" I hereby declare that I have read through this report entitle "*Analysis on the Effect of Pressure and Flow Rate Hydrogen Towards the Performance of Thermodynamic Potential of Proton Exchange Membrane Fuel Cell*" and found that it has complied with the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

Signature : .....

Supervisor's Name : .....

Date : 24/6/15

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# ANALYSIS ON THE EFFECT OF PRESSURE AND FLOW RATE HYDROGEN TOWARDS THE PERFORMANCE OF THERMODYNAMIC POTENTIAL OF PROTON EXCHANGE MEMBRANE FUEL CELL

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**A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power)**

**Faculty of Electrical Engineering**
**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2015**

" I declare that this report entitle *"Analysis on the Effect of Pressure and Flow Rate Hydrogen Towards the Performance of Thermodynamic Potential of Proton Exchange Membrane Fuel Cell"* is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature : .....

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Date : 24/6/2015

## ACKNOWLEDGEMENT

First and foremost, I would like to express my appreciation to my supervisor, Mr. Mohd Shahril b. Ahmad Khiar for the guidance and motivation throughout the progress of this project. I also want to thank to lecturers and staffs of Faculty Electrical Engineering, Universiti Teknikal Malaysia (UTeM) for their cooperation during I complete the final year project that had given valuable information, suggestions and guidance in the compilation and preparation this final year project report.

Deepest thanks and appreciation to my parents, family and others for their cooperation, encouragement, constructive suggestion and full of support for the report completion, from the beginning till the end. Thanks for their encouragement, love and emotional supports that they had given to me.

Besides, thanks to all of my friends and everyone, who had given me the advice, courage and support in completing this project. Their views and tips are very useful. Last but not least, I would like to thank all the lecturers who have been very friendly and helpful in providing me with the necessary information for my project.

Thank you.

## ABSTRACT

Currently, the demand for the energy source in Malaysia keeps increasing day by day. On the other hand, the energy source in Malaysia keeps decreasing as a result from the demand. Therefore, the government encouraged the use of renewable energy as an alternative energy source such as Proton Exchange Membrane (PEM) Fuel Cell. The PEM Fuel Cell used hydrogen as a fuel to produce electricity. However, the PEM Fuel Cell has some problem in which it affects the performance of PEM Fuel Cell. There are a few parameters such as pressure and flow rate hydrogen that affects on the performance of PEM Fuel Cell. Besides that, the existing method that has been used to analyze the data of the PEM Fuel Cell needs an expensive. Therefore, the problem that occurs in the PEM Fuel Cell specifically the effect of pressure and flow rate hydrogen should be investigated and analyzed. Then, the new method which is a signal processing technique will be introduced in the future. This technique is recommended to investigate the identification signal of the pressure and flow rate hydrogen towards the changing behavior in PEM Fuel Cell. From the polarization curve and periodogram results, it is clearly revealed that when the pressure hydrogen increased, the performance thermodynamic potential of PEM Fuel Cell will be increased. Besides that, when the hydrogen flow rate is increased, the performance voltage of PEM Fuel Cell will be decreased because the hydrogen flow rate is related with the moisture of hydrogen. Moreover, the identification signal of pressure and flow rate hydrogen by using signal processing technique is show that the changing pressure and flow rate hydrogen has an affects on the changing characteristic behavior in PEM Fuel Cell.

## ABSTRAK

Pada masa ini, permintaan terhadap sumber tenaga di Malaysia terus meningkat dari hari ke hari. Sebaliknya, sumber tenaga di Malaysia terus berkurangan akibat dari permintaan. Oleh itu, kerajaan menggalakkan penggunaan tenaga boleh diperbaharui sebagai sumber tenaga alternatif seperti Proton Exchange Membran (PEM) Fuel Cell. PEM Fuel Cell menggunakan hidrogen sebagai bahan api untuk menghasilkan tenaga elektrik. Walau bagaimanapun, PEM Fuel Cell mempunyai beberapa masalah di mana ia memberi kesan kepada prestasi PEM Fuel Cell. Terdapat beberapa parameter seperti tekanan dan kadar alir hidrogen yang memberi kesan kepada prestasi PEM Fuel Cell. Selain itu, kaedah yang sedia ada yang telah digunakan untuk menganalisis data PEM Fuel Cell adalah sangat mahal. Oleh itu, masalah yang berlaku dalam PEM Fuel Cell khusus kesan tekanan dan kadar alir hidrogen perlu disiasat dan dianalisis. Kemudian, kaedah baru yang merupakan teknik pemprosesan isyarat akan diperkenalkan pada masa akan datang. Teknik ini adalah disyorkan untuk menyiasat isyarat pengenalan tekanan dan kadar alir hidrogen ke arah tingkah laku yang berubah-ubah dalam PEM Fuel Cell. Dari lengkung polarisasi dan keputusan periodogram, ia jelas menunjukkan bahawa apabila tekanan hidrogen meningkat, potensi termodinamik prestasi PEM Fuel Cell akan meningkat. Selain itu, apabila kadar aliran hidrogen ditambah, voltan prestasi PEM Fuel Cell akan menurun kerana kadar aliran hidrogen berkaitan dengan kelembapan hidrogen. Selain itu, isyarat pengenalan tekanan dan kadar alir hidrogen dengan menggunakan teknik pemprosesan isyarat menunjukkan bahawa tekanan yang berubah-ubah dan kadar alir hidrogen mempunyai kesan ke atas tingkah laku ciri yang berubah-ubah dalam PEM Fuel Cell.

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| | |
|---|---|
| PEM | Proton Exchange Membrane |
| RE | Renewable Energy |
| R&D | Research and Development |
| MOSTI | Ministry of Sciences, Technology and Innovation |
| CI | Current Interruption |
| EIS | Electrochemical Impedance Spectroscopic |
| DC | Direct Current |
| $H_2$ | Hydrogen |
| $H_2O$ | Water |
| $O_2$ | Oxygen |
| MCFC | Molten Carbonate Fuel Cell |
| SOFC | Solid Oxide Fuel Cell |
| AFC | Alkaline Fuel Cell |
| PAFC | Phosphoric Fuel Cell |
| DMFC | Direct Methanol Fuel Cell |
| IFC | Institute of Fuel Cell |
| UKM | Universiti Kebangsaan Malaysia |
| NASA | National Aeronautics and Space Administration |
| ECG | Electrocardiogram Signal |
| EEG | Electroencephalography |
| GNSS | Global Navitigation Satellite System Signal |
| AC | Alternative Current |
| $V_{RMS}$ | Root Mean Square Voltage |
| $V_{DC}$ | Direct Current Voltage |
| $V_{AC}$ | Alternative Current Voltage |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Project Background

Nowadays, Malaysia more focused on the renewable energy because of the increasing demand of electricity. Every year the demand for the energy sources in Malaysia keep increasing and hence the prices for the energy sources will become more expensive day by day. The main energy source is used in industrial, transportation, residential and commercial. The statistics of the U.S Energy Information Administration in 2012 shows that the main energy source consumed in Malaysia is petroleum, which is 40% while the natural gas is 36%. The other energy source that has been used is coal, biomass, and hydropower with 17%, 4% and 3% respectively.

Thus, the government introduces and promotes a renewable energy (RE) in Malaysia through Eight Malaysia Plan with a goal to achieve the target of 5% usage of the renewable energy [1]. In addition, the renewable energy can reduce dependency on fossil fuel and contribute towards reducing the effects of climate. Hence, the implication of the renewable energy can minimize enlargement energy utilization and conserve the environment for the future. Thus, for more than 10 years, Malaysia had tried many different policies, programs, funding and schemes that introduce and promote the implementation of renewable energy as an alternative energy [2].

National Green Technology Policy was launched on July 2009 by the Prime Minister, Datuk Seri Najib Tun Razak. The purpose of this policy is to develop new invention that used a green technology. The green technologies are related to the RE because it use clean

energy that can reduce pollution and have long-term reliability. Therefore, through the government policies, the hydrogen Proton Exchange Membrane (PEM) fuel cell was introduced in Malaysia. Approximately RM40 million has been allocated for academic research institutions for fuel cell study and development [3].

There is a lot of research that develops the PEM Fuel Cell such as the Institute of Fuel Cell, Universiti Kebangsaan Malaysia (IFC, UKM) and at Hydrogen Economy, Universiti Teknologi Malaysia (HE, UTM), [3]. Ministry of Sciences, Technology and Innovation (MOSTI) are also investing almost 41 million in research and development (R&D) of hydrogen and a fuel cell. The research and development of fuel cell focused on the PEM Fuel Cell which uses hydrogen as a fuel. However, the development of fuel cell in Malaysia is rather slow and still new compared to the other country such as Japan and Switzerland. Malaysia was popular with other renewable energy such as solar, hydroelectric and biomass.

Basically, the PEM fuel cell generates electricity through the chemical reaction in the fuel cell without any combustion phenomenon takes place. It uses hydrogen as a fuel to generate electricity. However, there is a lot problem that is related to the performance of PEM Fuel Cell. Therefore, this problem has forced to study the effect of pressure and flow rate towards the performance of PEM Fuel Cell.

## 1.2 Problem Statement

Currently, the demand of electrical energy is keep growing, but the energy source is decreasing. Therefore, the fuel cell is introduced in the world and used in many applications. Malaysia government also encourages the usage of the renewable energy and hoping it to reach the goal of 5% usage. However, the fuel cell is rarely used and not commercial in Malaysia. To achieve the target, the RE such as the PEM Fuel Cell should be used in our industrial, transportation, residential and commercial. Government also provides the budget for the research and development on the fuel cell.

However, the PEM Fuel Cell consist some problems that will affect on the characteristic of the PEM Fuel Cell such as the physical of membrane, density of PEM Fuel Cell, type of coolant and so on. The characteristic of the PEM Fuel Cell also can have effects on the performance of the PEM Fuel Cell. There are a lot of phenomena that can affect the performance of PEM Fuel Cell such as drying, flooding and others. The changing of the performance of PEM Fuel Cell is depending on some parameter such as pressure, flow rate, humidity, and temperature. Thus, to overcome the problem, all the parameter that will be effected on the performance of PEM Fuel Cell should be identified and analyze.

In previous research, there are a lot of methods that can be used to analyze the result of the performance of PEM Fuel Cell. For example, the methods that can use are current interruption (CI) and electrochemical impedance spectroscopy (EIS) but it has a problem such as the price of equipment and long life of equipment. Therefore, the signal processing method can be used because the signal processing only used software to simulate the signal. The signal processing method is different from the others because it can used to monitor the PEM Fuel Cell in micro monitoring. However, this method is not commonly used in research of PEM Fuel Cell.

## 1.3 Objectives of Project

There are several objectives to accomplish to complete this project which are:

i. To study the effect of pressure and flow rate towards the performance of PEM Fuel Cell.
ii. To analyze the effect of the pressure and flow rate of the hydrogen towards the performance of thermodynamic potential in the PEM Fuel Cell.
iii. To investigate the signal identification of pressure and flow rate of hydrogen towards the changing behavior in PEM Fuel Cell by using signal processing technique.

## 1.4 Scope of Project

The model of PEM Fuel Cell that is used in this project is H-2000W from Horizon Fuel Cell Sdn Bhd. The H-2000W PEM Fuel Cell consists of 48 cells and the power rating of it is 2000 Watt. The pressure and flow rate of hydrogen are used as a parameter for the testing purposes. The digital flow rate meter from Vögtlin Instruments AG flow technology will be used to measure a flow rate of hydrogen. The hydrogen pressure will be varied for 0.1 Bar, 0.2 Bar, 0.3 Bar, 0.4 Bar and 0.5 Bar while the load value will be used from 0A to 36 A. However, the hydrogen pressure that used for hydrogen flow rate parameter testing is 0.2 Bar and 0.5 Bar only and the load current will be varied from 0A to 36 A. Thus, the outcome of the testing is focused on the current, voltage and the signal that produce from the oscilloscope. The oscilloscope with type GW-Instek GDS-3254 is used to capture the output voltage signal of the PEM Fuel Cell. Besides, the test also used a DC load 3353 to measure the voltage of the PEM Fuel Cell with varying the current of the PEM Fuel Cell. After that, two methods will be used which is performance analyze and periodogram analyze for analyzing process. The periodogram analyze, the Matlab version 2013a will use as a tool to produce a result of the periodogram technique.

## 1.5 Significant of Project

In this project, it has several significant that will be produced in this project. The first significant is the performance and behavior of the H-2000 W PEM Fuel Cell from the signal processing aspects can be know for the pressure and flow rate hydrogen parameter. The signal processing will be used because the result from the DC load is directly while by using a signal processing the result will be produced in more detail. The other significant is to represent the micro monitoring experiment of the signal that will know the behavior inside of the PEM Fuel Cell. On the other hand, the project also can recognize the signal identification of the PEM Fuel Cell by using a periodogram technique.

## 1.6 Outline of Report

In this thesis, it is consists of five chapters. In Chapter 1, the research background, problem statement, objectives, scope, and outline of this thesis will be described. Besides that, Chapter 2 will discuss about literature review that related to this project, that is including theory of fuel cell that consists of history, principle of PEM Fuel Cell, type of fuel cell, etc. In Chapter 3, the methodology of this project will be discussed in more detail. The explanation of the experimental setup, testing process and data analysis will be discussed in this chapter. Besides that, in Chapter 4, it will be discussed about the analysis and the final result of the project. Lastly, in Chapter 5 the conclusion of the project will be discussed and the recommendation from the funding research that have been made.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter will review all of the research related to this project. It includes the principle of PEM Fuel Cell system and signal processing technique. In Section 2.2, it will be discussed regarding the history and the principle of the fuel cell, while in Section 2.3, the theory and basic principle of the fuel cell will be further discussed. In Section 2.4, it will be focused on a review of the previous related works of fuel cell about the parameter of effect the performance of PEM Fuel Cell and periodogram method.

## 2.2 Principle of Fuel Cell

The fuel cell is a device that used a reverse of the electrolysis process. The electrolysis process is created in 1800. However, in 1838 William Robert Grove obtains the idea to create a fuel cell that used a reverse electrolysis process [4]. The electrolysis process separated the water to the two elements which is hydrogen and oxygen as a mention in Equation 2.1.

$$2H_20_{(l)} \rightarrow 2H_{2\,(g)} + 0_{2\,(g)} \tag{2.1}$$

In the process of the fuel cell, the hydrogen ($H_2$) will combine with the oxygen ($O_2$) to produce energy, heat and water ($H_2O$). The fuel cell is an electrochemical device that dynamically converts the energy of a chemical reaction between hydrogen and an oxidant into

electrical energy that are used for our consumption [4]. The equation for this process is presented in Equation 2.2.

$$2H_{2\,(g)} + 0_{2\,(g)} \rightarrow 2H_20_{(l)} + Energy \quad (2.2)$$

Previous researcher produced the hydrogen by using the other renewable energy resources such as solar, wind, and biomass. Thus, it can be considered as green power because it is environmentally friendly, clean, and sustainable. In addition, it also can operate with less noise and can provide energy in a controlled way with higher efficiency than conventional power plants.

The principle of the fuel cell is the same as the principle of the battery. It consists of two electrodes which are anode and cathode. The electrolyte will be placed between anode and cathode. The hydrogen will enter into the fuel cell through the anode side, while air or oxygen will enter through the cathode side. The atoms of hydrogen will be separated into a proton and electron. The proton passes through the electrolyte while the electrons will create a separate current and the chemical reaction will occur along the catalyst [4].

Figure 2.1 shows the demonstration reaction of the hydrogen in the fuel cell. Energy is released from the PEM Fuel Cell because there are presence of chemical reaction between hydrogen and oxygen. Then, in the external of membrane, the electron will be moving and then chemical energy directly transformed into electricity.

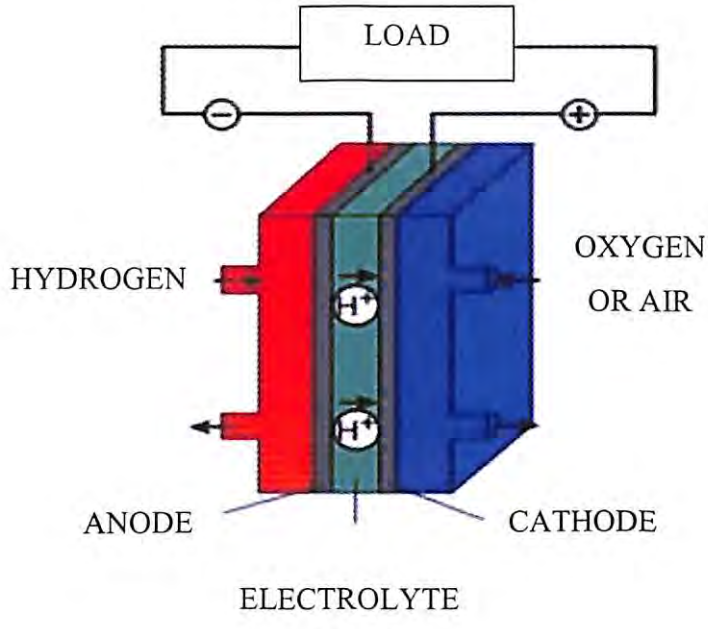


Figure 2.1: Diagram of a single PEM Fuel Cell [5]

## 2.3 Types of Fuel Cell

Fuel cell consists of six different types. There are several differences characteristic to distinguish the fuel cell. The differences characteristic of fuel cell types is operating temperature, materials, and a slightly different interaction.

### 2.3.1 Proton Exchange Membrane Fuel Cell

Proton Exchange Membrane (PEM) Fuel Cell is also known as a Polymer Electrolyte Membrane (PEM) Fuel Cell [6]. In the early 1960s, PEM Fuel Cell technology is invented at General Electric through the work of Thomas Grubb and Leonard Niedrach. Through the program with the U.S. Navy's Bureau of Ships Electronics Division and the U.S. Army Signal Corps, general electric is successfully developed a small fuel cell [4].

The electrolytes of PEM Fuel Cell use a water-based and solid polymer membrane. The catalysts of PEM Fuel Cell use platinum because it has most chemically active substance for low temperature hydrogen separation. However, the cost of platinum is more expensive than other type of fuel cell. Basically, PEM Fuel Cell operates at low temperature, which is between 70°C and 90°C and produce high power density [3,6]. The efficiency of this fuel cell is 40% and can even reach up to 50%. PEM Fuel Cell is suitable used for vehicle, building, rechargeable batteries and portable application. Figure 2.2 shows the cross-sectional of PEM Fuel Cell. It used pure hydrogen as a fuel to react the chemical in the fuel cell. The hydrogen enters to the fuel cell through anode electrode while oxygen enters through cathode electrode. Then, the water will be produced. Equation 2.3 presents the reaction in the PEM Fuel Cell.

$$H_2 + \frac{1}{2} O_2 \rightarrow H_2O \tag{2.3}$$

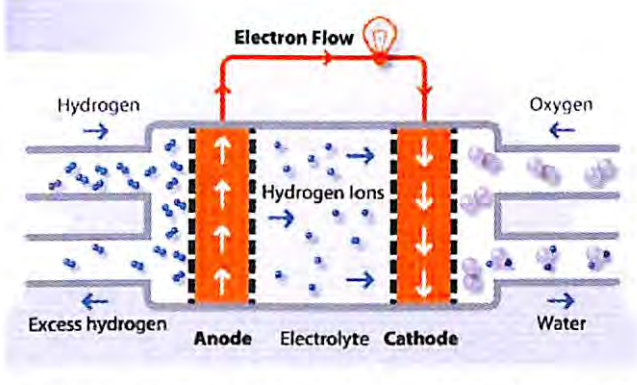


Figure 2.2: Proton Exchange Membrane Fuel Cell work [7]

### 2.3.2 Molten Carbonate Fuel Cell

Molten Carbonate Fuel Cell (MCFC) uses a molten carbonate salt mixture as the electrolyte fuel cell. The content of the salt mixture is lithium carbonate and potassium carbonate. It can act as an excellent conductor of ion if the temperature is higher. The electrolyte of MCFC is contained in a porous ceramic matrix [6]. Basically, MCFC can produce a higher efficiency, which is 50% to 60%. It can run continuously due to the high

operating temperature from 600°C to 1000°C. Hence, MCFC is suitable for central, stand-alone and combined heat power. Most of the fuel cell power plants of megawatt capacity use MCFC as a combined heat and power plants.

Figure 2.3 shows the operation MCFC that used a hydrogen and carbon monoxide as a fuel that enter through the anode of electrode. It also required oxygen and carbon dioxide to be entered through the cathode of electrode. Then, at the electrolyte, the chemical will be reacting and carbonate ions will be active and produce electricity [6]. The overall reaction of the MCFC will be producing water and the carbon dioxide when the hydrogen, oxygen and carbon dioxide react together in the MCFC. Equation 2.4 shows the reaction of MCFC.

$$H_2 + \frac{1}{2} O_2 + CO_2 \rightarrow H_2O + CO_2 \tag{2.4}$$

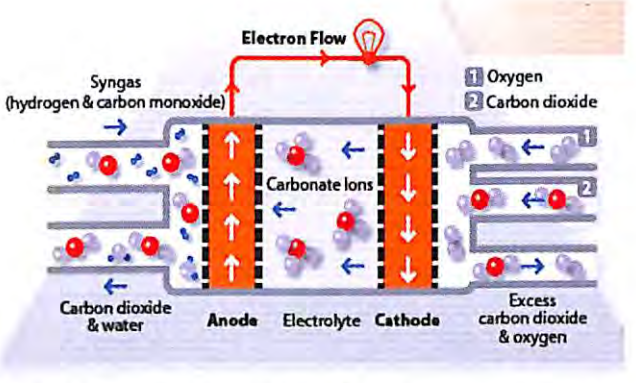


Figure 2.3: Molten Carbonate Fuel Cell cross-sectional view [7]

### 2.3.3 Solid Oxide Fuel Cell

In the late 1930s, Swiss scientist Emil Baur and his colleague H. Preis do an experiment on the solid oxide electrolyte by using many materials such as zirconium, yttrium, cerium, lanthanum, and tungsten [4]. These materials are an excellent conductor and also produce high temperature. The operating temperature of Solid Oxide Fuel Cell (SOFC) is 800°C to 1000°C. Thus, the efficiency of the SOFC is also higher which is from 50% to 60%.