FORMULATION OF A MAXIMUM POWER POINT TRACKING (MPPT) ALGORITHM FOR HYDROKINETIC ENERGY HARNESSING

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ABSTRAK

Tesis ini adalah mengenai analisis prestasi berdasarkan algoritma Pengesanan Titik Kuasa Maksimum (MPPT) yang dihasilkan oleh tenaga hidrokinetik. Matlamat dalam penyelidikan ini adalah untuk merumuskan algoritma Carian Mendaki Bukit Modified dengan gabungan pengawal PI untuk mendapatkan kuasa yang paling banyak daripada sistem sambil merendahkan ayunan. Eksperimen telah dijalankan dengan menggunakan Penjana Segerak Magnet Kekal (PMSG), penerus jambatan tiga fasa, dan penukar rangsangan DC. Idea MPPT bergantung pada pengesanan voltan dan arus keluaran penerus untuk menghasilkan arus rujukan (IMPP). Pengawal PI digunakan untuk mengubah suai isyarat ralat antara IMPP dan arus aruhan sebenar (Idc) untuk menyediakan kitaran tugas untuk penukar rangsangan. Keputusan akan dinilai berdasarkan penggunaan tenaga dan kecekapan prestasi antara HCS dan algoritma yang dicadangkan. Keputusan menunjukkan bahawa kaedah yang dicadangkan mempunyai 558.7W dengan 87.78% kecekapan dalam memanfaatkan kuasa.

ABSTRACT

This thesis is about a performance analysis based on Maximum Power Point Tracking (MPPT) algorithm generated by the hydrokinetic energy. The goal in this research is to formulate Modified Hill-Climbing Search algorithm with combination of PI controller to get the most power out of the system while lowering the oscillations. The experiment was conducted by using Permanent Magnet Synchronous Generator (PMSG), a three-phase bridge rectifier, and a DC boost converter. The MPPT idea relies on detecting the rectifier output voltage and current to produce reference current (IMPP). The PI-controller was employed to modify the error signal between IMPP and actual inductance current (Idc) to provide the duty-cycle for boost converter. The results will be evaluated based on energy harnessing and performance efficiency between HCS and proposed algorithm. The results demonstrate that the proposed method has 558.7W with 87.78% of efficiency in harnessing the power.

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β	Pitch angle
ω	Turbine rotational speed (rad/s)
ρ	Water density (1000kg/m^3)
λ	Tip ratio
Ω	Rotor speed
ΔS	Step size
A	Turbine cross-sectional(m^3)
V	Velocity of water (m/s)
R	Radius of turbine
Cp	Power coefficient of turbine

LIST OF ABBREVIATIONS

MPPT	Maximum power point tracking
IPC	Indirect power control
DPC	Direct power control
TSR	Tip speed ratio
OT	Optimum torque
Tm	Mechanical torque
Pm	Mechanical power
HCS	Hill-climbing search
MHCS+PI	Modified hill-climbing search with PI controller

CHAPTER 1

INTRODUCTION

1.1 Background

Because of its potential in a range of river crossing places around the world, river based on hydrokinetic turbines perform a clean and ecological way to harness the water energy of streams and might make a big contribution to the renewable energy sector in the future. The hydrokinetic energy harnessing in the river is one of the available energies to maintain a clean environment, sustainable energy, and reliability for the benefit of future generations. However, the energy-harvesting endeavour a technology based on hydrokinetics is rapidly gaining traction. Nonetheless, a number of concerns and obstacles must be considered, particularly in control systems, in order to extract the greatest power. Commonly, there has been a significant oscillation on the output power and current during a steady-state operation because of the river's fluctuating water levels. Therefore, the controller and energy extraction effectiveness on the hydrokinetic energy harnessing will reduce. On the ground of hydrokinetic energy harnessing, some enhancements were recently created based on MPPT algorithm include the design of PI controller that aimed to boost the power output and lowering the oscillation due to variation of water. In addition to wind, biomass, solar and geothermal energy, hydrokinetics has been located studies as a possible future energy source.

The hydrokinetic method has a number of benefits, including the ability to produce electricity without the use of a dam or other structures, as well as minimal environmental effect. This method of energy capture can be used in waterways and other fluid facilities with a high water rate. The maximum power point tracking (MPPT) algorithm can be executed to the hydrokinetic structure to obtain additional power by keeping the ideal balanced voltage through the load. Furthermore, the variation of water rate in a stream is a difficult problem to solve, particularly when designing a control system capable of harnessing extreme output power with great performance efficiency.

The MPPT algorithm of wind energy (WECS) and PV (solar) was adopted in this reading to be executed in harnessing hydrokinetic energy. This is because the concept of setup, hardware for the electrical and the movable for generator is alike to WECS. As a result, the MPPT algorithm from WECS is the main reference for detailed exploration in this field. The MPPT algorithm could be divided into 3 categories. There is indirect power control (IPC), direct power control (DPC), and soft process computing (SCM). The MPPT IPC algorithm maximizes the mechanical force (Pm), whereas the MPPT DPC algorithm maximizes the output power (Po) directly.

For large wind turbine systems, IPC-based MPPT algorithms for instance the tip speed ratio (TSR) and optimum torque (OT) are widely use. The sensor must calculate the wind speed as well as the turbine and generator's rotational speeds, according to the machine algorithm. The quantum neural network (QNN) was used as a regulator to improve the performance of the WECS TSR and (OT) MPPT methods. Small-scale wind turbine systems will benefit from the DPC MPPT algorithm. This algorithm is also sensor less, and it does not necessitate knowledge of turbine parameters in order to design the control algorithm. As a result, this type of algorithm is more dependable, less complex, and less expensive.

Because of its versatility and simplicity, perturb and observe (P&O), also identified as Hill-Climbing Search (HCS), is commonly used. The Modified Hill-Climbing Search (MHCS+PI) algorithm was projected to resolve the wrong direction tracking problem in the traditional HCS algorithm. In numerous, MPPT algorithms based on soft computing methods were projected. The methods show promise, as they are more efficient and perform well in a variety of wind speeds. However, due to the large number of iterations and training expertise in the programming, the system is highly erudite and the convergence speed is slow. The working and disconnected steps are needed to train the dissimilar set of neural network parameters for the optimal neural network controller, according to reference. As a result, the trained neural network can easily map the input-output data relationship.

Formulations based on MPPT algorithm for hydrokinetic energy has been presented in this paper to harness the extreme power in water variation thus reduce the oscillation. The circuit contains of a Permanent Magnet (PMSG), rectifier and direct current boost converter. The use of an updated Hill-Climbing Search algorithm in combination with PI regulator has existed to increase the system's ability to capture maximum output power and performance efficiency.

1.2 Problem statement

With a growing understanding of the value of a sustainable climate, it is now widely acknowledged that conventional reliance the on fossil fuels come at a high price to the surroundings, resulting in CO-2 emissions, greenhouse gas issues, and pollution. Keep in mind that much of the world's oil, particularly in emerging nations like Malaysia, nevertheless, reliant on fossil fuels, which fast increasing depleting. As a result, renewable energy plays a major role in supplying reliable power generation as a green and clean energy source.

Since hydrokinetic energy harvesting in rivers is a relatively new technology in Malaysia, the number of issues must be addressed. Among the issues are regarding the flow pattern and variation of river. According to Khan et al. (2011), the variation of the river is a significant challenge to extract the energy. As a result, the output power and system efficiency will be dropped significantly. Therefore, the MPPT algorithm is applied to obtain maximum power under varying and turbulent water flow conditions. The aim of this research is to propose a new formulation of the Modified Hill-Climbing Search (MHCS+PI) MPPT algorithm for hydrokinetic energy harnessing in order to minimize output power oscillation and thus increase production power and performance.

1.3 Objective

The goal of this assignment is to create a design and formulate a new algorithm for hydrokinetic energy which can reduce the oscillation that causes the loss of power. In this project, the tools that we need are turbine model, PMSG, rectifier bridge types, DC-boost converter, and also a controller system. All of these items can be getting throughout Mat lab Simulink software that has been install. The objectives of the research are:

1. To formulate and simulate Modified Hill-Climbing Search (MHCS+PI) MPPT algorithm for hydrokinetic energy harnessing using Mat lab Simulink.
2. To compare energy harnessing and performance efficiency between HCS and MHCS+PI algorithm.

1.4 Scope

The aim of this project is to ensure that hydrokinetic energy can work at high and low speeds of flowing water, to design and analyse the structure and effect of water variation from the river, and to compare Hill-Climbing Search and Modified Hill-Climbing Search in terms of output power. Mat lab Simulink software is used to analyse all of these.

1.5 Thesis outlines

For chapter 1 (introduction), a quick summary of the research are discussed. Contains of the background, problem statement, the study's objectives, and the study's scopes. In chapter 2 (literature review), it presented previous research efforts in the areas of renewable energy, hydrokinetic energy history, and algorithm form. There is also a study of other related research studies. The analysis is arranged chronologically to show how previous research attempts laid the foundation for future research, consisting of current study. The analysis is in-depth so that the current research initiative may be able to be better calibrated to contribute to the existing body of literature while still appropriately defining the scope and direction of the project. Methodology (chapter 3) is the following identification of the project's motivation and goals. This chapter served as a roadmap for completing the assigned project. The completed approach framework had been illustrated and designed as a roadmap for achieving the project's goals. After the methodology has been completed, the result is obtained in chapter 4. This chapter's goal is to demonstrate and analyse the information collected during the experiment. To discuss the data, it is presented in the shape of a table, which is then converted in the graph. The final thoughts of study are presented in chapter 5 (conclusion). The conclusion would essentially respond to the study's objectives. This chapter will also cover the guidelines for future study.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of renewable energy

Renewable energy is energy resulting from usual resources such as wind, water and geothermal energy that can remain naturally (Twiddle, J. 2006). This form of energy can help to minimize pollution all over the planet. It is also may be the most suitable option for the worldwide problem such as weather change that is really happening rapidly these days. As a upshot of the over use of the greenhouse, climatic change has happened. At night, gases like carbon dioxide, nitrogen oxide and anymore function as a comforter, keeping the planet warm. The gases capture the warmness that the planet emits at night time. Human activities, on the other hand, have modified the absorption of these gases by day to day. As a effect, extreme of these gases can affect the weather change to happen (Twiddle, J. 2006). So, to resolve this problematic the good ways is utilized the renewable energy sources. Because fuel is difficult to come by and expensive, renewable energy is ideal for usage in rural and distant places. It could be an alternate technique by applying of the renewable energy source there (Twiddle, J. 2006).

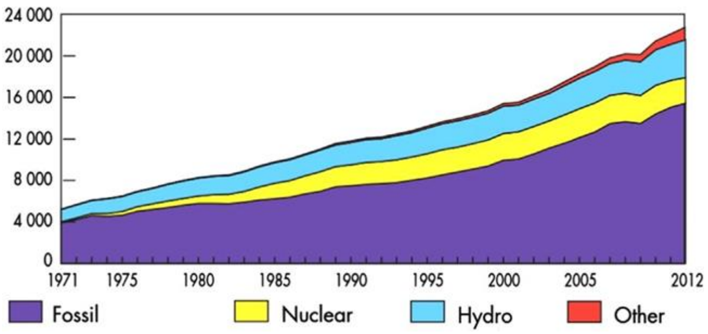

Figure 2.1 Fuels used to generate power in the world from 1971 to 2012
Source: IEA (2014)

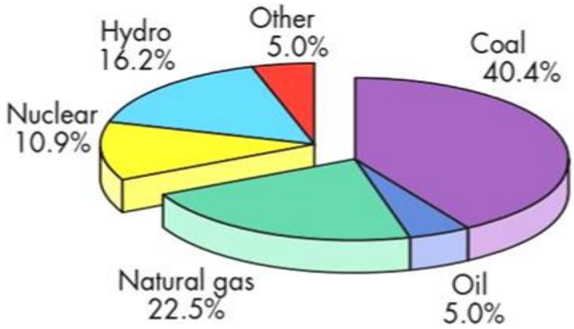

Figure 2.2 Various energy sources are used to generate power around the world
Source: Azd Zayoud (2016)

2.2 Hydro energy

The energy produced by the movement of water is known as hydrokinetic energy. Tides, waves, ocean currents, and free-flowing rivers on the planet contain an untapped, strong, highly concentrated, and clean energy resource. Hydrokinetic energy are clean and environmentally friendly technique to harness the power (water) of streams, and their possible in a number of stream crossing places around the world means they could make a substantial contribution to the renewable energy sector in the future. The river's hydrokinetic energy harvesting is one of the potential energies for ensuring clean energy's long-term viability, reliable, and sustainable energy for the future generation. The turbine (rotor fan) rotates on a shaft connected to the generator as the water current flows through it. The fluid velocity is proportional to the rotational speed. Horizontal axis turbines can resemble wind turbines in appearance, and in the same way that wind turbines operate, they collect kinetic energy from moving water. To focus the flow past the turbine, the rotor is often enclosed within a duct (often funnel-shaped). This will allow for a wider range of current velocities to be used and more electricity to be generated per unit of rotor area. The rotor's axis is in vertical-axis turbines is perpendicular to the flow. Vertical axis turbines available of varieties shape and size and they can even be enclosed within a duct.

2.2.1 Advantages and disadvantages of hydrokinetic energy

Hydrokinetic energy is a new technology which can provide the power to consumers as the conventional energy likes gas, coal and anymore. But, it still has some advantages and disadvantages in using this hydrokinetic. The advantages are can be used as base load source, do not need a dam to operates, low emission and low operating cost while for disadvantages are support only at low capacity area, limited reservoir and drought potential. However, the droughts are usually a brief interruption in the normal water cycle, and they should only cause a small delay in electricity production.

2.3 Turbine

Turbine is a rotational mechanical device that converts the flowing fluid energy into useful work. When used in conjunction with a generator, the results of the work by a turbine can be used to generate electrical power. A turbine is a turbo machine containing with least one of moving constituent, the assembly of rotor, which includes a shaft or a drum with attached blades. The blades rotate as a result of the moving air, imparting the rotor with rotational energy. Wind-mills and water wheels are examples of early turbines.

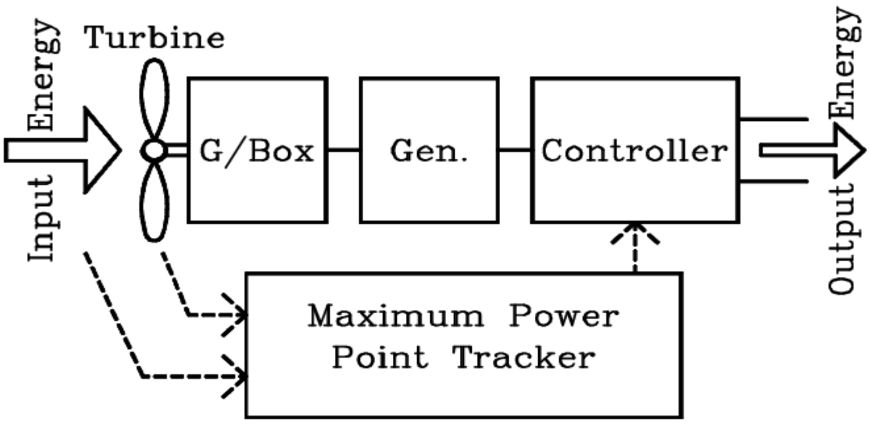

Figure 2.3 Turbine
Source: Andrew Mark Tuckey (1997)

According to Fatemeh Behrouzi (2016), there are some roughly two primary classifications of turbine which are axial axis (Horizontal) and vertical axis (Cross-flow) turbines. For river applications, vertical-axis turbine are most popular while axial axis turbine are used for ocean extraction power. In vertical-axis, the Darrieus turbines are the supreme common selections, where use H-Darrieus or squirrel cage Darrieus (Straight-blade). There is still no agreement on whether horizontal axis or vertical-axis will be the top preferences for using water current power; however vertical-axis turbines appear to have rewards over the horizontal axis turbine in numerous sides. Vertical axis turbines have an axis that is perpendicular to the inflow direction, whereas horizontal-axis turbines have axes which in corresponding. This assets meaning that the vertical axis turbine can receive inflow from any way and thus does not require an evaporating mechanism. It is also lesser in operation, has less mechanical complexity, low prices of generator coupler due to its location on water, and the ability to plan at large scales produces a lot of energy.

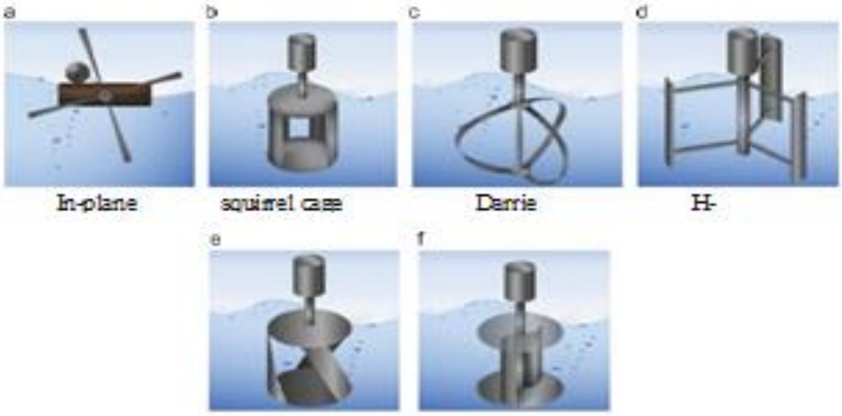

Figure 2.4 Vertical-axis turbines
Source: Anuj Kumar (2016)

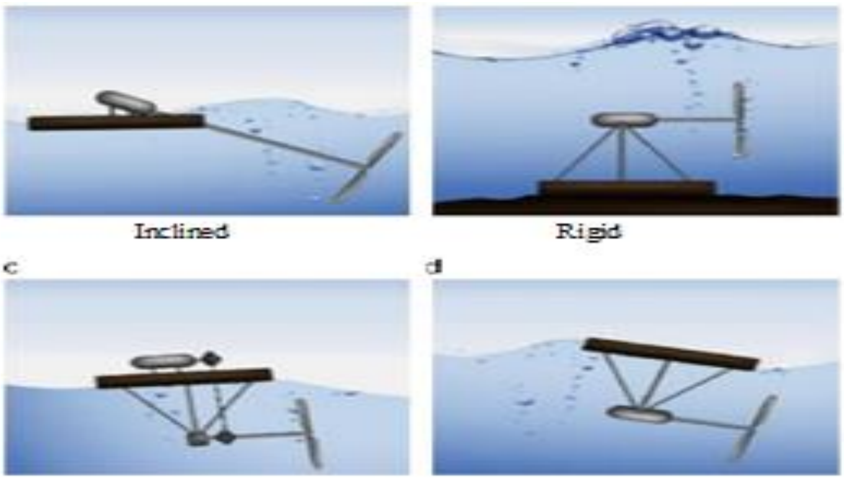

Figure 2.5 Horizontal-axis turbines
Sources: Anuj Kumar (2016)

2.4 Permanent Magnet Synchronous Generator (PMSG)

A strong permanent magnet synchronous generator is one that uses a permanent magnet instead of a coil to provide the excitation field. According to Stephen (2011), a shaft generates the magnetic field by mounted permanent magnet mechanism and current induced into the stationary armature; the rotor and magnetic field revolve at the same speed, which is referred to as synchronous. The rotor incorporates the magnet in the majority of designs, and the stator is the stationary armature that is electrically attached to a load in the rotating assembly in the middle of the generator. The frequency of the induced voltage in the stator (armature conductors), which is traditionally measured in a unit hertz, is proportionate to RPM, or the rotor's rotational speed, which is generally expressed in revolutions per minute (or angular speed). Every physical rotation of the rotor results in more magnetic poles going past the armature windings if the rotor windings are arranged in such a way that they create the effect of more than two magnetic poles. A full period of a magnet field oscillation is equal to the passage of a north and South Pole.

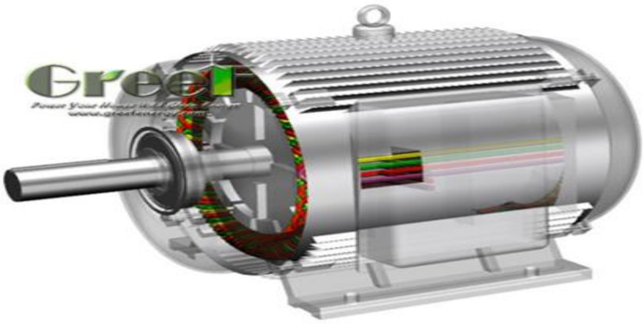

Figure 2.6 Permanent Magnet Synchronous Generator (PMSG)
Source: New Energy Equipment (2016)

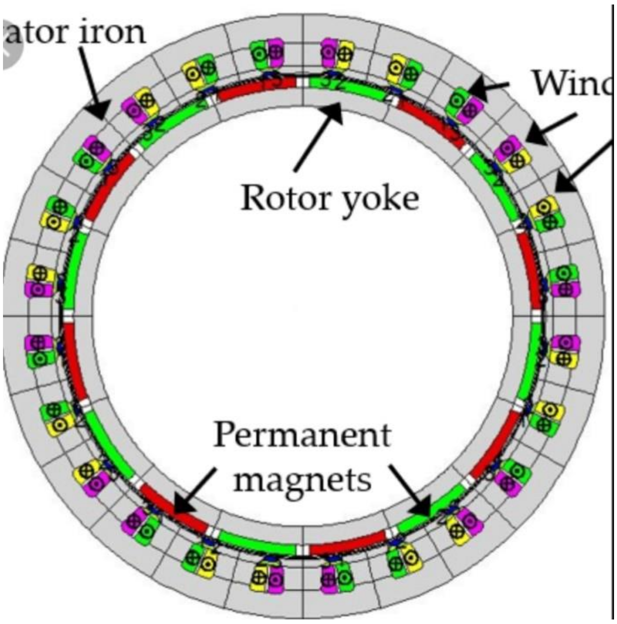

Figure 2.7 Winding of PMSG
Source: Hadi Heidari (2015)

2.5 Rectifier

According to D.W. Hart (2011), a rectifier is an electrical device that converts alternating current (AC) to direct current (DC) which flows in one direction only. The inverter performs the reversing process. Rectifiers have several uses, but they're most typically used in direct current source and HVDC power transmission systems. Rectification can be utilised for more than only generating direct current for power generation. Depending on the types of ac supply and rectifier circuit layout, additional smoothing of the output voltage may be required to achieve a uniform steady voltage. Rectifier contains about 8 types which are single-phase, three-phase, controlled and uncontrolled, half-wave and full-wave, bridge rectifier and centre-tapped rectifier.

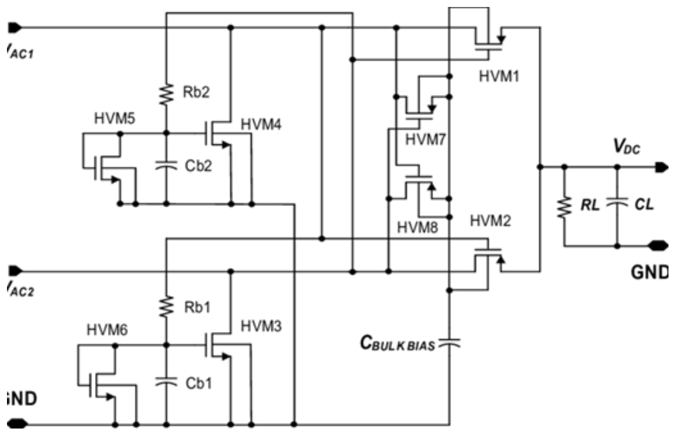

Figure 2.8 Schematic circuits for high voltage rectifier

Source: Vijith Vijayakumaran Nair (2015)

2.5.1 Bridge rectifier

Bridge rectifier is the most efficient circuit to transform the alternating current (AC) to direct current (DC). It contain of four diodes which are connected in closed-loop. If we applied the AC voltage source in bridge circuit, during positive half-cycle, terminal one will be positive and the diode one and three will be forward bias and current can flow into it. But during negative cycle, the diode one and three become reversed bias and the current cannot flows into it.

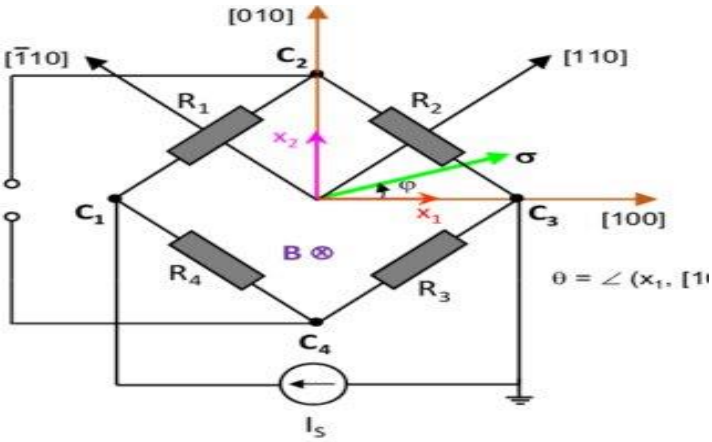

Figure 2.9 Bridge circuit

Source: Hadi Heidari (2015)

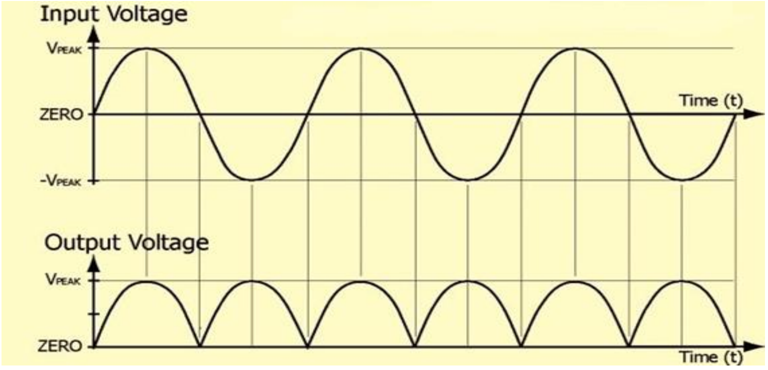

Figure 2.10 Waveform
Source: ElectroSome

In this bridge rectifier, there are several advantages and drawbacks. Talk about efficiency, bridge rectifier provides high efficiency compare with half-wave rectifier. Apart from that, about DC output signal, bridge rectifier provide smoother signal as compare to the half-wave rectifier. The drawbacks of bridge rectifier are the circuit complex in designing. Another drawback are will cause more losses of power due to more diode been used.

2.6 DC boost converter

DC boost converter is the simplest switch mode types. DC to DC power converter is known as a boost converter that increases voltage while decreasing the current from input to the output (load). It's a type of switched-mode power source with at least two semiconductors (a diode and a transistor) and at least one energy storage part, such as a capacitor, inductor, or both. To minimize the ripple voltage, the filter which made from the capacitor will be added to convert's output and input sides. Any acceptable DC source, such as battery, solar panel, rectifiers, and DC generators, can be used to power the boost converter. DC to DC conversion is a procedure that converts one DC voltage to another DC voltage. There are about 3 categories of DC boost converter which are boost converter, fly back converter and buck converter. Boost functioning as step up the voltage while buck boost step down the voltage. Most of these components are being used power electronics circuit.

Figure 2.11 Buck boost converter
Source: www.google.com

Figure 2.12 DC boost converter
Source: www.google.com

CHAPTER 3

METHODOLOGY

3.1 Modelling

In this chapter, it will discuss about the measures needed to develop and produce the proposed Modified Hill-Climbing Search design. The project was divided into 3 major tasks, including modelling, MPPT process and software development.

3.1.1 Turbine modelling

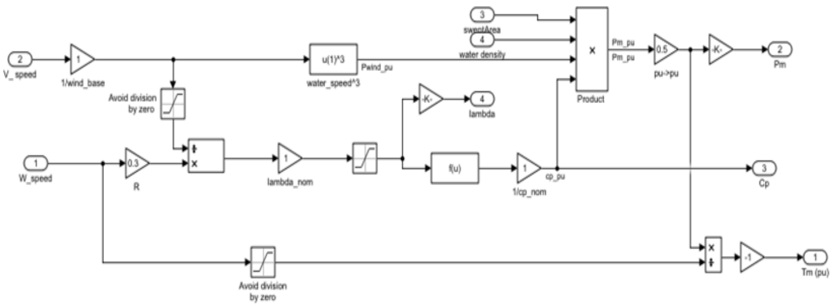

Figure 3.1 Turbine circuit

In this modeling, the input for the hydrokinetic is water velocity while the mechanical power (Pm) is the output. For the torque(Tm), it will used to rotate the shaft (rotor) of generator. To determine the capacity of energy that may be harnessed in the river, use the formula as stated below:

$$Pm = \frac{1}{2}\,\rho A V^3 Cp \qquad 3.1$$

Where ρ is the water density (1000kg/m3), A is the turbine's cross-sectional area (m3), V is the water current velocity (m/s), and Cp is the turbine's power coefficient.

To get power coefficient (Cp), we need to use the formula of

$$Cp = (\lambda, \beta) \tag{3.2}$$

Where β is the fixed pitch angle in water turbine and λ is a tip ratio which defined as:

$$TSR(\lambda) = \frac{\omega R}{V} \tag{3.3}$$

Where, the ω is the turning rate of the turbine and R is radius (turbine). The turbine specific implies that nearby contain single TSR value at which turbines are running at full effectiveness. To accomplish maximum energy harvesting, the TSR rate must be reserved at an ideal working point for wholly water current velocity. The TSR, form, and radius of the turbines affect the turbines' power coefficient (Cp). The following is the formula for the bond between Cp and TSR utilized in this study:

$$C_P(\lambda) = -0.022\lambda^6 + 0.04\lambda^5 - 0.26\lambda^4 + 0.72\lambda^3 - 0.77\lambda^2 + 0.27\lambda - 0.011 \tag{3.4}$$

The mechanical torque (T_m) can be calculated as below:

$$Tm = \frac{Pm}{\omega m} \tag{3.5}$$

Where, mechanical strength is (P_m) and spinning speed is (ω_m). It depicts the hydrokinetic turbine's modeling based on the derivation of Eqs (3.1 to 3.5). It has been noticed that the generated power by the turbine depending on the value of water density (ρ), the swept region (A), coefficient of power (Cp) and input water velocity (V).

3.1.2 Analysis of PMSG and Rectifier

Permanent Magnet (PMSG) has been used to transform the spinning speed of the turbine into electrical energy. The PMSG's back electromotive force (E) with constant flux is given by:

$$E = k\omega_m \quad 3.6$$

Where, a constant coefficient is K and ω_m is the generator rotational speed in (rad/s). The terminal phase voltage in a stable state is given by:

$$V_s = E - I_s\,(R_s + j\omega_e L_s) \quad 3.7$$

Where, I_s (current stator), Rs (resistance of stator) and Ls (inductance stator) respectively. The formula for calculating the link between electrical and mechanical frequencies is as follows:

$$\omega_e = p\omega_m \quad 3.8$$

Where p is the total of poles (PMSG). The implement of the rectifier bridge is to transform the generated Vac from the PMSG to a Vdc. The relationship between Vdc and Vac can be stated as below:

$$Vdc = \frac{3\sqrt{6}}{\pi}\,Vs \quad 3.9$$

The approximate link between Vdc and ω_m can be identified from 5 to 8.

$$V_{DC} \approx \omega_m \quad 3.10$$

The output power (Pg) can be stated as when the output power conversion from PMSG to DC power during the rectification process is at unity power factor with no losses.

$$Pg = 3VsIs = VdcIdc \quad 3.11$$

3.1.3 Boost converter circuit

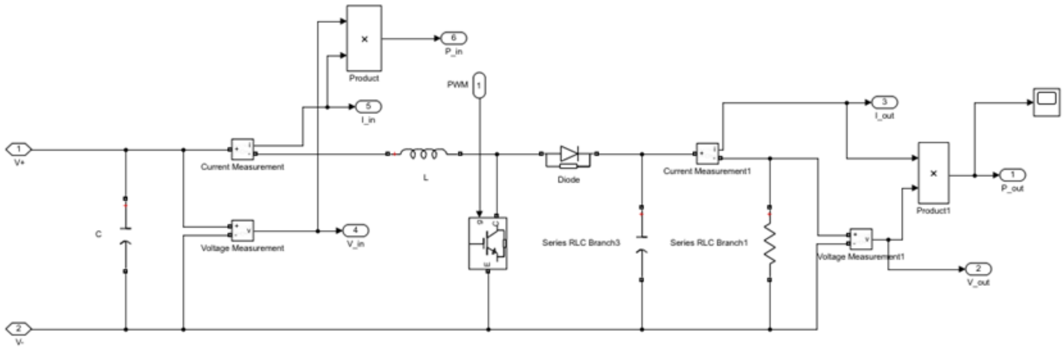

Figure 3.2 Boost converter circuit

Because of its effectiveness in power transfer, the DC Boost converter is widely employed. The duty-cycle (D) of the boost converter can be changed to manage the output voltage. The load seen by the generator will change as the duty-cycle (D) is altered. As a result, the output voltage as well as the rotating of rotor will be attuned appropriately. The ratio among Vout and Vdc is set by:

$$\frac{V_{out}}{V_{DC}} = \frac{1}{1-D} \quad 3.12$$

Where, D (duty-cycle) and V_{DC} is Vout from the rectifier. The value of the inductor and capacitor in (CCM) operation can be set by:

$$L = \frac{V_{DC}D}{2\Delta I_L fs} \quad 3.13$$

Where ΔI_L (desired current of inductor) and fs (switching frequency). The value of the capacitor (C) can be calculated using the formula below:

$$C = \frac{V_{out}D}{2\Delta_{vo}Rfs} \quad 3.14$$

Where $\Delta_{vo}$the output voltage peak ripple and R is the resistance load.

Table 3.1 Parameter used for boost converter

Parameter	Value
Input capacitor, C (μF)	100
Output capacitor, C (μF)	245
Inductance, L (mH)	1.85
Load resistance, (Ω)	10
Switching frequency, (kHz)	20

3.2 MPPT process

To guarantee that this procedure produces the desired outcomes in merging to the hydrokinetic MPPT at any of water velocity, it acceptable to prove that the role P (D), involving the power (P) and duty-cycle (D), has a lone extreme point matching with the MPPT of hydrokinetic explained.

$$\frac{dP}{d\Omega} = 0 \tag{3.15}$$

Where, (Ω) is the rotor speed. By applying chain rule, the equation become as:

$$\frac{dP}{d\Omega} = \frac{dP}{dD} . \frac{dD}{dV_{WG}} . \frac{dV_{WG}}{d\Omega_e} . \frac{d\Omega_e}{d\Omega} = 0 \tag{3.16}$$

Where VWG is the rectifier output voltage level and dΩe is the generator phase voltage angular speed. The turbine rotor speed is related to the generator speed as follow:

$$\Omega_e = p.\Omega \tag{3.17}$$

$$\frac{d\Omega_e}{d\Omega} = p > 0$$

The rectifier output voltage VWG is proportional to the generator phase voltage Vph.

$$\frac{dV_{ph}}{d\Omega_e} > 0 \tag{3.18}$$

$$\frac{dV_{WG}}{d\Omega_e} > 0$$

Bearing in mind equation, it holds:

$$\frac{dP}{d\Omega} = 0 \quad \frac{dP}{dD} = 0 \qquad 3.19$$

Thus, the job of P (D) has a single great point, coinciding with the WG MPP, and the duty-cycle (D) adjustment according to the control law convergence to the WG MPP under any water speed condition.

Because of the adjustment of duty-cycle follow the direction of dP/dD=0, for the right side, the turbine will rotate at high speed. So to drop the speed, the value of duty-cycle need to be reduce (decrease) to make sure the rotor speed reduction thus will increase the output power until it reach at steady state operational conditions (Koutroulis Kalaitzakis. 2006). Similarly to left side(low speed), the value of duty-cycle need to be increase to make sure the rotor speed in high condition until it reach at steady state operational (dP/dD=0). The aim for have an optimal curve is to make sure the rotational of turbine can be controlled by adjusting the speed to make it reach at the ideal point. If the rotational of turbine were not controlled, can cause it to rotate freely and will damage the others component such as permanent magnet, shaft and anymore. To protect this equipment, we must control the rotational of the turbine.

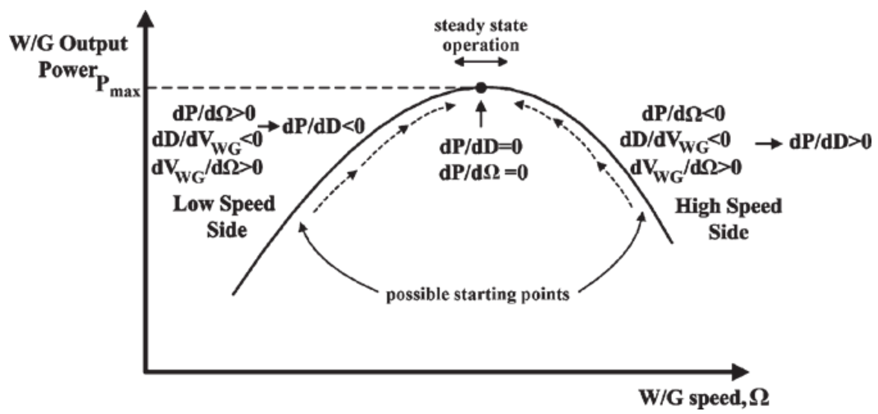

Figure 3.3 HCS idea based on regulating duty-cycle
Source: Koutroulis (2006)

3.2.1 Hill-Climbing Search

Hill-Climbing Search (HCS) algorithm is originated based on perturbs and observes (P&0) idea that used to hike power curve of the turbine. Any variations in output power and rotor rotating speed in relation to the velocity of water will be monitored by the algorithm. HCS algorithm is known as fixed step size(ΔS). So, to get the maximum output power, we need to add the step size to progress up the power curve. Figure 18 shows the flowchart for Hill-Climbing Search (HCS) algorithm.

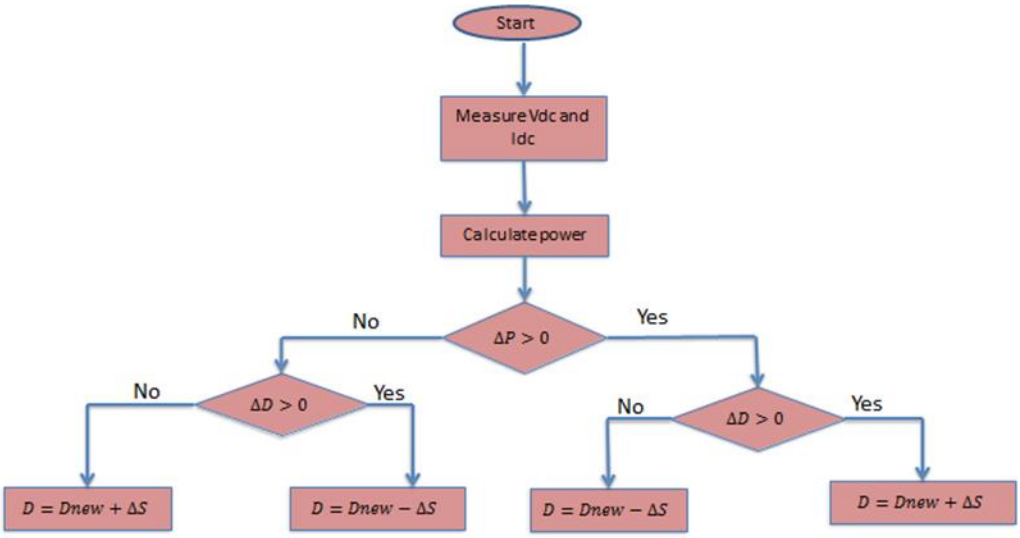

Figure 3.4 HCS flowchart algorithm

3.2.2 Proposed Modified Hill-Climbing Search with PI controller

The propose Modified Hill-Climbing Search will develop the static step size by dropping the fluctuation at steady-state conditions. In this propose algorithm, the step size (ΔI) will be a variable and we can control it by multiplied a fixed value in order to provide flexible algorithm with maximum energy harnessing. Figure 19 show the flowchart for the MHCS+PI controller.

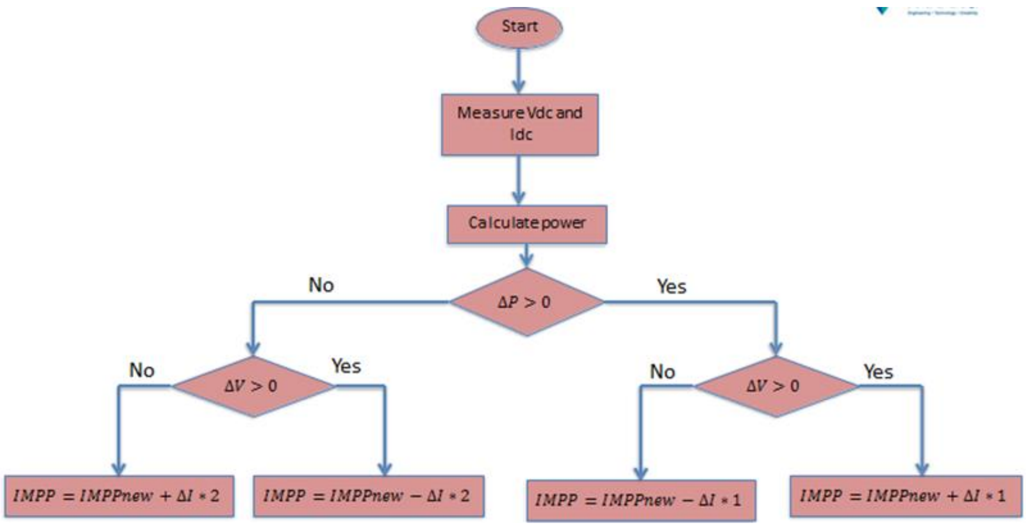

Figure 3.5 MHCS+PI flowchart algorithm

To get more detail on the propose algorithm, the following stage will describe the MHCS+PI algorithm,

Stage 1: Measure the$V_{DC} and\ I_{DC}$.

Stage 2: Measure the power and change in electrical power (ΔP) .

Stage 3: Compute the different in electrical voltage(ΔP).

Stage 4: Define direction (P&O).

Stage 5: Increase or decrease the I_{MPP} and step size (ΔI) as determined by the formulation given:

$$I_{MPP} = I_{MPPnew} \pm \Delta I \qquad 3.20$$

To control the algorithm, we need to rise up the (ΔI) with multiply by 1 when it is at the left region of P_{MPP} otherwise lessen the step size with multiply by 2.

Stage 6: Update the following real value of V, I and P for the following sample period.

Stage 7: Estimate the error signal between I_{MPP} and I_{DC} and supplied to the PI controller.

The error signal is produced by comparing the actual current (IDC) from the rectifier with the reference current (IMPP) from the MPPT algorithm, as presented in Figure 20. Then, the error signal will be supplied to PI controller for regulation process and will produce the PWM to boost converter. The value for gain that has been used was shown in table 2.

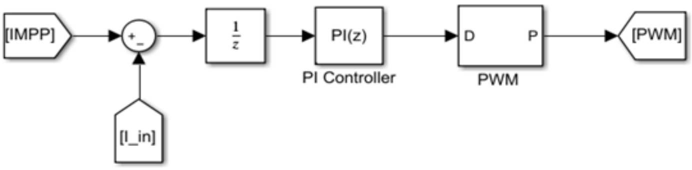

Figure 3.6 PI controller block diagram

In this system, a PI controller is used to analyze an error signal especially current that has been drawn from the rectifier and also MPPT algorithm to produce the PWM signal before it switch to boost converter.

Table 3.2 Gain value

Gain	**Value**
P	50
I	400

3.3 Software development

In these subtopics, the software developments are building. For designing the circuit topology, the first step is installing the Mat lab Simulink software. This is because the whole project starting from designing the hydrokinetic turbine, boost converter, voltage current filter and MPPT algorithm for hydrokinetic energy are based on Simulink software.

Figure 3.7	Matlab software

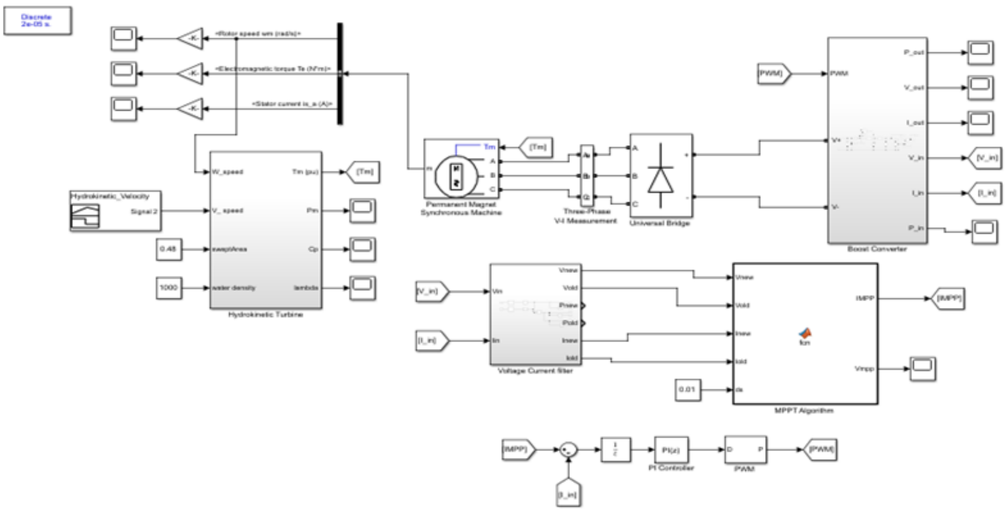

Figure 3.8	MHCS+PI circuit

Figure 3.8 shows the complete circuit for Modified Hill-Climbing Search algorithm in this research. It contain of four subsystems which are hydrokinetic turbine, voltage current filter, MPPT block function and also boost converter. The main input in this research is velocity of water. The investigation for hydrokinetic system based on the river is carried out by using the Mat lab/Simulink environment. In this study, there are two performances of indicator that will be considered. The main one are the capacity to track the maximum output power based on MPPT algorithm and the next are the ability to track the performance efficiency between HCS and MHCS+PI controller when there is fluctuation of the water.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this topic, it will discuss approximately the maximum energy harnessing and performance efficiency for the proposed MPPT algorithm in order to compare between Hill-Climbing Search (HCS) and Modified Hill-Climbing Search (MHCS+PI). The proposed algorithm will be tested for performance review if it achieve the target result which is dP/dD=0. At this point, the hydrokinetic will operates at ideal speed and power. But, the issue is the water velocity can't be determine because it be subject to the deepness of the river, geometries of the location and anymore. Because of this, the proposed methods are been introduced to solve the problems.

4.2 Calculation

To determine the maximum output power, the value from theory and simulation result need to be compare. All the value from simulation must be almost the same as theory otherwise it will incorrect data. So, to get the maximum power based on velocity of water, the formula is as below:

$$Pm = \frac{1}{2}\rho AV^{3}Cp \times 80\% \quad 4.1$$

Where 80% is the boost converter efficiency at worst according to Texas instrument.

Table 4.1 Calculation for output power (W)

Velocity of water (m/s)	Output power (W)
0.2	$Pm = \frac{1}{2} \times 1000 \times 0.48 \times 0.2^3 \times 0.46 \times 0.8 = 0.71$
0.4	$Pm = \frac{1}{2} \times 1000 \times 0.48 \times 0.4^3 \times 0.46 \times 0.8 = 5.65$
0.6	$Pm = \frac{1}{2} \times 1000 \times 0.48 \times 0.6^3 \times 0.46 \times 0.8 = 19.08$
0.8	$Pm = \frac{1}{2} \times 1000 \times 0.48 \times 0.8^3 \times 0.46 \times 0.8 = 45.22$
1.0	$Pm = \frac{1}{2} \times 1000 \times 0.48 \times 1.0^3 \times 0.46 \times 0.8 = 88.32$
1.2	$Pm = \frac{1}{2} \times 1000 \times 0.48 \times 1.2^3 \times 0.46 \times 0.8 = 152.62$
1.4	$Pm = \frac{1}{2} \times 1000 \times 0.48 \times 1.4^3 \times 0.46 \times 0.8 = 242.35$
1.6	$Pm = \frac{1}{2} \times 1000 \times 0.48 \times 1.6^3 \times 0.46 \times 0.8 = 361.76$
1.8	$Pm = \frac{1}{2} \times 1000 \times 0.48 \times 1.8^3 \times 0.46 \times 0.8 = 515.08$
2.0	$Pm = \frac{1}{2} \times 1000 \times 0.48 \times 2.0^3 \times 0.46 \times 0.8 = 706.56$

4.3 Result

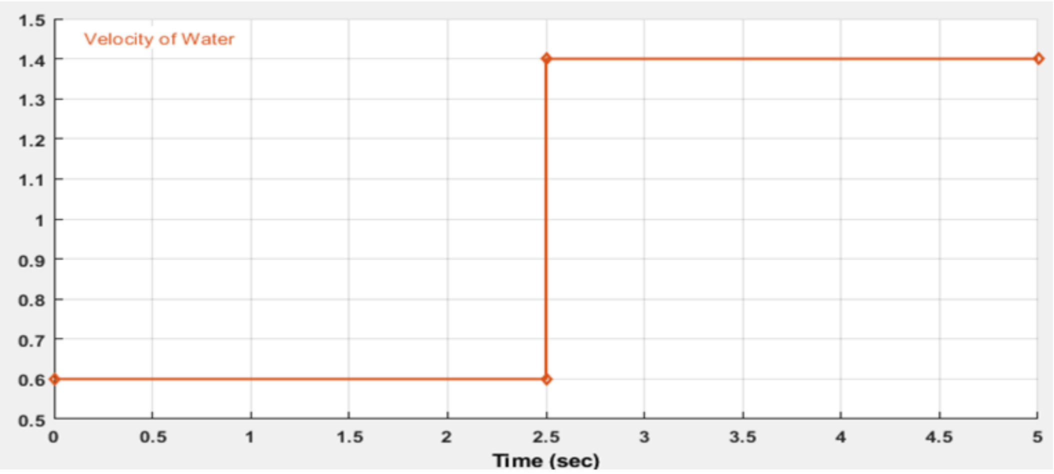

Figure 4.1 Input signal for hydrokinetic turbine

Figure 4.1 depicts the velocity of water (m/s) vs. of time (s). The velocity of water is approximately 0.6 m/s when the time (s) varies from 0 to 2.5s, and approximately 1.4 m/s when the time (s) varies from 2.5s to 5s. In this research, the water velocity from 0.2 m/s until 2.0 m/s has been used to capture the extreme output power due to oscillation of water.

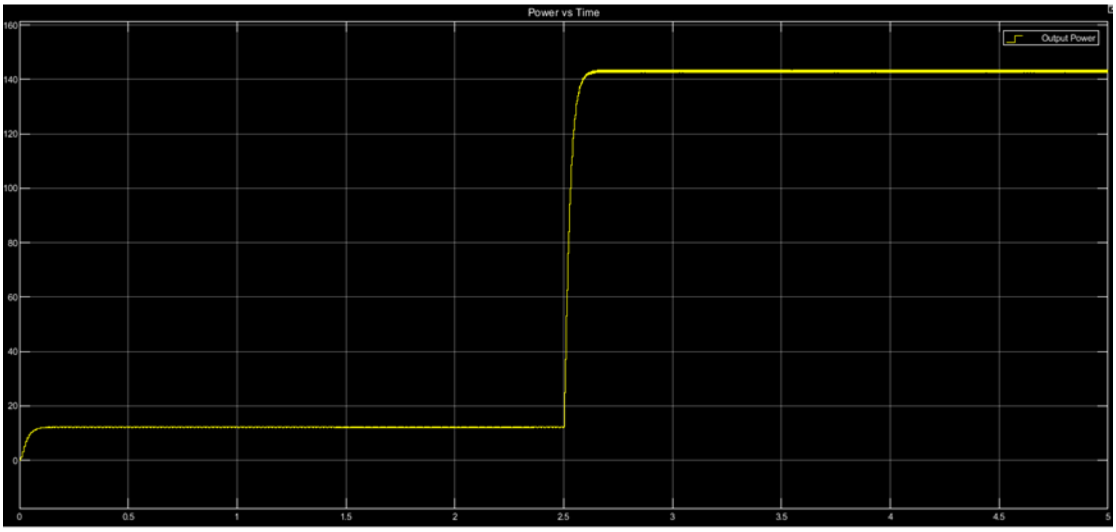

Figure 4.2 Output power for HCS at 0.6m/s and 1.4m/s

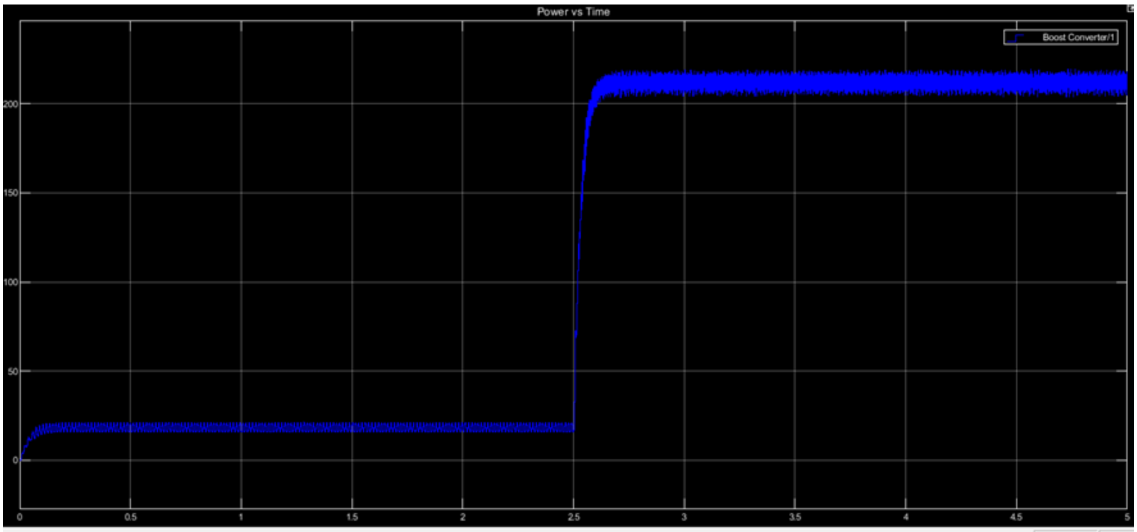

Figure 4.3 Output power for MHCS+PI at 0.6m/s and 1.4m/s

Figure 4.2 and figure 4.3 shows the maximum output power (W) that produced based on certain velocity of water. When the input signal (figure 4.1) of 0.6 m/s and 1.4 m/s was applied to the turbine, the output power for HCS (figure 4.2) are about 12.21 W and 142.90 W while for MHCS+PI (figure 4.3) got about 17.91 W and 216.50 W. Same as other data, when we applied 1.0 m/s and 2.0 m/s velocity of water, the output power for HCS are about 54.95W and 413.1W while for MHCS+PI we got about 76.03W and 558.7W. Both energy harnessing were demonstrated in figure 4.4 and 4.5 below. For the others data, used the same concept which are apply the different of input signal according to the targeted velocity of water to get the maximum output power thus can compared the performance efficiency between both MPPT algorithm.

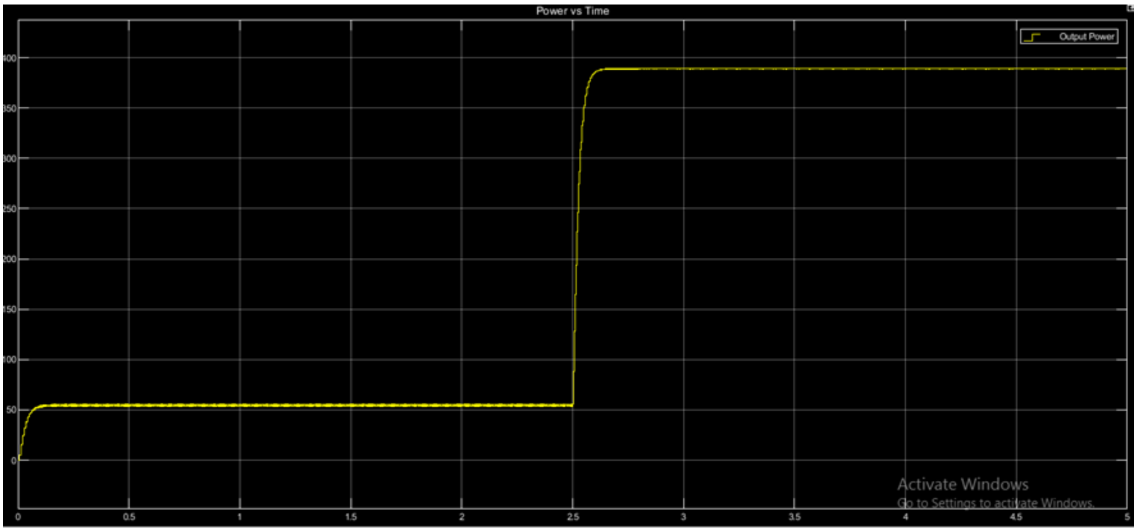

Figure 4.4 Output power for HCS at 1.0m/s and 2.0m/s

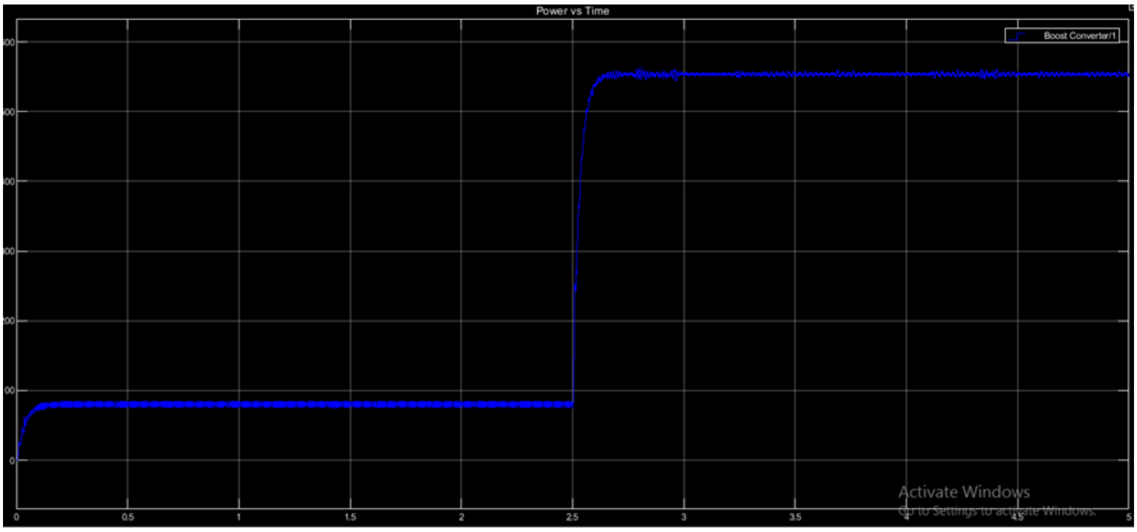

Figure 4.5 Output power for MHCS+PI at 1.0m/s and 2.0m/s

To find the performance efficiency used the formula as stated below:

$$\mathrm{Eff}(\%) = \frac{\mathrm{Pout}}{\mathrm{Ptheory}} \times 100 \qquad 4.2$$

Where Pout is the output power (W) from the simulation of HCS and MHCS+PI.

Table 4.2 Energy harnessing and performance efficiency for HCS and MHCS+PI

Velocity of water (m/s)	**Theory**	**HCS (W)**	**MHCS+PI (W)**	**HCS (%)**	**MHCS+PI (%)**
0.2	0.71	0.38	0.61	54.3	85.88
0.4	5.65	3.49	5.63	61.71	99.66
0.6	19.08	12.21	17.91	64.0	93.88
0.8	45.22	28.33	39.64	62.65	87.66
1.0	88.32	54.95	76.03	62.22	86.08
1.2	152.62	91.45	138.60	59.92	90.82
1.4	242.35	142.90	216.50	58.96	89.33
1.6	361.76	221.80	305.40	61.31	84.42
1.8	515.08	310.20	417.20	60.22	81.00
2.0	706.56	413.10	558.70	58.47	79.07

Based on table 4.2 above, it shows all the maximum energy harnessing and performance efficiency between both algorithm according to the different velocity of water. From this table, MHCS+PI can harness more energy compared to the HCS algorithm.

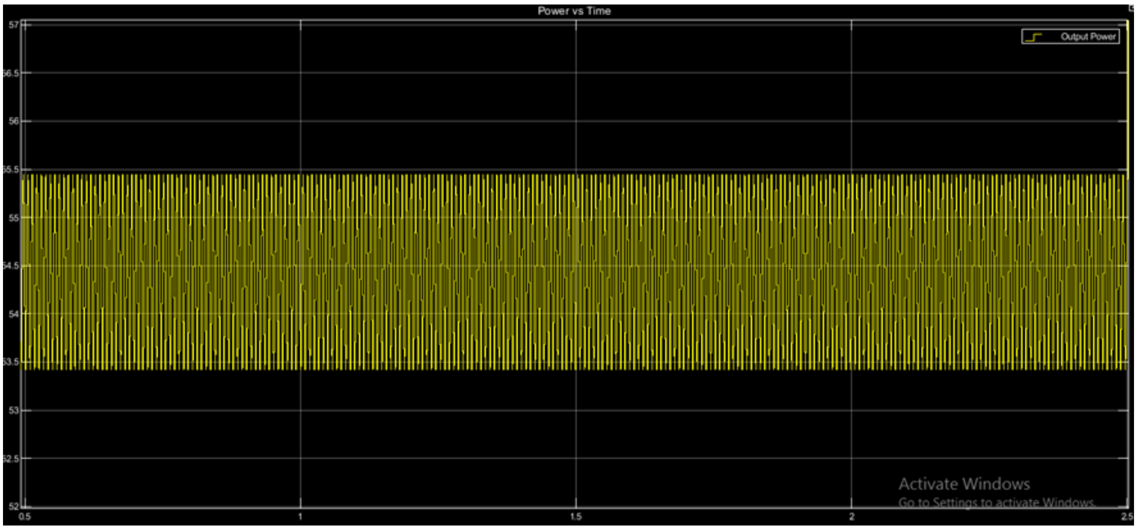

Figure 4.6 Oscillation of HCS algorithm

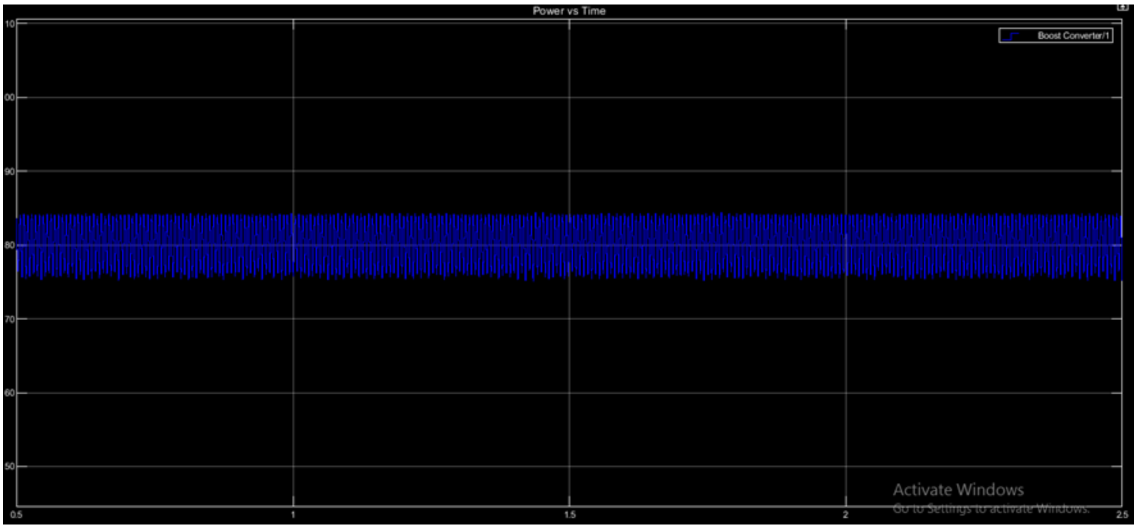

Figure 4.7 Oscillation of MHCS+PI algorithm

From the figure 4.6 and 4.7 above, oscillation of water plays a significant role in determining the amount of power that can be generated by a turbine. When the fluctuation is too high, then more power loss will occur. Therefore, by proposed this MPPT algorithm, the rate of fluctuation in water has been reduced in turn able to increase the power to the maximum.

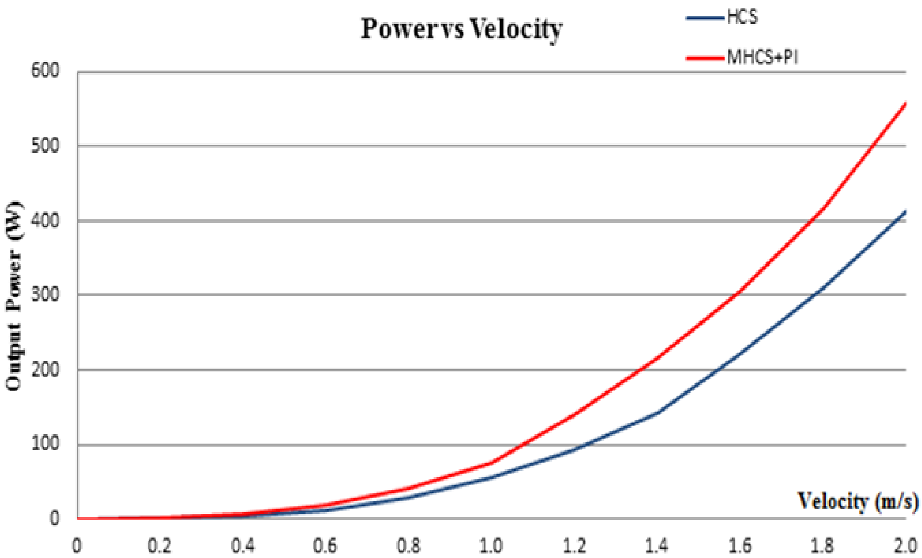

Figure 4.8 Comparison of output power between HCS and MHCS+PI algorithm

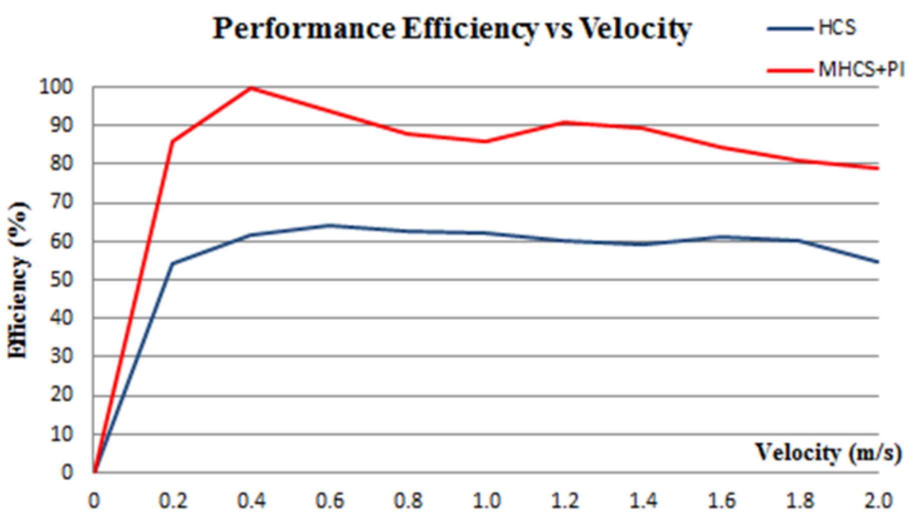

Figure 4.9 Comparison of performance efficiency between HCS and MHCS+PI algorithm

Based on the result above, MHCS+PI controller can harness the energy between 0.61W and 558.7W with 87.78% efficiency compared to HCS which can harness the energy between 0.38W and 413.1W with 60.38% efficiency. This shows that the proposed algorithm can harness higher energy under variyng and turbulent of water flow conditions. Thus, the result achieves the objective of the project which are to compare energy harnessing and performance efficiencies between HCS and MHCS+PI MPPT algorithm.

CHAPTER 5

CONCLUSION

5.1 Conclusion

In a nutshell, after doing study on the topics of hydrokinetic energy harnessing, we have gained a better understanding of the MPPT algorithm and its challenges related to the development process for producing effective power as well as their performances. Aside from that, because hydrokinetic energy does not require a dam or high water velocity to rotate the blade/turbine, so no sensor is required to calculate the water velocity and operate of the permanent magnet synchronous generator (PMSG). For the proposed MPPT, a controller has been considered to control the rotation of the turbines to extract maximum energy in varying and turbulent of water flow conditions. The end result demonstrated hydrokinetic turbine can harness between 0.61W and 558.7W with 87.78% efficiency by MHCS+PI algorithm. Furthermore, installing the hydrokinetic along a high water velocity can cause the rotor to break as well as the permanent magnet because high speeds will produce the heat. The physical part of a product's design must be fully realised.

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APPENDIX A
GANTT CHART

No.	Task Description	Mar 2021	April2 021	May 2021	Jun 2021	July 2021	Aug 2021	Sep 2021	Oct 2021	Nov 2021	Dec 2021	Jan 2022	Feb 2022
1	PSM briefing, introduction of project, literature review, methodology	■	■										
2	First general evaluation PSM 1(10%), research progress,preliminary result		■	■	■								
3	PSM 1 seminar, logbook and report submission				■								
4	Matlab simulation, design circuit, testing software					■	■	■	■	■	■		
5	First general evaluation PSM 2(10%)										■		
6	-Generate Matlab code, analysis simulation result such as Output power, efficiency, MPPT oscillation -Prepare slide for presentation								■	■	■	■	
7	Exselen presentation for PSM 2											■	
8	Thesis writing											■	■
9	Final thesis and logbook submission												■