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CONTROL SYSTEM OF PERMANENT MAGNET GENERATOR USING COMPACTRIO FOR SHRE TURBINE

AZIMI BIN CHE SOH

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CONTROL SYSTEM OF PERMANENT MAGNET GENERATOR USING COMPACTRIO FOR SHRE TURBINE

By

AZIMI BIN CHE SOH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Master of Science

November 2018

DEDICATION

To my wife and children, for her endless support and encouragement.

To my siblings.

And…

To my parents,

Che Soh bin Che Mohd Amin,

Wan Eshah binti Wan Ismail

for inspiring me to pursue my dreams

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Masters of Science

CONTROL SYSTEM OF PERMANENT MAGNET GENERATOR USING COMPACTRIO FOR SHRE TURBINE

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AZIMI BIN CHE SOH

November 2018

Chairman : Dr. Noor Izzri b. Abdul Wahad, PhD
Faculty : Engineering

The SHRE Turbine Generator is developed for one of the alternate applications in remote and rural areas in Sarawak. This system fits the purpose of supplying power electricity based on green energy concept. The turbine floats on the river by pontoons, supported with an anchor system to ensure that the system is sustainable. Additionally, it is equipped with 8 flipping set blades with a complete transmission system including a Permanent Magnet Generator (PMG). Due to money constraints, the 8 Servo motor was replaced with the PMG as an actuator for the controller testing not including the system start-up, shutdown, or supervisory control. It is assumed that the required load is always available for control purposes. The 8 PMG array on the pontoon was on 100% efficiency and the integration between 8 set conversion systems (consisting the AC/DC/AC conversion) should be done. Thus, system monitoring, proper enclosures, processor power, required memory and related concerns are not addressed. The SHRE turbine generator is a hybrid system with the combination of Hydrokinetic System, PV Solar System and stand-alone Diesel Generator (SAD) system and excludes a power storage element. PV Solar energy will be energized at the day time, while the diesel generator (SAD) to be triggered at night time as an supporting energy to the Hydrokinetic System especially when river velocity below than 2.0m/s. The Hydrokinetic System is able to meet any requirement load demand without supporting from PV Solar and SAD if the river velocity over then 2.0m/s.

This contributions study outline the development of multiple system turbines cascading 8 PMG from a previous project used in detail to prove that the Intelligent Permanent Magnet Generator Network Control (iPMGNC) control system is workable. It starts from an analysis performance based on LabVIEW software simulation, followed by the parameter measurement and integration between local host (computer) and compactRio, and the implementation of the control strategies/ algorithm on the SHRE Turbine system by using the ac motor simulator. All the controller objectives and strategy were highlighted for: automatically rotating for 8 PMG based on region graph; controller design; the robust CompactRio embedded system; and the smart

system protection from rotor over speed under abnormal conditions where it is necessary to avoid the PMG damage.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia Sebagai memenuhi keperluan untuk ijazah Master Sains

SISTEM KAWALAN UNTUK JANAKUASA MAGNET KEKAL DENGAN MENGGUNAKAN COMPACTRIO UNTUK SHRE TURBINE

Oleh

AZIMI BIN CHE SOH

November 2018

Chairman : Dr. Noor Izzri b. Abdul Wahad, PhD
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Sistem Janakuasa Turbin SHRE telah dibangunkan sebagai satu sumber bekalan tenaga alternatif untuk komuniti penduduk di kawasan pendalaman di Kapit Sarawak. Sistem ini sesuai untuk tujuan membekal tenaga elektrik berasaskan konsep tenaga hijau. Turbin diapungkan di atas sungai dengan menggunakan sistem apungan pontun, yang disokong dengan sistem penambat untuk memastikan sistem Janakuasa SHRE boleh bertahan lama. Disamping itu, sistem janakuasa ini dilengkapi dengan 8 set turbin jenis membalik-lipat yang lengkap dengan sistem transmisi termasuk Janakuasa Magnet Kekal (PMG). Disebabkan kekangan kewangan, sebanyak 8 unit servo motor telah digunakan sebagai ganti kepada PMG untuk dijadikan sebagai pengerak untuk pengujian sistem pengawal dan tidak termasuk sistem pemula, sistem penutup, atau sistem pengawalan penyeliaan. Dengan beranggapan bahawa kehendak beban yang diperlukan adalah sentiasa tersedia untuk tujuan kawalan. Sebanyak lapan set janakuasa (PMG) yang disusun di atas pontun dengan kecekapan sebanyak 100% dan integrasi dengan 8 set sistem penukar (yang terdiri daripada penukar AC/DC/AC) perlu dilakukan. Oleh itu, pemantauan sistem, penutup yang sesuai, kuasa pemproses, memori yang diperlukan dan kebimbangan yang lain tidak ditangani. Sisten janakuasa SHRE adalah merupakan sistem hibrid dengan gabungan antara Sistem Solar PV, Sistem Hydrokinetic dan sistem Janakuasa Diesel (SAD) dan tidak termasuk sistem simpanan tenaga. Tenaga Solar PV akan beroperasi pada waktu siang hari, manakala sistem SAD akan beroperasi ketika waktu malam sebagai tambahan tenaga kepada sistem hidrokinetic terutama ketika halaju arus sungai dibawah 2.0 m/s. Pada kelajuan arus sungai melebihi 2.0m/s sistem hidrokinetik berupaya untuk memenuhi kehendak beban tanpa sokongan terhadap sistem Solar PV dan janakuasa diesel (SAD).

Kajian ini menggariskan perkembangan sistem turbin berganda menggunakan 8 set PMG dari projek terdahulu yang telah digunakan secara terperinci untuk membuktikan bahawa sistem kawalan terhadap Kawalan Rangkaian Janakuasa Magnet Kekal (iPMGNC) boleh digunakan. Ia bermula daripada prestasi analisis berdasarkan simulasi perisian LabVIEW, diikuti dengan pengukuran parameter dan integrasi antara

host tempatan (komputer) dan *compactRio*, dan perlaksanaan strategi kawalan/ algoritma pada sistem janakuasa turbin SHRE dengan menggunakan simulator motor ac. Semua objektif dan strategi pengawal difokuskan untuk: secara automatik putaran untuk 8 PMG berdasarkan graf rantau; rekabentuk pengawal; sistem dalaman CompactRio yang mantap; dan perlindungan sistem yang pintar daripada putaran rotor yang terlalu laju dibawah keadaan yang tidak normal di mana ianya amat diperlukan untuk elak PMG daripada rosak.

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My loving thanks to my family for their greatest support, motivation and love in the completion of this project. Last but not least, a bunch of thanks to all my friends and those who are involved directly or indirectly in helping me to complete this project for all their kindly support, assistance and suggestions.

I certify that a Thesis Examination Committee has met on 22 November 2018 to conduct the final examination of Azimi B. Che Soh on her thesis entitled "Control System of Permanent Magnet Generator Using CompactRio for SHRE Turbine" in accordance with the Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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This is to confirm that:

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LIST OF ABBREVIATIONS

PR	Power Regulation
LC	Load Consumption
PMG	Permanent Magnet Generator
PV	Photovoltaic
SAD	Stand-alone Diesel
iPMGNC	Intelligent PMG network controller
JKR	Jabatan Kerja Raya (Public Work Department)
RE	Renewable Energy
REHS	Renewable Energy Hybrid System
SRES	Stand-alone Renewable Energy
TS	Transmission System
CFT	Cross Flow Turbine
WB	Work Bundle
SHRE	Sustainable Hydrokinetic Renewable Energy
NI	National Instrument
MC	Magnetic Clutch
ADCP	Acoustic Doppler Current Profiler

CHAPTER 1

INTRODUCTION

1.1 Background

A major concern for remote areas in Malaysia such as Sarawak is access to electricity. The cost involved in transporting power from large hydroelectric plants to these remote areas is often very high. Extending thousands of kilometres of grid cables across the jungle only to provide electricity for a small village is absurd and impractical in economic terms. To find the solution to this problem, researchers and policy makers are turning to renewable and green energy. Currently, hydrokinetic projects are popular because the course of action has been proven to be a low-cost solution in generating electricity. The hydrokinetic system is suitable for supplying electric power to desolate and hilly areas. With water being the most abundant element on earth, hydrokinetic technology has been identified as one of the most viable and well-conceived alternatives to generate renewable energy, serving as a valuable alternative to diesel-generators apart from photovoltaics.

In May 2010, Jabatan Kerja Raya (JKR) commenced a research project to study the possibility of extracting energy to cater for the electrical consumption by schools and longhouses in Lepong Gaat, Kapit, Sarawak. The initial site survey was carried out by JKR and University Malaysia Sarawak (UNIMAS). Based on the results of the site survey, JKR came up with a prototype turbine called JARIMAS turbine, as shown in Figure 1 below. Based on the operational concept of the Sustainable Hydrokinetic Renewable Energy (SHRE) project and the original design by JARIMAS, a minimum value of 1.5 m/s river flow is required to rotate the turbine beneath the water in order to generate 5 kW of power. The maximum river flow should be 2.9 m/s to ensure the safety operation of the turbine and to avoid over-rotation of the generator speed revolution per minute (rpm). The results also show that energy extraction increases with water velocity where the rpm reading of the designed turbine depends on water velocity (JKR Malaysia and UNIMAS, 2010). Therefore, there are strong considerations for the conduct of studies in order to locate, monitor, and estimate the river flows which are most suitable for the turbine placement.

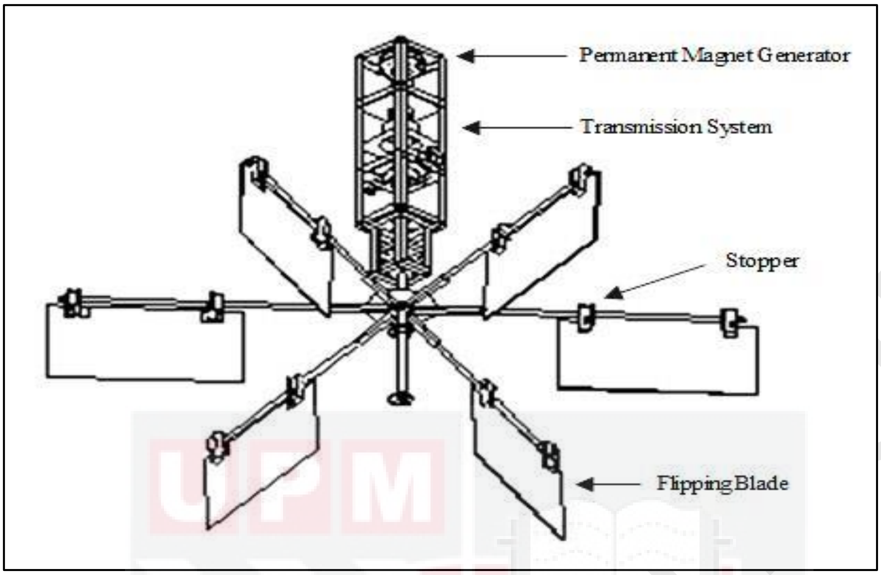

Figure 1.1: JARIMAS Prototype Turbine

Based on the JARIMAS design, the kinetic energy from the river current is transferred to a set of turbine blades, connected to the main shaft by a hub to the generator shaft to produce electricity of 1.8 kW per turbine. The target outcome is for the JARIMAS turbine to generate 3.6 kW of electricity for schools and long houses in the remote community area at Nanga Gaat, Kapit, Sarawak. For purposes of lowering maintenance costs and given the unstable condition of the river water level throughout the year, JKR decided to build four sets of JARIMAS turbines on two sets of pontoon, as illustrated in Figure 1.2 below.

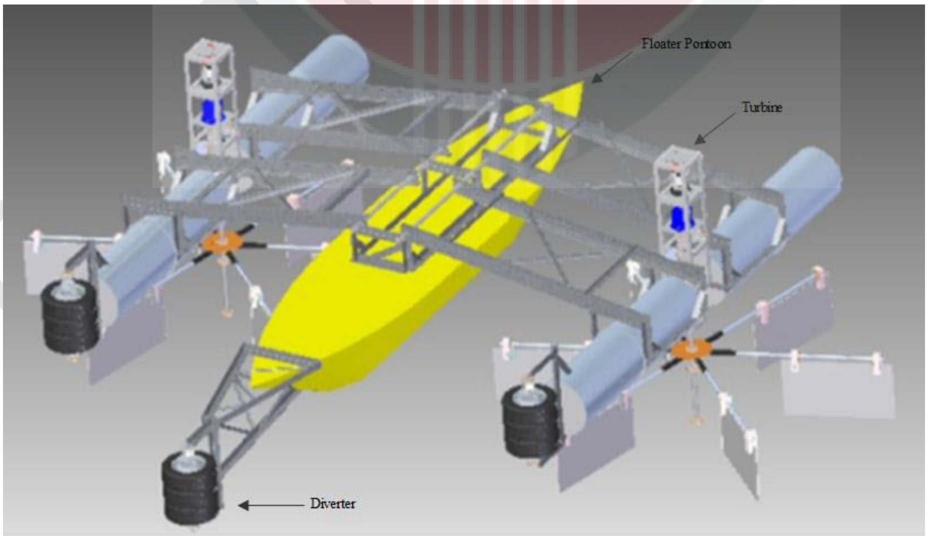

Figure 1.2: A Pair of JARIMAS Turbine on Pontoon

To continue the previous JARIMAS study, JKR has to take up the challenge of producing and upgrading the electrical power generation from 3.6 kW to 40 kW for the benefit of the remote community areas in Kapit, Sarawak. The SHRE turbine system has been designed as a floating structure (pontoon) that is equipped with generators and electronic equipment and can be mobilized everywhere along the river. Turbine systems will be installed and placed in the interior territories of Sarawak to integrate them with the existing Diesel Generator system; in terms of cost effectiveness, supporting the full operation of the generator has proven to be very expensive.

1.2 Problem Statement

Several alternatives are currently being explored to reduce the overall running cost of generating electrical energy in remote areas. One of the feasible solutions is to replace the fuel power generator with renewable energy from river streams. The implementation of regenerative energy solutions such as solar, micro-hydro, and hydrokinetic power systems would be the best way to reduce the running cost of operating power generators. To enable widespread adoption of this technology, a sustainable, robust and intelligent system must be in place to maintain the source energy supply, especially to the remote areas.

The hybrid power generation system based Hydrokinetic SHRE Turbine technology and PV Solar system developed by JKR is the pioneer project in Malaysia even worldwide. Previous studies related hydrokinetic worldwide are deeply focused on development of hydrokinetic turbine blade (Güney & Kaygusuz, 2010; Khan et al., 2009; Khan, Iqbal, & Quaicoe, 2006; Vermaak et al., 2014), the potential of target site study (Behrouzi, Nakisa, Maimun, & Ahmed, 2016; Blanco, Junior, Figueiredo, & Negr, 2017; Borhanazad et al., 2013; Lalander, Grabbe, & Leijon, 2013; Previsic & Bedard, 2008), the performance analysis study of hydrokinetic system (Koko, Kusakana, & Vermaak, 2014; Kunaifi, 2009; Kusakana & Vermaak, 2013) and the estimated water velocity study for hydrokinetic study (C. Blanko, 2017; Almalik Faisel et al. 2018).

Till present, clearly shown no research yet that had been found regarding the control strategy and protection system for power generation of hydrokinetic system. Also, purpose built control system simply does not exist using the LabView software and CompactRio controller in hydrokinetic study. So, a complete study to analyse and identify the best algorithms for the 8 PMG hydro and hybrid systems are required to ensure that those components can operate smoothly in a stable and sustainable manner.

1.3 Research Objective

The main objective of the project is to design and develop a control system of PMG network using CompactRio for SHRE project. The following activities will be carried out in order to achieve the main objective:

1. To propose a control system algorithm modelling and implement the simulation techniques for mock up embedded systems between Labview and Compactrio.

2. To validate and analyse control strategy using software and hardware controller.

3. To propose and simulate a new power output reducer to protect PMG in hydrokinetic turbine using the system profile lookup table.

1.4 Research Scope and limitation

The scope of this research work is limited to the development of a turbine speed control algorithm suitable for the entire range of operation using the 8 PMG. Due to financial constraints, the 8 Servo motor replaces the PMG as an actuator for the controller testing not including system start-up, shutdown, or supervisory control. It is assumed that: (i) the required load is always available for control purposes; (ii) the 8 PMG array on the pontoon has 100% efficiency; and (iii) integration between the 8 sets of conversion system (consisting of the AC/DC/AC conversion) has been done. Thus, issues concerning system monitoring, proper enclosures, processor power, required memory, and related concerns are not addressed. The scope of the project is set out below:

- A complete CompactRio embedded system with National Instrument product will be designed and tested in a laboratory environment to control the mock up and validate an algorithm of intelligent permanent magnet generator network control (iPMGNC).

- Simulation using the LabView programs (VIs) to design the wireless acquisition of signal from sensors and to command the actuator of conveyer.

- A smart system to protect PMG during unstable weather conditions by cutting off the whole system or interchanging it with the existing systems.

1.5 Research Contributions

The contribution of this research is limited to the development of a turbine speed control algorithm which would be suitable for the entire range of hydrokinetic turbine operations. A set of control objectives and a control strategy are defined to manage the 8 PMG. Also, the contribution allows for system monitoring and adaptation as required to minimise risk of damage to the system.

The design of system iPMGNC controller has taken into account factors of ruggedness, robustness, and reliability to be implemented in the remote areas due to the integration between Labview software and Compactrio hardware. Thus, the control strategy system is formed based on a hybrid system.

1.6 Thesis Outline

This thesis is organised as follows:

Chapter 1 presents an introduction to the research including problem statement, objectives, scope of work, and its limitations.

Chapter 2 discusses the literature review regarding hydrokinetic turbine speed control systems. The chapter explores the various techniques and a small number of papers linked to this topic. It examines the closely related technology of wind turbine variable speed control and also delves into the current method of remote community electrification. This chapter ends with a summary and some proposals on how to further improve the system.

Chapter 3 deals with the modelling of iPMGNC for the SHRE turbine. The research turbine and related control hardware (power conversion hardware and industrial real-time controller) used for the field work portion of this research are also outlined, followed by details of the test site. The modelling will be extensively done on LabVIEW platform in communication with the robust instrument, CompactRio. Algorithm and real conditions are addressed in the controller. The methods of modelling and estimating the parameters are also elaborated. Finally, every condition and parameter between model simulations and experimental are conducted for validation.

Chapter 4 presents the results of the modelling based on every condition. The performance of these techniques are compared and examined based on several circumstances. Subsequently, the results with the variation of parameter selection on LabVIEW modelling are also included in this chapter for the purpose of analysing the performance of the proposed techniques.

Chapter 5 summarises the findings and conclusions of the research. Recommendations for future works are also explored.

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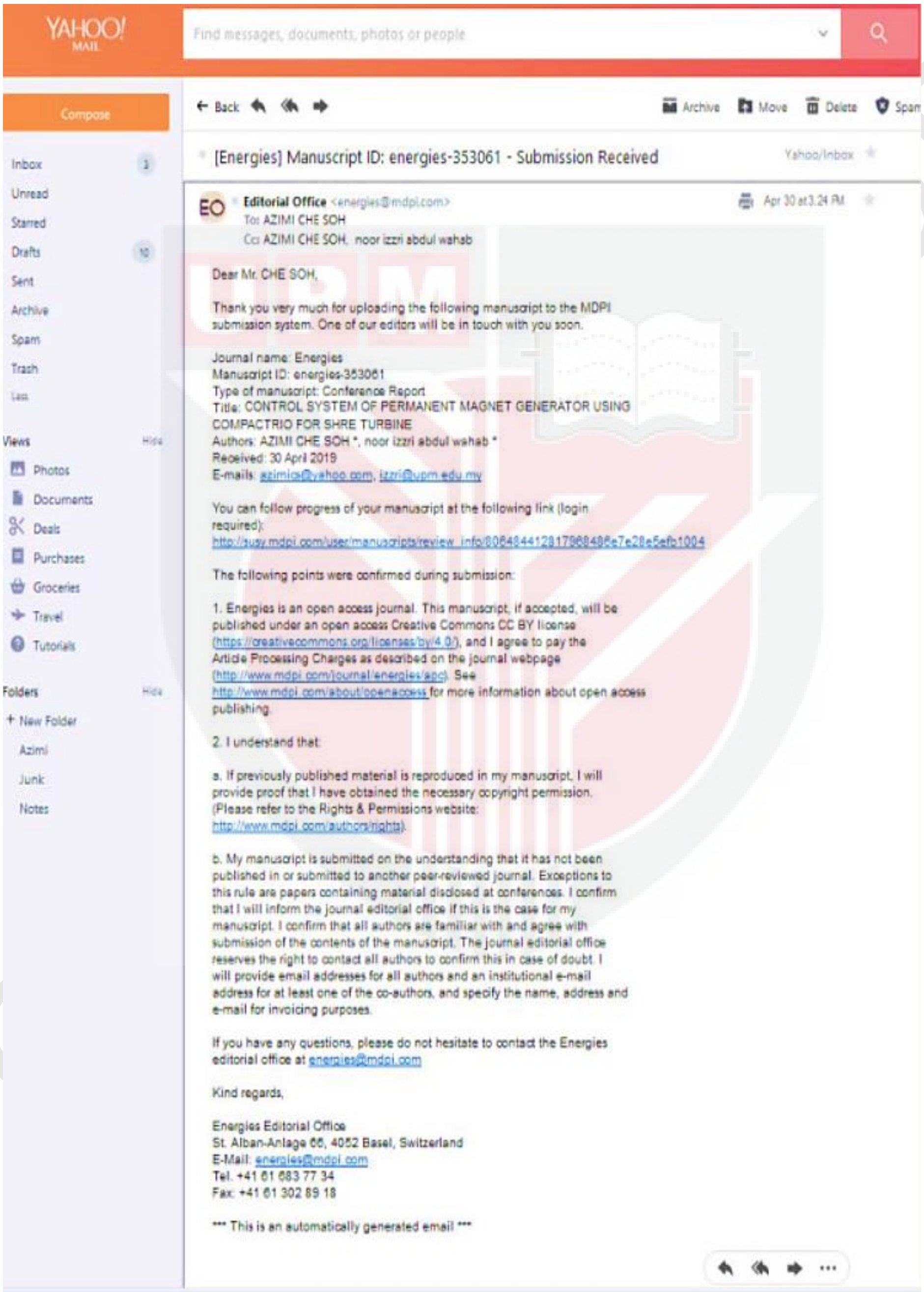
LIST OF PUBLICATIONS

Submitted: Control System of Permanent Magnet Generator Using Compactrio for SHRE Turbine



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