UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

DEVELOPMENT OF FUEL CELL AND SOLAR PROTOTYPE FOR MELAKA RIVER CRUISE BOAT

Mukhzani Ibnu Mustaffa
M041910006

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MUKHZANI IBNU MUSTAFFA

A report submitted
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DECLARATION

I Mukhzani Ibnu Mustaffa (M041910006) presented a report on the thesis entitled 'Development of Fuel Cell and Solar Prototype for Melaka River Cruise boat' for my final project report in the Master by taught course to be submitted to the university. The results were completed by me and this report was sent as part of the Master's requirements. This report has never been drawn up or submitted by any master and is not submitted simultaneously to any other master.

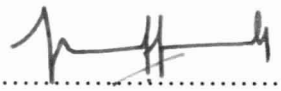
Signature : .....

Name : Mukhzani

Date : 24/3/21

APPROVAL

I, the supervisor of this student, confirm that I have read this thesis, that I am also here to declare the thesis in terms of scope and content as well as to meet the criteria for being recognized as a Master's degree in Mechanical Engineering.

Signature : 

Supervisor Name : Noreffendy Tamaldin

Date : 24/3/21

DEDICATION

In the name of Allah S W.T., the most benevolent and good, I praise Allah the Lord of the Universe and thank His Prophet, Muhammad S.A.W, for Allah 's grace and peace. I thank Allah the Almighty, above all, for giving us the chance to carry out this project study. I was able to complete the final year project report with HIS blessing.

I would like to express my deepest appreciation to my lecturer, Prof Ts Dr Noreffendy Tamaldin, for giving me a lot of brilliant advice and helping me manage my time to complete this final project. There is no word that can be said except gratitude for kindness and help. May God reward all the good works of Prof Ts Dr Noreffendy Tamaldin. He has helped me a lot in a country that is struggling with the COVID-19 pandemic virus. Even with the current pandemic where it is difficult to properly communicate with my supervisor, he keeps on pushing me and give me advice on how to conduct my thesis. Thanks to his guidance I manage to finish this thesis and gain more knowledge regarding the application of renewable energy.

I would also like to express my deepest thanks to my lovely family, especially my mother and my wife, for their endless inspiration and moral support. I was motivated not to give up, and my wife understood my job as a student and working at the same time.

ABSTRACT

Melaka River Cruise is one of the main attractions for Malacca tourism. They have 21 boats in operation which covers a total of 3780km per day on peak season. This high usage of fossil fuel for the boats in an urban environment will produce high amount of carbon emission that will cause air pollution. As a green city, Malacca should be the example for other cities to raise the awareness for greener environment. Replacing the fossil fuel with renewable energies are seen as one of the main solutions to reduce this air pollution. A lot of research has been done on renewable energy application and some countries are already applying it in their transportation industry especially in their urban environment. Renewable energies such as solar, wind and Fuel Cell are in abundance and does not produce harmful by product as long as we know how to properly harness it. This research is aimed to proof the concept of application for Fuel Cell and Solar PV as main power source for Melaka River Cruise boat and replacing the use of ICE with fossil fuel. The application of Fuel Cell and Solar PV are tested on a prototype boat. All the data such as voltage, current, resistance and power are recorded in a renewable energy monitoring device so it can be analyzed. From these data, graphs are plotted so each value for each renewable energy can be compared and calculated. The solar panel and the hydrogen fuel cell used in the prototype have an efficiency of 5.27% and 90.48%, respectively. The same components in the scaled up version have efficiencies 18.5% and 46%, respectively. In this study also, we can measure the resistance. Normally resistances values are predicted in a simulation base research. But by capturing real value of resistance, we can analyze how it effects voltage, current and power. We then studied the characteristic of energy behavior of Fuel Cell and solar. Then from these data, we will upscale it to a much bigger power output power application. One of the findings of our experiments on the prototype is that we can see variation of current output for Fuel Cell, whereas Solar PV is giving constant current output. This means that for our prototype, Hydrogen Fuel Cell is producing current at a much slower rate compare to Solar PV. This may affect its reaction for any variations in motor demand. By understanding the concept of upscaling the equipment for Hydrogen Fuel Cell and solar PV, we then calculate on how to apply to actual boat size. From this then we will search what equipment currently available that match our spec. After that we will give suggestions on an actual setup that can be applied on Melaka River Cruise boat. In terms of actual application, Fuel Cell is seen as more applicable in terms of power output, space area and weight. Solar PV do have its potential, but due to its low efficiency and reliant on sunlight intensity, it is more practical to use it in a hybrid mode.

APLIKASI FUEL CELL DAN TENAGA SURIA KE ATAS MODEL BOT UNTUK KEGUNAAN MELAKA RIVER CRUISE.

ABSTRAK

Melaka River Cruise adalah antara tarikan utama pelancong di bandar Melaka. Mereka mempunyai 21 bot yang beroperasi sejauh 3780km sehari pada kapasiti yang maksimum. Jumlah penggunaan bot yang sangat besar ini akan menyebabkan banyak pencemaran udara kerana bot enjin akan melepaskan carbon ke atmosfera. Sebagai bandar yang dikenali sebagai bandar hijau, Melaka sepatutnya menjadi contoh kepada bandar-bandar lain dalam meningkatkan kesedaran dari segi pentingnya menjaga alam persekitaran. Menggantikan penggunaan minyak untuk enjin bot ini dengan menggunakan tenaga yang boleh diperbaharui dilihat sebagai salah satu solusi untuk mengurangkan pencemaran udara. Banyak ujikaji telah dijalankan berkenaan tenaga yang boleh diperbaharui ini dan ada sesetengah negara yang sudah mengaplikasikan penggunaan tenaga ini terutamanya didalam industri pengangkutan di bandar-bandar utama mereka. Tenaga yang boleh diperbaharui seperti tenaga suria, angin dan Fuel Cell adalah sangat banyak dan tidak menghasilkan produk yang boleh mencemarkan udara selagi cara yang betul digunakan. Tesis ini bertujuan untuk membuktikan konsep tenaga yang boleh diperbaharui ini untuk digunakan ke atas model bot dan menggantikan penggunaan enjin dan minyak. Aplikasi Fuel Cell dan tenaga suria diuji ke atas model bot dan semua data seperti voltan, tenaga arus, kuasa dan rintangan akan direkodkan ke dalam komputer untuk dikaji. Daripada data-data ini, graf akan dibuat supaya setiap data boleh dibandingkan antara satu sama lain. Panel solar dan Fuel Cell yang digunakan untuk model bot masing-masing mempunyai efisiensi sebanyak 5.27% dan 90.48%. Komponen yang sama untuk skala besar yang dicadangkan mempunyai efisiensi sebanyak 18.5% dan 46%. Didalam ujikaji ini juga, kami berjaya untuk merekodkan nilai rintangan. Biasanya nilai rintangan ini akan disimulasi sahaja. Tetapi dengan merekodkan nilai rintangan sebenar, kami dapat menganalisa bagaimana rintangan ini akan memberi kesan kepada voltan, tenaga arus dan kuasa yang dihasilkan oleh tenaga yang boleh diperbaharui ini. Kami juga berjaya mengenal pasti karakter berbeza diantara Fuel Cell dan tenaga suria. Dalam sebahagian daripada analisis kami, kami dapati yang Fuel Cell menghasilkan variasi tenaga arus, tetapi Solar PV Berjaya menghasilkan tenaga arus secara konstan. Ini menunjukkan bahawa untuk prototype kami, Fuel Cell sedikit lambat menghasilkan arus. Ini boleh membuatkan Fuel Cell bertindak lebih lambat jika ada sebarang variasi dari beban motor.Kemudian daripada data-data yang diperolehi ini, kami akan membuat kiraan untuk aplikasi kepada penggunaan kuasa yang lebih besar. Selepas itu, kami akan mengenal pasti bagaimana untuk mengaplikasi penggunaan tenaga yang boleh diperbaharui ini keatas Melaka River Cruise dengan bersandarkan alatan-alatan yang berada di pasaran sekarang. Di dalam kajian ini, kami dapati Fuel Cell lebih praktikal untuk digunakan disebabkan kuasa yang dihasilkan, keluasan yang diperlukan dan berat yang jauh berbeza dengan yang lain. Tenaga suria juga mempunyai potensi, tetapi disebabkan kerbergantungan yang tinggi kepada cahaya matahari dan kadar effisiensi yang rendah, menyebabkan tenaga suria lebih mudah digunakan secara system hybrid.

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CHAPTER 1

INTRODUCTION

1.1 Background

Melaka River Cruise Establishment is an idea and concept from Melaka's ninth former chief minister, Tun Haji Mohd Ali Bin Mohd Rustam. Melaka River Cruise currently operates with 21 boats. The journey for this boat service is 9 km for each trip which takes 45 minutes. The average total number of journeys are 20 daily, and the current fuel consumption for all boats are around RM 5000 per day. The engine capacity of the boat ranging from 115 to 150 hp.

To ensure a sustainable and high quality of life, it is important to provide safe, environmentally friendly, and reliable energy supplies. However, it must face social, political, environmental, and economic challenges. The heavy usage of fossil fuels raises pollution, causing significant negative externalities and environmental degradation. The by-product of natural petroleum will come into existence and will not be available in future.

Internal combustion engine vehicle emissions are also a serious concern as it mainly uses fossil fuel. So, a lot of the latest technologies being developed are focusing on electrical conveyance. Renewable energy resources also have an important role to play in meeting today's and future energy needs. Besides, it is more environmentally sustainable than traditional fossil fuels and will not be lost in the future.

Enhancing energy production and increasing the supply of carbon-free fuels to energy supply will succeed in building a more sustainable and efficient future. Solar and hydrogen are

part of the renewable energy resources that are being studied for long-term sustainable alternative to fossil fuels.

1.2 Problem Statement

Base on Third IMO GHG Study 2014, it is expected that global carbon emission in marine transportation will increase by 50-250% (Smith et al. 2015). In Eleventh Malaysia plan, Malaysia set a goal to reduce its GHG emission from 26.8% up to 40%. Currently Malaysia is ranked third after Indonesia and Philippines in terms of CO_2 emission from the transport sector in ASEAN countries. Electric Vehicles are seen as one of the solutions for this problem (KeTHHA 2017). Some of this Electric Vehicles may use Renewable Energy as their main source of power.

Carbon emissions are form of CO and CO_2. Simple carbon emission calculation will be using Tier 1 guide which is emission factor provided by Lloyds register. For CO, the pf is 0.0016 kg/kWh (Zainol et al. 2020). By using a simple formula for emission (VOWTAP 2014);

$E = kW \times Act \times LF \times EF$

E = emission, grams/year,

kW = kilowatts (engine rating)

Act = activity, hours/year

LF = engine load factor (for the activity)

EF = emission factor g/kW-hr

Assuming engine load factor is 0.7 and activity per year is 3650 hours. Carbon emission from 150 hp outboard engine will be

$E = 112kW \times 3650hrs/year \times 0.7 \times 1.6\ g/kWh = 457856g/year$

This is an estimation for only one boat. However, a more thorough method had been done in Manjong, Perak on fishing boats with outboard engine of 115 hp, it is found that this

type of engine produces about 500 ppm carbon emission. Of course, this will varies depend on the engine efficiency and load factor (Zainol et al. 2020).

State of Melaka received about 15 million tourists per year. The Melaka River Cruise company estimated that, they handle about 1 million passengers yearly. On average, each of their 21 boats consumes around RM 200 of petrol fuel. The cost of RM 200 fuel is estimated around 105 litres of fuel with the assumption that 1 litre of petrol price equivalent to RM 1.90. The 105 litres of fuel usage per day are estimated for one boat. So, with the total of 21 boats operating, the total cost would be around 2205 litres of petrol per day on average. Since Melaka River Cruise consumed high amount of fossil fuel, it releases a huge amount of carbon emission that contributes to the greenhouse effect and increase the global warming.

First, this research aims to change the power source of the Melaka River Cruise propulsion engine from using fossil fuel into using renewable energy instead. Research on Solar and Fuel Cell are evaluated to observe which energy gives better advantages. By changing the power source for the Melaka River Cruise, it can reduce the environmental pollution generated by internal combustion engine which produce a lot of CO_2. Excessive amount of CO_2 produced could cause the greenhouse effect and indirectly it can increase the surrounding temperature.

The experiment is conducted using a small-scale reversible hydrogen fuel cell and solar panel. For the fuel cell setup, items used are one piece of reversible fuel cell, two units of 1.5V batteries and distilled water. The fuel cell will act as main source of power supply. To make a fuel cell as a power source, hydrogen and oxygen gas must be supplied to the fuel cell. In this case, hydrogen and oxygen gas are contained in a round cylinder filled with distilled water. An anode catalyst triggers the fuel to undergo oxidation reactions that produce ions. The ions are moving through the electrolyte from the anode to the cathode. During this time, electrons will flow from the anode to the cathode through an external circuit, which produces direct current.

The hydrogen ions and electrons are then mixed with the oxygen at the anode that creates H_2O. For the test of solar power, a solar panel with a maximum power of 1W was used.

1.3 Objectives

The core objectives of this project are as follow:

a) To plan and execute a conceptual design of renewable energy powered marine vessel.

b) To determine actual power output of fuel cell and solar energy based on scaled down prototype system.

c) To identify with the help of experimentation and simulation if Melaka River Cruise boat can be powered by renewable energy thus eliminating the use of fossil fuel.

1.4 Scope of project

The scopes of this project are:

a) Collecting and verifying actual data for current power consumption of Melaka River Cruise.

b) Analysing the capability and possibility of a river boat to be powered by fuel cell and solar with the help of a prototype.

c) The prototype boat is not an exact scale down version of the actual river cruise boat as this project is just a proof of concept. Thus the equipment used is widely commercially available and not custom made for this specific project.

d) Measuring on how much power a fuel cell and solar can produce using experimentation on prototype boat and doing some calculations from the data collected.

e) Researching and finding the best solar panel and fuel cell to be installed in Melaka River Cruise.

1.5 Organization of report

This thesis explores six chapters to explain the areas discussed in this report. The chapters are introduction, literature review, methodology, result, discussion and conclusion.

Chapter 1 explains the context of the research to be carried out. It describes the problems which motivate the study to be conducted. Three clear objectives are stated to give clear direction of this thesis. The project scope are underline to show how the thesis is constructed.

Chapter 2 explores the literature review as to see what are the current state of fuel cell and solar power for transportation purpose especially on marine transportation. Information from other researches were analysed to understand their concept and to find any gap in their researches so we can construct a good method to conduct this research to achieve better results.

Chapter 3 explains the methodology in conducting these experiments. Both fuel cell and solar energy are tested several times in order to obtain sufficient data so it can be properly analised. Four main data are collected which is power, voltage, current and resistance. All detail procedures, equipment spec and condition during experiments are explained in this chapter.

Chapter 4 describes the result from the collected data obtained from the experiments. This chapter also explains the behaviour of the energy that are translated into graphs so the trend can be identified and whether the expected goals were achieved.

Chapter 5 is the discussion on the application of these experiments on the prototype boat. Explanation on how each energy performs and how to upscale the equipment to produce higher power output. Setup for actual application on Melaka River Cruise also were explored to analyse which method are the most effective and practical.

Finally chapter 6 is the conclusion and recommendation. How these experiments can be further improve for further studies and how the actual application on Melaka River Cruise boats can be properly applied.

CHAPTER 2

LITERATURE REVIEW

2.1 Fuel Cell

Fuel cells are electrochemical component that can produce Direct Current from supply of hydrogen and oxygen through an electrolysis process. Only heat and water will be its emission product. This cell is combustion free, thus there will be no subsequent CO2 emissions (Muthukumar 2020). The word 'fuel cell' was think up by the industrialist Ludwig Mond, who in 1889 found the crucial discovery that the electrochemical oxidation of hydrogen was the thermodynamically more effective mechanism for the release of energy. Mond considered it as 'fuel' rather than a battery because it keeps on receiving supply of hydrogen and oxygen for its electrolysis process (Thomas and John Meurig 2020). Electricity is required for the electrolysis process. The electrolysis process will than produce hydrogen and oxygen. Hydrogen and oxygen that are produced can be stored and be used back to produce electricity by using the same fuel cells.

Fuel cells are electrochemical converters; they directly turn hydrogen and oxygen into electricity using their anode and cathode during the chemical process (Thomas and John Meurig 2020). The component consists of electrodes, electrolyte catalysts and gases in fuel cells. Materials that are used for the membrane, flow channel plate, catalyst and gas diffusion layer are Polytetrafluoroethylene, graphite NCK 194, platinum and carbon cloth. There are two electrochemical reactions which are conducted in anode and cathode between the two electrodes. The hydrogen in the anode is divided into protons and electrons (Muthukumar 2020). The protons flow through the membrane to the cathode, and the electron passes through

the external electrical circuit. The current is known as the movement of electrons. The oxygen that comes from the cathode acts with the protons and electrons and forms water. A single fuel cell can produce low electrical power, which is very low for vehicles to run on. To overcome this, we simply just use the concept of batteries, by arranging and connecting batteries in series, we can produce more power. So, several hydrogen fuel cells will be stacked or merged in series and more power can be produced (Muthukumar 2020).

Hydrogen also can be obtained from various domestic sources. The global demand for fuel cells is projected to mature with billions of revenues each year for stationary and portable applications. Mature market has a potential of creating lots of new job opportunities. Fuel cells does not produce noise when generating electricity and it does not produce NOx (Baroutaji and Ahmad 2019). On top of that, hydrogen is safer compare to other fuels because it can quickly evaporate if there are any leakage. Fuel cell powered vehicles produce less grams of CO_2 compared to most other fuels except Hydrogen produced from natural gas (Ambrose and Angelina 2017).

2.1.1 Type of Fuel Cells

Normally fuel cell is classify based on their electrolyte types. There are several electrolytes used for the electrolysis process of the fuel cell.

a) Phosphoric Acid Fuel Cell: it has low power output density. Thus, comparing it to others with same power output, it will consume more space and are much heavier. Due to its high operation temperature, it takes longer time to start up.

b) Alkaline Fuel Cell: it has lower efficiency due to the chemical reaction of its electrolyte and acidic carbon dioxide that produces solid potassium carbonate particles.

c) Solid Oxide Fuel Cell: it operates at a high temperature thus giving extra thermal stress to its components. The structure also is complex thus making it expensive to build.

d) Molten Carbonate Fuel Cell: this type of cell is mainly used in high energy demand area. It operates at a high temperature and expose more to high corrosion. Its components are more expose to the chance of cracking because of this.

e) Proton Exchange Membrane Fuel Cell: its electrolyte consists of ion exchange membrane. Higher power density compares to other FC.

Operating temperature of fuel cell may affect its lifetime. Fuel Cell that runs at higher temperature tends to fail or break faster compare to Fuel Cell that runs at a much lower temperature. Fuel Cell are chosen depending on the power output needed and its working temperature. Molten Carbonate FC and Solid Oxide FC are normally used on steam and gas turbine due to their capability to operate within higher temperature range and producing higher power output. For lower power output and low working temperature, Alkaline FC and Proton Exchange Membrane FC are preferred. However, nowadays Proton Exchange Membrane FC are preferred. Alas, there are more research and studies on it, and they are more commercially available (Inal and Deniz, 2020).

2.1.2 Fuel Cell Application in Transportation

Transportation Greenhouse Gas (GHG) emissions are getting extremely serious especially in major cities. As of this moment, at least 80% of major cities have below minimum air quality standard. In Europe at least 25% of this low quality of air are attributed to transportation (Ajanovic and R.Haas 2020). Hydrogen fuels and their use have already been adopted in several nations as part of the solution such as Canada, Japan, the United States and Germany. These countries are showing tremendous dedication in implementation hydrogen fuel cell as a potential power source (Ahmed and Adeel 2016). Fuel Cell Vehicle has been developed and tested by car manufacturers. Their goal is to replace combustive engines. Tesla are focusing

on electric vehicles meanwhile Toyota has opened Fuel Cell Vehicle (FCV) patents for hydrogen to give a boost to the marketing of zero-emission vehicles (Ambrose and Angelina 2017). In 2007, GM launched "Project Driveway," a fuel cell-equipped 119-vehicle fleet of Chevrolet equinoxes that have been powered by more than 5,000 customers in everyday usage of over 3 million miles. This was the world's biggest fleet of fuel cell vehicles ever built at the time. Hyundai is also developing a truck powered by heavy fuel cells for potential entry to the US market (Thomas and John Meurig 2020). General Motors (GM) developed its first fuel cell road vehicle in the United States as early as 1966, the Chevrolet Electrovan (Ahmad and Adeel 2016).

Hydrogen FCV uses electricity generated by electrochemical reactions between hydrogen and oxygen in contrast to conventional fossil fuel-fired mechanical energy, with water being a by-product. Water is harmless compared to harmful by product produce by fossil fuel such as sulphur dioxide (SO_2), nitrogen oxides (NO and NO_2) and CO_2 (Ambrose and Angelina 2017). Hydrogen can be used in different transport applications where a longer driving range and higher load capacity are needed. Hydrogen also do not require long charging time like battery powered vehicle (Ajanovic and R.Haas 2020). In May 2019, England announced that their 20 double-decker fuel cell buses would be introduced in London. However, the company that handle this experience some economical problem, but has now been partially rescued (Thomas and John Meurig 2020).

Fuel cell forklifts are now commercially viable and about 25 000 forklifts are currently in use worldwide. Medium-sized fuel cell forklifts have already been tested at major airports such as Toronto Pearson, Hamburg, and Munich. These forklifts have many advantages, such as very low noise, no emissions and very few maintenance requirements. They have about the same dimensions as traditional batteries, but do not need an exchange of batteries, which is impossible for most modern forklifts. Refuelling time was also a significant improvement for