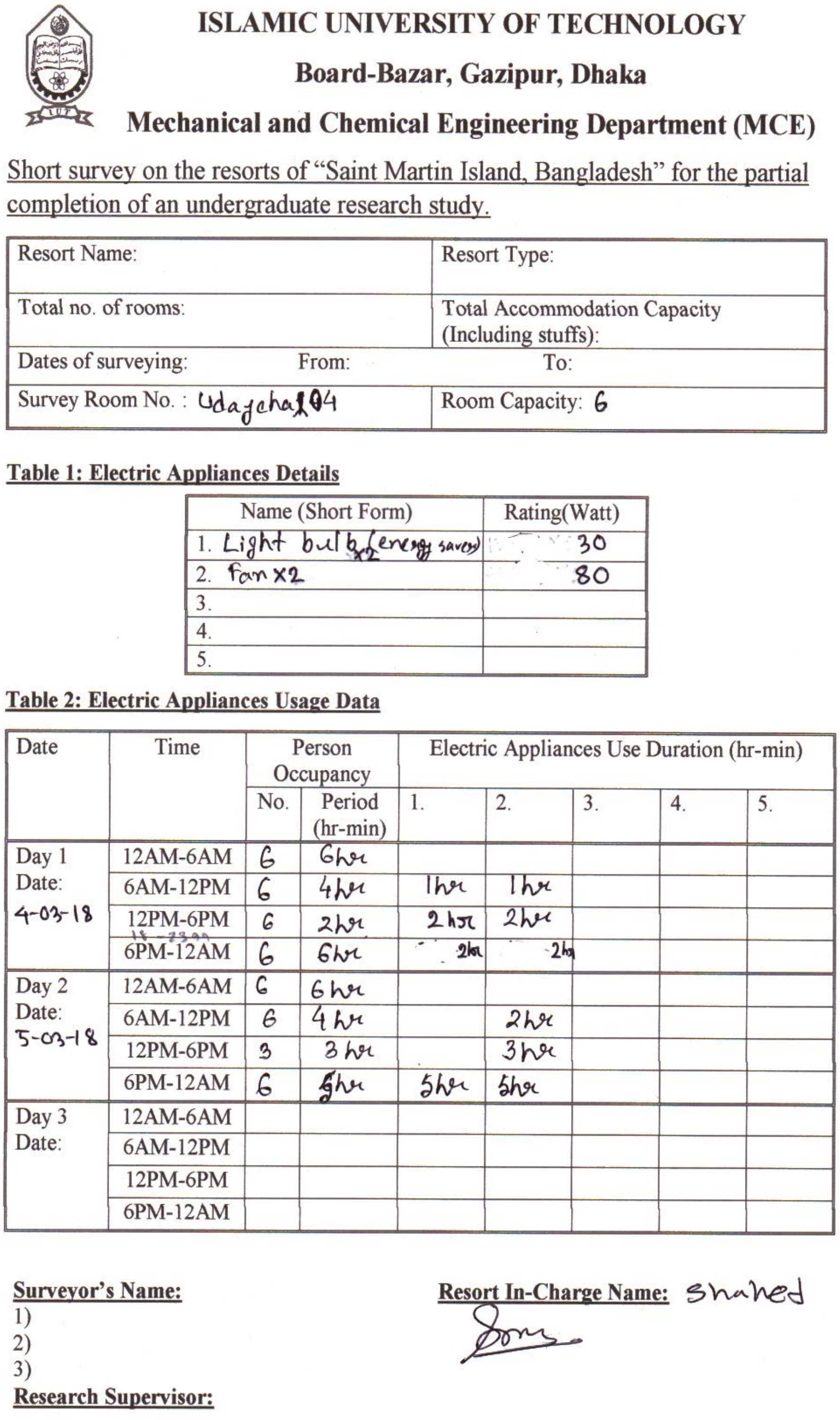
Table 2: Electric Appliances Usage Data

Date	Time	Person Occupancy		Electric Appliances Use Duration (hr-min)				
		No.	Period (hr-min)	1.	2.	3.	4.	5.
Day 1 Date: 4-03-18	12AM-6AM	4	6hr					
	6AM-12PM	4	6hr	1hr	1hr			
	12PM-6PM	4	3hr	1hr	1hr			
	6PM-12AM	4	3hr	3hr	3hr			
Day 2 Date: 5-03-18	0 - 5.99 12AM-6AM	4	6hr					
	6 - 11.99 6AM-12PM	4	6hr		2hr			
	12 - 17.99 12PM-6PM	4	3hr	1hr	1hr			
	16 - 24 6PM-12AM	4	4hr	4hr	4hr			
Day 3 Date:	12AM-6AM							
	6AM-12PM							
	12PM-6PM							
	6PM-12AM							

Surveyor's Name:
1)
2)
3)

Resort In-Charge Name: Shahed

Research Supervisor:



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Resort Name:	Resort Type:
Total no. of rooms:	Total Accommodation Capacity (Including stuffs):
Dates of surveying: From:	To:
Survey Room No. : Udayachal 104	Room Capacity: 6

Table 1: Electric Appliances Details

Name (Short Form)	Rating(Watt)
1. Light bulb x2 (energy saver)	30
2. fan x2	80
3.	
4.	
5.	

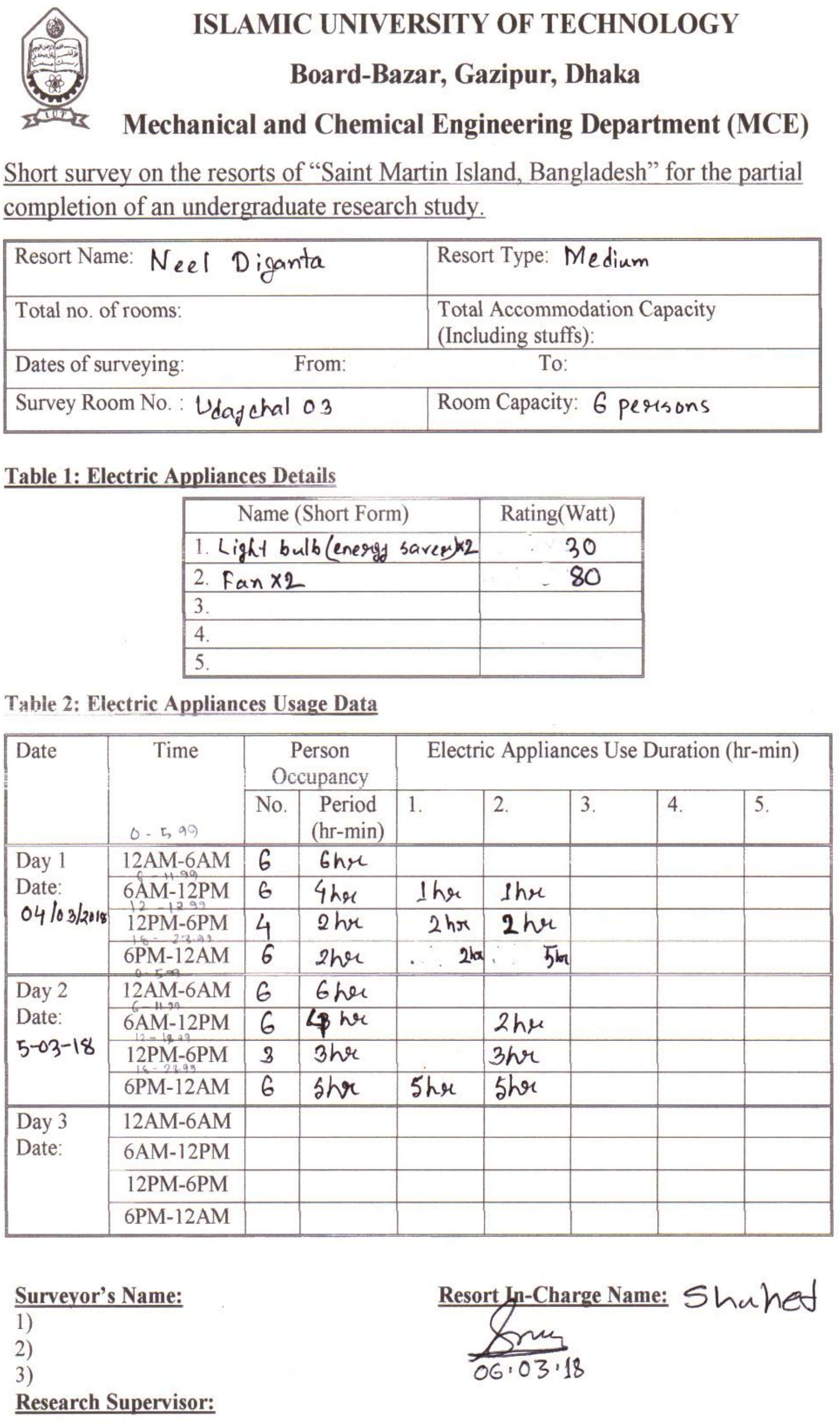
Table 2: Electric Appliances Usage Data

Date	Time	Person Occupancy		Electric Appliances Use Duration (hr-min)				
		No.	Period (hr-min)	1.	2.	3.	4.	5.
Day 1 Date: 4-03-18	12AM-6AM	6	6hr					
	6AM-12PM	6	4hr	1hr	1hr			
	12PM-6PM	6	2hr	2hr	2hr			
	6PM-12AM	6	6hr	2hr	2hr			
Day 2 Date: 5-03-18	12AM-6AM	6	6hr					
	6AM-12PM	6	4hr		2hr			
	12PM-6PM	3	3hr		3hr			
	6PM-12AM	6	6hr	5hr	5hr			
Day 3 Date:	12AM-6AM							
	6AM-12PM							
	12PM-6PM							
	6PM-12AM							

Surveyor's Name:
1)
2)
3)

Resort In-Charge Name: Shahed

Research Supervisor:



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Mechanical and Chemical Engineering Department (MCE)

Short survey on the resorts of "Saint Martin Island, Bangladesh" for the partial completion of an undergraduate research study.

Resort Name: Neel Diganta	Resort Type: Medium
Total no. of rooms:	Total Accommodation Capacity (Including stuffs):
Dates of surveying: From:	To:
Survey Room No. : Udaychal 03	Room Capacity: 6 persons

Table 1: Electric Appliances Details

Name (Short Form)	Rating(Watt)
1. Light bulb (energy saver) x2	30
2. Fan x2	80
3.	
4.	
5.	

Table 2: Electric Appliances Usage Data

Date	Time	Person Occupancy		Electric Appliances Use Duration (hr-min)				
		No.	Period (hr-min)	1.	2.	3.	4.	5.
Day 1 Date: 04/03/2018	0-5.99 12AM-6AM	6	6hr					
	6-11.99 6AM-12PM	6	4hr	1hr	1hr			
	12-17.99 12PM-6PM	4	2hr	2hr	2hr			
	18-23.99 6PM-12AM	6	2hr	2hr	5hr			
Day 2 Date: 5-03-18	0-5.99 12AM-6AM	6	6hr					
	6-11.99 6AM-12PM	6	4hr		2hr			
	12-17.99 12PM-6PM	3	3hr		3hr			
	18-23.99 6PM-12AM	6	5hr	5hr	5hr			
Day 3 Date:	12AM-6AM							
	6AM-12PM							
	12PM-6PM							
	6PM-12AM							

Surveyor's Name:
1)
2)
3)

Research Supervisor:

Resort In-Charge Name: Shahed

06.03.'18

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Short survey on the resorts of "Saint Martin Island, Bangladesh" for the partial completion of an undergraduate research study.

Resort Name:		Resort Type:
Total no. of rooms:		Total Accommodation Capacity (Including stuffs):
Dates of surveying:	From:	To:
Survey Room No. : Udaychal 05		Room Capacity: 6

Table 1: Electric Appliances Details

Name (Short Form)	Rating(Watt)
1. Light x2 bulb (energsaver)	30
2. Fan x2	80
3.	
4.	
5.	

Table 2: Electric Appliances Usage Data

Date	Time	Person Occupancy		Electric Appliances Use Duration (hr-min)				
		No.	Period (hr-min)	1.	2.	3.	4.	5.
Day 1 Date: 4-03-18	12AM-6AM	6	6hr					
	6AM-12PM	6	4hr	1hr	1hr			
	12PM-6PM	6	3hr	2hr	2hr			
	6PM-12AM	6	2hr	2hr	2hr			
Day 2 Date: 5-03-18	12AM-6AM	6	6hr					
	6AM-12PM	6	4hr	~~2hr~~	2hr			
	12PM-6PM	6	2hr	~~2hr~~	2hr			
	6PM-12AM	6	5hr	5hr	5hr			
Day 3 Date:	12AM-6AM							
	6AM-12PM							
	12PM-6PM							
	6PM-12AM							

Surveyor's Name:

1)

2)

3)

Research Supervisor:

Resort In-Charge Name: Shahed