UNIVERSITI PUTRA MALAYSIA

PERFORMANCE ANALYSIS OF HYDROKINETIC HYBRID SYSTEM WITH WATER VELOCITY ESTIMATION TECHNIQUE FOR RURAL ELECTRIFICATION IN EAST MALAYSIA

ALMALIK FAISEL BIN MOHD SAUPI

FK 2019 25

PERFORMANCE ANALYSIS OF HYDROKINETIC HYBRID SYSTEM WITH WATER VELOCITY ESTIMATION TECHNIQUE FOR RURAL ELECTRIFICATION IN EAST MALAYSIA

By

ALMALIK FAISEL BIN MOHD SAUPI

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

November 2018

DEDICATION

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

To my siblings.

And…

To the memory of my parents,

Mohd Saupi bin Yusoff (1953-1980),

Bidah bt Deraman (1953 -2003)

"May Allah bless them..."

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 Master of Science

PERFORMANCE ANALYSIS OF HYDROKINETIC HYBRID SYSTEM WITH WATER VELOCITY ESTIMATION TECHNIQUE FOR RURAL ELECTRIFICATION IN EAST MALAYSIA

By

ALMALIK FAISEL BIN MOHD SAUPI

November 2018

Chairman : Nashiren Farzilah binti Mailah, PhD
Faculty : Engineering

The electricity coverage in Sarawak is the lowest compared to Sabah and Peninsular Malaysia at 78.74%, 82.5% and 99.62%, respectively. Majority of the population (84.4%) in the Kapit District, Sarawak resided in rural areas and mostly situated along the main riverbanks has great potential to generate electrical energy with a hydrokinetic system. Yearly water velocity data is the most significant parameter to perform a hydrokinetic analysis study. Nevertheless, the data retrieved from local river databases are inadequate for river energy analysis, thus hindering its progression. Instead, flow rates and rainfall data had been utilised to estimate the water velocity data. To date, there is still no study that has been found on estimating of water velocity data in unregulated river using water level. Therefore, a novel technique of estimating the daily average water velocity data in unregulated rivers is proposed. The modelling of regression equation for water velocity estimation on-site was performed. Two regression model equations were generated to estimate water level and water velocity on-site. They were proven to be valid as the Coefficient of Determination (R^2) values 87.4% and 87.9%, respectively. The combination of both regression model equations can be used to estimate long term time series water velocity data for type-C unregulated river in rural areas. Six data sets of daily average water velocity data throughout the year was estimated on-site from 2010 to 2015 using 6 years of water level data taken from hydrological stations upstream. The Hydrokinetic-PV solar-Diesel-Battery hybrid system model was simulated using Hybrid Optimization Model for Renewable Electric (HOMER) software using six years of estimated water velocity data on-site. From the simulation results, it can be concluded that the Hydrokinetic-PV solar-Battery hybrid system is more economical than other hybrid systems. This is especially in terms of using 100% renewable energy resources with the lowest of Cost of Energy (COE). The COE of this hybrid system is 62% lower than the existing stand-alone diesel generator in any other state of the water velocity. However, if 10% of energy shortage is allowable per year, the COE of proposed hybrid system is 73% lower than COE of

existing diesel generator. It clearly shows that the Hydrokinetic-PV solar-Battery hybrid system is the best solution for the remote school electrification and is able to eliminate the use of existing diesel generators.

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

ANALISA PRESTASI SISTEM HIBRID HYDROKINETIC DENGAN TEKNIK ANGGARAN HALAJU AIR UNTUK BEKALAN ELEKTRIK LUAR BANDAR DI MALAYSIA TIMUR

Oleh

ALMALIK FAISEL BIN MOHD SAUPI

November 2018

Pengerusi : Nashiren Farzilah binti Mailah, PhD
Fakulti : Kejuruteraan

Liputan pengunaan tenaga elektrik di Sarawak adalah yang paling rendah jika dibandingkan dengan Sabah dan Semenanjung Malaysia iaitu masing-masing 78.74%, 82.5% dan 99.62%. Majoriti penduduk (88.4%) di Daerah Kapit Sarawak adalah tinggal di kawasan luar bandar dan kebanyakannya menetap di sepanjang tebing sungai utama adalah sangat berpotensi untuk menjana tenaga elektrik dengan menggunakan sistem hidrokinetik. Data halaju air tahunan adalah merupakan parameter yang paling utama untuk menjalankan kajian analisis hydrokinetik. Walau bagaimanapun, data yang diambil daripada pangkalan data stesen hidrologi tempatan adalah tidak mencukupi untuk melakukan analisis tenaga menggunakan arus sungai, sekali-gus menghalang perkembangannya di dalam kajiannya. Sebaliknya, data kadar aliran sungai dan data hujan telah digunakan untuk menganggarkan data halaju air. Sehingga kini, masih belum dijumpai sebarang kajian mengenai pengiraan data halaju air untuk sungai aliran bebas dengan menggunakan paras air. Oleh itu, satu teknik baru untuk menganggarkan data purata harian air dalam sungai aliran bebas adalah dicadangkan. Pemodelan persamaan regresi untuk menganggar halaju air di tapak telah dilakukan. Dua persamaan model regresi dihasilkan untuk menganggarkan paras air dan halaju air di tapak. Kedua-dua persamaan regrasi tersebut terbukti sah kerana nilai Pekali Penentuan (R^2) adalah masing-masing 87.4% dan 87.9%. Gabungan kedua-dua persamaan model regresi boleh digunakan untuk menganggarkan data halaju air siri jangka masa panjang untuk sungai aliran bebas jenis-C di kawasan pedalaman. Sebanyak enam set data purata air harian sepanjang tahun telah dianggarkan di tapak dari tahun 2010 hingga 2015 dengan menggunakan data paras air yang diambil dari stesen hidrologi di bahagian hulu sungai. Model sistem hibrid Hidrokinetik-Solar PV-Diesel-Bateri telah disimulasikan dengan menggunakan perisian HOMER dengan menggunakan data halaju air anggaran selama enam tahun di tapak. Dari keputusan simulasi, dapat disimpulkan bahawa sistem hibrid Hidrokinetik-Solar PV-Bateri adalah lebih ekonomik berbanding dengan sistem hibrid yang lain. Terutama

sekali dari segi pengunaan sepenuhnya (100%) sumber tenaga boleh diperbaharui dengan kos tenaga (COE) yang paling rendah. COE bagi sistem hibrid ini adalah 62% lebih rendah berbanding dengan penjana diesel yang sediada di dalam apa jua situasi halaju air. Walau bagaimanapun, jika 10% kekurangan tenaga tahunan dibenarkan di dalam sistem hibrid ini, COE sistem hibrid yang dicadangkan ini adalah 73% lebih rendah berbanding COE oleh penjana diesel sedia ada. Ianya jelas menunjukkan bahawa sistem hibrid Hidrokinetik-Solar PV-Bateri adalah penyelesaian terbaik untuk bekalan elektrik di sekolah-sekolah di kawasan luar bandar dan mampu untuk menamatkan penggunaan penjana diesel sedia ada.

ACKNOWLEDGEMENTS

In the name of Allah S.W.T, the most Compassionate and the most Merciful;

Praise be to Allah, which has given me the strength, patient, guiding and opportunity to successfully completed this thesis

It would not have been possible to write this thesis without the help and support of some people. I would like to express my sincere gratitude and endless thanks to my supervisor, Dr. Nashiren Farzilah Binti Mailah for her guidance, advice, encouragement and continuous support to accomplish this research successfully. Besides, I would like to express my appreciation to my co-supervisor, Assoc. Prof. Dr. Mohd Amran bin Mohd Radzi for their assistance and suggestion to improve my research. Theirs advices have been abundantly helpful all the time of research. He has been one of the most punctual people that I ever met.

Moreover, I would like to thank the other members of supervisory committee, Dr. Norhafiz bin Azis, Assoc. Prof. Ir. Dr. Mohammad Lutfi bin Othman and Assoc. Prof. Dr Jeyraj a/l Selvaraj for their precise comments and guidance.

I certify that a Thesis Examination Committee has met on 16 November 2018 to conduct the final examination of Almalik Faisel bin Mohd Saupi on his thesis entitled " Performance Analysis Of Hydrokinetic Hybrid System With Water Velocity Estimation Technique For Rural Electrification In East Malaysia" in accordance with the Universities and University Colleges 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 Master of Science.

Members of the Examination Committee were as follows:

Norhafiz bin Azis, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohammad Lutfi bin Othman, PhD
Associate Professor, Ir.,
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Jeyraj a/l Selvaraj, PhD
Associate Professor
Faculty of Engineering
University of Malaya
Malaysia
(External Examiner)

_____
RUSLI HAJI ABDULLAH, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 31 January 2019

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

Nashiren Farzilah binti Mailah, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Amran Mohd Radzi, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Norman bin Mariun, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

_____
ROBIAH BINTI YUNUS, PHD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012; there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: _____ Date: _____

Name and Matric No.: Almalik Faisel bin Mohd Saupi (GS39256)

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____

Name of Chairman of Supervisory Committee: Dr. Nashireh Farzilah binti Mailah

Signature: _____

Name of Member of Supervisory Committee: Associate Professor Dr. Mohd Amran bin Mohd Radzi

Signature: _____

Name of Member of Supervisory Committee: Professor Dr. Norman bin Mariun

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

LPSP	Loss of Load Supply Probability
CO	Carbon Monoxide
CO2	Carbon Dioxide
LPG	Liquid Petrol Gas
TNB	Tenaga Nasional Berhad
UNIMAS	University Malaysia Sarawak
PWD	Public Work Departmen
JARIMAS	JKR Applied Research University Malaysia Sarawak
GUI	Graphic User Interface
GA	Generic Algorithm
iHOGA	improved Hybrid Optimization by Genetic Algorithms
PQA	Power Quality Analyzer
km	Kilometre
R2	Coefficient of Determination
Sig.	Significant
r	Coefficient of Correlation
P	Significant Level
RA	Regression Analysis
ADCP	Acoustic Doppler Current Profiler
SFM	Surface Floating Method
GI	Galvanized Iron
PVC	Polyvinyl chloride

CHAPTER 1

INTRODUCTION

1.1 Background

It is apparent that electricity is one of the basic necessities apart from clean water supply, heat and light from the sun, food, medical and transport facilities in order to survive the contemporary world. However, in order to supply and electrify small rural communities by way of distributing and stepping down the high voltage power lines along inhabitable areas are uneconomical and impractical in terms of initial and maintenance costs (Anyi, Kirke, & Ali, 2010; Vermaak, Kusakana, & Koko, 2014). As a consequence, diesel generators have become favorable to the communities to electrify the residential houses and schools due to them being cheap and offers the most durability and reliability in supplying electrical power (Anyi et al., 2010; Vermaak et al., 2014). However, these diesel generators also have some drawbacks such as: noise and air pollution; too heavy and difficult to carry to the rural areas; high cost of energy per kilowatt hour; and having expensive operating and maintenance costs for the rural area people, which mainly consists of low-paid workers such as fishermen and farmers (Ahlborg & Hammar, 2011; Anyi et al., 2010; Cust, Singh, & Neuhoff, 2007; Foster, Wagner, & Byrnes, n.d.; Vermaak et al., 2014). Recognizing this fact, the researches in power generation system based on renewable energy resources have grown rapidly where the energy from the sun, wind, hydro, biomass, tide, waves and geothermal heat are harnessed as future energy resources.

Government policies play an important role as the key factor in the development of renewable energy in many countries worldwide (Cust et al., 2007; Derek J. Bertsch, 2011; Karekezi & Kithyoma, 2003; Kaygusuz, 2012). The Malaysian National Renewable Energy Policy and Action Plan announced on the 2nd of April 2010 (KeTTHA, 2008) shows the commitment of the government in supporting renewable energy and green technologies with the main agenda to enhance the utilization of renewable energy resources in order to contribute towards national electricity supply security and sustainable socio-economic development. Its main objective is to increase renewable energy (RE) contribution into the national power generation mix and conserve the environment for future generation (KeTTHA, 2008). Consequently, studies related to the renewable and green energy have captured the interest of local researchers. As a result, an effort is made to create substantial innovation in power generation system using renewable energy resources to improve the lifestyle of the residents especially to rural area communities. The standard of living for the majority of the population in rural areas is very poor due to the limited or no basic facilities such as roads, hospitals, clean water supply and electricity which hinders the development and progression (Kaygusuz, 2012).

Kapit is the largest division in Sarawak with an area of 38,934 sq. km. covering three main districts: Kapit; Song; and Belaga. They constitute almost one-third of the total land area of Sarawak (124,450 sq. km.) (Sarawak Energy, 2015). The terrain of Kapit is approximately 80% mountainous covered with dense primary forests. About 88.4% of the Kapit's populations are located in rural areas (Sarawak, 2010; Sarawak Energy, 2015), where the grid-connected power supply is not readily accessible. The communities live in 534 longhouses and some are attached with schools situated along the major rivers. These houses and schools exist without grid transmission line that uses portable diesel generators for lighting (Ministry of Education Malaysia, 2013; Sarawak Energy, 2015). Out of 1,452 schools in Sarawak, 50 schools are located in Kapit District were registered under the Malaysian Ministry of Education (MOE) (Ministry of Education Malaysia, 2012a, 2012b). 29 of these schools are electrified by a private utility such as Sarawak Electricity Supply Corporation (SESCO). The rest of 21 schools are equipped with 24-hour electricity power supplies using decentralized diesel generators as a primary source initiated by the MOE. The use of decentralized diesel generator for schools in rural areas has strained the government finances periodically. Over RM 1.0 million/year has been spent for each rural school in Sarawak to bear the operating, maintenance and diesel fuel cost to ensure that the amenities in these rural schools are on par with those at urban schools (Ministry of Education Malaysia, 2012a, 2012b).

Hence, in order to overcome the rising cost of operation and maintenance (O&M) of diesel generator, as well as to address the global warming concerns due to the increasing greenhouse gases emission each year, the MOE has launched a rural area electricity program via green technology through the provision of RM 1.5 billion from the green technology policy, in which the action plan has gained approval (KeTTHA, 2008; Mahmud, 2011). The benefits of this green energy policy in terms of profit and high return of investment have attracted the industry players to contribute expertise in providing electric energy supply using renewable energy, particularly to rural areas. The location of Kapit's rural school settlement in Sarawak are shown in Figure 1.1. The schools are mostly located on the main river bank with an abundance of strong water flow that has the potential to generate electrical energy using hydrokinetic system technology.

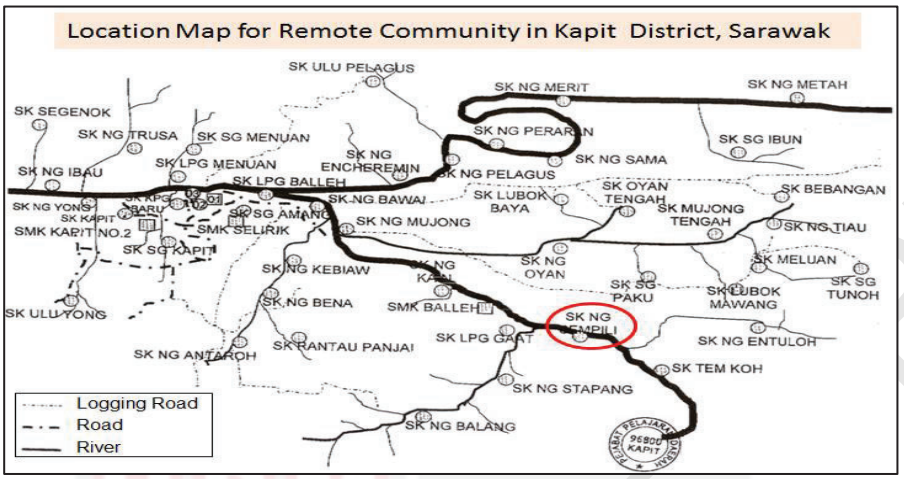

Figure 1.1: Location of Schools in Rural Area in Kapit, Sarawak (Ministry of Education Malaysia, 2012a)

Kapit District, Sarawak has been chosen as the target location of this study due to the finding done by H. Borhanazad et al. (2013). In the study, it was found that East Malaysia has lower electricity coverage of 82.51% and 78.74% for Sabah and Sarawak respectively compared to electricity coverage in Peninsular Malaysia which has 99.62%. Furthermore, Sarawak has the highest concentration of poor population while having up to 40 available rivers that have high potential for electricity generation using hydrokinetic technology. In addition, hydrokinetic technologies are designed with the aim to harness energy from moving water to generate electrical power without the negative impacts to environment and do not interfere with the placement of the original inhabitants (Güney & Kaygusuz, 2010; Khan, Bhuyan, Iqbal, & Quaicoe, 2009).

1.2 Problem Statement

Recent studies related to the hydrokinetic system across nations are heavily focused on the 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, Mekhilef, Boroumandjazi, & Saidur, 2013; Lalander, Grabbe, & Leijon, 2013; Previsic & Bedard, 2008), and only three studies was found had looked into the performance of hydrokinetic study in Province Riau, Indonesia and KwaZulu-Natal in South Africa (Koko, Kusakana, & Vermaak, 2014; Kunaifi, 2009; Kusakana & Vermaak, 2013b). As for the Malaysian context, only one research was found to investigate the development of Vertical Axis Cross Flow Hydrokinetic Turbine Blade as given in Appendix A through Sustainable Hydrokinetic Renewable Energy (SHRE). This study was initiated by Public Works Department Malaysia (PWD) in collaboration with University Putra Malaysia (UPM). To date, there are still no research that has been found

regarding the hydrokinetic performance analysis study especially in Malaysia river environment.

For the implementation of hydrokinetic performance analysis study, the daily water velocity data collected throughout the year are the significant parameter that ascertains the 24-hour operation of the system. Nonetheless, such data is not supplemented by the Malaysian Department of Irrigation and Drainage (DID). Many researchers highlighted the scarcity of hydrokinetic resources assessment as the global river databases from DID are impractical for river energy analysis (Lalander, 2013; Vermaak et al., 2014). Due to the difficulties of water velocity data retrievable from global river database, K. Schulze et al. (2005), E. Lalander (2013), K. Kusakana (2013) and S.P. Koko (2014) used the water flow rate data to estimate water velocity data for hydrokinetic performance analysis studies, provided that the project site is near a hydrological station. In the absence of hydrological station, the rainfall data was gathered by Kunifii (2009) in a hydrokinetic performance analysis study in the Province of Riau, Indonesia. However, the methodology used by the author to estimate the water velocity is not described in detail and it requires further research.

The rainfall data is not suitable to be used for water velocity estimation at the targeted site, i.e. Balleh River at Sk.Nanga Sempili. This is because the rainfall data taken from one location at upstream does not describe the total amount of rainfall occurs at the upstream due to the Balleh River being over than hundred kilometers upstream from the site location. The usage of water level data is more accurate as it reflects the total amount of rainfall in the upper-reaches of the river regardless of the distance of the river to upstream. M. Previsic, R. Bedard and E. Lalander emphasized that water level does influence the water velocity. Also, the correlation between velocity and water discharge is non-linear (Lalander, 2013; Previsic & Bedard, 2008). The nearest hydrological station in Entawau, does not provide flow rate data but only provide daily average water level data and rainfall data. The gap that this research tries to bridge is the absence of study estimating water velocity of river by using water level data. As such, this research proposes a new technique that estimates long terms series of daily average water velocity data throughout the year in unregulated rivers for further hydrokinetic performance analysis.

The motivation of this research is to obtain the long-term series of daily average water velocity data throughout the year for unregulated river for further performance analysis study of hydrokinetic system in Malaysia; thereby, accelerating the growth of electricity supply development in rural areas. This research is very important as it provides an alternative solution and a simpler method to estimate daily average water velocity data throughout the year compared to the existing method which is more complicated and dangerous site in term of flood. The study of hydrokinetic systems will not grow rapidly if there is no solution to produce water velocity data in Malaysia or worldwide. Another motivation of this research is to study the performance of Hydrokinetic-PV solar-Diesel-Battery hybrid system that is to be installed in rural area in

East Malaysia. Apart from that, it is aimed to eliminate the existing use of diesel generators, which burden the communities in terms of diesel cost and maintenance.

1.3 Aim and Objectives

The aim of this study is to supply a 24-hour electricity to rural area of East Malaysia especially Kapit District, Sarawak using hybrid hydrokinetic and solar energy systems. The main objectives of this study are listed as follows:-

1) To propose a guideline and technique to estimate water velocity in unregulated river using regression analysis method.

2) To design and analyze the performance of the proposed Hydrokinetic-PV solar-Diesel-Battery hybrid system modeling using Hybrid Optimization Model Electric Renewable (HOMER) simulation software based on the proposed estimated water velocity methodology.

3) To determine the best configuration of hybrid system in terms of full use of renewable energy that is able to eliminate the existing used stand-alone diesel generator on-site.

1.4 Scope of Work

Based on the previous study by S.P. Koko et al. (2014), Kunifi (2009) and K. Kusakana and H.J. Vermaak (2013), the performance of hydrokinetic hybrid system was analyzed using estimated water velocity using water flow rates and rainfall data. In this study, to estimate water velocity data using flow rate data is impossible due data that is not available. These data are not provided by Hydrological Station Entawau (HSE) but provides for water level and rainfall data.

This study is then expanded by designing an alternative solution to obtain the average daily water velocity data at the site by comparing water velocity data with water level data through regression analysis using the SPSS simulation software. The daily average water velocity data for one-year period is obtained from the estimation of daily water level data on-site for a period of one-year based on the daily average water level data obtained from the HSE located 20 km upstream. The accuracy of the mathematical equation modelling to estimate the water velocity data in this research is only valid for type-C channel stream at Sk. Nanga Sempili School with a gradient less than 2%. The performance analysis study of Hydrokinetic-PV solar-Diesel-Battery hybrid system using HOMER simulation software is done by using the estimated daily average water velocity data of one-year period. Finally, the best configuration of hybrid system is proposed on the selected location.

1.5 Contributions of Research

The contributions of this research are:-

1) The outcome of this work is to derive a standard procedure or guideline to estimate daily average water velocity data throughout the year for unregulated rivers, which is easy, safe and can be handled by unskilled workers. This method also can be expandable to other types of river in rural area worldwide.

2) The estimated daily average water velocity data throughout the year, which is obtained from this study, can be used for further hydrokinetic performance analysis study especially in rural area, East Malaysia.

1.6 Thesis Layout

This thesis consists of five chapters.

Chapter 1 introduces the background of this research work. The importance of hybrid power generation system for rural electrification area using renewable energy resources is highlighted. Hydrokinetic system is discovered to be the new green technology that can be used for rural area electrification in East Malaysia. In this chapter, the problem statement, aim and objectives, and the contribution of the works are also stated.

Chapter 2 presents literature reviews related to this research topic. It begins with a comparison and explanation between Stand-alone Renewable Energy Power Generation System (SRES) and Hybrid Renewable Energy Power Generation System (HRES). This chapter also gives an overview of the rural electrification using HRES throughout the world including of the Malaysian perspective. The detailed reviews of performance study of hydrokinetic system are explored in this chapter especially on the measurement and estimation of water velocity data on-site. Lastly, reviews on the most suitable simulation tools for the performance analysis study on hybrid system are mentioned.

Chapter 3 elaborates the steps in achieving the set research objective that is to propose the best configuration of hybrid system based on hydrokinetic system and to eliminate the existing use of diesel generator set on-site. It starts with the selection of HOMER simulation software as a tool for hybrid performance analysis studies. Then, a method of data collection on-site as input parameters to meet the HOMER simulation software requirements is described. The discussions are focused on standard procedure or guideline and new technique to estimate daily average water velocity data on-site within one-year period using data obtained from (i) Hydrological Station at Entawau (HSE) such as daily water level, daily rainfall data and (ii) measurement data on-site such daily

water level and water velocity data mentioned in detail. All data are analyzed using SPSS software to produce a regression equation modeling that is validated. Another set of data needed for HOMER is solar irradiation data that are obtained from the NASA Website. The rest of the data such as load data are collected on-site and the cost of components of hybrid system are collected from manufacturers. These data are then inputted into HOMER simulation software for performance analysis hybrid study.

Chapter 4 presents all results obtained from the experimental work that were discussed in Chapter 3. All the result of data were collected on-site to fulfill the HOMER simulation requirement such energy consumption, solar radiation data, rainfall data and estimated water velocity data had presented. In order to estimate daily average water velocity data throughout the year, a statistic analysis process such correlation and regression analysis method us required. This process would produce a regression equation model and is validated. All the results regarding the process to estimate water velocity and water velocity data within six years are also presented and discussed. Next, this chapter presents and discusses the simulation results of configuration of hybrid system using various water velocity data.

Finally, Chapter 5 concludes the overall results of the experimental work and proposes the best configuration of hybrid system for the selected site. This chapter also includes a few recommendations that can be implemented in this research area in the future.

REFERENCES

Ahlborg, H., & Hammar, L. (2011). Drivers and barriers to rural electrification in Tanzania and Mozambique (p. 7). World Renewable Energy Congres Sweden.

Akikur, R. K., Saidur, R., Ping, H. W., & Ullah, K. . (2013). Comparative study of stand-alone and hybrid solar energy systems suitable for off-grid rural electrification: A review. *Renewable and Sustainable Energy Reviews*, *27*, 738–752. https://doi.org/10.1016/j.rser.2013.06.043

Ali, B., Sopian, K., Abdul Rahman, M., Othman, M. Y., Zaharim, A., & Razali, A. M. (2009). Hybrid photovoltaic diesel system in a cable car resort facility. In *European Journal of Scientific Research* (Vol. 26, pp. 13–19). Retrieved from http://www.eurojournals.com/ejsr_26_1_02.pdf

Anyi, M., Kirke, B., & Ali, S. (2010). Remote community electrification in Sarawak , Malaysia. *Renewable Energy*, *35*(7), 1609–1613. https://doi.org/10.1016/j.renene.2010.01.005

Arikunto, S. (2007). *Quasi Experiment*. Universiti Pendidikan Indonesia. Retrieved from http://a-research.upi.edu/operator/upload/s_ptm_023517_chapter3.pdf

Arkel, R. v., Owen, L., Allison, S., Tryfonas, T., & Winter, A. (2006). Design and preliminary testing of a novel concept low depth hydropower device, (July), 1–14. https://doi.org/10.2514/6.2006-4994

Ashok, S. (2007). Optimised model for community-based hybrid energy system. *Renewable Energy*, *32*(7), 1155–1164. https://doi.org/10.1016/j.renene.2006.04.008

Asmus, P., & Wheelock, C. (2009). *PikeResearch Executive Summary*. Retrieved from http://www.navigantresearch.com/wp-content/uploads/2009/05/HYDRO-09-Executive-Summary.pdf

Atikur Rahman, M. M., Al Awami, A. T., & Rahim, A. H. M. A. (2014). Hydro-PV-wind-battery-diesel based stand-alone hybrid power system. In *1st International Conference on Electrical Engineering and Information and Communication Technology, ICEEICT 2014*. https://doi.org/10.1109/ICEEICT.2014.6919044

Atwa, Y. M., & El-Saadany, E. F. (2010a). Optimal allocation of ESS in distribution systems with a high penetration of wind energy. *Power Systems, IEEE Transactions …*, *25*(4), 1815–1822. https://doi.org/10.1109/TPWRS.2010.2045663

Atwa, Y. M., & El-Saadany, E. F. (2010b). Optimal allocation of ESS in distribution systems with a high penetration of wind energy. *Power Systems, IEEE Transactions …*, *25*(4), 1815–1822. https://doi.org/10.1109/TPWRS.2010.2045663

Azahari, A. W., Sopian, K., Zaharim, A., & Al Ghoul, M. (2008). A New Approach For Predicting Solar Radiation In Tropical Environment Using Satellite Images – Case Study Of Malaysia. *ENVIRONMENT and DEVELOPMENT*, *4*(4), 373–378.

Azhar Ghazali, M., & Abdul Rahman, A. M. (2012). The Performance of Three Different Solar Panels for Solar Electricity Applying Solar Tracking Device under the Malaysian Climate Condition. *Energy and Environment Research*, *2*(1), 235–243. https://doi.org/10.5539/eer.v2n1p235

Azhari, A. W., Sopian, K., Zaharim, A., & Al Ghoul, M. (2008). A New Approach

For Predicting Solar Radiation In Tropical Environment Using Satellite Images – Case Study Of Malaysia. *ENVIRONMENT and DEVELOPMENT*, *4*(4), 373–378.

Bank Negara Malaysia. Statutory requirements (2016).

Barakat, A., El Baghdadi, M., Rais, J., Aghezzaf, B., & Slassi, M. (2016). Assessment of spatial and seasonal water quality variation of Oum Er Rbia River (Morocco) using multivariate statistical techniques. *International Soil and Water Conservation Research*, *4*(May), 0–1. https://doi.org/10.1016/j.iswcr.2016.11.002

Behrouzi, F., Nakisa, M., Maimun, A., & Ahmed, Y. M. (2016). Global renewable energy and its potential in Malaysia : A review of Hydrokinetic turbine technology. *Renewable and Sustainable Energy Reviews*, *62*, 1270–1281.

Bekelea, G., & Boneya, G. (2012). Design of a photovoltaic-wind hybrid power generation system for Ethiopian remote area. *Energy Procedia*, *14*(0), 1760–1765. https://doi.org/10.1016/j.egypro.2011.12.1164

Bhat, S. A., Meraj, G., Yaseen, S., & Pandit, A. K. (2014). Statistical Assessment of Water Quality Parameters for Pollution Source Identification in Sukhnag Stream: An Inflow Stream of Lake Wular (Ramsar Site), Kashmir Himalaya. *Journal of Ecosystems*, *2014*, 1–18. https://doi.org/10.1155/2014/898054

Blanco, C., Junior, B., Figueiredo, N. M. De, & Negr, E. (2017). Assessment of hydrokinetic energy resources downstream of hydropower plants. *Renewable Energy*, *101*, 1203–1214.

Borhanazad, H., Mekhilef, S., Boroumandjazi, G., & Saidur, R. (2013). Potential application of renewable energy for rural electrification in Malaysia. *Renewable Energy*, *59*(10), 210–219. https://doi.org/10.1016/j.renene.2013.03.039

Chen, C., Duan, S., Cai, T., Liu, B., & Hu, G. (2011). Optimal allocation and economic analysis of energy storage system in microgrids. *Power Electronics, IEEE …*, *26*(10), 2762–2773. https://doi.org/10.1109/TPEL.2011.2116808

Cust, J., Singh, A., & Neuhoff, K. (2007). Rural Electrification in India: Economic and Industrial Aspects of Renewables, (December), 36. Retrieved from http://www.dspace.cam.ac.uk/handle/1810/195432

Dalwadi, P., Shrinet, V., Mehta, C. R., & Shah, P. (2011). Optimization of Solar-Wind Hybrid System for Distributed Generation, 8–10.

Darus, Z. M., Hashim, N. A., Manan, S. N. A., Rahman, M. A. A., Maulud, K. N. A., & Karim, O. A. (2009). The Development of Hybrid Integrated Renewable Energy System (Wind and Solar) for Sustainable Living at Perhentian. *European Journal of Social Sciences*, *9*(4), 557–563.

Daut, I., Irwanto, M., Irwan, Y. M., Gomesh, N., Rosnazri, & Ahmad, N. S. (2011). Potential of Solar Radiation and Wind Speed for Photovoltaic and Wind Power Hybrid Generation in Perlis , Northern Malaysia (pp. 6–7).

David L.Rosgen. (1994). Classification of natural Rivers. *Elsevier*, *22*, 169–199.

Derek J. Bertsch. (2011). *Hydrokinetic Energy : Trying to Navigate the Energy and Water Law Framework to Develop New Renewable Energy Technology* (Vol. 17211).

Elhadidy, M. A., & Shaahid, S. M. (1999). Optimal sizing of battery storage for hybrid (wind+ diesel) power systems. *Renewable Energy*, *18*(PERGAMON), 77–86. https://doi.org/10.1016/S0960-1481(98)00796-4

Energy Commission of Malaysia. (2015). *Malaysia energy statistics Handbook 2015*. Retrieved from http://meih.st.gov.my

Fadaeenejad, M., Radzi, M. A. M., AbKadir, M. Z. A., & Hizam, H. (2014). Assessment of hybrid renewable power sources for rural electrification in Malaysia. *Renewable and Sustainable Energy Reviews*, *30*, 299–305. https://doi.org/10.1016/j.rser.2013.10.003

Fantidis, J. G., Bandekas, D. V., & Vordos, N. (2015). Study of a Wind/PV/Battery Hybri System -Case study at Plaka in Greece. *J Estr*, *8*(2), 157–173.

Fenton, N., & Martin, N. (2008). Chapter 1 of Risk Assessment and Decision Analysis with Bayesian Networks. CRC Press (pp. 1–30). Retrieved from http://www.bayesianrisk.com/sample_chapters/Chapter 1 There is more to assessing risk than statistics.pdf

Foster, J., Wagner, L., & Byrnes, L. (n.d.). *A Review of Distributed Generation for Rural and Remote Area Electrification*. Retrieved from http://eemg.uq.edu.au/filething/get/140/2014-3.pdf

Gan, L. K., Shek, J. K. H., & Mueller, M. A. (2015). Hybrid wind-photovoltaic-diesel-battery system sizing tool development using empirical approach, life-cycle cost and performance analysis: A case study in Scotland. *Energy Conversion and Management (Elsevier)*, *106*, 479–494. https://doi.org/10.1016/j.enconman.2015.09.029

Gashi, F., T, S. F. I., Bilinski, H., Shala, A., & Gashi, A. (2017). Impact of Kishnica and Badovci Flotation Tailing Dams on Levels of Heavy Metals in Water of Graçanica River (Kosovo). *Journal of Chemistry*, *2017*, 1–10. https://doi.org/10.1155/2017/5172647

Gilman, P., Lilienthal, P., & Lambert, T. (1995). Micropower System Modeling With HOMER. In *National Renewable Energy Laboratory* (pp. 379–418).

Ginter, V. J., & Pieper, J. K. (2011). Robust gain scheduled control of a hydrokinetic turbine. *IEEE Transactions on Control Systems Technology*, *19*(4), 805–817. https://doi.org/10.1109/TCST.2010.2053930

Givler, T., & Lilienthal, P. (2005). Using HOMER® Software , NREL's Micropower Optimization Model, to Explore the Role of Gen-sets in Small Solar Power Systems Case Study: Sri Lanka. *Contract*, (May), 1–31. https://doi.org/10.1016/j.apenergy.2011.11.059

Goel, S., & Ali, S. M. (2013). Feasibility Study of Hybrid Energy Systems for Remote Area Electrification in Odisha , India by Using HOMER. *International Journal Of Renewable Energy Research*, *3*(3).

Güney, M. S., & Kaygusuz, K. (2010). Hydrokinetic energy conversion systems: A technology status review. *Renewable and Sustainable Energy Reviews*, *14*(9), 2996–3004. https://doi.org/10.1016/j.rser.2010.06.016

Hafez, O., & Bhattacharya, K. (2012). Optimal planning and design of a renewable energy based supply system for microgrids. *Renewable Energy*, *45*, 7–15. https://doi.org/10.1016/j.renene.2012.01.087

Hailong Zhou. (2012). *Maximum Power Point Tracking Control Of Hydrokinetic Turbine And Low-Speed High-Thrust Permanent Magnet Generator Design*. Missouri University Of Science And Technology. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a565000.pdf

Halasa, G., & Asumadu, J. A. (2009). Wind-Solar Hybrid Electrical Power Production to Support National Grid: Case Study - Jordan. *Energy and Power Engineering*, *1*(2), 72–80. https://doi.org/10.4236/epe.2009.12011

Harrelson, C. C., Rawlins, C. L., & Potyondy, J. P. (1994). *Stream channel*

reference sites: an illustrated guide to field technique. *USDA United State Department of Agriculture*. USA. https://doi.org/Gen. Tech. Rep. RM-245.

IBM SPSS Statistic Version 22. (2013). Retrieved May 2, 2016, from https://ibm-spss-statistics-base.en.uptodown.com/windows

Islam, M. R., Saidur, R., & Rahim, N. A. (2011). Assessment of wind energy potentiality at Kudat and Labuan, Malaysia using Weibull distribution function. *Energy*, *36*(2), 985–992. https://doi.org/10.1016/j.energy.2010.12.011

Johnson, J. B., & Pride, D. J. (2010). *River, tidal and ocean current hydrokinetic energy technologies: Status and future opportunities in Alaska*. *Alaska Center for Energy and Power*. Retrieved from http://www.uaf.edu/files/acep/2010_11_1_State_of_the_Art_Hydrokinetic_Final.pdf

Johnson, V. E. (2013). Revised standards for statistical evidence (Vol. 110, pp. 19313–19317). https://doi.org/10.1073/pnas.1313476110

Jose L. Bernal-Agustın, R. D.-L. (2009). Simulation and optimization of stand-alone hybrid renewable energy systems. *Renewable and Sustainable Energy Reviews*, *13*(8), 2111–2118. https://doi.org/10.1016/j.rser.2009.01.010

Karekezi, S., & Kithyoma, W. (2003). *Renewable energy development*. *The Workshop for African Energy Experts on Operationalizing the NEPAD Energy Initiative*.

Katuwal, H., & Bohara, A. K. (2009). Biogas: A promising renewable technology and its impact on rural households in Nepal. *Renewable and Sustainable Energy Reviews*, *13*(9), 2668–2674. https://doi.org/10.1016/j.rser.2009.05.002

Kaur, K., & Brar, G. S. (2016). Solar-Biogas-Biomass Hybrid Electrical Power Generation for a Village (a case study). In *International Journal of Engineering Development and Research*.

Kaygusuz, K. (2012). Energy for sustainable development: A case of developing countries. *Renewable and Sustainable Energy Reviews*, *16*(2), 1116–1126. https://doi.org/10.1016/j.rser.2011.11.013

Kenfack, J., Neirac, F. P., Tatietse, T. T., Mayer, D., Fogue, M., & Lejeune, A. (2009). Microhydro-PV-hybrid system: Sizing a small hydro-PV-hybrid system for rural electrification in developing countries. *Renewable Energy*, *34*(10), 2259–2263. https://doi.org/10.1016/j.renene.2008.12.038

KeTTHA. (2008). National Renewable Energy Policy and Action Plan. Retrieved April 2, 2017, from http://seda.gov.my/?omaneg=00010100000001010101000100001000000000000000000000&s=31

Khan, M. J., Bhuyan, G., Iqbal, M. T., & Quaicoe, J. E. (2009). Hydrokinetic energy conversion systems and assessment of horizontal and vertical axis turbines for river and tidal applications: A technology status review. *Applied Energy*, *86*(10), 1823–1835. https://doi.org/10.1016/j.apenergy.2009.02.017

Khan, M. J., Iqbal, M. T., & Quaicoe, J. E. (2006). Design considerations of a straight bladed darrieus rotor for river current turbines. In *IEEE International Symposium on Industrial Electronics* (Vol. 3, pp. 1750–1755). https://doi.org/10.1109/ISIE.2006.295835

Khatib, T., Mohamed, A., Mahmoud, M., & Sopian, K. (2015). Optimization of the tilt angle of solar panels for Malaysia. *Energy Sources, Part A:*

Recovery, Utilization and Environmental Effects, *37*(6), 606–613. https://doi.org/10.1080/15567036.2011.588680

Knight, K. M., Klein, S. A., & Duffie, J. A. (1991). A Methodology For The Synthesis of Hourly Weather Data. *Solar Energy*, *46*(2), 109–120.

Koko, S. P., Kusakana, K., & Vermaak, H. J. (2014). Micro-Hydrokinetic for Remote Rural Electrification. *International Journal of Electrical, Robotics, Electronics and Communications Engineering*, *8*(11), 1465–1469.

Kolhe, M., Ranaweera, K. M. I. ., & Gunawardana, A. G. B. S. (2013). Techno-Economic Optimum Sizing of Hybrid Renewable Energy System Rural Electrification in Sri Lanka. In *IEEE Conference Publications* (pp. 1898–1903).

Kose, F., & Kaya, M. N. (2013). Analysis on meeting the electric energy demand of an active plant with a wind-hydro hybrid power station in Konya, Turkey: Konya water treatment plant. *Renewable Energy*, *55*, 196–201. https://doi.org/10.1016/j.renene.2012.12.047

Kunaifi. (2009). *Options for the Electrification of Rural Villages in the Province of Riau , Indonesia*. Murdoch University, Pearth Australia.

Kusakana, K., & Vermaak, H. J. (2013a). Feasibility Study Of Hydrokinetic Power For Energy Access In Rural South Africa (pp. 433–438). https://doi.org/10.2316/P.2012.768-071

Kusakana, K., & Vermaak, H. J. (2013b). Hydrokinetic power generation for rural electricity supply: Case of South Africa. *Renewable Energy*, *55*, 467–473. https://doi.org/10.1016/j.renene.2012.12.051

Kuusisto, E., Bartram, J., & Ballance, R. (1996). HYDROLOGICAL MEASUREMENTS; Water Quality Monitoring -A Practical Guide to the Design and Implimentation of Freshwater Quality Studies and Monitoring Programmes. In R. B. J.Bartram (Ed.), *Chapter 12 Hydrological Measurement*.

Lal, D. K., Dash, B. B., & Akella, A. K. (2011). Optimization of PV / Wind / Micro-Hydro / Diesel Hybrid Power System in HOMER for the Study Area. *International Journal on Electrical Engineering and Informatics*, *3*(3), 307–325.

Lal, S., & Raturi, A. (2012). Techno-economic analysis of a hybrid mini-grid system for Fiji Island. *Ijee*, 1–10.

Lalander, E. (2013). *Hydrokinetic Resource Assessment*. Uppsala University Sweden.

Lalander, E., Grabbe, M., & Leijon, M. (2013). On the velocity distribution for hydro-kinetic energy conversion from tidal currents and rivers. *Journal of Renewable and Sustainable Energy*, *5*(2), 1–19. https://doi.org/10.1063/1.4795398

Lau, K. Y., Yousof, M. F. M., Arshad, S. N. M., Anwari, M., & Yatim, A. H. . (2010). Performance analysis of hybrid photovoltaic_diesel energy system under Malaysia Condition. *Energy*, *35*, 3245–3255.

Li, C., Ge, X., Zheng, Y., Xu, C., Ren, Y., Song, C., & Yang, C. (2013). Techno-economic feasibility study of autonomous hybrid wind/PV/battery power system for a household in Urumqi, China. *Energy*, *55*, 263–272. https://doi.org/10.1016/j.energy.2013.03.084

Li, X., Song, Y. J., & Han, S. B. (2008). Frequency control in micro-grid power system combined with electrolyzer system and fuzzy PI controller. *Journal of Power Sources*, *180*(1), 468–475. https://doi.org/10.1016/j.jpowsour.2008.01.092

Liakbar, S. M. A., Shahidul, M. I., Syed Shazali, S. T., Abang Kamarudin, A. M. N., Ramji, H., & Ruduan, A. H. (2011). Green Energy Extraction: An Approach with Cross Flow Micro Hydro Turbine. In *Proceedings of EnCon 2011 4th Engineering Conference Kuching, Sarawak, Malaysia, 29th Nov-1st December.*

Lilienthal, P., & Lambert, T. (2009). HOMER Classic (support).

Lilienthal, P., Lambert, T., & Givler, T. (2009). HOMER LEGACY Software, NREL USA. Retrieved January 1, 2016, from http://www.homerenergy.com/HOMER_legacy

Ling, T., Soo, C., Liew, J., Nyanti, L., Sim, S., & Grinang, J. (2017). Application of Multivariate Statistical Analysis in Evaluation of Surface River Water Quality of a Tropical River. *Hindawi (Journal of Chemistry)*, *2017*. https://doi.org/10.1155/2017/5737452

Liu, C. W., Lin, K. H., & Kuo, Y. M. (2003). Application of factor analysis in the assessment of groundwater quality in a blackfoot disease area in Taiwan. *Science of the Total Environment*, *313*(1–3), 77–89. https://doi.org/10.1016/S0048-9697(02)00683-6

Liu, G., Rasul, M. G., Amanullah, M. T. O., & Khan, M. M. K. (2011). Feasibility study of stand-alone PV-wind-biomass hybrid energy system in Australia. *Asia-Pacific Power and Energy Engineering Conference, APPEEC*. https://doi.org/10.1109/APPEEC.2011.5749125

Lopez, N., & Espiritu, J. F. (2011). An approach to hybrid power systems integration considering different renewable energy technologies. *Procedia Computer Science*, *6*, 463–468. https://doi.org/10.1016/j.procs.2011.08.086

Lukuyu, J. M., & Cardell, J. B. (2014a). Hybrid Power System Options for Off-Grid Rural Electrification in Northern Kenya. *Smart Grid and Renewable Energy*, *5*(May), 89–106. https://doi.org/10.4236/sgre.2014.55009

Lukuyu, J. M., & Cardell, J. B. (2014b). Hybrid Power System Options for Off-Grid Rural Electrification in Northern Kenya. *Scientific Research*, *5*(5), 89–106. https://doi.org/10.4236/sgre.2014.55009

Ma, T., Yang, H., & Lu, L. (2014). A feasibility study of a stand-alone hybrid solar-wind-battery system for a remote island. *Applied Energy*, *121*, 149–158. https://doi.org/10.1016/j.apenergy.2014.01.090

Mahmud, A. M. (2011). Evaluation of the Solar Hybrid System for Rural Schools in Sabah , Malaysia (pp. 2977–2984).

Mahmud, A. M., & Blanchard, R. E. (2016). Assessing a rural electrification program in Malaysia: System performance analysis on 11 solar PV-diesel hybrid systems. In *ICDRET 2016 - 4th International Conference on the Developments in Renewable Energy Technology* (pp. 1–6). https://doi.org/10.1109/ICDRET.2016.7421506

Mercier, P., Cherkaoui, R., & Oudalov, A. (2009). Optimizing a battery energy storage system for frequency control application in an isolated power system. *IEEE Transactions on Power Systems*, *24*(3), 1469–1477. https://doi.org/10.1109/TPWRS.2009.2022997

Ministry of Education Malaysia. (2010). Dokumen Kontrak untuk Perkhidmatan Pembekalan Elektrik Melalui Pengoperasian Dan Penyelenggaraan Set Janakuasa Bagi Sekolah-Sekolah Luar Bandar Di Negeri Sarawak Bagi Pakej Kapit 2. *Contract Document (2010)*.

Ministry of Education Malaysia. (2012a). Dokumen Kontrak untuk Perkhidmatan Pembekalan Elektrik Melalui Pengoperasian Dan Penyelenggaraan Set Janakuasa Bagi Sekolah-Sekolah Luar Bandar Di Negeri Sarawak Bagi Pakej 18 : Kapit 1. In *Contract Document (Pakej 18)*.

Ministry of Education Malaysia. (2012b). Dokumen Kontrak untuk Perkhidmatan Pembekalan Elektrik Melalui Pengoperasian Dan Penyelenggaraan Set Janakuasa Bagi Sekolah-Sekolah Luar Bandar Di Negeri Sarawak Bagi Pakej 19 : Kapit 2. In *Contract Document (Pakej 19)*.

Ministry of Education Malaysia. (2013). Senarai sekolah rendah di negeri sarawak. Retrieved January 11, 2017, from https://shenshenxuezi.files.wordpress.com/2013/11/sarawakrendah30jun13-wm.pdf

Mohamad, K. B. (2012). *Taklimat Projek Penyelidikan Sustainable Instream Horizontal MicroHydro Turbine Generator*.

Muhammad, S., Shah, M. T., & Khan, S. (2011). Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan. *Microchemical Journal*, *98*(2), 334–343. https://doi.org/10.1016/j.microc.2011.03.003

Nandi, S. K., & Ghosh, H. R. (2009). A wind-PV-battery hybrid power system at Sitakunda in Bangladesh. *Energy Policy*, *37*(9), 3659–3664. https://doi.org/10.1016/j.enpol.2009.04.03

Nandi, S. K., & Ghosh, H. R. (2010a). Prospect of wind-PV-battery hybrid power system as an alternative to grid extension in Bangladesh. *Energy*, *35*(7), 3040–3047. https://doi.org/10.1016/j.energy.2010.03.044

Nandi, S. K., & Ghosh, H. R. (2010b). Techno-economical analysis of off-grid hybrid systems at Kutubdia Island, Bangladesh. *Energy Policy*, *38*(2), 976–980. https://doi.org/10.1016/j.enpol.2009.10.049

NASA Surface Meteorology and Solar Energy. (2016). NASA Website, (Access on November 2016). Retrieved from https://eosweb.larc.nasa.gov/sse/

Nayar, C., Tang, M., & Suponthana, W. (2007). A case study of a pv/wind/diesel hybrid energy system for remote islands in the Republic of Maldives. *2007 Australasian Universities Power Engineering Conference, AUPEC*, 1–7. https://doi.org/10.1109/AUPEC.2007.4548114

New Energy Corporation. (2015a). Darrieus Type Hydrokinetic Turbine Blade 10KW. Retrieved January 1, 2017, from http://www.newenergycorp.ca/envirogen-005-series.html

New Energy Corporation. (2015b). *EnCurrent Hydro Turbines 5 and 10 kW Specifications*. Retrieved from http://www.newenergycorp.ca/Portals/0/documents/datasheets/ENC.005.010.DataSheet.pdf

Nfah, E. M., Ngundam, J. M., Vandenbergh, M., & Schmid, J. (2008). Simulation of off-grid generation options for remote villages in Cameroon. *Renewable Energy*, *33*(5), 1064–1072. https://doi.org/10.1016/j.renene.2007.05.045

Ngan, M. S., & Tan, C. W. (2012). Assessment of economic viability for PV / wind / diesel hybrid energy system in southern Peninsular Malaysia. *Renewable and Sustainable Energy Reviews*, *16*(1), 634–647. https://doi.org/10.1016/j.rser.2011.08.028

Notton, G., Diaf, S., & Stoyanov, L. (2011). Hybrid photovoltaic/wind energy

systems for remote locations. *Energy Procedia*, *6*, 666–677. https://doi.org/10.1016/j.egypro.2011.05.076

Ong, H. C., Mahlia, T. M. I., & Masjuki, H. H. (2011). A review on energy scenario and sustainable energy in Malaysia. *Renewable and Sustainable Energy Reviews*, *15*(1), 639–647. https://doi.org/10.1016/j.rser.2010.09.04

Othman, A. K., Abidin., W. A. W. Z., Lias., K., Marzuki., A. S. W., & Masri., T. (2008). Community based Micro Hydro Power : A Strategic Development in Sarawak , Borneo.

Oudalov, A., Chartouni, D., Ohler, C., & Linhofer, G. (2006). Value Analysis of Battery Energy Storage Applications in Power Systems.

Panayiotou, G., Kalogirou, S., & Tassou, S. (2012). Design and simulation of a PV and a PVeWind standalone energy system to power household in Cyprus Island. *Renewable Energy*, 355–363.

Pradhan, N., Karki, N. R., & Pokhrel, B. R. (2012). Reliability Evaluation of Small Standalone Hybrid Solar PV-Wind Power System, 259–264.

Previsic, M., & Bedard, R. (2008). *River In-Stream Energy Conversion (RISEC) Characterization of Alaska Sites*. *EPRI Report*.

Rawat, R., & Chandel, S. S. (2013). Simulation and Optimization of Solar Photovoltaic- Wind stand alone Hybrid system in Hilly Terrain of India. *INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH S.S.Chandel et Al*, *3*(3).

Rehman, S., & Al-Hadhrami, L. M. (2010). Study of a solar PV-diesel-battery hybrid power system for a remotely located population near Rafha, Saudi Arabia. *Energy*, *35*(12), 4986–4995. https://doi.org/10.1016/j.energy.2010.08.025

Rehman, S., Mahbub Alam, M., Meyer, J. P., & Al-Hadhrami, L. M. (2012). Feasibility study of a wind-pv-diesel hybrid power system for a village. *Renewable Energy*, *38*(1), 258–268. https://doi.org/10.1016/j.renene.2011.06.028

Saheb-Koussa, D., Haddadi, M., & Belhamel, M. (2009). Economic and technical study of a hybrid system (wind-photovoltaic-diesel) for rural electrification in Algeria. *Applied Energy*, *86*(7–8), 1024–1030. https://doi.org/10.1016/j.apenergy.2008.10.01

Saheb-Koussa, D., Koussa, M., Belhamel, M., & Haddadi, M. (2011). Economic and environmental analysis for grid-connected hybrid photovoltaic-wind power system in the arid region. *Energy Procedia*, *6*, 361–370. https://doi.org/10.1016/j.egypro.2011.05.042

Sarawak, S. P. U. (2010). *SARAWAK Facts and Figures 2010*. Kuching, Sarawak. Retrieved from http://www.spu.sarawak.gov.my

Sarawak Energy. (2015). Majlis Daerah Kapit (Pengenalan Bahagian Kapit, 2015). Retrieved January 25, 2015, from http://www.kapitdc.sarawak.gov.my/pengenalan.htm

Schainker, R. B. (2004). Executive overview: energy storage options for a sustainable energy future. *IEEE Power Engineering Society General Meeting, 2004.*, 1–6. https://doi.org/10.1109/PES.2004.1373298

Siddique, M. N., Muhammad, A., Nawaz, M. K., & Bukhari, S. B. A. (2015). Optimal integration of hybrid (wind--solar) system with diesel power plant \newline using HOMER. *Turkish Journal of Electrical Engineering & Computer Sciences*, *23*, 1547–1557. https://doi.org/10.3906/elk-1402-15

Sinha, S., & Chandel, S. S. (2014). Review of software tools for hybrid

renewable energy systems. *Renewable and Sustainable Energy Reviews*, *32*, 192–205. https://doi.org/10.1016/j.rser.2014.01.035

Sopian, K., Hj. Othman, M. Y., & Wirsat, A. (1995). The wind energy potential of Malaysia. *Data Bank Pergamon*, *6*, 1005–1016

Sopian, K., Othman, M. Y., Yatim, B., & Daud, W. R. W. (2005). Future Directions in Malaysian Environment Friendly Renewable Energy Technologies Research and Development. *ISESCO Science and Technology Vision*, *1*, 30–36.

Sornes, K. (2010). Small-scale Water Current Turbines for River Applications. *Zero Emission Resource Organization*, (January), 1–19. Retrieved from www.zero.no

Sundaray, S. K., Panda, U. C., Nayak, B. B., & Bhatta, D. (2006). Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of the Mahanadi river-estuarine system (India) - A case study. *Environmental Geochemistry and Health*, *28*(4), 317–330. https://doi.org/10.1007/s10653-005-9001-5

Tadesse, G., & Bekelle, G. (2011). *Feasibility study of Small Hydro/PV/Wind Hybrid System for Off Grid Rural Electrification in Ethiopia.* ADDIS ABABA UNIVERSITY.

Tanim, M. M., Chowdhury, N. A., Rahman, M. M., & Ferdous, J. (2014). DESIGN OF A PHOTOVOLTAIC–BIOGAS HYBRID POWER GENERATION SYSTEM FOR BANGLADESHI REMOTE AREA USING HOMER SOFTWARE. In *IEEE Conference Publications* (pp. 1–5). IEEE.

Taylor, J. R. (1997). *An Introduction to Error Analysis;The study of uncertainties in physical measurements*. University Sausalito California.

Teixeira, L. E., Caux, J., Beluco, A., Bertoldo, I., Antônio, J., Louzada, S., & Eifler, R. C. (2015). Feasibility Study of a Hydro PV Hybrid System Operating at a Dam for Water Supply in Southern Brazil. *Journal of Power and Energy Engineering*. https://doi.org/10.4236/jpee.2015.39006

Tiang, T. L., & Ishak, D. (2012). Technical review of wind energy potential as small-scale power generation sources in Penang Island Malaysia. *Renewable and Sustainable Energy Reviews*, *16*(5), 3034–3042. https://doi.org/10.1016/j.rser.2012.02.032

Vermaak, H. J., Kusakana, K., & Koko, S. P. (2014). Status of micro-hydrokinetic river technology in rural applications: A review of literature. *Renewable and Sustainable Energy Reviews*, *29*, 625–633. https://doi.org/10.1016/j.rser.2013.08.06

Wies, R. W., Johnson, R. A., Agarwal, A. N., & Chubb, T. J. (2004). Economic analysis and environmental impacts of a PV with diesel-battery system for remote villages. *IEEE TRANSACTIONS ON POWER SYSTEMS*, *20*(2), 692–700. https://doi.org/10.1109/PES.2004.1373209

Yang, H. X., Lu, L., & Burnett, J. (2003). Weather data and probability analysis of hybrid photovoltaic-wind power generation systems in Hong Kong. *Renewable Energy*, *28*(11), 1813–1824. https://doi.org/10.1016/S0960-1481(03)00015-6

Zhang, Q., Li, Z., Zeng, G., Li, J., Fang, Y., Yuan, Q., … Ye, F. (2009). Assessment of surface water quality using multivariate statistical techniques in red soil hilly region: A case study of Xiangjiang watershed, China. *Environmental Monitoring and Assessment*, *152*(1–4), 123–131. https://doi.org/10.1007/s10661-008-0301-y

Zhang, Z., Tao, F., Du, J., Shi, P., Yu, D., Meng, Y., & Sun, Y. (2010). Surface

water quality and its control in a river with intensive human impacts-a case study of the Xiangjiang River, China. *Journal of Environmental Management*, *91*(12), 2483–2490. https://doi.org/10.1016/j.jenvman.2010.07.002

BIODATA OF STUDENT

Almalik Faisel bin Mohd Saupi was born in 1975 in Kota Bharu city in Kelantan state of Malaysia. He received his high school education in Politechnic Kota Bharu, Kelantan and obtained his diploma on “Electric and Electronic”. He pursued his first degree in bachelor of electrical engineering from 1997 to 2000 at University Technology of Malaysia, Skudai, Johor. After graduation, he began his industrial experience from 2000 to 2004 in ROHM Wako Electronic Sdn. Bhd. as an Assistance Engineer and he has six months working experience on electronic machine maintenance in Wako Dengki, Kasaoka City, Japan. In April 2004, he joined the Department of Mechanization and Automation in Malaysia Agriculture Research Development Institute (MARDI) Serdang, Selangor as Assistance Research Officer. In April 2006, he joined Public Works Department, Malaysia as an Electrical Engineer and after three years he was awarded the Electrical Engineer Professional title. In April 2013, he joined the Sustainable Hydrokinetic Renewable Energy (SHRE) research team, which is one of the department units in PWD. PWD SHRE team collaborated with University Technology of Malaysia and University Putra Malaysia to develop hydrokinetic turbine. He currently is doing Master of Electrical Engineering at Universiti Putra Malaysia, Malaysia. His research interests include renewable energy systems by estimating of water velocity in unregulated river in rural area in East Malaysia for hydrokinetic hybrid systems performance analysis study under the supervision of Dr. Nashiren Farzilah bt Mailah and Assoc. Prof. Dr. Mohd Amran Mohd Radzi.

LIST OF PUBLICATIONS

1. Almalik Faisel Mohd Saupi, Nashiren Farzilah Mailah, Mohd Amran Mohd Radzi, Kamarul Baharin Mohamad, Saiful Zuhaimi Ahmad and Azimi Che Soh' - Journal MDPI : Water Article. Impact Factor: 2.069

Title: **An Illustrated Guide to Estimation of Water Velocity in Unregulated River for Hydrokinetic Performance Analysis Studies in East Malaysia**

Submitted: 16 May 2018, Accept on: 19 July 2018, Publish: 26 Sept 2018

Publisher: MDPI Water