Faculty of Engineering

LOW SPEED GENERATOR DESIGN FOR SMALL SCALE HYDROKINETIC TURBINE APPLICATION

JORDAN ISAAC ALISTAIR DING WAN

Bachelor of Engineering

Electrical and Electronics Engineering with Honours

2023

UNIVERSITI MALAYSIA SARAWAK

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LOW SPEED GENERATOR DESIGN FOR SMALL SCALE HYDROKINETIC TURBINE APPLICATION

JORDAN ISAAC ALISTAIR DING WAN

A dissertation submitted in partial fulfilment
of the requirement for the degree of
Bachelor of Engineering
Electrical and Electronics Engineering with Honours

Faculty of Engineering

Universiti Malaysia Sarawak

2023

ACKNOWLEDGEMENT

Upon completion of my Final Year Project 1 and Final Year Project 2, I am filled with a sense of accomplishment and gratitude as everything went smoothly.

First and foremost, I would like to thank God, the Almighty, for His guidance, strength, and protection throughout the journey of completing this project. Without His help and blessings, this project would not have been possible.

I am grateful to my supervisor which is Dr Noor Syazwani and Dr Martin Anyi and also the course coordinator, Ir Dr Abadi bin Chanik @ Azhar for their invaluable suggestions, endless support, dedication and patience in guiding me throughout this final year project (FYP).

I would also like to thank the University of Malaysia Sarawak for providing the resources, facilities and environment needed for me to complete my project.

I would express a special thanks to staff engineer of Elite Industry Sdn Bhd, Mr. Maverick who is willing to assists me with the material processing for my project.

I owe a deep debt of gratitude to my family and friends for their unwavering support and encouragement throughout the project. Their kind words, understanding and belief in me kept me going and motivated me to go the extra mile in completing this project.

ABSTRACT

This project aims to develop a low-speed permanent magnet generator intended for hydrokinetic applications, with a focus able to generate electrical output at a low speed of 300 revolutions per minute (RPM). The implementation of a large number of poles is used to optimize the performance of the generator. The expected impact of this research is that it could become one of the viable solutions to solve the problem of rural communities that experience limited access to electricity. Additionally, the outcomes of this research could contribute to the development of efficient and reliable low-speed generator technologies for hydrokinetic applications. The findings provide valuable insights into the design considerations and performance characteristics of such generators, which it could serve as a foundation for further advancements in the field of hydrokinetic turbine and encourage the exploration of low-speed generator technologies to harness renewable energy from hydrokinetic sources. Overall, this research aims to contribute to the development of more effective and sustainable energy solutions that can benefit rural communities by reducing the reliance on fossil fuels-based machines. The results of this project have the potential to be applied in a variety of settings, including residential and commercial, making it a valuable contribution to the field of renewable energy.

ABSTRAK

Matlamat projek ini adalah bertujuan untuk menghasilkan sebuah generator magnet kekal berkelajuan rendah yang direka khusus untuk aplikasi hidrokinetik, dengan tumpuan untuk menjana output elektrik pada kelajuan rendah 300 putaran per minit (RPM). Pelaksanaan bilangan kutub yang banyak diaplikasikan untuk mengoptimumkan prestasi generator ini. Impak yang dijangka daripada penyelidikan ini adalah ia boleh menjadi salah satu solusi untuk menyelesaikan masalah komuniti luar bandar yang menghadapi masalah bekalan elektrik yang terhad. Selain itu, hasil penyelidikan ini boleh menyumbang kepada perkembangan teknologi generator berkelajuan rendah yang cekap dan boleh dipercayai untuk aplikasi hidrokinetik. Penemuan ini memberikan idea yang bernas mengenai pertimbangan reka bentuk dan ciri prestasi generator, serta secara tidak langsung boleh menjadi asas untuk kemajuan pesat dalam bidang hidrokinetik dan mendorong penyelidikan teknologi generator berkelajuan rendah untuk mengeksploitasi tenaga boleh diperbaharui daripada sumber hidrokinetik. Keseluruhannya, penyelidikan ini bertujuan untuk menyumbang kepada pembangunan penyelesaian tenaga yang lebih efektif dan mampan yang boleh memberi manfaat kepada komuniti luar bandar dengan mengurangkan kebergantungan kepada jentera berasaskan bahan api fosil. Hasil daripada projek ini mempunyai potensi untuk diterapkan dalam pelbagai senario, termasuklah di kawasan kediaman dan komersial, menjadikannya sumbangan berharga kepada bidang tenaga boleh diperbaharui.

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LIST OF ABBREVIATIONS

AC	Alternating Current
DC	Direct Current
HKT	Hydrokinetic Turbine
LED	Light Emitting Diode
PMG	Permanent Magnet Generator
PMSG	Permanent Magnet Synchronous Generators
PMBLDCG	Permanent Magnet Brushless DC Generators
PMAG	Permanent Magnet Asynchronous Generators
RPM	Revolutions Per Minute

CHAPTER 1

INTRODUCTION

1.1 Background of Hydrokinetic Energy

Hydrokinetic energy is a form of renewable energy that harnesses the power of moving water to generate electricity which is similar to micro-hydropower system or hydropower system. However, in the context of micro-hydropower systems, a vital requirement is the uninterrupted flow of water obtained from a water intake located at a significantly higher elevation than the turbine. In situations where such a natural flow is not readily available in existing streams, the construction of a reservoir becomes necessary. However, the creation of a reservoir brings about a series of implications. Firstly, it significantly adds to the overall cost of the project. Moreover, the introduction of a reservoir fundamentally alters the dynamics and flow patterns of water, resulting in substantial changes to the distribution of nutrients and the overall ecosystem within river networks. The impacts of these modifications can extend far beyond the immediate vicinity of the reservoir, affecting the delicate balance of various interconnected ecological systems. Due to those reasons, the other alternatives is being search even though it is an undeniable facts that the conventional micro-hydropower system has been considered the most ideal option for powering off-grid communities in Sarawak as the topography is suitable [1], where Sarawak receives approximately 3850 mm of yearly rainfall, which is five times the global average[2].Because of the hot and humid tropical climate, a large network of rivers has formed and flows continuously throughout the year as depicted in Figure 1.1.1. Hence, the dependency of majority of Sarawak's off-grid rural residents on river as the mean of transportations and obtaining daily needs such as food and water, have made them to choose the upper courses of river and tributaries for their living area which can be seen in Figure 1.1.2.

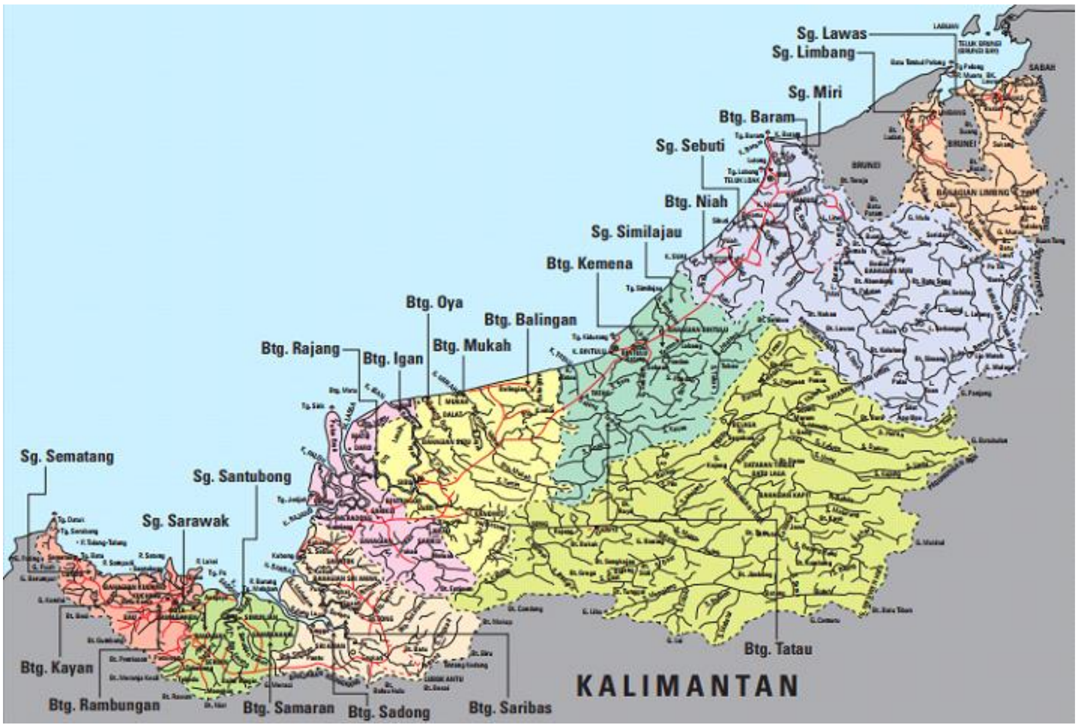

Figure 1.1.1: River System in Sarawak

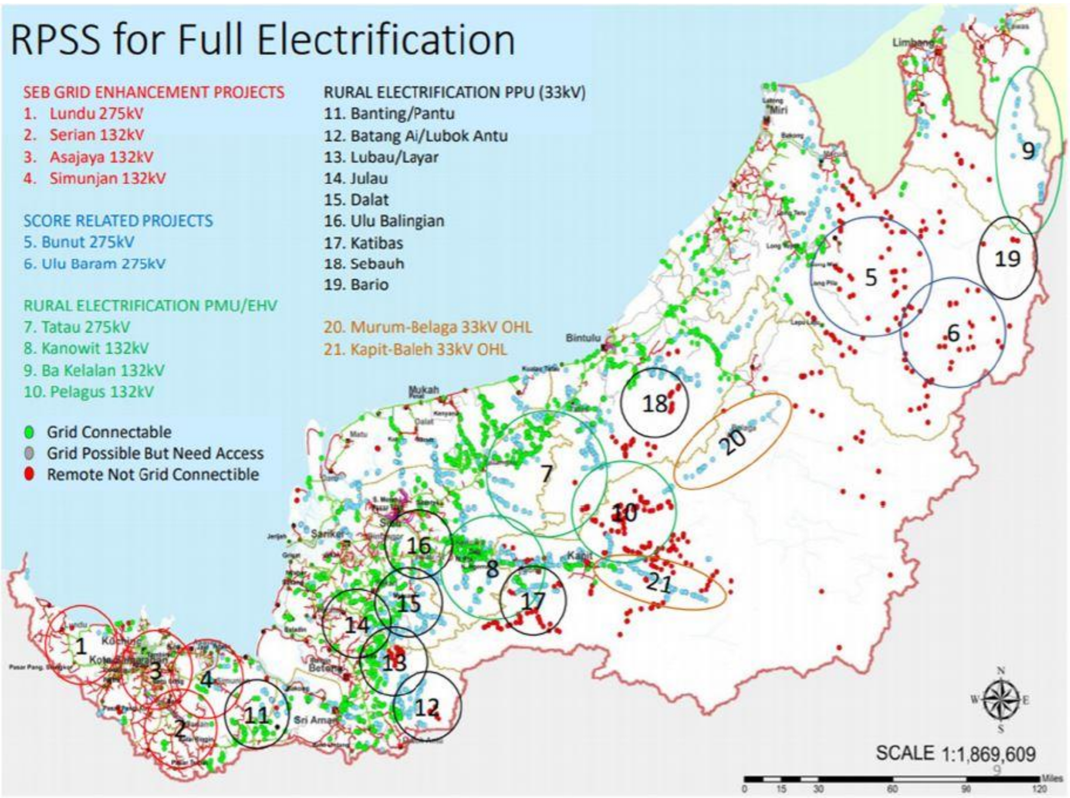

Figure 1.1.2: Off-grid Communities in Sarawak as of 2017[1]

Based on the reasoning given from previous points, hydrokinetic is also best suited to power up the rural community's houses. At first glance, it may seem that hydrokinetic system is not capable of providing sufficient power for the off-grid community to carry on their daily lives activities due to their smaller system when compared to the typical hydropower system. However, the truth is that, even the small-scale HKT prototype built with a 0.585 m reprofiled industrial fan rotor that is shown in Figure 1.1.4 managed to harvest 92.29 W of power from the Balui River that flows with a 1.26 m/s current velocity[3]. Thus, this system has the potential to generate 2.21 kWh of energy daily which is sufficient to power up a typical rural household as shown in Figure 1.1.3.

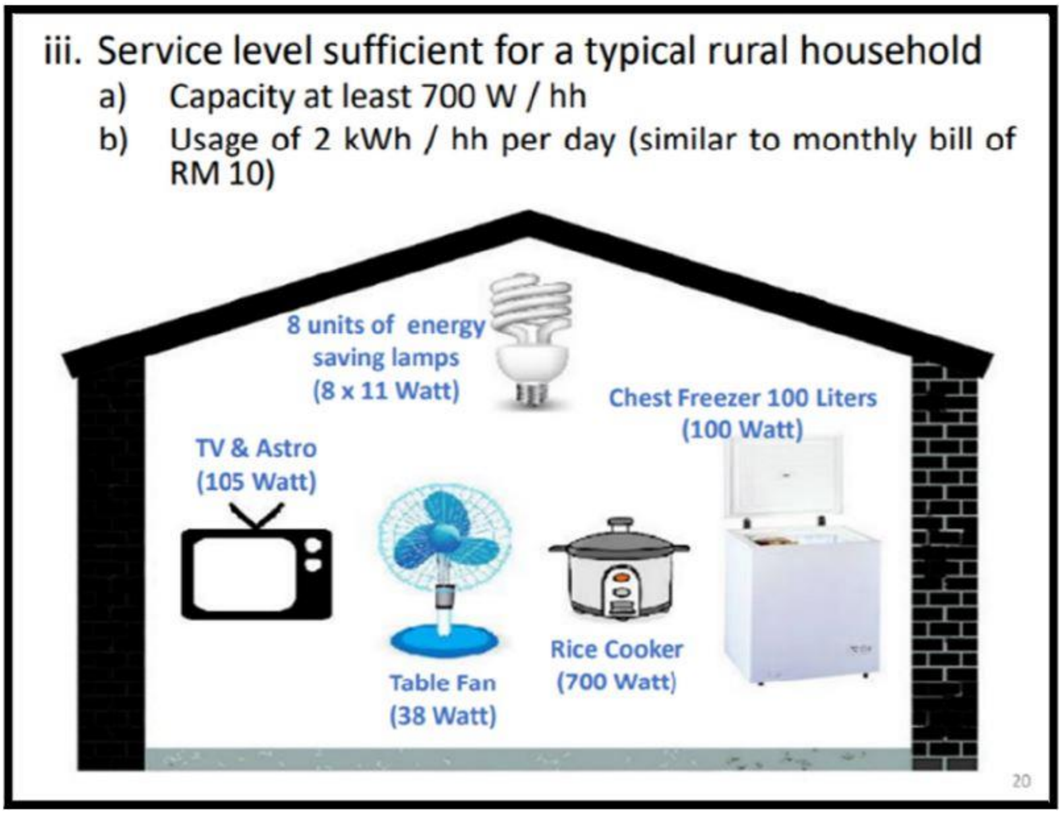

Figure 1.1.3: Power Consumption a Typical Rural Household [1]

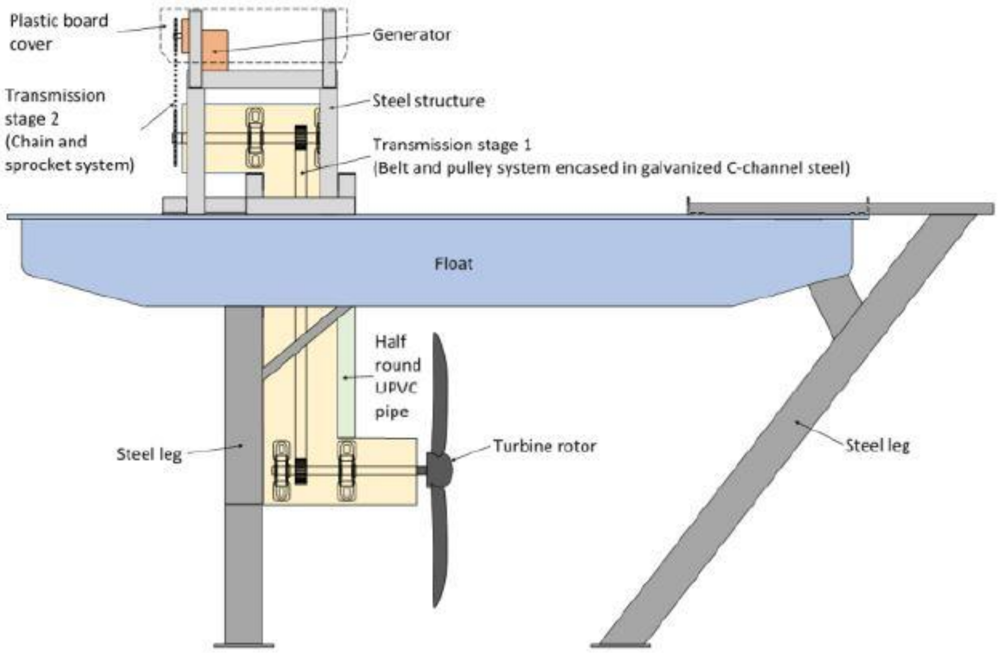

Figure 1.1.4: Schematic of Small-Scale Horizontal Axis HKT Turbine [3]

Power can be generated by the use of a variety of hydrokinetic technologies, such as tidal energy converters, wave energy converters, and hydrokinetic turbines, amongst others. Tidal energy converters generate electricity by harnessing the power of the ocean's tidal currents, whereas wave energy converters tap into the potential of the waves that break on the ocean's surface. As for HKT particularly, the working principle is very straightforward where the kinetic energy of moving water in rivers or estuaries is converted into mechanical energy by the blades of turbine. Next, the mechanical output is transferred to the generator, where it produces electrical energy. Finally, the electrical energy is distributed to the loads or stored in the battery. In comparison to conventional energy sources, hydrokinetic systems offer a few advantages, the most notable of which are reduced carbon emissions, less water consumption, and fewer negative effects on the environment.

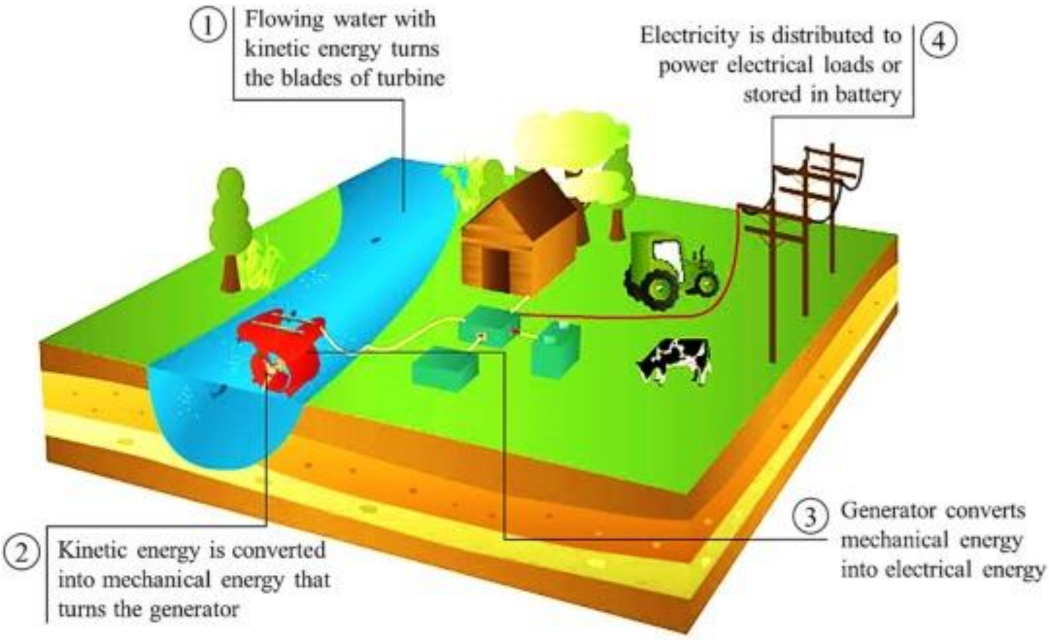

Figure 1.1.5: Hydrokinetic System Working Principle

Overall, hydrokinetic technologies have the potential to make a significant contribution to Malaysia's energy mix and can help the country transition to a more sustainable and reliable energy system. However, there are still many challenges to the widespread adoption of these technologies, and it will be important for the government, industry, and other stakeholders to work together to overcome these challenges and fully realize the potential of hydrokinetic energy in Malaysia.

1.2 Hydrokinetic Turbine Type

Hydrokinetic turbines convert the kinetic energy of flowing water into electricity. There are several different types of hydrokinetic turbines, each with their own distinct qualities and advantages. All types of the hydrokinetic turbine can be summarize as illustrated in the Figure 1.2.1 below.

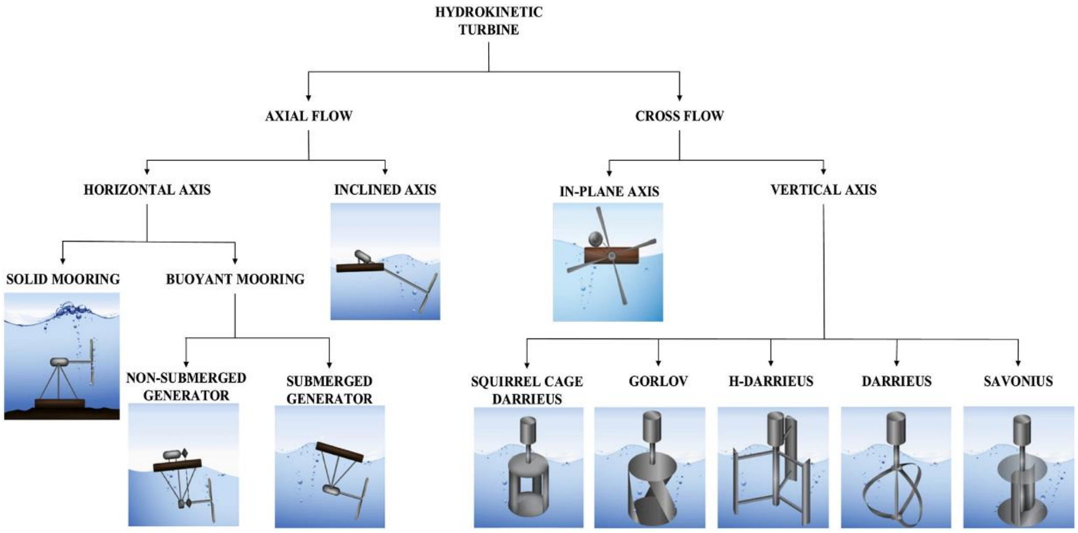

Figure 1.2.1: Type of hydrokinetic turbine

The horizontal axis turbine is the most frequent form of turbine used in hydrokinetic energy generation and is one type of hydrokinetic turbine. These turbines have horizontally aligned blades that revolve around a vertical axis. Typical applications include rivers and canals with moderate to high flow rates.

The vertical axis turbine is another type of hydrokinetic turbine with vertically oriented blades that rotate around a horizontal axis. The installation of these turbines is more versatile, and they can be utilised in a range of water bodies, including rivers, oceans, and tidal basins. Due to their simple design, they are also easier to maintain and repair.

The oscillating hydrofoil turbine is a third type of hydrokinetic turbine that uses a hydrofoil (a wing-like structure) to generate lift and move the turbine forward. These turbines are commonly used in ocean currents and can operate at high flow rates.

The crossflow turbine is the fourth form of hydrokinetic turbine, which consists of a cylinder with rotating vanes as water flows through it. These turbines are suitable for low-flow conditions and can be utilised in tiny streams and irrigation canals.

There are also hybrid hydrokinetic turbines, which incorporate elements of many turbine types. The tidal turbine, for instance, is a hybrid turbine that combines both horizontal and vertical axis turbines to harness the energy of tidal currents.

In conclusion, there are a variety of hydrokinetic turbines, each with their own distinct qualities and advantages. The most prevalent variety, horizontal axis turbines, are used in rivers and canals with moderate to high flow rates. Vertical-axis turbines offer greater location flexibility and are simpler to maintain and repair. In ocean currents, oscillating hydrofoil turbines are utilised, whereas crossflow turbines are optimal for low-flow settings. Tidal turbines are hybrid turbines that include components of many turbine types.

1.3 Problem Statement

48% of the Sarawak population of 2.5 million live in 6235 widely scattered villages [4]. Due to the small size of these communities, their scattered location, remoteness, and uneconomical grid connection, 5% of Sarawak's population remains without access to 24-h electricity from mains or solar power [5].In many rural areas, where the access to electricity is limited or non-existent the communities are mostly dependent on traditional forms of power generation, such as the diesel-powered generator for instance, which are noisy and require frequent maintenance where it is often neglected in remote areas due to limited resources and know-how. Fuel is expensive and difficult to bring into remote areas [1].

The next problem would be the pollution caused by the diesel-powered generator. In general, this machine will release Nitrogen oxide (NOx), carbon dioxide (CO2), and particulate matter. The released of these gases into the atmosphere by these generators, greatly lowering air quality in the nearby areas. Fuel contains 0.73 kilogramme of pure carbon per litre, whereas diesel fuel releases 2.6 kg of carbon dioxide per litre [6] . Consequently, this would lead to another phenomena which is global warming.

1.4 Objectives

The objectives for this project are:

1. To design a low-speed permanent magnet generator for hydrokinetic application
2. To evaluate the performance the performance of the low-speed generator

3. To develop a low-speed generator that can generate electrical output at 300rpm

This project focuses on designing a permanent magnet AC generator for hydrokinetic purpose that can generate electrical output. To achieve this objective, several factors must be taken into consideration. Firstly, it will be necessary to select the appropriate materials and design for the PMG to achieve the desired efficiency and power output. This may involve considering factors such as the size and shape of the magnets, the type of magnetic material used, the number of poles in the generator, and the number of turns in the coil. In addition to the design of the PMG itself, it will be necessary to carefully consider the operating conditions for the generator. This may involve determining the optimal flow rate and velocity of the water, as well as the load on the generator. Another important consideration is the durability and reliability of the PMG. Hydrokinetic systems are often exposed to harsh environments, and it is important to design a PMG that can withstand these conditions and continue to operate reliably over long periods of time. This may involve using materials and design features that are resistant to corrosion and other types of wear and tear. Finally, cost is always an important factor in the design of any product, and this is particularly true for low-speed PMGs intended for hydrokinetic applications. It will be important to design a low-speed PMG that is both cost-effective to manufacture and maintain, while still meeting the performance and durability requirements of the application. This may involve optimizing the materials and design of the generator to minimize production costs, as well as designing the generator for ease of maintenance and repair in the field. This project is expected to provide an extra electricity power supply for the rural communities.

1.5 Project Scope

1. Develop a detailed design for the low-speed generator, including drawings and specifications for all components and subsystems.
2. Prototyping and testing of the low-speed generator to verify that it meets the required specifications and performance targets.
3. Refine and optimize the design as needed based on the results of the prototyping and testing.

Chapter 2

LITERATURE REVIEW

2.1 Overview

This chapter covers the study of method used to optimize the performance of the low-speed generator. The study included the basic information about the types of both DC and AC generator, the type of permanent magnet used and the comparison between the low-speed generator and high-speed generator for hydrokinetic application.

2.2 DC Generator Type

There are several types of DC generators, each with its own unique characteristics and capabilities. Some of the main types include shunt generators, series generators, compound generators, and permanent magnet generators. The figure below illustrates the detailed classification of DC generators.

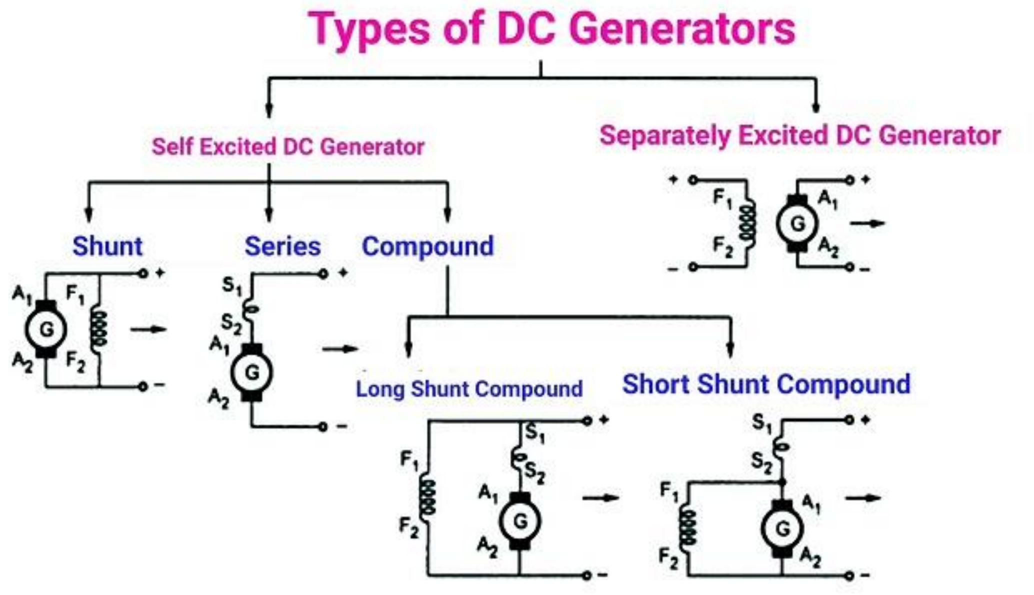

Figure 2.2.1: Types of DC Generator [7]

Shunt generators, also known as separately excited generators, are commonly used in small-scale applications, and are known for their ability to regulate voltage under varying load conditions. Their strong point is their ability to maintain a nearly constant voltage output, making them ideal for applications that require a stable voltage supply. The mathematical formula for calculating the voltage output of a shunt generator is given by:

$$V = E - IaRa$$

where V is the voltage output, E is the generator's induced emf, Ia is the armature current, and Ra is the armature resistance.

However, shunt generators also have a weak point in that they are not well-suited for handling large fluctuations in load demand, as this can result in significant voltage changes. This is because the armature current and resistance are inversely proportional, meaning that an increase in load demand will result in a decrease in armature resistance, leading to an increase in voltage output.

Series generators, also known as self-excited generators, are designed to operate at a high voltage and are typically used in large-scale power generation applications. In order to generate an electromotive force (emf), series generators utilize a series field winding that is connected in series with the armature winding, thereby producing the requisite magnetic field. A key advantage of series generators is their capability to accommodate substantial fluctuations in load demand while maintaining a relatively stable voltage output. This advantage stems from the fact that the series field winding is connected in parallel with the load, ensuring that alterations in load demand do not significantly impact the field current and, subsequently the voltage output.

However, their high operating voltage makes series generators more vulnerable to voltage fluctuations and can potentially result in damage to the generator or other electrical components. In addition, series generators are more sensitive to changes in excitation and may require additional control measures to maintain a stable voltage output.

Compound generators are a hybrid configuration of shunt and series generators specifically designed to leverage the advantages offered by both types. They employ a parallel-connected shunt field winding in conjunction with the armature winding, as well as a series-connected field winding in line with the armature winding. This enables them to regulate voltage with consistency amidst fluctuating load conditions, akin to shunt generators, while also facilitating effective management of substantial load variations, resembling the capabilities of series generators.

The main advantage of compound generators is their ability to adapt to a wide range of operating conditions. However, they can be more complex and expensive to manufacture compared to other types of generators. In addition, compound generators may require additional control measures to maintain a stable voltage output, similar to series generators.

Permanent magnet generators are a relatively new type of DC generator that utilizes permanent magnets to generate a magnetic field. They do not require a field winding and are therefore more efficient and lightweight compared to other types of generators. One of the main advantages of permanent magnet generators is their high efficiency and ability to operate at low speeds. They are also relatively lightweight and compact, making them suitable for a wide range of applications.

However, permanent magnet generators can be expensive to manufacture and are sensitive to temperature changes, which can affect their performance. In addition, the strength of the magnetic field produced by permanent magnets is limited, meaning that permanent magnet generators may not be suitable for high-power applications.

In conclusion, there are several types of DC generators available, each with its own unique capabilities and limitations. Understanding the strengths and weaknesses of each type can help determine the most suitable generator for a particular application.

2.3 AC Generator Working Principle and Their Type

AC generators, also known as alternators, are devices that convert mechanical energy into electrical energy. They are classified into different types based on the method of excitation, construction, and application. The most common types of AC generators are permanent magnet generators, wound rotor generators, and synchronous generators.

Permanent magnet generators utilize permanent magnets to generate a magnetic field. They are characterized by their simple construction, ease of maintenance, and high