EVALUATION OF STANDALONE HYBRID ENERGY POTENTIAL OF A LIGHTHOUSE IN TROPICAL REGION

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DEDICATION

I wish to dedicate my thesis work to my family, whom words of encouragement and patience has inspired me to always give my best. A sincere gratitude for my mother, Gertrude Benjamin, for the invaluable and unconditional support and encouragement. Also to my late father, Ng Kui Phin. Whom has always supported and believed in my capabilities. He taught me that even the largest task can be accomplished if it is done one stop at a time. Gone forever away from our loving eyes but the memory will always live as long as I shall live.

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ABSTRACT

The source of electricity supply in remote and island areas are commonly supplied by diesel generator or other fossil fuels based generation system. However, the increasing cost and harmful emissions of fossil fuels have pressured mankind to seek for alternative solution in generating electricity. The earth has vast renewable resources that can be harnessed to produce electricity. Hence, harnessing renewable resources can be an alternative solution in lowering the dependency on fossil fuels. This research focused on the possibilities of harnessing the energy around the offshore of a lighthouse located in the Strait of Malacca to reduce its dependency on diesel generator as its primary source of power supply. With the fact that the Strait of Malacca is blessed with tidal current energy, this research was conducted to design a hybrid renewable energy system that consists of tidal current and solar energy as its primary resources along with backup power such as generator and battery banks to support the electrical demand of a lighthouse. There were five hybrid system scenarios of different combination components were evaluated. A HOMER software was used to determine and compare the optimal configuration of the hybrid renewable energy system with the diesel generator based system. An evaluation of all possible combinations of standalone systems was carried out by considering the amount of fuel consumption, capacity shortage, excess electricity production, unmet energy, and renewable fraction parameters of each system scenario. The best among the five hybrid system scenarios was validated with diesel generator based system. The simulation results showed that the hybrid renewable energy system consisting tidal turbine, PV solar, generator, battery and converter is the best configuration system where it can reduce the consumption on diesel fuel by 84% in comparison to an entirely dependent diesel generator based system. Therefore, the hybrid renewable energy system is highly recommended for isolated or rural areas that have high potential on harnessing renewable energy sources.

ABSTRAK

Sumber bekalan elektrik di kawasan terpencil dan pulau biasanya dibekalkan oleh penjana diesel atau sistem penjanaan berasaskan bahan api fosil lain. Namun, peningkatan kos dan pelepasan bahan api fosil yang berbahaya telah mendorong manusia untuk mencari jalan penyelesaian alternatif dalam menjana bekalan elektrik. Bumi mempunyai sumber daya yang boleh diperbaharui yang dapat dimanfaatkan untuk menghasilkan tenaga elektrik. Oleh itu, memanfaatkan sumber yang boleh diperbaharui boleh menjadi penyelesaian alternatif dalam mengurangkan kebergantungan pada bahan api fosil. Kajian ini memfokuskan pada kemungkinan memanfaatkan tenaga di luar pesisir sebuah rumah api yang terletak di Selat Melaka untuk mengurangkan kebergantungannya pada penjana diesel sebagai sumber utama bekalan kuasa. Dengan hakikat bahawa Selat Melaka mempunyai tenaga arus pasang surut, kajian ini dijalankan untuk merancang sistem tenaga boleh diperbaharui hibrid yang terdiri daripada tenaga arus pasang surut dan tenaga suria sebagai sumber utama bersama dengan kuasa sandaran seperti penjana dan bateri dalam menampung keperluan elektrik rumah api. Terdapat lima senario sistem hibrid dari komponen gabungan yang berbeza yang dinilai. Perisian HOMER digunakan untuk menentukan dan membandingkan konfigurasi optimum sistem tenaga boleh diperbaharui hibrid dengan sistem berasaskan penjana diesel. Penilaian terhadap semua kemungkinan gabungan sistem kendiri dijalankan dengan mempertimbangkan jumlah penggunaan bahan bakar, pengurangan kapasiti, pengeluaran elektrik yang berlebihan, tenaga tidak terpesona dan parameter pecahan yang boleh diperbaharui bagi setiap senario sistem. Sistem yang terbaik antara lima senario sistem hibrid telah disahkan dengan sistem berasaskan penjana diesel. Hasil simulasi menunjukkan bahawa sistem kuasa tenaga boleh diperbaharui hibrid yang terdiri dari turbin pasang surut, solar PV, penjana, bateri dan penukar adalah sistem konfigurasi terbaik di mana ia boleh mengurangkan penggunaan bahan api diesel sebanyak 84% berbanding dengan sistem berasaskan penjana diesel sepenuhnya. Oleh itu, sistem tenaga boleh diperbaharui hibrid sangat digalakkan untuk kawasan terpencil atau luar bandar yang berpotensi tinggi untuk memanfaatkan sumber tenaga boleh diperbaharui.

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LIST OF ABBREVIATIONS

RE	-	Renewable Energy
HRES	-	Hybrid Renewable Energy System
AC	-	Alternating Current
DC	-	Direct Current
OTEC	-	Ocean Thermal Energy Conversion
OFB	-	One Fathom Bank
RED	-	Reversed Electro-dialysis
PRO	-	Pressure Retarded Osmosis
OWC	-	Oscillating Water Column
NOCT	-	Nominal Operating Cell Temperature
LED	-	Light Emitting Diode
SO_2	-	Sulphur Dioxide
CO_2	-	Carbon Dioxide
NO_x	-	Nitrogen Oxides
HOMER	-	Hybrid Optimization Model For Electric Renewables
NASA	-	National Aeronautics And Space Administration
FiT	-	Feed-In Tariff
OCT	-	Ocean Current Turbine
GHI	-	Global Horizontal Irradiance

LIST OF SYMBOLS

N_{EA}	-	Number of electrical appliances
P_{EA}	-	The power rating of electrical appliance
h	-	Hour
E_{pv}	-	PV power output
E_T	-	Turbine power output
E_{TMax}	-	Turbine maximum power output
A	-	Area
PR	-	Performance ratio
r	-	Ratio
ρ	-	Density
V	-	Velocity
C_p	-	Power coefficient
η	-	Efficiency
kWh	-	Kilo Watt Hour

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

This research is carried out to study the possibilities of designing hybrid energy system by introducing renewable energy (RE) resources that are available around the study area to support the electrification demand of a lighthouse located in an isolated area. The tower is located in the middle of the sea. Hence, solar and tidal current are the sources selected for the study due to their enormous and abundant energy resource around the building. The background study, problem statement, objectives, scope and significance of the study will be explained in this chapter to have a clear view regarding the research.

1.2 Background of The Study

Electrical power is one of the essential amenities in today's world that tend to be sought by humankind. With the rapid development of the global economy, energy requirements have increased remarkably, especially in developing countries. Currently, more than 70% of the worldwide electricity demand is supplied by finite sources such as coal, crude oil, and natural gas (Al-falahi et al., 2017). Producing electricity from finite sources are not only well-known in causing environmental issues such as global warming, carbon dioxide (CO2) emission, greenhouse effect, and others, but the sources are also depleting and soon will be diminished if excessive and continuous usage is carried out to generate electricity. Whether it is fossil fuel, nuclear energy or combination of both, it has been a deadly addiction to the world, and due to such matter, the society's interest in energy saving and environmental protection has begun to increase day by day (Apergis and Payne, 2012; Fazelpour *et al.*, 2014; Khan *et al.*, 2014; Al-falahi *et al.*, 2017).

The production of electricity in current scenarios are in many shapes and forms. Some power plant wholly dependent on fossil fuel as its resource, while some has integrated its system into a hybrid generation system. The nations have begun coordinating their framework in Green Technology to generate electricity. RE is demanded in the energy policies in many countries to secure the future electricity supply, especially for developing countries, including Malaysia. For instance, National Renewable Policy and Action Plan were launched by the Ministry of Energy Green Technology and Water in 2009. This policy aims to enhance the utilisation of green energy in contributing to the national electricity supply security and sustainable socio-economic development (Faez Hassan et al., 2012). Renewable Energy Act (2011) and Sustainable Energy Development Authority Act (2011) are the newly enacted laws which have the same intention to boost the utilisation of green energy by the industries in the generation of electricity (Mekhilef *et al.*, 2014).

The unavailability of gaining electricity from the grid is usually experienced by people who lived in remote areas. Therefore, their main power supply often comes from the usage of diesel generators. However, the elimination of using diesel generators is strongly supported in every country due to vast of problematic issues related to diesel, such as causing environmental impacts to the surroundings. Besides that, the fuel price is also fluctuating through time-based on the oil price. Thus it is not only expensive but also high in maintenance cost (Ani, 2016). The lack of an electrical network in remote areas and the prohibitively high connection cost of grid extension, as well as rough topography, often lead to the exploration of alternative options (Kusakana *et al.*, 2009; Mhlanga and Dzobo, 2019). In a nutshell, there is a need to include renewable and cleaner sources to generate electricity in both on-grid and off-grid system as to secure the future power supply especially for developing countries such as Malaysia (Shafie et al., 2011).

Generation of electricity can be processed by conventional sources such as coal or combine with one or more types of renewable energies in a power system. Studies made by past researchers have shown that a single kind of RE can be used to generate electricity only if it is sufficient enough to cater to the power demand of the load. However, in the case of a standalone system, it is best to combine whichever available

energy resources in that particular area to obtain optimum output that is great enough to cater to the energy demand. This combined system is also called a hybrid system. The system can either be off-grid and on-grid, depending on its geographical area whether it's possible to be connected to the power line transmission or not (Zohuri and Zohuri, 2018).

A hybrid energy system can be in many types and forms. They may range in size from relatively large island grids of many megawatts to individual household power supplies on the order of one kilowatt. A hybrid renewable energy system (HRES) usually consists of two or more RE sources used together to provide increased system efficiency as well as more excellent balance in energy supply. RE often provides energy in important common areas such as in electricity generation, air and water heating/cooling, transportation and also off-grid energy services (Zohuri and Zohuri, 2018).

Remote areas such as islands and villages commonly used diesel generators to power the energy supply. However, due to inflation in fuel cost in Malaysia, a significant rise in diesel price and extra cost in transportation is being charged it brings more stress to people. Fortunately, RE resources are usually affluent in remote areas depending on the geographic location. Due to the rising cost of diesel fuel and the rapidly declining cost of RE technologies, the energy supply by renewables is now becoming competitive with conventional energy, thus encouraging widely utilisation of RE systems for off-grid power supply, such as PV–battery, wind–battery, PV or wind-based pumped storage, micro-hydro turbine, or hybrid systems. Wind speed in Malaysia is low with a mean average of 2m/s resulting in wind-based systems not being used extensively. Hence the wind approach is only available in some areas in Malaysia (Lawan *et al.*, 2019).

1.3 Problem Statement

At present, generators are used as the primary power source to support daily power consumption, but the usage of electricity is strictly for essential electrical

appliances of the lighthouse such as continuous running radar system, lights, air-conditioner and others. The tower has few diesel generators operating alternately. Only one generator is needed to work at a time while other generators are considered as contingency plans. Besides that, diesel fuel is relatively expensive since fuel price fluctuates according to economics inflation and also, scheduled generator maintenance causes an increase in the overall cost of operation and maintenance of the system. Transporting the diesel fuel from the land to the lighthouse will also add up the summation cost for the whole system hence will increase the yearly financial cost to support the lighthouse. Besides, the disability to provide more electrical supply since more fuel will be needed to generate electricity, causing only specific or limited activities can be done around the study area (Zohuri and Zohuri, 2018). The environmental impacts to the surrounding area worthy of attention since it contributes to the climate change and thus concludes that the usage of these generators needs to be reduced with an eco-friendlier and reliable system that can meet the power demand by the lighthouse continuously.

Though the electricity generated from the generator is excellent enough to cater to the power demand of the lighthouse, but the drawbacks from this system have led to few problems. In short, electrical supply from the generator is not the best system for any building or places especially when there is an alternative solution for this specific matter. This issue has encouraged society to find alternative ways of generating electricity. With the technological advancement of green and vast free energy resources available in the surrounding, HRES would be the best optimum configuration to be applied to the area. Finding the best configuration is the primary purpose of this research. Combining the solar system with diesel generator may be suitable to be implemented but having more RE resources working together would be the best options in producing the best energy output. For instance, the two vast resources that can be harnessed at the lighthouse located in the middle of the sea are tidal current and solar. Thus, the best optimum power configuration is by combining all of the available green energies; solar system and tidal current turbine along with backup storage system to cater the electricity demand (in kWh) of the lighthouse.

1.4 Research Objectives

Before developing a comprehensive hybrid renewable energy system based on renewable energy resources, it is essential to identify the current status of the main power supply and understand the issue and its problems. Hence, the objective of this research is:

(a) To investigate the energy load consumption of the lighthouse and the availability of renewable energy resources around the lighthouse.

(b) To determine the types of components and sizing based on resources and energy demand to form hybrid renewable energy.

(c) To evaluate the hybrid renewable energy system in comparison with the generator-based system based on fuel consumption, renewable fraction, unmet electrical load, capacity shortage, and excess of electricity.

1.5 Scope of The Study

Several things will be considered under the project scope that includes the location, software used, types of RE resources and the types of energy converters as well as the limit sizing of component used. The lighthouse is located in the Strait of Malacca with coordinates of latitude and longitude 2˚53’3” N and 100˚59’8” E respectively (see Appendix A). Researchers has confirmed that the location has the potential to harness one of the ocean energy, which is tidal current. Besides that, the availability to get sunlight during the day makes it available for solar power. Hence tidal turbine and PV solar are the two types of energy converters in the study. In addition to that, due to the limitation of space for PV panel installation (Marine21, 2008), therefore the PV power is set to a limit up to 10kW only and to produce more energy from renewable resources from the overall system, the maximum output from the generator is limit to half of the daily peak demand load. Furthermore, a hybrid optimization model for electric renewables (HOMER) software is used as an energy simulation tool for the study.

1.6 Significant of The Study

The findings of the study will rebound to the benefit of society considering that renewable energy system plays an important role in reducing the fuel cost and obtaining a healthier environment with less pollution. The concern on depletion of fossil fuel as well as green effect due to electricity generation lead mankind to seek for an alternative way that is reliable and effective. Hence, implementing renewable energy system at the lighthouse can help to minimize the dependency on fuel thus reducing the cost and also save the earth from pollutions. Besides that, the present of turbines, solar, and other related components in hybrid system proposed at the lighthouse can provide more job opportunities at the lighthouse. Therefore, can secure one's job or increase his/her income.

1.7 HOMER Software

Hybrid Optimization Model Electric Renewable or HOMER is an algorithm used in optimization process and sensitivity analysis. It is used to design and evaluate technically and financially the options for off-grid and on-grid power systems either for remote, standalone, or distributed generation applications. This software has been chosen to carry out the study since it is mostly used for optimization software. HOMER can optimize many system configurations through optimization simulation and sort them according to their cost-effectiveness. Besides that, HOMER can also offer sensitivity analysis where number of input variables can be fed into the simulation to observe the impact on its output.

1.8 Thesis Outline

This thesis consists of six chapters. The outline of the thesis are as follows:

Chapter 1 covers the research background as an overview of this project. Some issues related to the research as discussed in the problem statement and the objectives are stated clearly as well as the scope of this project.

Chapter 2 contains the literature review related to past research on the hybrid power system. The explanations are based on the information gathered from the journals, reports, internet, books, and other relevant articles.

Chapter 3 contains the research methodology that described the overall flow of the research in designing a hybrid power system that consists of a tidal turbine, PV, generator, batteries and converter. The power load consumption of the lighthouse will also be explained in this chapter.

Chapter 4 discussing the results and analysis of the performance of power systems in different scenarios obtained from the simulation done by using Homer software. Then the proposed HRES system will be validated with existing HRES system.

Lastly, in Chapter 5, the conclusion and recommendations for further study in this field were stated.

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