TECHNO-ECONOMIC ASSESSMENT OF HYDROKINETIC TURBINE (HKT) APPLICATION IN MALAYSIA

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by

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Dissertation submitted in partial fulfilment of
The requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

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Universiti Teknologi PETRONAS,
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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

BEH JIE LIN

ABSTRACT

Non-renewable energy has been highly depending by our world. Fossil fuel and coal of the common types of non-renewable energies which depleting day by day and giving negative impacts to the environment. To overcome these, governments, NGO, and companies had begun to explore on renewable energy sources such as solar, geothermal energy, biomass, wind, and hydroelectric power. Each of these sources has their own method of electricity generated. Wind energy is one of the most noteworthy control-era assets at that point hydro takes over a huge portion of the world in water. Moreover, hydrokinetic turbine and dam applications had been utilized to create power using hydro but the power capacity still does not support the rural areas as the application is large and requires a tremendous water resource. The aim of this study is to investigate the technical and economical feasibility of hydrokinetic turbine (HKT) deployment in Malaysia. A conventional HKT and an enhanced design HKT have been proposed in the research project, to assess the economic feasibility for their application in Malaysia. The methodology is separated into two phases: desk research and techno-economic assessment (TEA) to estimate the cost of the turbine. Cost correlation has been performed in this study with a flow velocity of the water turbine of 0.72m/s. Swept area of the turbine, power coefficient, and velocity of water are the parameters of technical aspect to determine the power capacity of the turbines. Cost of the turbines are determined in three different cases using different size of turbine. By comparing in terms of technical and economical, enhanced design HKT has a higher power capacity and higher cost as compared to conventional HKT.

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Cp	Power coefficient of turbines
ρ	Density of water
V	Velocity flow of upstream
P	Rated capacity of turbine

LIST OF ABBREVIATIONS

HKT	Hydrokinetic Turbine
TEA	Techno-economic Assessment
LCCA	Life Cycle Cost Analysis
NPV	Net Present Value
VAHT	Vertical Axis Hydrokinetic Turbine
HAHT	Horizontal Axis Hydrokinetic Turbine

CHAPTER 1

INTRODUCTION

In this section, background of the study, problem statement, objectives, and scope of the study will be presented.

1.1 Background of Study

Non-renewable energy such as fossil fuel and coal have been highly dependent by human, resulting in the situation worse. Be beyond any doubt that world vitality, particularly in developing countries such as Malaysia is still intensely dependent on fossil fuels, which are quickly being drained. At current production rates, worldwide demonstrated saves of rough oil and characteristic gas are estimated to final for 41.8 and 60.3 a long time, separately. (Lata-García, Jurado, Fernández-Ramírez, & Sánchez-Sainz, 2018). In addition, environmental issues brought on by the emission of pollutants are a main concern. Finding more sustainable alternatives as well as environmentally beneficial is crucial as a result (Omar bin Yaakob, 2013). Therefore, the role of renewable energy is important for supplying a sustainable control age as it is green and clean energy.

Renewable energy is produced by continuously replenishing sources or ways. These energy sources include geothermal energy, hydro power, wind power, and solar power. It is crucial to understand that using renewable energy will result in the replacement of non-renewable energy since it provides stable control supplies and fuel improvement, which improve energy security and reduce the likelihood of fuel spills while reducing the need for imported power. A contribution to global electricity of 16.16% has helped to boost the electricity industrial development, where hydropower accounts for about 1290 GW, one of the largest contributors (IRENA, 2018).

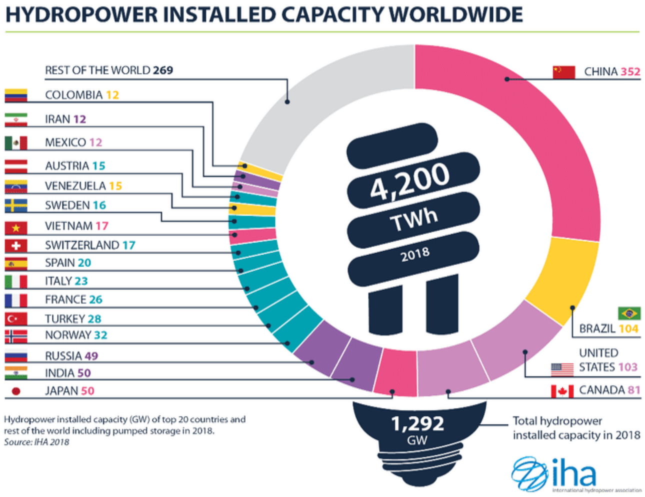


Figure 1.1: Worldwide total hydropower installed capacity (IHA, 2019)

Of these so-called green vitality sources, hydropower is the foremost proficient, in both specialized and economical terms, with a cost competitive to fossil powers. It is the water that the dams have been holding it back. Since the Asia Pacific region produced about 32% of the world's hydropower in 2010, the dam is rarely beneficial (Wikipedia, November 2020). The concept of hydropower is simple. Hydropower era through the utilize of water transport frameworks can be an important worldwide renewable vitality asset, but generally small of this potential has been precisely evaluated or created universally (Kusakana, 2014).

The hydrokinetic turbine (HKT) has long been recognized as a technology that can harness the energy of moving water and transform it into electrical energy. HKT uses the same wind turbine application, but this turbine is also frequently utilized in river or ocean flow. According to (Niebuhr, Van Dijk, Neary, & Bhagwan, 2019), HKT generates the electricity by fluid flowing through hydrofoil shaped blades with the aid of hydrodynamic forces relies on hydrodynamic forces that generate electricity by fluid flow over the hydrofoil-shaped blades. The vertical axis and the horizontal axis are the two different types of turbines. The vertical axis turbine is still in the development and research stages, but the horizontal axis design has been favored by the developers.

1.2 Problem Statement

All around the world, there had been a rise in the atmospheric emissions of greenhouse gases including carbon dioxide and methane. Examples include burning coal or gasoline for heating a building or clearing land for development, which release carbon dioxide and methane, respectively. In Malaysia, as awareness of the need for a sustainable environment is growing, it is widely acknowledged that conventional reliance on fossil fuels, including burning them, destroying forests, and raising livestock, which is contributing to climate change. To replace non-renewable energy, it is necessary to look into other sources in order to circumvent these problems.

In addition to being sustainable for use in the future, a perfect renewable energy generation system should also have as little negative influence as possible on society and the environment. Solar energy, geothermal energy, hydropower, and biomass are examples of renewable energy sources that are naturally occurring and cannot be renewed. Among all the renewable energy, hydroelectric generation significantly contributes to small hydro development. However, the development of hydrokinetic turbines (HKT) is not found in Malaysia.

Before the deployment, the technical and economical feasibilities are important to be investigated. This research article is aimed to define the data from other countries and re-apply for the similar concept of HKT in Malaysia to research the technical and economical feasibility.

1.3 Objectives

Aim of the project:

1. To investigate the technical and economical feasibility of hydrokinetic turbine (HKT) deployment in Malaysia.

Research Objectives:

1. To determine technical and economical parameters for HKT deployment by desk research.
2. To analyze the technical and economical performance of hydrokinetic turbine (HKT) in Malaysia.

1.4 Scope of Study

i. The study is to perform the technical and economical of the vertical axis hydrokinetic turbine

ii. Data Analysis is chosen to generate cost correlation methodology

iii. Conventional and Enhanced Design Hydrokinetic turbine are chosen to perform the analysis

iv. Power coefficient of conventional and enhanced design HKT are 0.268 and 0.436

v. Three different cases with a 1m, 2.5m, and 5m diameter were chosen in this study, to perform the analysis of turbines

CHAPTER 2

LITERATURE REVIEW

2.1 Renewable Energy

Fossil fuels like coal, petroleum, and natural gas have been the main sources of energy since the late 1800s till the present. Environmentalists who have posited that, power generation in Malaysia has been heavily dependent on fossil fuel in 1990s. In addition, conventional oil has run out during the past 35 years, whereas natural gas and coal are expected to last 107 years and 37 years, respectively (Buswig et al., 2020). Natural resources that are continually replenished and are available on a human time scale are known as renewable energy sources (Wikipedia, 12 July 2022). There are few advantages of introducing renewable energy which are obtaining a better air quality, cleaner atmosphere, improved public health, and protection of natural habitat. However, according to U.S. Energy Information Administration, (April 2022). The most popular renewable energies in the 2000s were hydropower and wood energy. The amount of energy consumption from geothermal, energy, biomass, solar energy and wind energy have increased.

The present installed renewable energy share in Malaysia is merely 2%. By 2025, Malaysia wants to increase the percentage of installed renewable energy to 20% (Ong, Mahlia, & Masjuki, 2011)

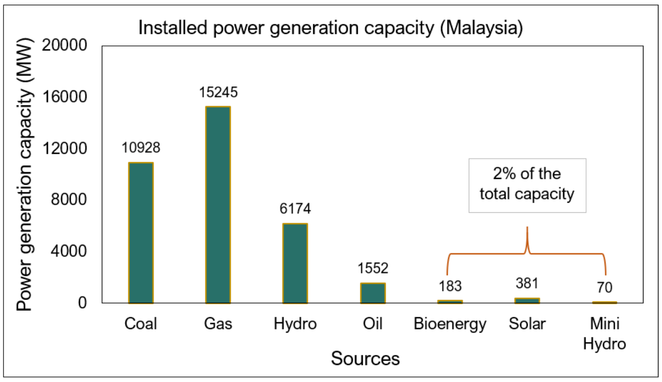
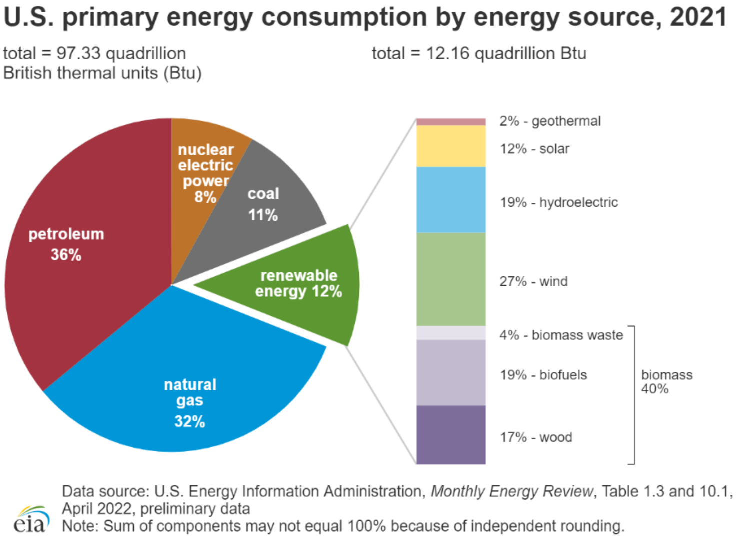


Figure 2.1: Installed Power Generation Capacity in Malaysia



Data source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2022, preliminary data
Note: Sum of components may not equal 100% because of independent rounding.

Figure 2.2: Power Energy Consumption by Energy Sources in 2021 (Energy Information Administration, April 2022)

2.2 Sources of Energy

A clean and pollution-free switch to renewable energy must be made soon due to the depletion of natural resources as well as the impact that usage is having on the environment. The list of clean and dependable renewable energy sources that can aid to reduce greenhouse gas emissions that contribute to global warming includes geothermal, hydropower, solar, wind, and biomass (Behrouzi, Nakisa, Maimun, & Ahmed, 2016).

2.2.1 Direct Solar Energy

The energy source for those renewable energy source technologies that directly draws on the energy of the Sun is referred to as "direct" solar energy. One of the most abundant and readily available sources of energy on Earth is sunlight. According to (Owusu & Asumadu-Sarkodie, 2016), “the total energy from solar radiation falling on the planet was more than 7500 times the World’s total yearly primary energy consumption of 450 EJ”.

2.2.2 Wind Energy

Wind energy is a quick creating source of vitality since 1996. (Vilsboell, Pinegin, Fischer, & Bugge, 1997) "Wind energy" and "wind power" are two phrases that can be used to describe the wind that produces mechanical or electrical power. The moving air transforms to kinetic energy, is what we called wind energy. The primary method of reducing global warming is to use turbines to generate power either on land or offshore (in fresh or salt water) (land) (Owusu & Asumadu-Sarkodie, 2016).

2.2.3 Geothermal Energy

According to EIA (2018), the Greek words geo (earth) and thermal are the origin of the word geothermal (heat). One of the renewable energy, the heat from the earth's interior is continuously created. Since areas of the earth's interior can be accessed by drilling, the geothermal gradient averages around 30 °C/km, which is significantly higher than the average gradient (Chaudhuri, Maji, Seal, Pal, & Mandal, 2018). Geothermal power is predictable and consistent as it has the potential to operate as base-load power plants (Kulasekara & Seynulabdeen, 2019).

2.2.4 Biomass

Living or once-living organisms produce biomass energy. Plants, including corn and soy, are the most frequently used biomass material for energy. Later, the energy from the organisms might be used to generate heat or power (National Geographic Society (2019). Pyrolysis is the process of turning solid fuel formed of plan materials into electricity. Despite the fact that biomass is primarily the combustion of organic materials to generate power, wood is not burned nowadays, making the process considerably more energy efficient and cleaner. Biomass converts household, industrial, and agricultural waste into gas fuel, solid, and liquid at a lower cost to the environment and the economy (Headquarters, 1996 - 2020).

2.3 Hydropower

Hydropower is one of the oldest sources of energy out of all the renewable energy sources mentioned above, clean and reliable, cheap alternatives, which uses water to generate electricity (Tigabu, Guta, & Admasu, 2019). As mentioned in (M. Salleh et al., 2018), Natural gas and coal, which together account for about 43.70 percent of all electricity generated, produce more than half of it. Next in line are renewable hydropower (which generates 87 percent of all electricity), diesel (2 percent), fuel oil (1.2 percent), and other renewable energy sources (including wind, biomass, and solar), as shown in the graph below. Hydropower has the best technological availability, dependability, and adaptability of any technology (Evans, Strezov, & Evans, 2009).

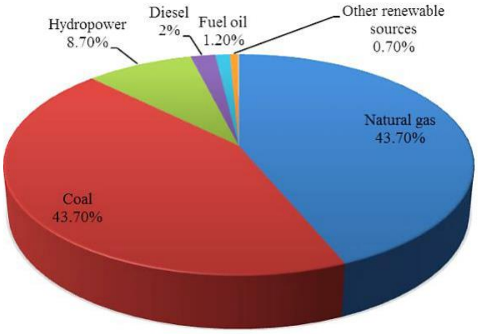


Figure 2.3: Electrical power production resources in Malaysia (M. Salleh et al., 2018)

In nature, energy cannot be destroyed nor created. Hydropower can be generated using water conveyance system, converted the kinetic energy of water in open channels. According to (Lata-García et al., 2018), the clean method to produce energy using the potential of oceans and rivers is known as hydrokinetic (HKT). Based on type energy used to produce the power, hydropower can be categorized as hydrokinetic turbines (HKT) which utilizes the moving water energy to extract power from running water current (velocity of water), and conventional hydropower which extracts power by using the static head. (Tigabu et al., 2019).

The gravitational energy is converted from the regular system into electrical energy. In order to generate power, this framework needs a dam or store that is situated in a high location, such a hill. There are a few significant obstacles to this framework, however, as it can be a massive structure. Dams damage the ecosystem and restrict fish movement. Additionally, they cannot be utilised to obtain energy for power systems from vast potential sources like ocean currents or low-quality rivers (Suman, Javaid, Nandan, Bahl, & Haleem, 2021). Therefore, conventional hydropower is not preferable as it needs a bigger site to produce speed with minimum head velocity. An unconventional hydropower system called HKT, where free-flowing water is used to generate electricity rather than large amounts of water (Behrouzi et al., 2016).

2.4 Application of Hydrokinetic Turbine

Waves, ocean currents, tides, marine thermal gradients, or the natural flow of water in rivers can be obtained from hydrokinetic technology. This technology is known as hydrokinetic turbine (HKT). It is a class of renewable energy device, by gaining the energy of flowing water without the need for conventional hydroelectric facilities like dams and penstocks. The moving water (kinetic energy) is subsequently transformed into energy (Tian, Zhang, Yuan, Che, & Zafetti, 2020). The hydrokinetic turbine operates on similar principles as a wind turbine, with the exception of the flowing medium. (M. B. Salleh, Kamaruddin, & Mohamed-Kassim, 2019). A hydrokinetic turbine will produce greater power since water is around 800 times denser than air. Based on Bridge Gap Renewables Inc, 2022, the aim of hydrokinetic turbines is to produce power. The turbines are designed to be installed underwater in fixed, floating, anchored, or towed configurations in any region where the effective water current is preferably flowing with a minimum speed of approximately 0.25 m/s. Also, the energy produced (E_{HKT}) by the hydrokinetic system can be calculated using equation 1 (Kusakana, 2014).

$$E_{HKT} = \frac{1}{2} \times \rho_W \times A \times V^3 \times C_{p,H} \times \eta_{HKT} \times t \tag{1}$$

where, A is the area of the turbine (m^2), v is the velocity of water current (m/s), ρ_W is the density of water (kg/m^3), η_{HKT} is the combined efficiency of hydrokinetic turbine, $C_{p,H}$ is the coefficient of the hydrokinetic turbine performance, and the generator, and t is the time (s) (Van Ruijven, Schers, & van Vuuren, 2012)

For the purpose of producing electricity, there are two main types of hydrokinetic turbines, each with its own concepts and operating procedures, which are horizonal axis turbines and vertical axis turbines. The needed electrical output of the turbine, the kind of flow, and the velocity all effect the turbine's design (Kusakana, 2014)

2.4.1 Horizontal Axis Hydrokinetic Turbine

The most innovative energy systems that transforms the kinetic energy into electrical energy is known as horizontal axis hydrokinetic turbine (HAHT) (Nachtane, Tarfaoui, El Moumen, Saifaoui, & Benyahia, 2019). The propeller-style rotors used in horizontal axis turbines have axes that are parallel to the fluid flow. (i) Inverted axis turbines I have mostly been studied for little river energy converters, as seen in the figure below. Other axis-flow turbines (ii, iii, and iv) are theoretically and visually similar to modern wind turbines. (Koko, 2014). Additionally, inclined axis turbines are frequently used to convert the energy of minor rivers. The blades of a lift-based turbine are composed of cross sections of hydrofoils in two dimensions. A generator converts the shaft power into electricity by connecting directly to the shaft, via a gearbox, or indirectly using a hydraulic transmission (Laws & Epps, 2016).

There is currently no agreement on whether a horizontal or vertical axis turbine will be the best option for exploiting water current energy, however from some views, the vertical axis turbine appears to offer advantages over the level turbine (Behrouzi et al., 2016).

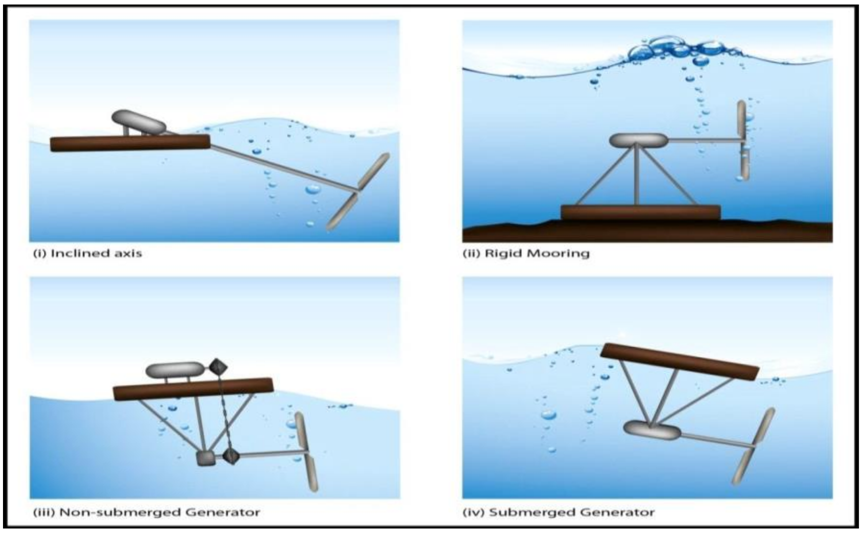


Figure 2.4: Horizontal axis turbine (Koko, 2014)

2.4.2 Vertical Axis Hydrokinetic Turbine

Vertical axis hydrokinetic turbines (VAHT) referred to as cross-flow water turbines, revolve around an axis that head away from the direction of the flow. In general, vertical axis turbines prefer to have their axes pointed in the opposite direction from the direction of the incoming flow, whereas even axis turbines prefer to have their axes parallel. This property implies that a vertical axis turbine can recognize an approaching flow from any direction and so does not need a yaw mechanism, is more quiet and peaceful in operation, has decreased mechanical complexity, low generator coupling costs because of placement over water, and the ability to design on a large scale to generate high power (Behrouzi et al., 2016). The vertical-axis HKT systems are preferred in low-power river current applications because they operate significantly better at lower water flow rates, basically no more than 1.0 m/s, in shallow channels, and with varying water speeds (M. B. Salleh et al., 2019).

Vertical axis turbines feature rotor axes that are parallel to the water's surface and perpendicular to the water flow, as seen in the figure below. They can be divided into two groups: vertical axes and in-plane axes (axes on the water's surface's horizontal plane) (axis vertical to water plane). The in-plane axis turbine (i) a drag-based device, is said to be less effective than its lift-based counterparts. The most common vertical axis turbine (ii, iii, iv, v & vi) is the Darrieus, of which the straight-bladed Darrieus type and the squirrel cage are seen to be feasible alternatives for hydro uses. (Kusakana, 2014).

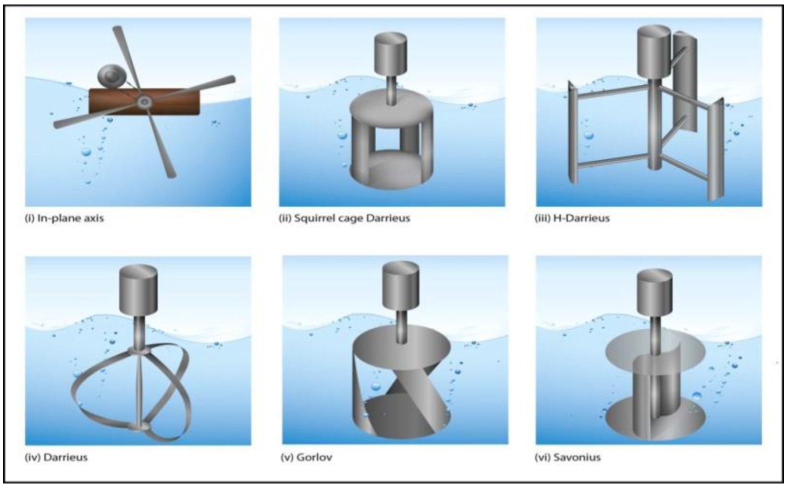


Figure 2.5: Vertical axis turbine (Koko, 2014)

2.4.3 Recent Studies on Development of Conventional and Enhanced Design HKT in Malaysian Flow Condition

In Malaysia, the development of hydrokinetic turbine is still developed by researchers, to explore the possibility of hydrokinetic development. The potential HKTs for low-velocity flows in Malaysia river can be obtained by Savonius turbine and conventional turbine.

The Savonius turbine (figure 2.6) is a two-bladed vertical axis turbine invented by Sigurd Johannes Savonius. The flow velocities can be operated as low as 0.7 m/s (Sarma, Biswas, & Misra, 2014). As mentioned in (M. B. Salleh et al., 2019), power harnessing efficiency values around 15% reported for the conventional Savonius design. The conventional turbine (figure 2.7) is a three-bladed in plane axis turbine invented by Waterotor Energy Technologies. The design simplicity of conventional HKT for manufacturing can operate in flow velocities as low as 0.5m/s (Maldar et al., 2020). A total of 27% power harnessing efficiency is reported for the conventional turbine design (Asterita, 2012, and Kadam et al.,2018).

In Malaysia, hydrokinetic current velocities are reported in the range of 0.5-1.4 m/s (Shashikumar, Vijaykumar, & Vasudeva, 2021). Drag-based turbines like conventional HKT, although a potential choice, have demonstrated comparatively lower power harnessing efficiency than axial-flow turbines. The design of an existing HKT and propose a new enhanced design HKT for operation in Malaysia flow conditions, are invented to optimize the efficiency of the power generation economically.

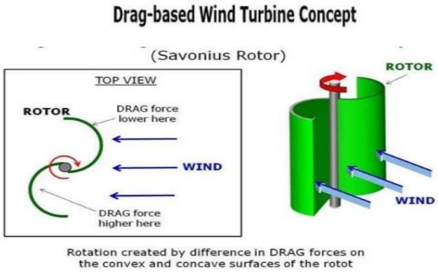


Figure 2.6: Savonius Turbine

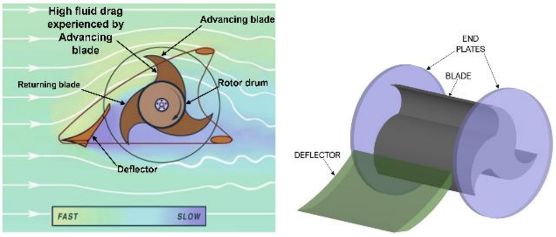


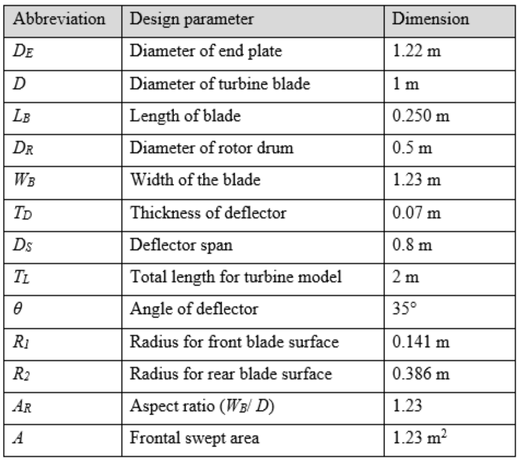
Figure 2.7: Conventional Hydrokinetic Turbine

2.5 Techno-economic Assessment (TEA)

A method of analyzing the economic assessment of an industrial product, service or process is defined as techno-economic assessment (TEA), Software modelling is utilized to perform TEA in order to estimate capital costs, estimate costs, and estimate revenues based on financial and technical input parameters (Wikipedia, 15 June 2022). The combination elements of TEA include process design, equipment sizing, modelling, capital cost performance and cost estimation performance. The second stage of TEA will be evaluating the economic feasibilities with the guidance of research and development by quantifying risk and uncertainty. To summarize results of TEA, Visualization tools such as sensitivity analysis graphs and tornado diagrams are performed in a visually coherent form and concise form (Wikipedia, 15 June 2022).

In this research project, conventional HKT and enhanced design HKT are used, and considered for economic and technical assessments. There are some main components to be considered in the present analysis, they are blades, shaft, generator and supporting arms. Table 2.1 features the design parameters for the conventional turbine to be considered in technical and economic feasibility in Malaysia.

Table 2.1: Design parameter for conventional hydrokinetic turbine



Abbreviation	Design parameter	Dimension
D_E	Diameter of end plate	1.22 m
D	Diameter of turbine blade	1 m
L_B	Length of blade	0.250 m
D_R	Diameter of rotor drum	0.5 m
W_B	Width of the blade	1.23 m
T_D	Thickness of deflector	0.07 m
D_S	Deflector span	0.8 m
T_L	Total length for turbine model	2 m
θ	Angle of deflector	35°
R_1	Radius for front blade surface	0.141 m
R_2	Radius for rear blade surface	0.386 m
A_R	Aspect ratio (W_B/ D)	1.23
A	Frontal swept area	1.23 m^2

Enhanced Design hydrokinetic turbine, the second turbine, will be performing technical and economical feasibility in Malaysia. The studies were done and flow velocity ranged from 0.5-1.5 m/s (interval 0.1). Surrounding flow characteristics were studied based on the turbulence intensity and velocity seamlines. Table 2.2 shows the design parameter for enhanced design HKT. The evaluation and assessment will be presenting in methodology and result part.

Table 2.2: Design Parameter for Enhanced Design Hydrokinetic Turbine

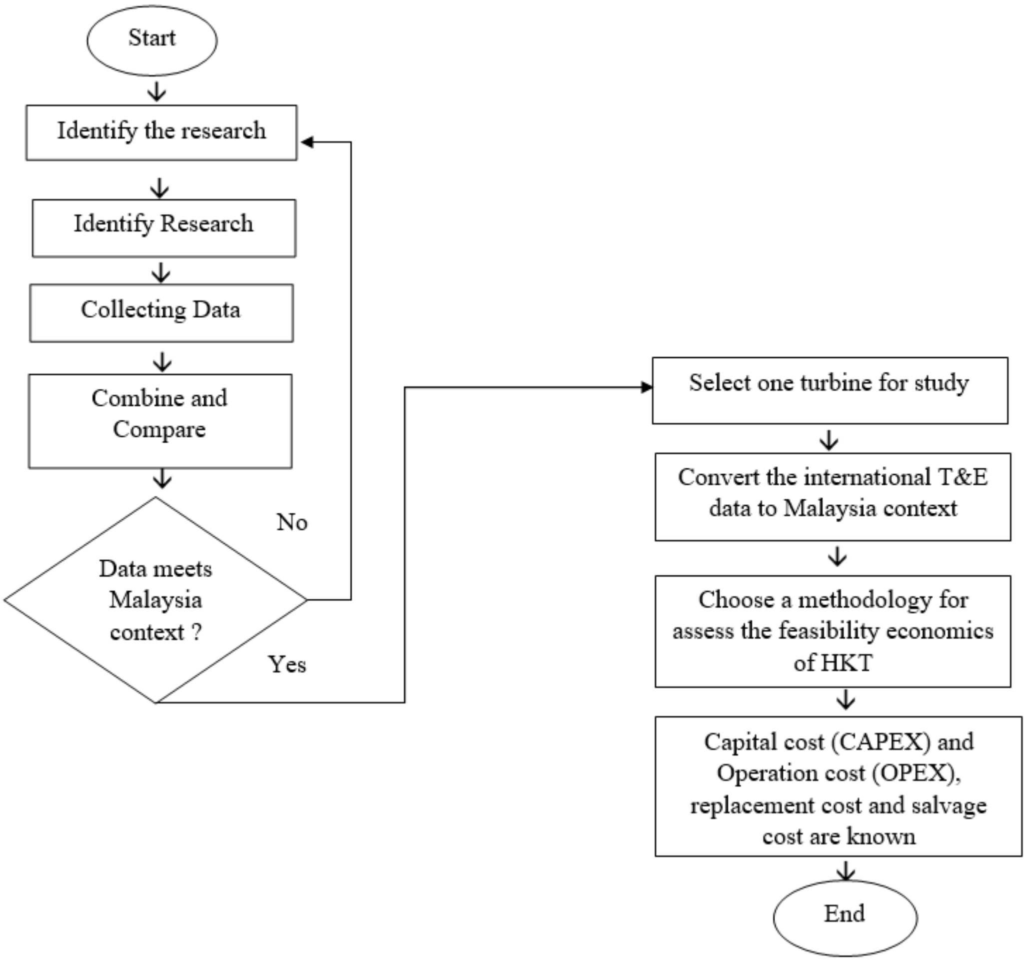
Abbreviation	Design Parameter	Dimension
T_H	Total design height	1.45m
D	Diameter of turbine blade	1m
L_B	Length of blade	0.375m
I_L	Inlet Length	0.25m
D_L	Diffuser length	0.8m
Θ_I	Inlet convergence angle	20°
Θ_D	Diffuser divergence angle	15°
R_{IA}	Radius of inlet wall arc	0.475m
R_{DA}	Radius of diffuser wall arc	1.575m
T_D	Thickness of deflector	0.07m
D_s	Deflector span	0.57m
θ	Angle of deflector	37°
R_1	Radius for front blade surface	0.212m
R_2	Radius for rear blade surface	0.364m
A_R	Aspect ratio (W_B/D)	1.23
A	Frontal swept area	1.23m^2

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

In this research project, the methodology has been presented into two phases, which are desk research and techno-economic assessment (TEA).



3.2 Desk Research

Desk Research or secondary research is a methodology using existing data from summarization and collating, to improve research's overall efficacy. Desk research can be used to find research materials that have already been published in research reports and other comparable documents. Desk research has the advantage of being less expensive and time-consuming because the data needed is readily available and does not require much effort to gather. In this research project, there main parameters, which are: 1) Identify the economic parameters, 2) resource assessment of Malaysia River, and 3) hydrokinetic turbine selection, will be discussed in this section.

3.2.1 Economic Parameters Identification

The Life Cycle Analysis (LCCA) and analysis is used to examine the economics of Hydrokinetic Turbine. The most popular method for determining the total cost of facility ownership is the life cycle cost analysis (LCCA). Three categories of costs are considered in the LCCA: (1) original capital expenses (costs associated with component purchases, construction installations, assembling, and shipping, as well as maintenance and operating costs), (2) replacement costs, and (3) residual values (salvage values). On top of that, The economic evaluation methods encompass a number of indicators, including net present value (NPV) and internal rate of return (IRR).

The economics of hydrokinetic turbine is evaluated by calculating the Net Present Value (NPV). A common technique for calculating the time value of money to evaluate long-term projects is the net present value, or NPV. The Net Present Value (NPV) of hydrokinetic in investment project is computed using the following formula (Tigabu et al., 2019):

$$\mathrm{NPV}=-\frac{A_o}{(1+i)^0}+\frac{A_1}{(1+i)^1}+\ldots+\frac{A_n}{(1+i)^n} \tag{2}$$

where A_0 is net cash flow, n is the service life of the project and i is an interest rate that investment wishes to earn.

Projects are ranked based on their internal rate of return (IRR). A project is classified as economically feasible if its IRR is higher than the rate of inflation. The formula for evaluating the IRR is provided as (Tigabu et al., 2019):

$$0=-\frac{A_o}{(1+i)^0}+\frac{A_1}{(1+i)^1}+...+\frac{A_n}{(1+i)^n} \qquad (3)$$

3.2.2 Resource Assessment of Malaysia River

Hydrokinetic systems transform water's kinetic energy into electricity or other sources of energy. Malaysia Rivers has been used to do desk research to figure out the flow depth of water, current velocities in Malaysia. Table 3.1 features the optimization studies by researchers on Malaysia river. The hydrokinetic current velocities in Malaysia are reported in the range of 0.5-1.4m/s. The flow depth at most investigated locations is in the range of 50-100m.

Table 3.1: Research on hydrokinetic resource in Malaysia

Authors	Work Done	Findings/Gaps
Yakoob et al., 2006	Analyzed the Tides table data to identify region with high velocity currents	Low hydrokinetic current velocity (0.8 m/s) and shallow depths (50-100 m) found around the Malaysian coast
Lee and Seng, 2008	Employed Tidal prediction TPXO software to measure flow velocity in the Malaysian seas	Pangkor Island and Sandakan coast identified as the locations with peak power density
Lim and Koh., 2009	Adopted the Princeton Ocean Model to simulate current flow around Malaysia	Total power of 1847 KWh/m^2 is extractable from Sibu, Kota Belud, and Pulau Jambongan if an HKT with efficiency of 45% can operate in the flow of 1.1 m/s
Sakmani et al., 2013	Explored the locations in Strait of Malacca using the Hamburg Shelf Ocean Model	Pulau Pangkor identified with a velocity of 0.48 m/s. However, shallow depth up to 50 m
Rigit et al., 2013	Investigated Sarawak coastline using the Tides table data	Kuala Igan is the only potential location with enough depth. However, has a low flow velocity of 0.51 m/s

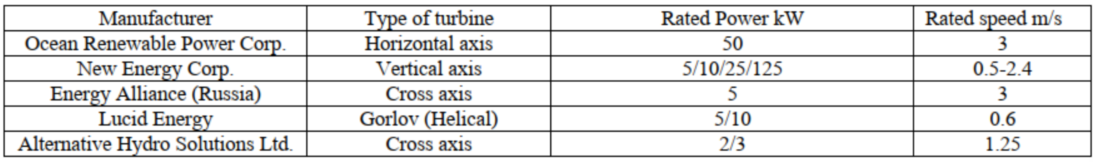
Zainol et al., 2013	Studied the unexplored locations in Strait of Malacca using Tidal Data	Identified Port Klang as the site with highest annual extractable power density of 591.19 KW/ m^2 for an HKT operating with 40% efficiency
Bonar et al., 2013	Estimated the extractable power by rows of HKTs in the Strait of Malacca using Advanced CIRCulation scheme (ADCIRC) for current flow	Low flow velocity and shallow depths are a critical barrier to large HKT deployment in Malaysia. Small-scale HKTs can be deployed at Port Dickson
Aroog et al., 2013	Evaluated flow velocity at the Terengganu coast using floating buoys	Extremely low average current velocity of 0.138 m/s measured for depths around 20 m

3.2.3 Hydrokinetic Turbine Selection

In terms of design, functionality, and operating principles, hydro-kinetic turbines are comparable to wind turbine technology. They are therefore simple to install without the need for river diversion or reservoir construction. There are multiple efforts being made by various developers to create portable Hydrokinetic turbines, to expand the applications and uses. These turbines come in a variety of types, and the most well-known manufacturers are given in Table 3.2.

In this research project, conventional HKT and enhanced design HKT are considered in Malaysia context. Drag-based turbines like conventional HKT, although a potential choice, have demonstrated comparatively low power harnessing efficiency than axial-flow turbines. Thus, conventional and enhanced design HKT are used to estimate the economics feasibility in Malaysian waters.

Table 3.2: Manufactures of Hydro-kinetic turbines



Manufacturer	Type of turbine	Rated Power kW	Rated speed m/s
Ocean Renewable Power Corp.	Horizontal axis	50	3
New Energy Corp.	Vertical axis	5/10/25/125	0.5-2.4
Energy Alliance (Russia)	Cross axis	5	3
Lucid Energy	Gorlov (Helical)	5/10	0.6
Alternative Hydro Solutions Ltd.	Cross axis	2/3	1.25

3.3 Techno-economic Assessment (TEA) of Hydrokinetic Turbine

For this study project, the following parameters will be used to conduct the TEA of the conventional and enhanced design HKT, i.e., capital cost of HKT, Replacement Cost, O&M, Real interest rate, Cost Recovery Factor, Net Present Value (NPV), IRR annual cost, annual benefit, and cash flow diagram. The important economic factors that we took into consideration are listed in Table 3.3.

Table 3.3: Economic Parameters

Metric	**Value**	**Reference**
Nominal interest rate in %	2.5	Malayan Banking Berhad
Annual Inflation in %	3.4	Malayan Banking Berhad
Replacement in year	8	
Project life in year	25	

3.3.1 Initial Capital Cost

The initial capital cost is defined as the balance of station cost and the sum of turbine system cost, which includes a generator, turbine, foundation, installation, power electronic devices and shipping cost. Financing fees are determined and added separately through the fixed charge rate. Thus, the costs are not included in these prices. A debt service reserves fund, which is expected to be zero for balance sheet financing, is also not included in the costs.

3.3.2 Replacement Cost

The cost to replace an existing asset with an equivalent asset at the present market is known as replacement cost. It involves the procedure for repairing key turbine parts, like blades and generators. The annual replacement cost is calculated and evaluated using the replacement cost, which is not intended to include inflation into account. The replacement cost for conventional and enhanced design HKT were assumed to be equal to the investment cost for this research project.

3.3.3 Operation and Maintenance Cost (O&M Cost)

The cost of maintaining and operating a HKT component is known as its operations and maintenance cost (O&M). The total O&M cost of the system is the sum of the O&M costs of each system component. Because of the changing complexity, different designs may have different O&M costs. To extract a useful O&M cost history, many new specifications, however, lack sufficient operating experience. In order to estimate the operation and maintenance costs for this study, the operation year was divided into 5 groups, and the resulting cost structure is shown in Table 3.4.

Table 3.4: O&M Cost Pattern

Year	O&M Cost
1-5	1.5% of capital cost
6-10	1.5% of capital cost + 1.5% of previous O&M cost
11-15	1.5% of capital cost + 3% of previous O&M cost
16-20	1.5% of capital cost + 4.5% of previous O&M cost
21-25	1.5% of capital cost + 6% of previous O&M cost

3.4 Cost Correlation Methodology

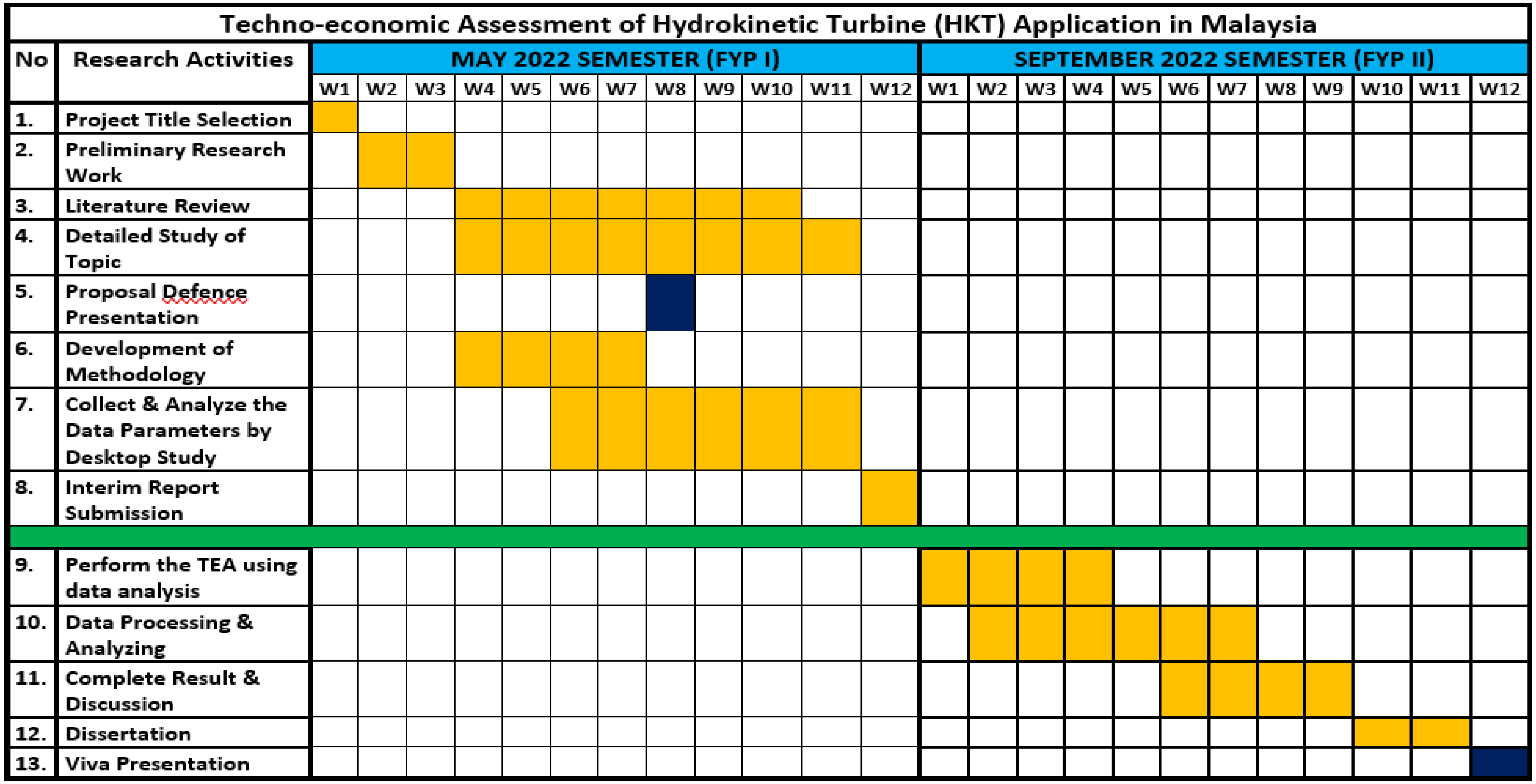
After collecting and analyzing data, curves have generated by plotting cost on Y-axis and dependable variable on X-axis. Regression analysis is a statistical technique that lessens the potential for change in evaluating a variable that depends on other independent variables (Kumar & Saini, 2017). If a general equation is required for a specific area, it can be the best choice for predicting extreme events. The trend line was fitted between the points after the data was plotted on the chart.

The power regression has been used to formulate the co-relation by comparing the cost data of different turbine component parts to their dependable parameter. The equations for each component of the strategy were determined once the power trend line in the chart was fitted. The following is the definition and selection of the mathematical model for cost items of identified parameters of hydrokinetic turbines:

$$C_{(a,b,c)} = a \times (P)^{b} \times (V)^{c} \qquad (4)$$

where a, b and c are coefficients, P is installed capacity in kilo Watt (kW), V is velocity of upstream flow (m/s), V is velocity of upstream flow (m/s), and C is cost in dollar (USD) (Kumar & Saini, 2017).

3.5 Gantt Chart



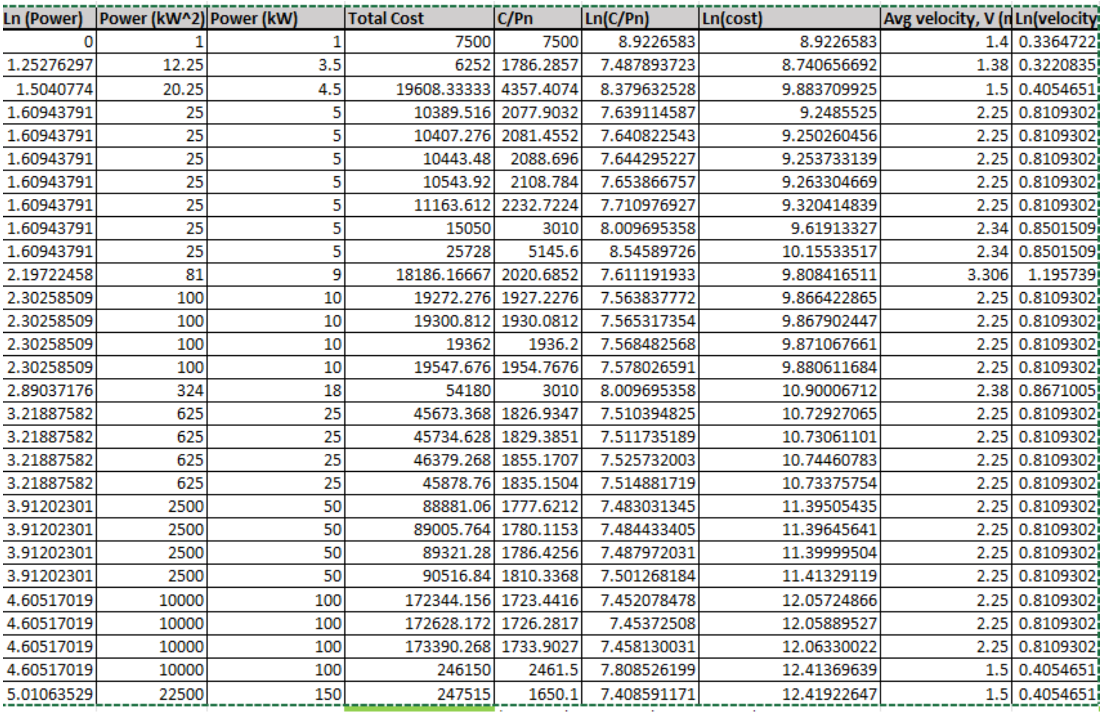
Techno-economic Assessment of Hydrokinetic Turbine (HKT) Application in Malaysia																									
No	Research Activities	MAY 2022 SEMESTER (FYP I)												SEPTEMBER 2022 SEMESTER (FYP II)											
		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
1.	Project Title Selection	🟨																							
2.	Preliminary Research Work		🟨	🟨																					
3.	Literature Review				🟨	🟨	🟨	🟨	🟨	🟨	🟨														
4.	Detailed Study of Topic				🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨													
5.	Proposal Defence Presentation								🟦																
6.	Development of Methodology				🟨	🟨	🟨	🟨																	
7.	Collect & Analyze the Data Parameters by Desktop Study						🟨	🟨	🟨	🟨	🟨	🟨													
8.	Interim Report Submission												🟨												
🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
9.	Perform the TEA using data analysis													🟨	🟨	🟨	🟨								
10.	Data Processing & Analyzing														🟨	🟨	🟨	🟨	🟨	🟨					
11.	Complete Result & Discussion																		🟨	🟨	🟨	🟨			
12.	Dissertation																						🟨	🟨	
13.	Viva Presentation																								🟦

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Analysis of Desk Research

The results of desk research are then listed out in an excel form. The analysis of desk research has been determined based on the articles published in recent years, governing the power of the turbine and the cost of the turbine such as manufacturing cost, research and development cost, assembly cost, material cost and generator cost. The velocity of flow and installed capacity were depended on the sizes of hydrokinetic turbines.



Ln (Power)	Power (kW^2)	Power (kW)	Total Cost	C/Pn	Ln(C/Pn)	Ln(cost)	Avg velocity, V (n	Ln(velocity
0	1	1	7500	7500	8.9226583	8.9226583	1.4	0.3364722
1.25276297	12.25	3.5	6252	1786.2857	7.487893723	8.740656692	1.38	0.3220835
1.5040774	20.25	4.5	19608.33333	4357.4074	8.379632528	9.883709925	1.5	0.4054651
1.60943791	25	5	10389.516	2077.9032	7.639114587	9.2485525	2.25	0.8109302
1.60943791	25	5	10407.276	2081.4552	7.640822543	9.250260456	2.25	0.8109302
1.60943791	25	5	10443.48	2088.696	7.644295227	9.253733139	2.25	0.8109302
1.60943791	25	5	10543.92	2108.784	7.653866757	9.263304669	2.25	0.8109302
1.60943791	25	5	11163.612	2232.7224	7.710976927	9.320414839	2.25	0.8109302
1.60943791	25	5	15050	3010	8.009695358	9.61913327	2.34	0.8501509
1.60943791	25	5	25728	5145.6	8.54589726	10.15533517	2.34	0.8501509
2.19722458	81	9	18186.16667	2020.6852	7.611191933	9.808416511	3.306	1.195739
2.30258509	100	10	19272.276	1927.2276	7.563837772	9.866422865	2.25	0.8109302
2.30258509	100	10	19300.812	1930.0812	7.565317354	9.867902447	2.25	0.8109302
2.30258509	100	10	19362	1936.2	7.568482568	9.871067661	2.25	0.8109302
2.30258509	100	10	19547.676	1954.7676	7.578026591	9.880611684	2.25	0.8109302
2.89037176	324	18	54180	3010	8.009695358	10.90006712	2.38	0.8671005
3.21887582	625	25	45673.368	1826.9347	7.510394825	10.72927065	2.25	0.8109302
3.21887582	625	25	45734.628	1829.3851	7.511735189	10.73061101	2.25	0.8109302
3.21887582	625	25	46379.268	1855.1707	7.525732003	10.74460783	2.25	0.8109302
3.21887582	625	25	45878.76	1835.1504	7.514881719	10.73375754	2.25	0.8109302
3.91202301	2500	50	88881.06	1777.6212	7.483031345	11.39505435	2.25	0.8109302
3.91202301	2500	50	89005.764	1780.1153	7.484433405	11.39645641	2.25	0.8109302
3.91202301	2500	50	89321.28	1786.4256	7.487972031	11.39999504	2.25	0.8109302
3.91202301	2500	50	90516.84	1810.3368	7.501268184	11.41329119	2.25	0.8109302
4.60517019	10000	100	172344.156	1723.4416	7.452078478	12.05724866	2.25	0.8109302
4.60517019	10000	100	172628.172	1726.2817	7.45372508	12.05889527	2.25	0.8109302
4.60517019	10000	100	173390.268	1733.9027	7.458130031	12.06330022	2.25	0.8109302
4.60517019	10000	100	246150	2461.5	7.808526199	12.41369639	1.5	0.4054651
5.01063529	22500	150	247515	1650.1	7.408591171	12.41922647	1.5	0.4054651

Figure 4.1: Different authors with power capacity and cost of the turbines

Upon obtaining the data, regression analysis is used to perform the analysis, by plotting independent variable which is cost on Y-axis, and dependable variable, power capacity on X-axis respectively.

By comparing the cost of the data of various components of turbine corresponding to their dependable parameter, total cost of the turbines has been analyzed through the regression model and a best curve fit has been obtained in figure 4.1. Cost equation of the turbine can be given as:

$$C\ (ln(\$)) = -1.8489P2 + 199.1P + 1981.5 \qquad (5)$$

Where P, is the rated capacity of the turbine. The estimation of the cost of the turbine is then used to perform in conventional HKT and enhanced design HKT

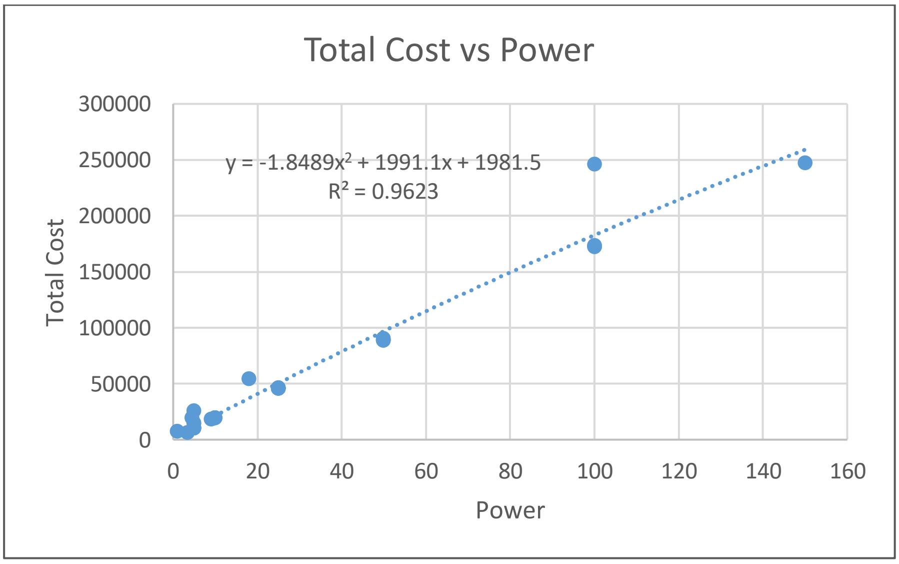


Figure 4.2: Relation between total cost and power

4.2 Costing of the turbine

The cost correlation of the turbine has been developed by linear regression by carrying various combinations of power and velocity. The regression analysis is then developed different coefficients values for turbine and given as:

$a = 12056; b = 0.8334; c = -0.6482.$

Formulation of the cost equation is given in figure 4.3 and figure 4.4. The linear regression line has been drawn out in MS-Excel software, which given:

$$C\ (turbine) = 12056\ x\ P^{0.8334}\ x\ V^{-0.6482} \tag{6}$$

Figure 4.3 shows the relationship between the cost of turbine per kW and power capacity and upon getting, the coefficient is given as (c= -0.6482). Figure 4.4 features the relationship between C/P^n and velocity, and coefficient b is found which is (b= 0.8334). Upon getting coefficient a, it governs the average of 4 turbines, and by complying with the context of article of “Techno-Economic Analysis of Hydrokinetic Turbines”. Generated correlation has been used to carry out the techno-economic analysis of conventional HKT and enhanced design HKT.

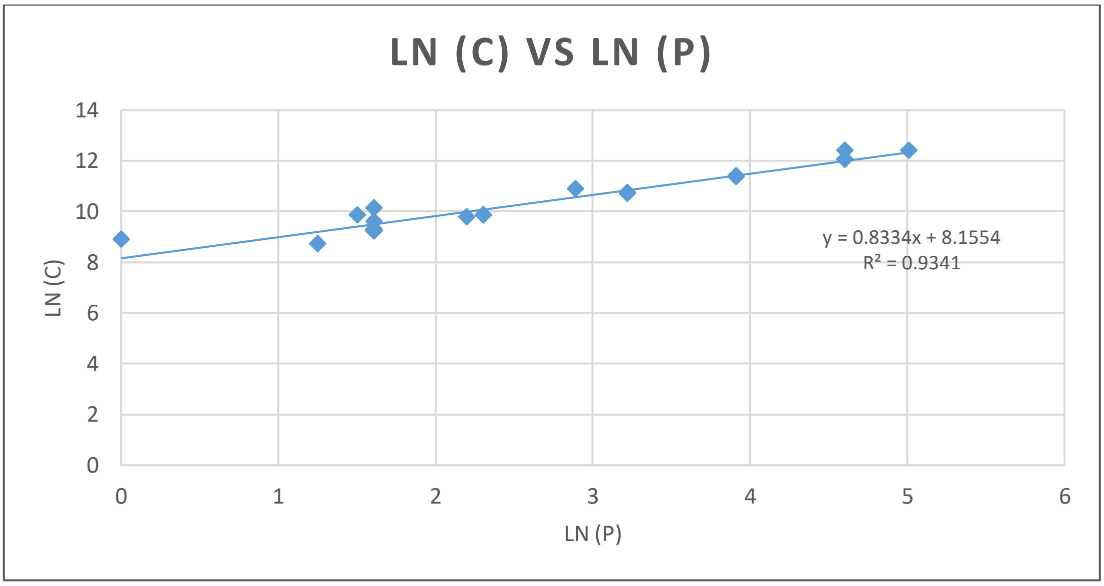


Figure 4.3: Relation between cost and power capacity of the turbine

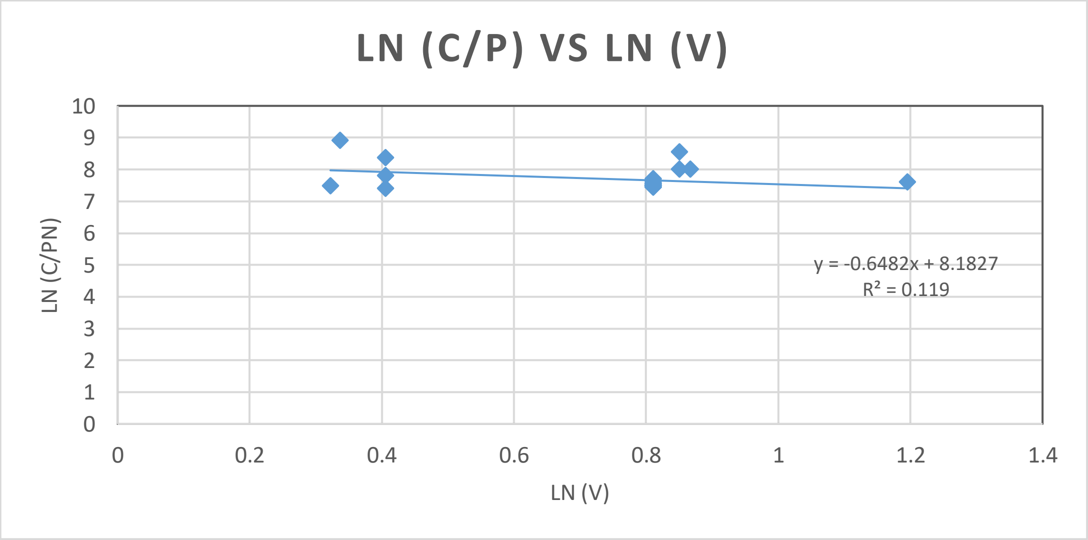


Figure 4.4: Relation between C/P and V of turbine

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4.3 Analysis of Conventional HKT and Enhanced Design HKT

Technical and economics of turbine have been analyzed and the result is presenting in this section. Based on the study scope, 1m, 2.5m and 5m diameter were chosen to be fix variable in the analysis. Table 4.1 shows the design parameter for technical analysis. The parameters are then applied to the technical and economics of turbines in order to find the power capacity and cost of the turbines of the conventional and enhanced design hydrokinetic turbine.

Table 4.1: Technical Design Parameters

Design Parameter	Dimension
density of water, ρ	1000kg/m^3
power coefficient, Cp (conventional HKT)	0.268
power coefficient, Cp (enhanced design HKT)	0.436
flow rate of water turbine, Q	2.07m^3/s
upstream flow velocity, V	0.72m/s
Turbine length, h	2m

Table 4.2: Result Output with Different Cases

	Diameter (m)	Swept Area (m^2)	Velocity (m/s)
CASE 1	1	0.7853982	2.635605858
CASE 2	2.5	4.9087385	0.421696937
CASE 3	5	19.634954	0.105424234

Velocity and Swept Area are one of the technical aspects that comes across comparison between enhanced design and conventional hydrokinetic turbine in different cases. Enhanced design HKT has a higher flow velocity flow through the turbine compared to conventional HKT as shown in figure 4.5 and 4.6.

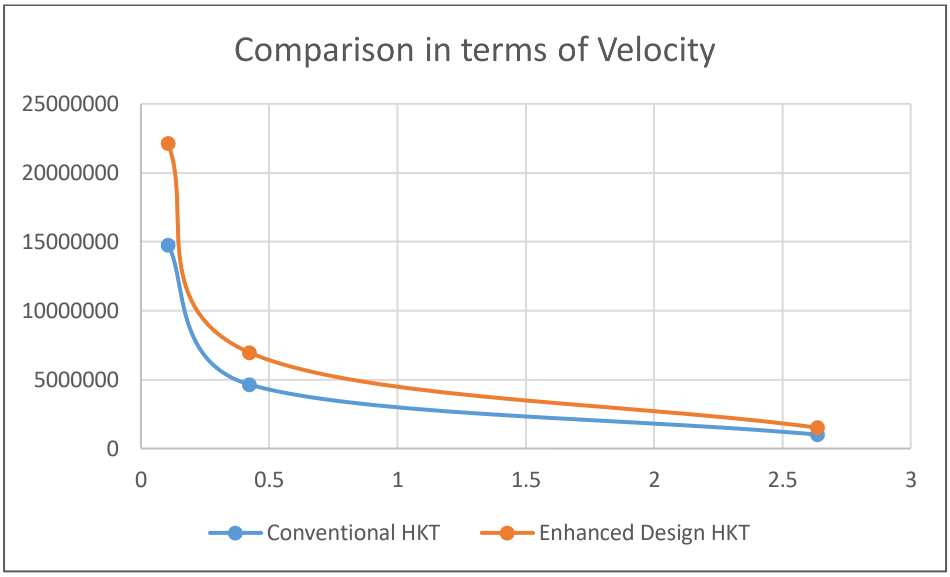

Figure 4.5: Relationship in terms of Velocity for Both Turbines

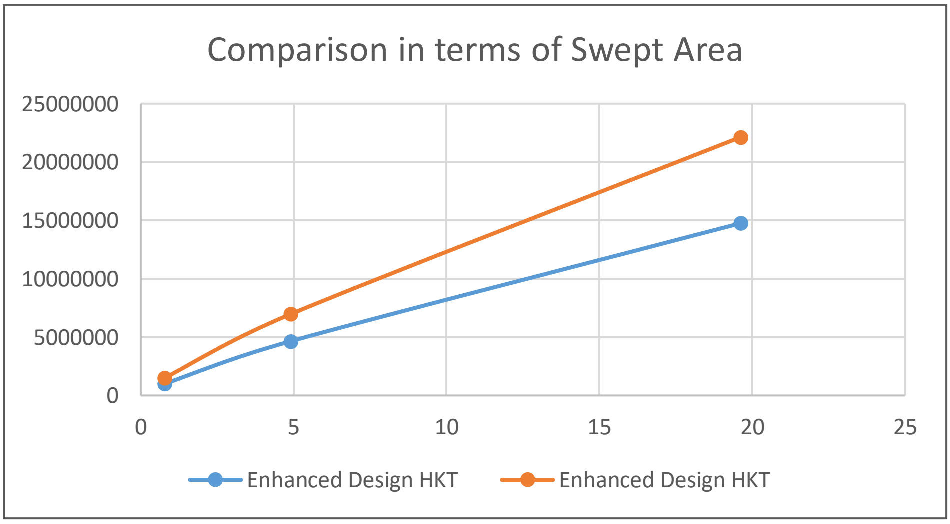

Figure 4.6: Relationship in terms of Swept Area for Both Turbines

4.3.1 Technical Aspects

Power capacity and flow velocity, which would decide the size of the turbines. A power equation of hydrokinetic turbine given as follow:

$$P = 0.5\rho A V^3 C_p \tag{7}$$

where ρ is the density of water (kg/m^3), V is the flow velocity of water (m^3/s), swept area of turbine (m^2), C_p is the power coefficient of the turbine. By computing the equation, the power capacity of conventional and enhanced design HKT are calculated.

Table 4.4: Power Capacity of Both Turbines in Different Cases

		Conventional HKT	Enhanced Design HKT
CASE 1	Power(kW)	39.28	63.90
CASE 2	Power(kW)	245.51	399.41
CASE 3	Power(kW)	982.04	1597.65

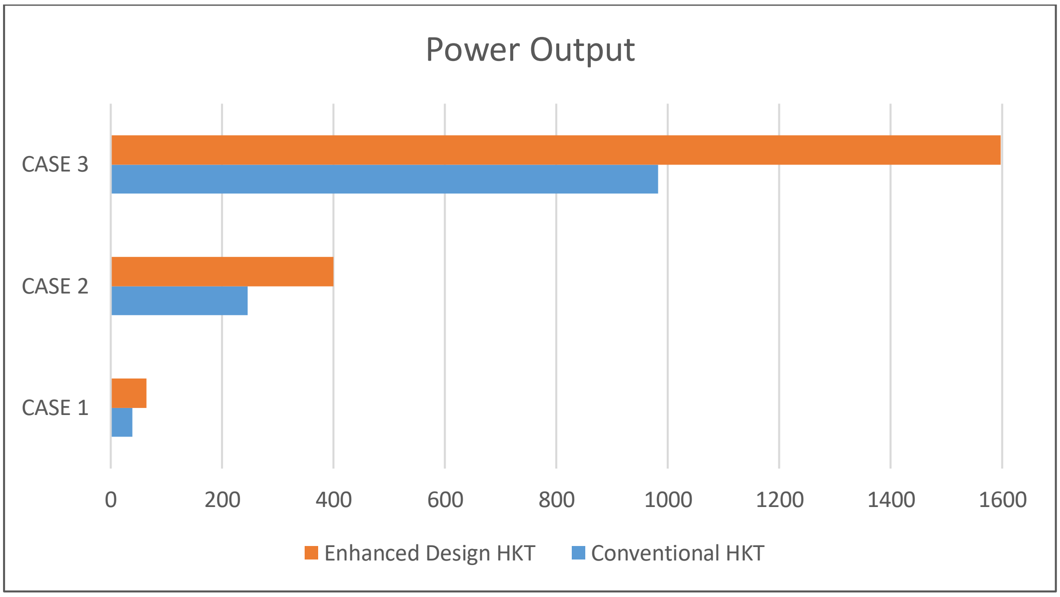

Figure 4.7: Comparison of Power Output in Different Cases

A comparison between conventional and enhanced design HKT in terms of power output has been performed in figure 4.7. A bigger swept area has a higher power capacity. Upon comparing in terms of conventional and enhanced design HKT, the power capacity of turbine is the main parameter which affects the cost and the power capacity. In this research project, enhanced design HKT in case 3 (5m diameter) has the highest power output as the power coefficient of enhanced design HKT has a bigger value which is 0.436.

4.3.2 Economics Analysis

Cost correlation has been carried out for conventional and enhanced design HKT turbines using the equation with 3 coefficients, *a*, *b*, and *c*. In these three cases, the cost of the turbine in the third case has the biggest cost, with a lower velocity and bigger swept area.

$$C_{(a,b,c)} = a \times (P)^{b} \times (V)^{c}$$

where a, b and c are coefficients, *P* is installed capacity in kilo Watt (kW), *V* is velocity of upstream flow (m/s), *V* is velocity of upstream flow (m/s), and *C* is cost in dollar (USD)

Table 4.3: Cost of Both Turbines in Different Cases

		Conventional HKT	Enhanced Design HKT
CASE 1	Cost ($)	1009338.561	1514179.522
CASE 2	Cost ($)	4648611.711	6973708.257
CASE 3	Cost ($)	14759786.27	22142189.92

4.4 Conventional Turbine Techno-Economic Analysis

In the present work, cost correlation of different sizes of turbine are determined and the cost correlation has been developed. The cost of the turbine depends very much on the installation of the turbine, such as diameter, velocity and swept area. Variation of analysis have been done in conventional turbine to show how diameter, swept area, and velocity affects the total cost of the turbine. As it is seen in figure 4.8, total cost and power output of conventional turbine increases linearly when the turbine diameter increases in every case. It is same when comes to the swept area of the turbine. When the area of the turbine increases, the higher the cost of the conventional turbine. The higher power capacity has a higher cost than lower capacity at the same velocity range of water. In this research analysis, the velocity of water acts as a fixed variable, which is 0.72m/s throughout the analysis.

Based on figure 4.9, power output and total cost of the turbine decreases when the velocity increases. The cost of the turbine is 52215$ per kW when it happens in the third case. It shows how much the swept area can affect the cost of the turbine.

	Conventional HKT:		
Diameter (m)	Power output (kW)	Total cost (x10^5)	
1	39.28187135	10.09	
2.5	245.511696	46.486	
5	982.0467839	147.5978	
Velocity (m/s)	Power output (kW)	Total cost (x10^5)	
2.6356059	39.28187135	10.09	
0.4216969	245.511696	46.486	
0.1054242	982.0467839	147.5978	
Swept Area (m^2)	Power output (kW)	Total cost (x10^5)	USD/kW
0.7853982	39.28187135	4.36	11099.26755
4.9087385	245.511696	65.73	26772.65527
19.634954	982.0467839	512.782	52215.63865

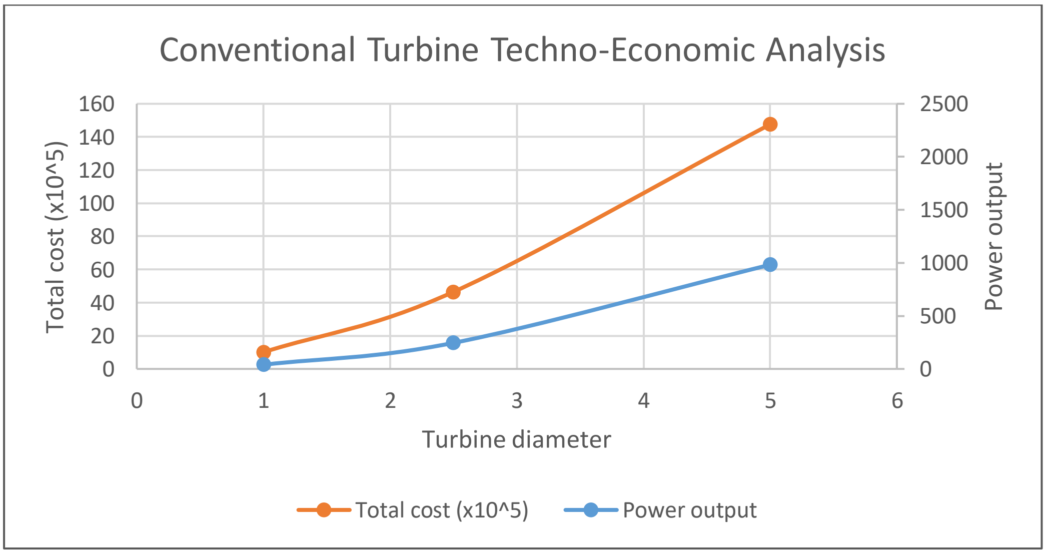

Figure 4.8: Diameter of Conventional Turbine Techno-Economic Analysis

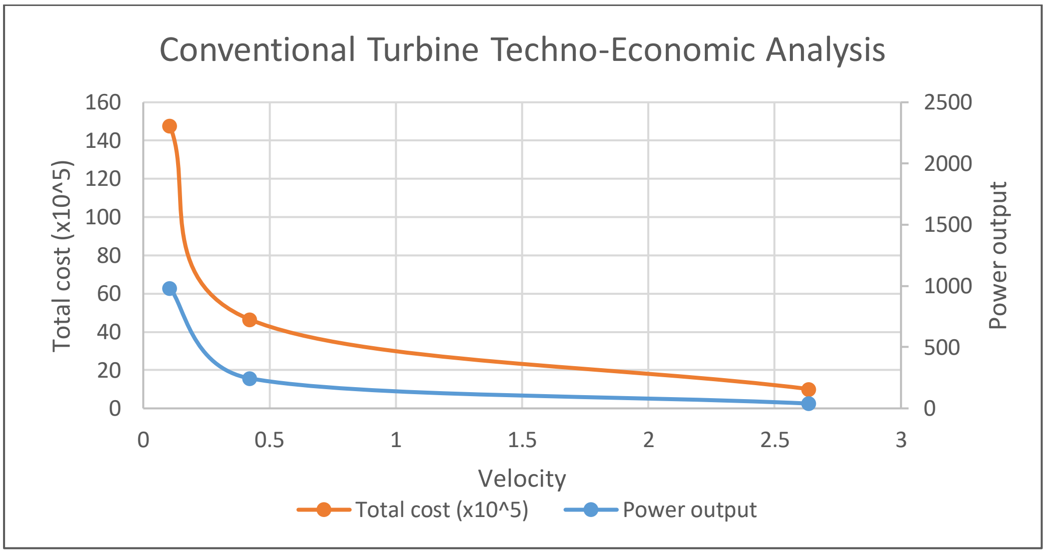

Figure 4.9: Velocity of Conventional Turbine Techno-Economic Analysis

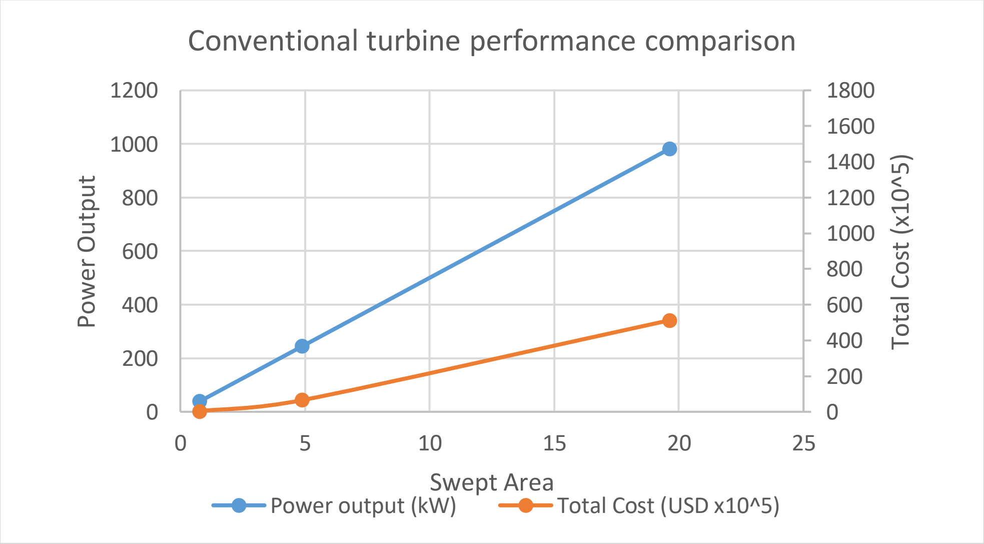

Figure 4.10: Swept Area of Conventional Turbine Techno-Economic Analysis

4.5 Enhanced Design Turbine Techno-Economic Analysis

	Enhanced HKT:		
Diameter (m)	Power Output (kW)	Total Cost (x10^5)	
1	63.90632802	15.14179	
2.5	399.4145502	69.73708	
5	1597.658201	221.42189	
Velocity (m/s)	Power Output (kW)	Total Cost (x10^5)	
2.6356059	63.90632802	15.14179	
0.4216969	399.4145502	69.73708	
0.1054242	1597.658201	221.42189	
Swept area (m^2)	Power output (kW)	Total Cost (USD x10^5)	USD/kW
0.7853982	63.91	6.53	10217.43095
4.9087385	399.41	98.64	24696.62048
19.634954	1,597.66	769.26	48149.26031

A similar analysis has been conducted for enhance design HKT. Enhanced design turbine, which is called ducted turbine has harnessed power efficiency in recent studies. One important factor which is thought to have contributed to speeding up commercialization of ducted turbine is the power coefficient of the turbine. As compared to conventional turbine, power coefficient of the enhanced design turbine is 0.436, higher than the conventional.

Figure 4.12 features the variation of the cost of the turbine with the increase in velocity of water. The cost and power output of enhanced design HKT is higher than the conventional, as this is because the ducted has the highest power coefficient. It is observed that at low-capacity enhanced design turbine cost is lower and when the velocity of water increases, the cost of the enhanced design HKT decreases. An important thing has been observed that the higher capacity turbine has no power generation at low speed and has average flow velocity range between 0.5-1.5m/s.

The study shows that the average cost of enhanced design HKT is lower which is USD 48149/kW compared to the USD52215/kW of the conventional HKT.

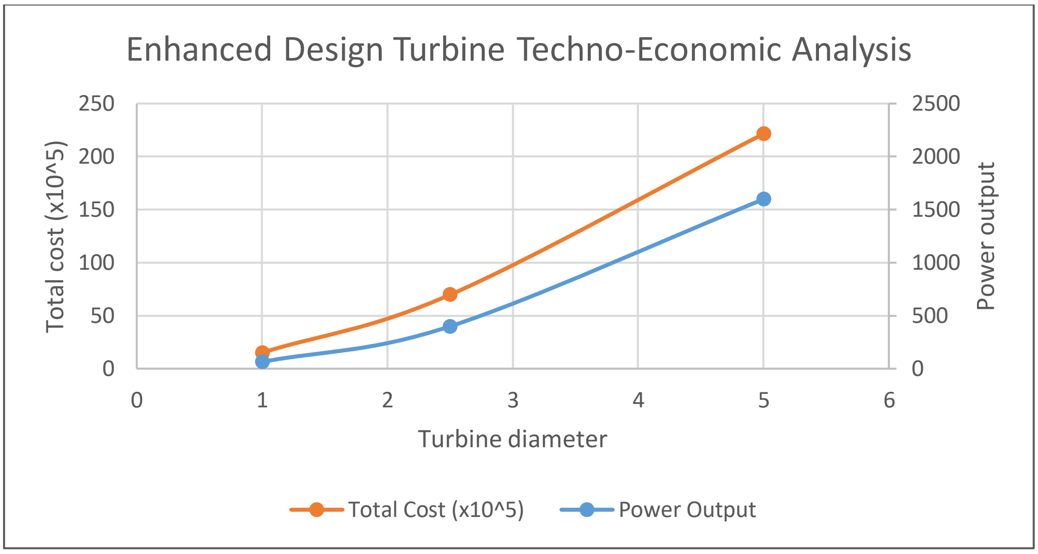

Figure 4.11: Diameter of Enhanced Design HKT Techno-Economic Analysis

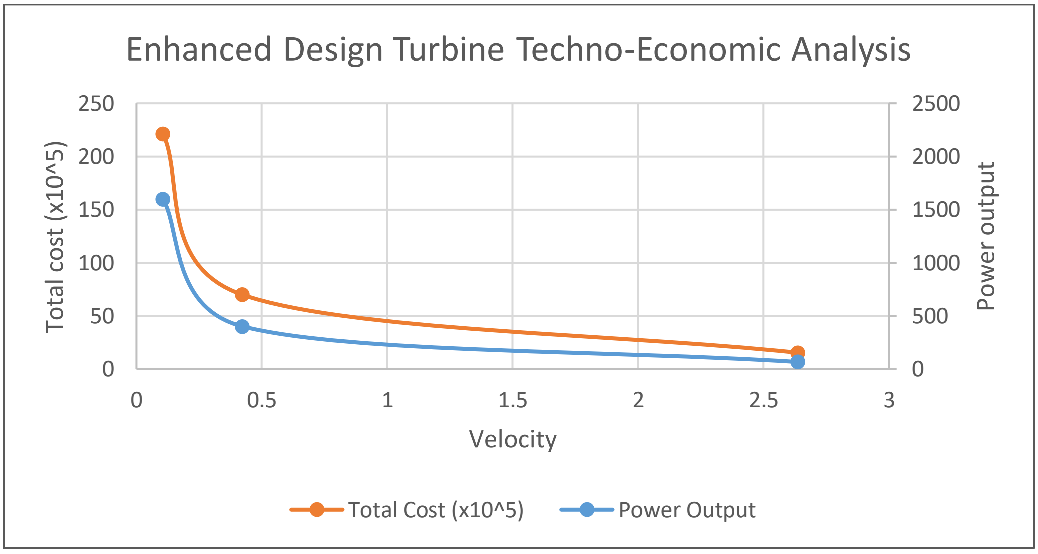

Figure 4.12: Velocity of Enhanced Design HKT Techno-Economic Analysis

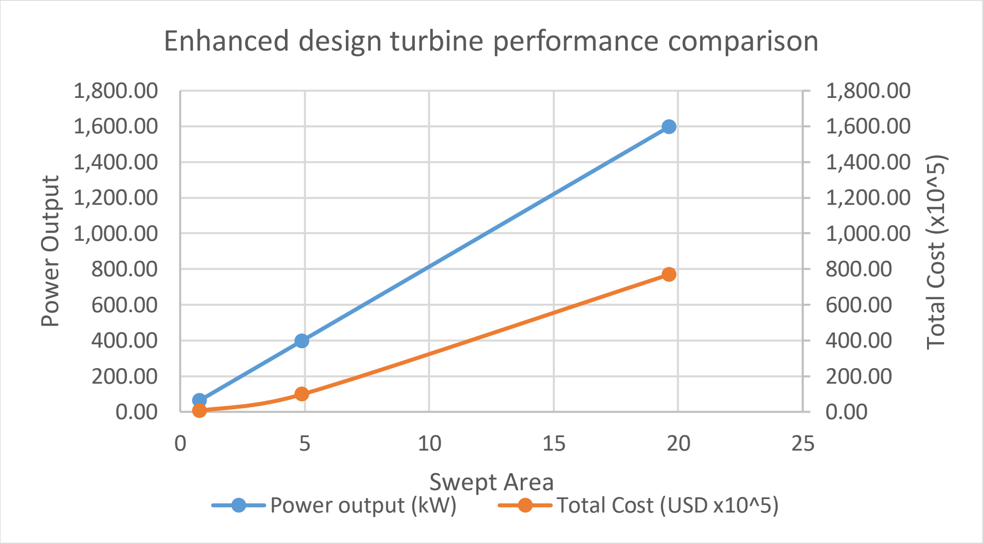

Figure 4.13: Swept Area of Enhanced Design HKT Techno-Economic Analysis

4.6 Comparison Between Conventional and Enhanced Design HKT

Based on the analysis of data obtained, t-test will be carried out to perform the comparison of the means of two groups which are conventional and enhanced design HKT. It is basically used in hypothesis testing to determine whether it has an effect on the population of interest after the analysis.

Using the same parameters, the turbine diameter ranged from 0.25 to 4.95m is performed in the t-test. Using the formula given below, the pair t test result can determine.

$$t = \frac{(x1-x2)}{\sqrt{\frac{(s1)^2}{n1}+\frac{(s2)^2}{n2}}} \qquad (8)$$

From the analysis of t-test, the value for pair t test is 0.13, which is significant to the data. It is sufficient evidence to conclude that there is a significant difference of conventional and enhanced design HKT measurement. The mean average data of conventional HKT is significantly higher compared to enhanced design HKT.

Table 4.5: T-test: Paired two Sample for Means

	Variable 1	*Variable 2*
Mean	1815314.74	1579323.824
Variance	1.93805E+12	1.46691E+12
Observations	48	48
Pearson Correlation	1	
Hypothesized Mean Difference	0	
df	47	
t Stat	9.034213549	
P(T<=t) one-tail	3.82057E-12	
t Critical one-tail	1.677926722	
P(T<=t) two-tail	7.64115E-12	
t Critical two-tail	2.011740514	

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

The study aimed at performing technical and economics feasibility of hydrokinetic turbine. Due to its higher performance as described in the literature based on Malaysian hydrokinetic conditions, the base model for this study was chosen to be the combination of the conventional and enhanced design HKT. The flow depth at most investigated locations is in the range of 50-100 m, where the current velocity in this analysis used is 0.7 m/s. From the technical analysis, it is clearly featured that power efficiency of enhanced design HKT obtained is much higher than conventional HKT. The importance of economics of hydrokinetic turbine is highly depended on the velocity flow in the turbine and power coefficient. On top of that, correlation methodology was performed and obtained. The cost equation of the turbine was obtained by data analytics. Based on the economic performance, the study illustrated that the average cost of enhanced design HKT is lower which is USD 48149/kW compared to the USD52215/kW of the conventional HKT. The comparisons of two turbines in terms of velocity and swept area were undergone. With the case of velocity flow of 0.72m/s, the total cost of the turbine increases when the diameter increases. The analysis of the power output and total cost of the turbines decreases when the velocity increases in the cases. The power efficiency of enhanced design hydrokinetic turbine is more harnessed and better compared to conventional turbines.

5.2 Recommendation and Future Works

Based on the study, current work has found out that some improvements for analysis. The following are further works that can be carried out to obtain a better result for enhanced design hydrokinetic turbine such as it is recommended to carry out further studies for an optimal sizing of the enhanced design hydrokinetic turbine for a higher capacity and lower cost.

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