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FINAL YEAR PROJECT II

ANALYSIS ON THE EFFECT OF HUMIDITY AND TEMPERATURE TOWARDS THE PERFORMANCE OF THERMODYNAMIC POTENTIAL OF PROTON EXCHANGE MEMBRANE (PEM) FUEL CELL

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" I hereby declare that I have read through this report entitle "*Analysis on the Effect Of Humidity and Temperature Towards the Performance Of Thermodynamic Potential of Proton Exchange Membrane (PEM) Fuel Cell*" and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

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ANALYSIS ON THE EFFECT OF HUMIDITY AND TEMPERATURE TOWARDS THE PERFORMANCE OF THERMODYNAMIC POTENTIAL OF PROTON EXCHANGE MEMBRANE (PEM) FUEL CELL

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

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I declare that this report entitle "*Analysis on the Effect of Humidity and Temperature Towards the Performance of Thermodynamic Potential of Proton Exchange Membrane (PEM) 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 it is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : .....

Date : .....

To my beloved mother, father and brothers

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Alhamdulillah, thanks to Allah SWT, with His willing I have received the opportunity to complete this Final Year Project, which is title "Analysis on the Effect Of Humidity and Temperature Towards the Performance Of Thermodynamic Potential of Proton Exchange Membrane (PEM) Fuel Cell". This final year project report was prepared for Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for student in final year to complete the undergraduate program that leads to the degree of Bachelor of Electrical Engineering (Industrial Power).

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ABSTRACT

The rapid reduction of the fossil fuel sources encourages the usage of the renewable energy (RE) as the alternatives source of electricity. Proton Exchange Membrane (PEM) fuel cell is one type of RE that recently being explored by the researches. In Malaysia, the application of PEM fuel cell is not yet been commercialise for the residential application. Besides, the characteristics of the PEM fuel cell can be rapidly changed due to few factors. Hence, the two of the main factors are humidity and temperature. Therefore, the effect of humidity and temperature towards the characteristics behaviour of PEM fuel cell have been studied and analysed. Hence, the signal analysis of the characteristics behaviour of PEM fuel cell is done using the signal processing technique. Humidity percentage is varied into two levels in order to analyse the characteristics performance of PEM fuel cell at various load currents. Meanwhile, the temperature is varied into a range of values and the load current is varied. Besides that, the performance characteristics analysis is used to analyse the characteristics behaviour of PEM fuel cell. In part of that, new technique which is signals processing techniques using periodogram is introduced. Therefore, the signal identification of humidity and temperature towards changing behaviour in PEM fuel cell can be investigated. The experiment proved that by increasing the humidity from 0% humidity to 80% humidity, the voltage of the PEM fuel cell increase to 5.95%, meanwhile by increasing the temperature from 20˚C to 40˚C, there is about 0.8V of PEM fuel cell voltage can be increases. It shows that the parameters of humidity and temperature influencing the performance of the PEM fuel cell. By increasing the humidity and temperature values, the performance can be escalating at optimum values.

ABSTRAK

Pengurangan sumber bahan api fosil yang pesat menggalakkan penggunaan tenaga boleh diperbaharui (RE) sebagai sumber alternatif bagi elektrik. *Proton Exchange Membrane (PEM) Fuel Cell* adalah salah satu jenis RE yang sedang dikaji oleh penyelidik pada masa kini. Di Malaysia, penggunaan *fuel cell* masih belum dikomersialkan dalam aplikasi kediaman dan hanya digunakan dalam penyelidikan. Ciri-ciri *fuel cell* yang boleh diubah hasil daripada beberapa faktor, dengan itu prestasi *fuel cell* boleh meningkat atau menurun berdasarkan ciri-ciri tingkah laku yang dipengaruhi oleh parameter seperti kelembapan dan suhu. Kesan kelembapan dan suhu terhadap prestasi *PEM fuel cell* telah dikaji dan dianalisis. Oleh itu, analisis isyarat ciri-ciri tingkah laku di *PEM fuel cell* dilakukan dengan menggunakan teknik pemprosesan isyarat. Peratusan kelembapan diubah kepada dua peringkat untuk melihat ciri-ciri prestasi pada *PEM fuel cell* di arus beban yang berbeza. Sementara itu, suhu diubah kepada lima nilai suhu dan arus beban diubah. Analisis ciri-ciri prestasi dan teknik pemprosesan isyarat yang periodogram telah digunakan untuk menganalisis ciri-ciri tingkah laku parameter terhadap *PEM fuel cell*. Eksperimen membuktikan bahawa dengan meningkatkan kelembapan dari 0% kelembapan kepada 80% kelembapan, voltan *PEM fuel cell* meningkat kepada 5.95%, sementara itu dengan meningkatkan suhu daripada 20˚C kepada 40˚C, voltan bagi *PEM fuel cell* meningkat sebanyak 0.8V. Keputusan membuktikan bahawa parameter kelembapan dan suhu mempengaruhi prestasi *PEM fuel cell*. Dengan meningkatkan kelembapan dan suhu nilai, prestasi boleh meningkat pada nilai optimum.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The fossil fuels had been used for over centuries, and the usage of the fuels made the source of the fossil fuels becoming limited. The growth of the source of fossil fuel is becoming crucial because the demand of the energy rapidly increasing. So, in order to fulfil the energy demand by the user, the power sector in Malaysia need to developed the usage of renewable energy. Besides that, in order to prevent the country to depend only on a single source, the green technology can be one of the solutions for it [1].

The rapid reduction of the fossil fuel sources encourages the usage of the renewable energy (RE) as the alternatives source of electricity. The renewable energy is added as the fifth source of energy when the Five-Fuel Diversification Policy replaced the four fuel policy back in 1999 with the target to contribute 5% of the total energy mix by 2010 in the eight of Malaysia Plan (2001-2005) [1]. Therefore, fuel cell is one of renewable energy that being explore by Malaysian researchers nowadays.

Fuel cells are electrochemical devices that convert chemical energy to electricity and thermal energy. Fuel cell systems are available to meet the needs of applications ranging from portable electronics to utility power plants [2]. The used of fuel cell in distribution generation is becoming popular because of less environmental pollution, higher efficiency, cleanliness and safe operation [3].

The fuel cell system undergoes the process of electrolysis of water in order to separate the hydrogen and oxygen. A fuel cell works much like a battery. In both batteries and the fuel cells two electrodes, an anode and a cathode are separated by an electrolyte. Whereas a storage battery contains all the substances in the electrochemical oxidation

reduction reactions involved and has, therefore, a limited capacity, a fuel cell is supplied with its reactants externally and operates continuously as long as it is supplied with fuel [4].

1.2 Problem Statement

Fuel cell as the renewable energy is rarely known. In Malaysia, the application of fuel cell is not yet commercialise in residential application. In addition, the application of the fuel cell nowadays is infrequently used and only used in research. Thus, the study on the fuel cell should be done to introduce the fuel cell as one of alternative energy in Malaysia.

In fuel cell, there are a few problems that will be faced. The characteristics of the fuel cell can be changed because of a few factors. Therefore, the performance of the fuel cell can be increase or decrease based on the characteristics of it. Factors that can influence the characteristics of the fuel cell could be the phenomena of flooding, drying, and blocking of water inside membrane and many other factors. On the other hand, the performance change depends on a few parameters such as humidity and temperature of fuel cell. So, these parameters need to be analysed in order to overcome these problems.

There are many techniques that can be used to analyse the effect of the parameters towards the performance of PEM fuel cell, such as electrochemical impedance spectroscopic (EIS) and current interruption (CI). However, previous technique of EIS and CI has a few disadvantages which are costly and it is hardware and once broken it cannot be used anymore. Besides that, analysing the performance of PEM fuel cell using the signal processing techniques is not widely used. Signal processing technique is used so that the micro monitoring of the PEM fuel cell can be done.

1.3 Objectives

There are a few objectives of the project. The objectives of this project are:

i. To study the effect of humidity and temperature towards the performance of PEM fuel cell
ii. To analyse the effect of humidity and temperature towards the performance of PEM fuel cell
iii. To investigate the signal identification of humidity and temperature towards the changing behaviour in PEM fuel cell by using signal processing technique

1.4 Scope of the Project

The scope of this project is to study the effect of humidity and temperature toward the performance of PEM fuel cell. Besides that, the effect of humidity and temperature towards the performance of PEM fuel cell will be analysed. Signal processing technique will be used to investigate the signal identification of the humidity and temperature. The PEM fuel cell used for this experiment is commercially 2000W, 48 cells PEM fuel cell stack H-2000 from Horizon Fuel Cell Technologies. The analysis of this project covered on the effect of relative humidity and temperature on the PEM fuel cell only. Humidity experiment will be analysed for 0% and 80% of humidity for current from 0Ampere (A) up to 36A for each humidity percentage. In addition, the temperature will be varied to 20ºC, 25ºC, 30ºC, 35ºC and 40ºC. The load current also will be varied at 0A, 3A, 6A, 9A, 12A, 15A and 18A for each of the temperature experiment. The techniques used to analyse the result of the PEM fuel cell are by performance characteristics analysis and signal processing techniques. The performance characteristics analysis will be focused on polarization curve. Meanwhile, the signal processing technique used in this project is focused on the periodogram technique only. The software used to run the technique is by the MatLab software.

1.5 Significant of Project

There is a few significant in conducting this project. The significant of this project is the effect of humidity and temperature towards the performance of thermodynamic potential on PEM fuel cell can be analyse. Besides that, periodogram technique is used to carry out the micro monitoring in order to observe the behaviour of PEM fuel cell. In addition, the signal identification of 2000W PEM fuel cell has been analysed using the periodogram technique.

1.6 Outline of Report

This progress report will consist of five chapters. Chapter 1 will be discussed on the research background, problem statement, objectives of the project, scopes of the project and last the outline of the report. Next, Chapter 2 will be explained about the introduction of the chapter, theory and basic principle, review of the previous related works, summary and discussion of the review and last. Furthermore, Chapter 3 will discuss the design methodology of this project. The project flowchart, experimental set up and data analysis are being discussed. Chapter 4 discusses the result and discussion of this project. Lastly, chapter 5 explained on the conclusion and recommendation of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the literature review which comprises the studies related to the background of the project will be discussed. The related information such as studies, thesis and research about topics related to this project will be reviewed through the journal or conference from the Institute of Electrical and Electronics Engineers (IEEE) sources, books and related previous journal. In Section 2.2, the theory and basic principle related to the PEM fuel cell will be discussed more to get the better understanding for this project. Next, in Section 2.3, the review of the previous related works such as journals; thesis or others will be explored one by one based on few previous related works. Based on the review from the previous subtopic, in Section 2.4 the summary and discussion for the review will be done.

2.2 Theoretical Background of Fuel Cell

Thermodynamics is the study of transformation of energy from one form to another. As the principle of fuel cell is an electrochemical device which converts chemical energy to electricity and thermal energy, so it is considered as the thermodynamic. Thermodynamics provide the theoretical limit or ideal case for fuel cell performance. The heat potential of a fuel is given by the fuel's heat of combustion or the enthalpy of reaction [5].

Moldrik P. in [6] explain that a fuel cell is a device, which uses the electrochemical reaction to transform chemical energy held by the fuel, aided by the oxidizing agent, to

electric power, water and heat. This transformation occurs within catalytic reactions on electrodes and it is mainly based on reversed principle of water electrolysis.

Fuel cells can be divided into several basic categories. The criteria applied in such classification include mainly the type of electrolyte used and the operation temperature [6]. There are many type of fuel cells, however the principal ones are Molten Carbonate Fuel Cell (MCFC), Proton Exchange Membrane Fuel Cell (PEMFC), Solid Oxide Fuel Cell (SOFC), Direct Methanol Fuel Cell (DMFC), Phosphoric Acid Fuel Cell (PAFC) and Alkaline Fuel Cell (AFC). Table 2.1 shows the parameters of individual types of a few fuel cells.

Table 2.1: Basic parameters of a few fuel cells [6]

Types	**Operating temperature (°C)**	**Off load voltage (V_{DC})**	**Power**	**Used fuel**
MCFC	600-700	0.7-1.0	MW	H_2 hydrogenous gas CO + air
PEMFC	50-120	1.1	kW	H_2 methanol + O_2 air
PAFC	150-210	1.1	Hundreds kW	H_2 hydrogenous gas + air

According to authors in [2] have claimed that the overall information of the principles of fuel cell and how it is considered as efficient and flexible energy conversion. Based on [2], fuel cell is a device that practices the electrochemical reaction which converts the chemical energy directly into electrical energy. It is also state that the net cell reaction of most type of fuel cell except the DMFC is the chemical reaction of hydrogen (H_2) which added to the half of oxygen and it create the hydrogen oxide (H_2O) particle. The system of the fuel cell can be divided into six basic subsystems which are fuel cell stack, fuel cell processor, air management, water management, thermal management and power conditioning system. Nevertheless, the fuel cell system can be applied to some applications such as portable power, transportation and stationary power.

2.2.1 Molten Carbonate Fuel Cell (MCFC)

Molten carbonate fuel cells are typically designed for mid-size to large stationary (or shipboard) power applications. MCFC consists of nickel and nickel-oxide electrodes surrounding a porous substrate which retains the molten carbonate electrolyte. Collector plates and cell separator plates are typically fabricated from stainless steel, which can be formed less expensively than the carbon plates in the PEMFC and PAFC cells. Thermal energy produced within the cell stack is transferred to the reactant and product gases and a separate cooling system is not usually required [2].

The MCFC operates at a very high temperature of approximately 650 ºC. At this temperature, precious metal catalysts are not required for the fuel cell reactions. In addition, the heat available from the stack can be used to produce steam and hot water in building cogeneration applications. Furthermore, at this temperature, fuel gases other than hydrogen can be used by reforming the fuel within the cell stack in a process called internal reforming [2].

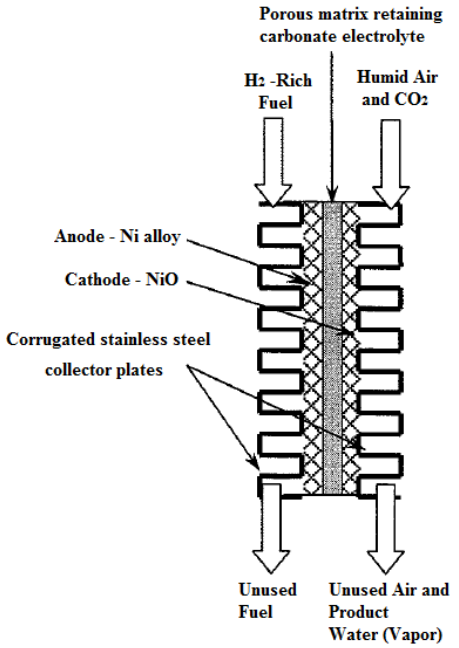

Figure 2.1: Schematic illustration of MCFC unit cell [2]

An MCFC consists of ion-conducting electrolyte matrix, two electron conducting electrodes, and an electron conducting separated plate reactant gas flow channels. The overall reaction of the electrode is a water producing reaction between oxygen and

hydrogen, with carbonate ion CO_3^{2-} acting as intermediate agent to transfer oxide ion from cathode to anode. Electrons produced at the anode pass through an external circuit before flowing to the cathode, and thus electric power can be extracted.

2.2.2 Proton Exchange Membrane Fuel Cell (PEMFC)

PEMFC or also known as polymer electrolyte membrane is one of the types of fuel cell which used the water based acidic polymer as its electrolyte. The PEMFC is known as the best fuel cell types among the other types of fuel cell. From Figure 2.2, the process of the PEMFC is shown.

As in Figure 2.2, the fuel cell is provided with a simultaneous supply of the fuel gas in which hydrogen in form of molecules H_2 on the anode side and the oxidising agent which is oxygen in form of molecules O_2 or air on the cathode side. The contact of H_2 hydrogen molecules with the platinum catalyser induces a reaction on the surface of proton membrane, whereas the hydrogen molecules decompose to individual atoms of H first, to be further degraded to H^+ protons and e^- electrons [6].

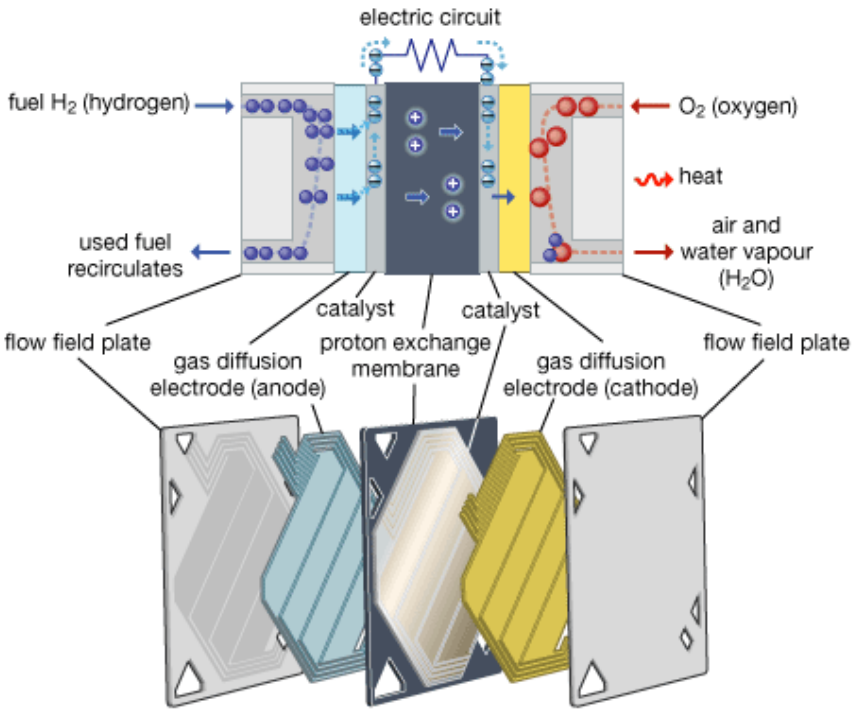

Figure 2.2: Simplified diagram of PEM fuel cell [7]

The fuel cell membrane is able to transmit positive hydrogen protons only as these are attracted by the oxygen ions on the cathode side. Once the hydrogen proton has passed through the membrane, there is a reaction occurring on the cathode side, which takes place between the H^+ hydrogen protons and the O^{2-}oxygen anion [6]. The chemical reactions for PEM fuel are in the Equation 2.1, 2.2 and 2.3.

$$\text{Anode}: 2H_2 \rightarrow 4H^+ + 4e^- \quad (2.1)$$

$$\text{Cathode}: O_2 + 4e^- + 4H^+ \rightarrow 2H_2O \quad (2.2)$$

$$\text{Overall reaction}: 2H_2 + O_2 \rightarrow 2H_2O \quad (2.3)$$

According to Moldrik P. in [6] PEM fuel cells work at temperatures ranging from 70 to 90°C and pressure between 1 and 2 bars (15 to 30 PSIG). Every cell is able to generate approximately 1.1 V DC in open circuit. However, it depends on the brand name of PEMFC that were use.

2.2.3 Phosphoric Acid Fuel Cell (PAFC)

PAFC is the first fuel cell to be commercially available. The PAFC consists of porous carbon electrodes surrounding a porous matrix that retains the liquid phosphoric acid electrolyte. Except for the nature of electrolyte, the PAFC structure resembles the PEMFC with porous carbon electrodes and carbon collector plates located on either side of the electrolyte-electrode assembly [2].

The PAFC operate with efficiencies that are comparable to the PEMFCs but the power density is much lower than the PEMFC. The operating temperature is about 200ºC. This temperature is high enough to facilitate the recovery of heat produced within the stack for water and space heating in building applications [2].

2.3 Related Previous Works

A few papers have been review as guidance while completing this project. The paper of the related previous works have been divided into four categories which is basic PEM fuel cell, temperature effect on PEM fuel cell, relative humidity effect on PEM fuel cell and signal processing techniques.

2.3.1 Humidity Effect on PEM Fuel Cell

Humidity is one of the important parameter that influences the performance of the PEM fuel cell. Humidity is practically related to the water management of the fuel cell. Excess of humidity could lead for flooding condition. Fouquet N. in [8] states that in a PEM fuel cell, the electrolyte is a polymer membrane that ensures the proton conductivity between anode and cathode while being electronically insulated. Protons are able to cross the membrane only if attached to water molecules. Thus, it is of prime importance to ensure at all time steady minimum water content in the electrolyte. Fouquet, in his experiment humidity is analysed at dry, nominal and flooded condition. Fouquet used the method of fuel cell impedance model inspired by the Randles model. Results show that the method is reliable monitoring system for the flooding and drying condition.

Chen D. elaborates about the modelling and simulation of a PEM fuel cell humidification system in [9]. The fuel cell cooling water has been used to humidify and increase the temperature of the dry hydrogen gas. The hydration of the fuel cell membrane should be control properly, so that the performance of it can be improve and extended life. Water management is one of the ways to control the hydration of it. In the research, it state that excess of humidity will cause the water blockage of flow channel, porous electrode and backing layer of it. Simulation and modelling of the membrane humidifier is analysed based on the thermodynamic laws. The simulation results show on the integrated humidifier that the performance of the fuel cell improved by humidifying the water content of the fuel cell with minimum flooding.

The research of humidity control system of PEM fuel cell has been explained by Chui J. in [10]. The PEM fuel cell membrane humidifier system is being analyse using