APPENDIX

LIST OF PUBLICATIONS

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This thesis results in the following papers:

1. W. Chanpeng and Y. Khunatorn, "Mathematical model of a Proton Exchange Membrane Fuel Cell", Proceeding of 7th Eco-Energy and Material Science and Engineering Symposium, November 19-22, 2009, Chiang Mai, Thailand.
2. Winai Chanpeng and Yottana Khunatorn, "Simulation of Dynamic Behavior of a Proton Exchange Membrane Fuel Cell", International Conference on Green and Sustainable Innovation 2009, December 2 – 4, 2009, Chiang Rai, Thailand
3. Winai Chanpenga, Yottana Khunatorna and Boonyang Plangklang, "Model and Experiment Analysis of 1.2 kW PEMFC Electrification", Procedia Engineering 8 (2011) 106–114
4. Winai Chanpenga and Yottana Khunatorn, "The effect of the input load current changed to a 1.2 kW PEMFC performance", Energy Procedia 9 (2011) 316 – 325

W. Chanpeng and Y. Khunatorn,
"Mathematical model of a Proton Exchange Membrane Fuel Cell"
Proceeding of 7th Eco-Energy and Material Science and Engineering Symposium,
November 19-22, 2009, Chiang Mai, Thailand.

Mathematical model of a Proton Exchange Membrane Fuel Cell

W. Chanpeng and Y. Khunatorn

Abstract— *This paper presents a simulation model of a proton exchange membrane fuel cell. The model in this work is based on physical laws to investigate the dynamic performance of a polymer electrolyte membrane fuel cell. Parametric which effect to PEMFC performance are studied. The case of pure hydrogen on the anode side and air at the cathode side is analyzed by keeping cell temperature at 65°C. Model validation is carried out comparing experimental and simulated results. The model results show parameters which affect to PEMFC performance. This mathematical model can be predicted the behavior and performance of PEM fuel cell.*

Keywords— ***PEM fuel cell; simulation model; PEM performance; dynamic behavior***

1. INTRODUCTION

Due to limitation of fossil-fuel resources in the green planet and environment concerns, it is very important to look for new power sources. One of that is Fuel Cell technology. The fuel cell (FC) is an energy-conversion device and it is an alternative way that can produce electricity without harmful emissions. FC uses chemical reaction process to convert chemical energy directly into electrical energy. Fuel cell systems use hydrogen and oxygen or hydrogen and air as a fuel which feed into anode and cathode side of fuel cell [1-10]. One of the various existing fuel cell systems, the proton exchange membrane fuel cell (PEMFC) is the most popular type of fuel cell, especially for transportation and power generation [7].

Many researches and development of PEMFC have received much attention. Some of them are pointed on mathematical model to study some of parameters that effected to both single and stack cells [1]-[5]. Performance testing and application of PEMFC are evaluated in order to get optimize operation [6[, [7]. A phenomenon occurs inside fuel cell is very difficult to predict. Also, parameters that effected to PEM fuel cell performance are very to indicate. In order to understand the behavior and characteristics of PEMFC performance, the mathematical model is developed.

A mathematical model of PEM fuel cell is presented. Performance of PEM fuel cell is studied by changing some parameters in order to show the behavior and characteristics under various operation conditions. The objectives of this research are to study parametric which effect to PEMFC performance and develop the PEMFC model under various operation conditions.

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2. THEORYVAND RESEARCH METHODOLOGY:

In this paper, a mathematical model of PEMFC is developed based on energy, mass, and electrochemical equation. PEMFC model is one-dimension model. Some of parametric has been studied to evaluate the effect of a PEMFC system performance. The PEMFC performance can be expressed *i-v* curve shown in Figure 1. The characteristic of this curve depends on output voltage and current density. The output voltage depends on parameters which shown in physical equations. The model will be compared the experiment with previous public papers from experimental result [10]. The output voltage of developing fuel cell is less than thermodynamically predicted voltage output due to irreversible losses. There are three major types of fuel cell loss, which occurred in fuel cell as follow: Activation losses, Ohmic losses, and Concentration losses. Each contains parameters which depend on the physical dimensions of FC system. Activation losses are loss due to electrochemical reaction. Ohmic losses occur due to ionic electronic condition. Concentration losses are losses due to mass transport. Then, the output voltage for FC can be written as equation (1).

$$V = E_{thermo} - \Delta E_{act} - \Delta E_{ohmic} - \Delta E_{conc} \qquad (1)$$

where V - Real output voltage of fuel cell.

E_{thermo} - Thermodynamically predicted fuel cell voltage output.

ΔE_{act} - Activation loss due to reaction kinetics.

ΔE_{ohmic} - Ohmic loss from ionic and electronic condition.

ΔE_{conc}- oncentration loss due to mass transport.

Output voltage of FC depends on parameters that contain in three major losses which can be expressed in equation (2) through (5).

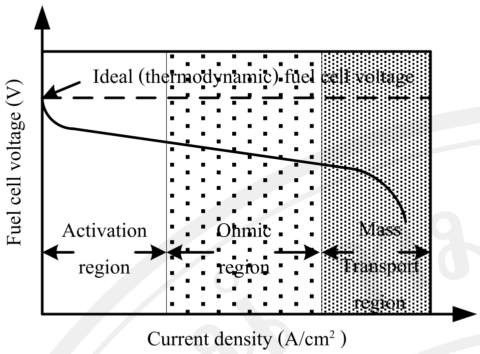


Figure 1. *i-v* curve schematic of FC

The activation losses mostly affect in initial part of curve. The ohmic losses are mostly apparent in the middle section of the curve, and the concentration losses are most significant in the tail of *i-v* curve. The result of chemical reactions inside a fuel cell is reversible single electrode potential, E_{thermo}, given by the Nernst equation as shown in equation (2).

$$E_{thermo} = E^{0}_{thermo} - \left[\left(\frac{RT}{nF}\right) ln\left(\frac{p_{H_2O}}{p_{H_2} \times \sqrt{p_{O_2}}}\right)\right] \quad (2)$$

where E^{0}_{thermo} is standard electrode potential, R is gas constant (8.3144 J/mol K), T is temperature in Kelvin scale, n is number of electrons per reacting ion or molecule, F is Faraday's constant (96,500 C/mol), p_{H_2O} is the partial pressure of water, p_{H_2} is partial pressure of hydrogen, and p_{O_2} is partial pressure of oxygen.

The activation loss due to reaction kinetics at the electrodes of a PEMFC is shown in equation (3). This equation is commonly known as Tafel equation [9].

$$\Delta E_{act} = \left(\frac{RT}{\alpha F}\right) ln\left(\frac{i + i_{loss}}{i_o}\right) \quad (3)$$

where α is an activity coefficient, i_{loss} is a current loss, i_O is an exchange current density for reaction with constant value, and i is an applied current density. The ohmic losses is resistance of ions flow in electrolyte and resistance of the flow of electrons through electrically conductive fuel cell components, R_{ohmic}. Ohmic losses (which includes ionic, electronic, and contact resistance, Ωcm^2) can be calculated from current density as.

$$\Delta E_{ohmic} = i\left(R_{ohmic}\right) \quad (4)$$

where R_{ohmic} is an effect of concentration losses due to mass transport is shown by equation (5).

$$\Delta E_{conc} = \left(\frac{RT}{n F}\right) ln\left(\frac{i_L}{i_L - i}\right) \quad (5)$$

where i_L is limiting current density with constant value and i is an applied current density.

Activation and concentration polarization can occur in both anode and cathode. The cell voltage, V_{cell} , is therefore:

$$V_{cell} = E_{thermo} - (\Delta E_{act} + \Delta E_{conc})_a - (\Delta E_{act} + \Delta E_{conc})_c - \Delta E_{ohmic} \quad (6)$$

Subscript *a* and *c* denote the anode and cathode sides of FC membrane, respectively.

2.1 SINGLE CELL VOLTAGE:

By substitution equations (3), (4) and (5) into equation (6), a relationship between fuel cell potential and current density, called fuel cell polarization curve, is obtained:

$$V_{cell} = E_{thermo} - \left(\frac{RT}{\alpha nF}\right) ln\left(\frac{i+i_{loss}}{i_{o,c}}\right) - \left(\frac{RT}{\alpha nF}\right) ln\left(\frac{i+i_{loss}}{i_{o,a}}\right) - \left(\frac{RT}{nF}\right) ln\left(\frac{i_{L,c}}{i_{L,c}-i}\right) - \left(\frac{RT}{nF}\right) ln\left(\frac{i_{L,a}}{i_{L,a}-i}\right) - i\left(R_{ohmic}\right) \quad (7)$$

where $i_{o,a}$ and $i_{o,c}$ are the exchange current density for the reaction of the anode and cathode side, respectively. $i_{L,a}$ and $i_{L,c}$ are the limiting current density of the anode and cathode side, respectively. Equation (7) is the single cell voltage, which calculated by vary the current density, i .

2.2 FUEL CELL STACK MODEL:

This section presents the various equations that are necessary for overall modeling of fuel cell system. The total stack voltage is calculated as follows.

$$V_{cell} = N \left\{ E_{thermo} - \left(\frac{RT}{\alpha nF}\right) ln\left(\frac{i+i_{loss}}{i_{o,c}}\right) - \left(\frac{RT}{\alpha nF}\right) ln\left(\frac{i+i_{loss}}{i_{o,a}}\right) - \left(\frac{RT}{nF}\right) ln\left(\frac{i_{L,c}}{i_{L,c}-i}\right) - \left(\frac{RT}{nF}\right) ln\left(\frac{i_{L,a}}{i_{L,a}-i}\right) - i\left(R_{ohmic}\right) \right\} \quad (8)$$

where N is a number of cell. The parameters, such as i_o , α, T, and i_L, are studied to determine the effect of PEMFC performance. Those parameters were presented in [8]. The PEMFC performance will be shown as i-v curve for a single cell.

3. EXPERIMENTAL SETUP:

Figure 2 shows an experiment setup schematic. It consists of hydrogen, oxygen tank, two pressure regulators, two mass flow rates, a single cell of FC and electronic load.

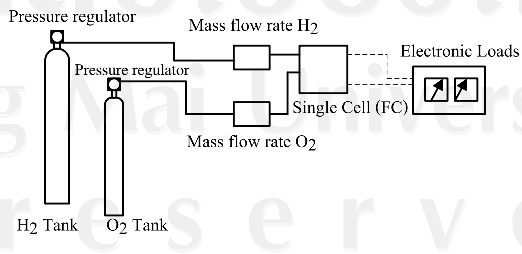
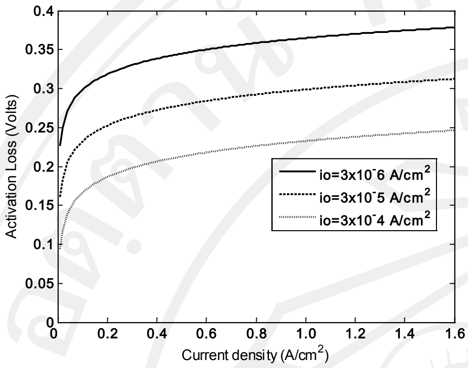


Figure 2. Experiment Setup Schematic

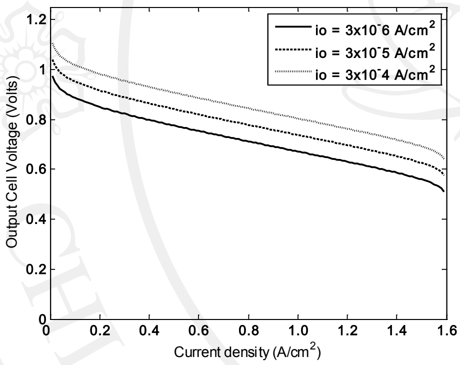
Cell temperature is setup at 65°C with open circuit voltage of FC 0.942 V.

4. SIMULATION RESULTS:

The simulation is shown in Figure 3. Activation loss due to an exchange current density, i_o, increased. The exchange current density increases by 10 times shows by 3a courses the decrease of output cell voltage by 12% in 3b. Assumption and some parameters in this model are referred to previous public data [8, 9].



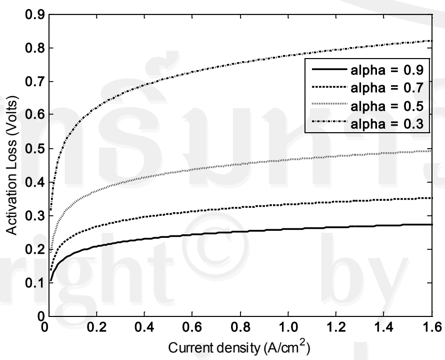
(3a)



(3b)

Figure 3 Changing of exchange current density.

Another parameter which effected to an activation loss is the activity coefficient, α. Figure 4 shows the activity coefficient by decreasing of α from 0.9 to 0.3 will coursed the FC performance as show in Figure 4b by 12% and 2 times decreased when α is very small. It shows that output voltage of cell will decrease if activity coefficient of cell decreased.



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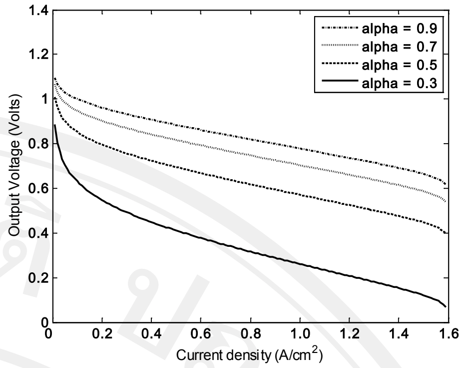
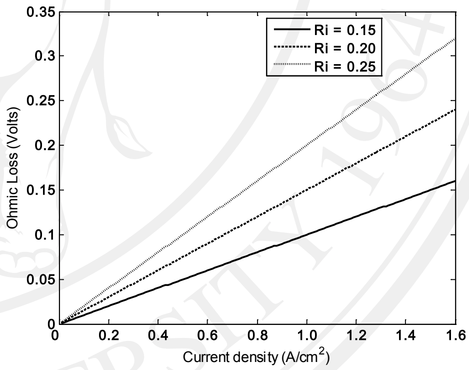


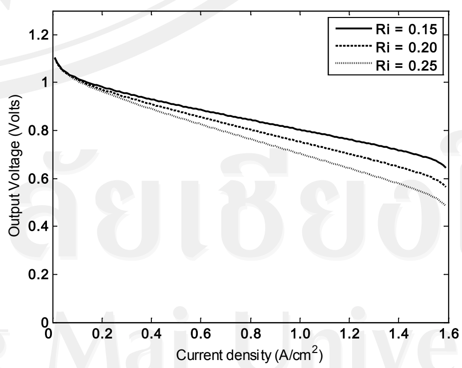
(4b)

Figure 4 The changing of activity coefficient.

Ohmic loss is one of the major losses in fuel cell at the middle of *i-v curve* which course by resistance of ions flow in the electrolyte and resistance of flow of electrons through the electrically conductive fuel cell components, R_{ohmic}. Figure 5 shows the performance of FC with the changing of R_{ohmic} by increase 33% will courses FC performance decreased about 12% as shown in Figure 5a and 5b, respectively. Figure 6 shows effect of limiting current density, i_L to fuel cell performance. The increasing of i_L by 6% will effect to FC performance about 5% as shown in Figure 6a and 6b, respectively.

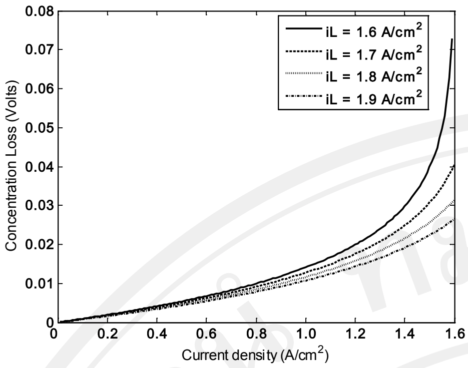


(5a)

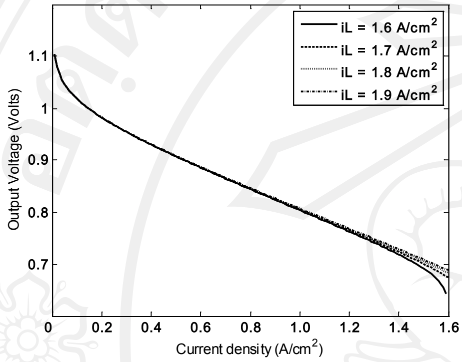


(5b)

Figure 5 The changing of resistance of ions flow in the electrolyte and resistance of the flow of electrons



(6a)



(6b)

Figure 6 The changing of the limiting current density in fuel cell.

Figure 7 is the activation loss by drawing the current from FC. The more current is drawn from the cell, the greater these losses

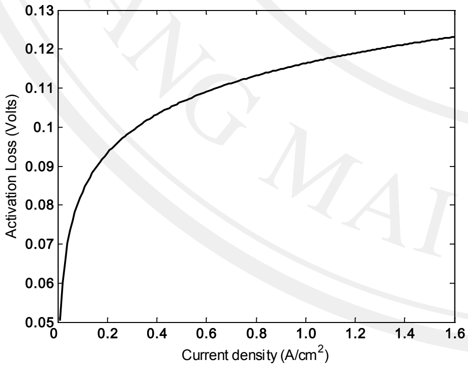


Figure7 The activation loss by drawing current .

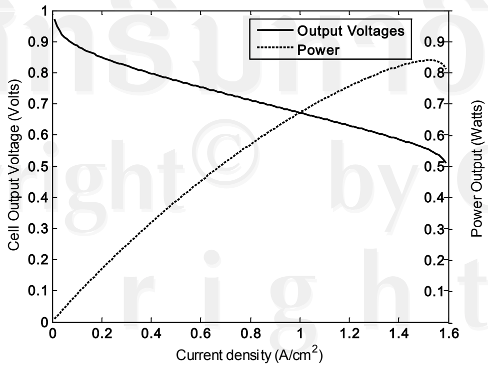
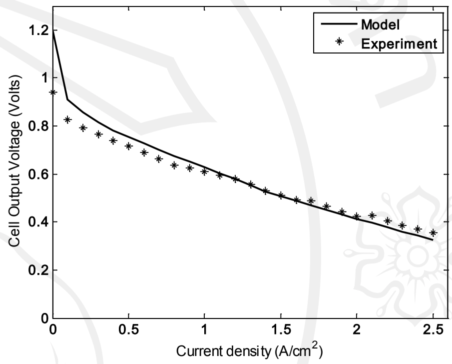


Figure 8. FC performance.

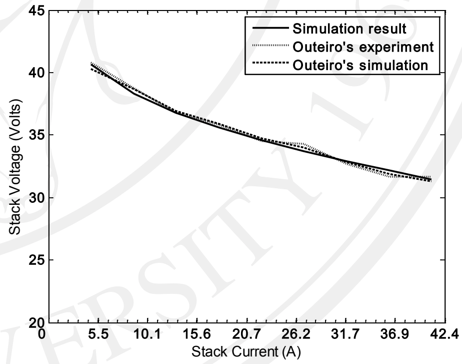
The fuel cell performance can be shown by *i-v* curve in Figure 8. The FC performance depends on the parameters as mentions before.

5. MODEL VARIDATION:

The validation of the mathematical model is done by comparing the simulation model with experimental result. The experiment is test under atmospheric pressure with pure hydrogen as a fuel and oxygen as an oxidant. Figure 9a shows that the result from both model and an experiment of a single cell fuel cell which give the same trend of FC performance. Figure 9b shows the comparison of simulation model and data from Outeiro's work. In this work is done by using hydrogen and air.



(9a)



(9b)

Figure 9 Comparison of mathematical model and an experimental (9a), previous public paper (9b)

The comparision of the resulting polarization curves from the model with experimental data and previos work at the same condition. The FC operating temperature is 65° C. It can be seen that the comparison is good. But, there is small difference between the modling results and experimental data at low current densities, and the model always over predicts the current density.

6) CONCLUSIONS:

In this work a simulation model of the proton exchange membrane fuel cell (PEMFC) system is presented. The model is defined by parametrical equations that predict and characterize the *i-v* curve of fuel cell operation. The model has been validated on both an experiment of single cell and previous public data. The mathematical model can be predict and determine the

PEMFC performance and parametric which affects to FC characteristic performance. The model developed in this paper can be used for the study of PEMFC behavior and parametric which affected to its performance. This model can be also perform a detailed analysis of the effect of the PEMFC system using the develpoed model.

7) ACKNOWLEDGEMENT:

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8) REFERENCES:

[1] Sampath Yerramalla, Asad Davari, Ali Feliachi, and Tamal Biswas *"Modeling and simulation of the dynamic behavior of a polymer electrolyte membrane fuel cell"* Journal of Power Sources 124, pp.104-113, June 11, 2003

[2] Lin Wang, Attila Husar, Tianhong Zhou, and Hongtan Liu *"A parametric study of PEM fuel cell performances"* International Journal of Hydrogen Energy 28, pp.1263-1272, 2003

[3] Fang-Bor Weng, Ay Su, Guo-Bin Jung, Yen-Chiao Chiu, and Shih-Hung Chan *"Numerical prediction of concentration and current distributions in PEMFC"* Journal of Power Sources 145, pp.546-554, July 18, 2005

[4] Ronald K.A.M Mallant *"PEMFC systems: the need for high temperature polymers as a consequence of PEMFC water and heat management"* Journal of Power Sources 118, pp.424-429, 2003

[5] J.-J. Hwang, and H.-S. Hwang *"Parametric studies of a double-cell stack of PEMFC using Grafoil^{TM} flow-field plates"* Journal of Power Sources 104, pp.24-32, July 18, 2002

[6] Leonard J. Bonville, H. Russel Kunz, Ying Song, Anthony Mientek, Minkmas Williams, Albert Ching, and James M. Fenton *"Development and demonstration of a higher temperature PEM fuel cell stack"* Journal of Power Sources 144, pp.107-112, March 16, 2005

[7] Cheng Wang, Zongqiang Mao, Fuyi Bao, Xiaoguang Li, and Xiaofeng Xie *"Development and performance of 5 kW proton exchange membrane fuel cell stationary power system"* International Journal of Hydrogen Energy 30, pp.1031-1034, 2005

[8] Colleen Spiegel *"PEM Fuel Cell Modeling and simulation Using MATLAB*, Book, Elsevier Inc, 2008

[9] Frano Barbir *"PEM Fuel Cells: Theory and Practice"* Book, Elsevier Academic Press, 2005

[10] M.T. Outeiro, R. Chibante, A.S. Carvalho, and A.T. de Almeida *"A parameter optimized model of a Proton Exchange Membrane Fuel Cell including temperature effects"* Journal of Power Sources, pp. 952-960, 2008

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Simulation of Dynamic Behavior of a Proton Exchange Membrane Fuel Cell

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Abstract

The objective of this paper is to simulate the dynamic behavior of a Proton Exchange Membrane Fuel Cell (PEMFC). This model is based on physical laws with clearing significance in replicating the fuel cell system. Model results show the transient behavior of the voltage within cell stack system when having an electrical load changed. Simulation of dynamic behavior of a proton exchange membrane fuel cell will be discussed in order to present a complete of modeling. The various characteristics of the fuel cell system will be plotted in order to show the dynamic behavior. The results of the model are compared to previous public information.

Keywords*:* Fuel Cell Simulation, PEMFC System, Dynamic Behavior, Simulation Modeling, Cell Stack System

1. Introduction

Fossil fuel reserves in the world are finite and will be came to the end in 70-150 years time [1]. Moreover, continued use of fossil fuels will produce green house effect that cause global warming and climate change. It is necessary to find new energy power sources or new technologies that give high efficiency of fuel usage and reduces green house gases. One of technologies is fuel cell (FC) technology. FC is an electrochemical energy conversion device that converts chemical energy of hydrogen and oxygen into electricity and heat by electrochemical redox reactions at the anode and the cathode of the cell, respectively, that produces water as the only byproduct. There are various existing fuel cell systems; the proton exchange membrane fuel cell (PEMFC) is the most popular type of fuel cell, especially for transportation and power generation.

Many researches of PEMFC have received much attention. Developments of PEMFC as electricity power sources are investigated [2, 3]. Some parametric which effected to PEM fuel cell performance also have been studied [4-6]. Moreover, mathematical modeling of PEMFC is developed in order to understand the behavior and performance of PEMFC under various operations [7-10].

Proton Exchange Membrane Fuel Cell (PEMFC) has advantage of highly efficient, being environmentally clean and reliable because it does not have moving parts. However, PEMFC is used as power sources for both small power station and vehicle [2, 3], and it has been shown to work well in steady mode of operation. However, dynamics mode under load changing is not known. The objective of this study is to show that the FC system can be used to produce electricity under load changing. In this paper, we will show the results of a study on the behavior and performance of a PEMFC under such conditions.

2. Theory and Principle of PEMFC

The study of physical structure and the operating principle of a PEM fuel cell is very important to understand its dynamic behavior [7-10]. Fig. 1 shows schematic of a single PEM fuel cell. Hydrogen and air are transported to anode and cathode channels in the active fuel cell section, respectively.

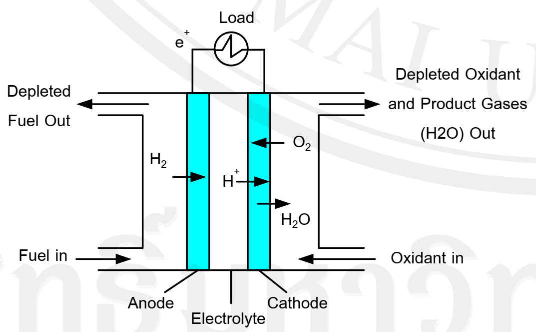

Fig. 1 Schematic diagram of a PEMFC [7]

PEMFC is constructed from a proton conducting polymer electrolyte membrane, usually a perfluorinated sulfonic acid polymer. The chemical reactions producing at the oxidation and reduction electrode of a PEMFC are shown in Eq.(1)-(2)

Anode: $H_2 \longrightarrow 2H^+ + 2e^-$ (1)

Cathode: $(0.5)\,O_2 + 2H^+ + 2e^- \longrightarrow H_2O$ (2)

3. Model description

3.1. Electrochemical model

The output cell voltage of developing fuel cell is less than thermodynamically predicted voltage output due to irreversible losses. Fig. 2 shows characteristic of *i-v* curve of FC performance that depends on output voltage and current density. The output cell voltage depends on parameters which shown in physical equations. There are three major types of fuel cell loss, which occurred in fuel cell as follow: Activation losses, Ohmic losses, and Concentration losses.

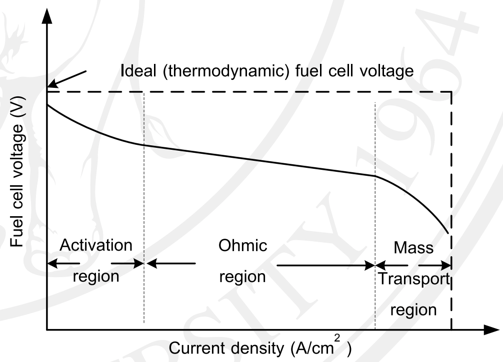

Fig. 2. *i-v* curve schematic of FC

The output cell voltage V_{cell} is the voltage operating at a load current, *i* can be expressed by Eq. (3)

$$V_{cell} = E_{thermo} - \Delta E_{act} - \Delta E_{ohmic} - \Delta E_{conc} \quad (3)$$

where V_{cell} is real output voltage of fuel cell, E_{thermo} is thermodynamically predicted fuel cell voltage output, ΔE_{act} is an activation loss due to reaction kinetics, ΔE_{ohmic} is ohmic loss from ionic and electronic condition, and ΔE_{conc} is concentration loss due to mass transport.

The activation losses mostly affect in initial part of curve. The ohmic losses are mostly apparent in the middle section of the curve, and the concentration losses are most significant in the tail of *i-v* curve. The result of chemical reactions inside a fuel cell is reversible single electrode potential, E_{thermo}, given by the Nernst equation as shown in Eq. (4).

$$E_{thermo} = E^0_{thermo} - \left[\left(\frac{RT}{nF}\right) ln\left(\frac{p_{H_2O}}{p_{H_2} \times \sqrt{p_{O_2}}}\right)\right] \quad (4)$$

where E^0_{thermo} is standard electrode potential, *R* is gas constant (8.3144 J/mol K), *T* is temperature in Kelvin scale, *n* is number of electrons per reacting ion or molecule, *F* is Faraday's constant (96,500 C/mol), p_{H_2O} is the partial pressure of water, p_{H_2} is partial pressure of hydrogen, and p_{O_2} is partial pressure of oxygen.

The activation loss due to reaction kinetics at the electrodes of a PEMFC is shown in Eq. (5). This equation is commonly known as Tafel equation.

$$\Delta E_{act} = \left(\frac{RT}{\alpha F}\right) ln\left(\frac{i + i_{loss}}{i_o}\right) \quad (5)$$

where α is an activity coefficient, i_{loss} is a current loss, i_o is an exchange current density for reaction with constant value, and *i* is an applied current density. The ohmic losses is resistance of ions flow in electrolyte and resistance of the flow of electrons through electrically conductive fuel cell components, R_{ohmic}. Ohmic losses (which includes ionic, electronic, and contact resistance, Ωcm^2) can be calculated from current density as.

$$\Delta E_{ohmic} = i\left(R_{ohmic}\right) \quad (6)$$

where R_{ohmic} is an effect of concentration losses due to mass transport is shown by Eq. (7).

$$\Delta E_{conc} = \left(\frac{RT}{nF}\right) ln\left(\frac{i_L}{i_L - i}\right) \quad (7)$$

where i_L is limiting current density with constant value.

PEMFC model is developed based on energy, mass, and electrochemical equation. Dynamic behaviors of PEMFC under various operation conditions have been studied to evaluate the performance of a PEMFC system while electrical load changing.

4. Simulation results

The model of PEMFC is developed based on the basis of the equations given in the previous section. Fig. 3. shows schematic of a PEMFC module in MATLAB with Simulink.

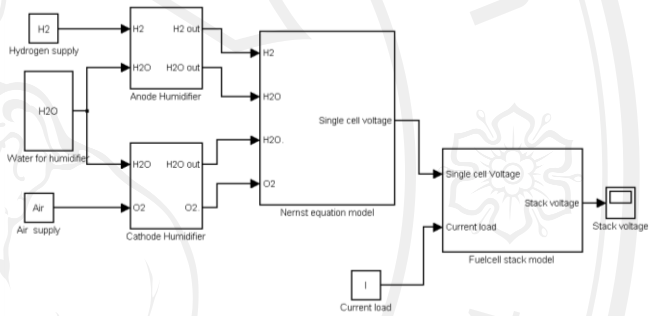

Fig. 3. The schematic of a PEMFC module.

Fig. 4 to Fig.7 show the voltage and current responses of PEMFC model with the different input load current. The simulation results take total simulated time about 1 second with 0.2 second per period.

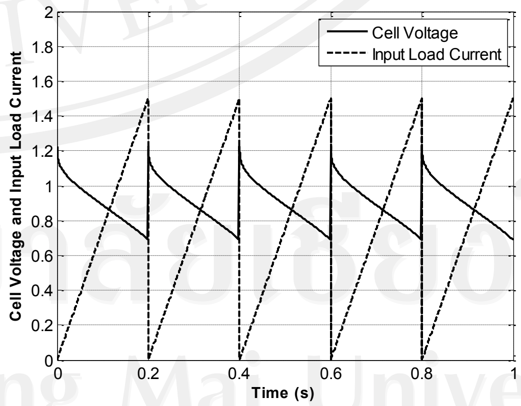

Fig. 4. Voltage and current responses of saw tooth input load current.

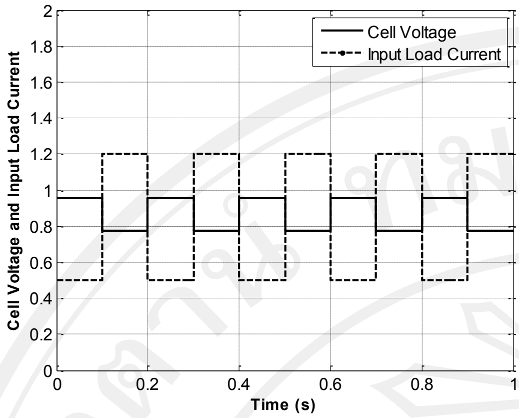

Fig. 5. Voltage and current responses of Step input load current

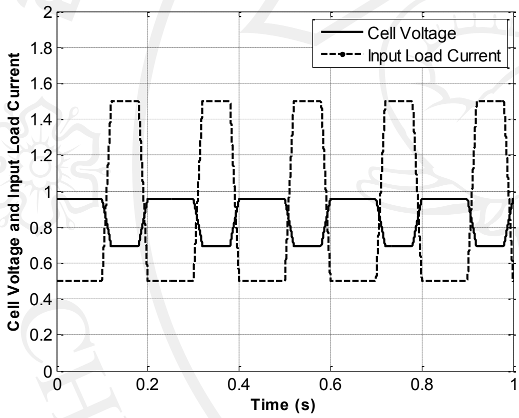

Fig. 6. Voltage and current responses of step input load current with dead time

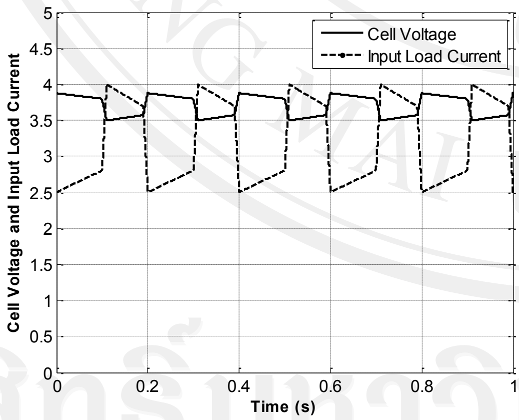

Fig. 7. Voltage and current responses of multi-step input load current

The input load currents have four different types, namely saw-tooth waveform as shown in Fig. 4, step waveform as shown in Fig. 5, step waveform with dead time as shown in Fig. 6, and multi-step waveform as shown in Fig. 7.

From the simulation result can be observed that the output cell voltages of PEMFC are changed when the input load current had been changed.

5. Conclusion

In this paper, a new dynamic model of PEMFC is proposed in order to predict responses of the electric load on the cell. Emphasis is placed on the output cell voltage response to the dynamic load. The results show the effects of load changes on fuel cell system. The sudden changing fuel cell load will effect to sudden drop in the output cell voltage. The output cell voltage response shows in the form of a ripple when varying input load current. This fluctuation may cause problems when the fuel cell operates as a major power source delivering high voltages. The proper control should be used whenever there is a sudden fluctuation in the load.

6. Acknowledgement

This work is sponsored by the Graduate School of Chiang Mai University. In addition, the authors gratefully acknowledge the Mechanical Engineering Department and Thermo-Fluid Laboratory staffs.

7. References

[1] Kamaruzzaman Sopia and Wan Ramli Wan Daud (2006).Challenges and future developments in proton exchange membrane fuel cells, *Renewable Energy,* vol. 31, pp. 719-727

[2] H.I. Lee, C.H. Lee, T.Y. Oh, S.G. Choi, I.W. Park, and K.K. Baek (2002). Development of 1 kW class polymer electrolyte membrane fuel cell power generation system, *Journal of Power Sourses,* vol.107, pp. 110-119

[3] Cheng Wang, Zongqiang Mao, Fuyi Bao, Xiaoguang Li, and Xiaofeng Xie (2005),

Development and performance of 5 kW proton exchange membrane fuel cell stationary power system, *International Journal of Hydrogen Energy*, vol.30, pp. 1031-1034

[4] Lin Wang, Attila Husar, Tianhong Zhou, and Hongtan Liu (2003). A parametric study of PEM fuel cell performances, *International Journal of Hydrogen Energy*, vol.28, pp. 1263-1272

[5] J.-J. Hwang, and H.-S. Hwang, (2002), Parametric studies of a double-cell stack of PEMFC using Grafoil^{TM} flow-field plates, *Journal of Power Sources,* vol.104, pp. 24-32

[6] M.T. Outeiro, R. Chibante, A.S. Carvalho, and A.T. de Almeida (2008), A parameter optimized model of a Proton Exchange Membrane fuel cell including temperature effects, *Journal of Power Sources,* vol.185, pp. 952-960

[7] Sampath Yerramalla, Asad Davari, Ali Feliachi, and Tamal Biswas (2003), Modeling and simulation of the dynamic behavior of a polymer electrolyte membrane fuel cell, *Journal of Power Sources,* vol.124, pp. 104-113

[8] P.R. Pathapati, X. Xue, and J. Tang (2005), A new dynamic model for predicting transient phenomena in a PEM fuel cell system, *Renewable Energy*, vol. 30, pp.1-22

[9] Alejandro J. del Real, Alicia Arce, and Carlos Bordons (2007), Development and experimental validation of a PEM fuel cell dynamic model, *Journal of Power Sources,* vol.173, pp. 310-324

[10] Qiang Shen, Ming Hou, Xiqiang Yan, Dong Liang, Zhenming Zang, Lixing Hao, Zhigang Shao, Zhongjun Hou, Pingwen Ming, and Baolian Yi (2008), The voltage characteristics of proton exchange membrane fuel cell (PEMFC) under steady and transient states, *Journal of Power Sources,* vol.179, pp. 292-296

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Model and Experiment Analysis of 1.2 kW PEMFC Electrification

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Abstract

This paper developed a model of PEMFC by using *MATLAB/Simulink* in order to analyze the operation performance of a Proton Exchange Membrane Fuel Cell of 1.2 kW. Also, the experimental is set up to study the performance of PEMFC. The results show that the operation performance of fuel cell depends on gas pressure, operation temperature, gas flow rate and gas humidity. All parameters which affected the system performance are evaluated. The results of both an experiment and model simulation are determined. The experimental results show the behavior of PEMFC when there is load changing. All aspects of PEMFC electrification will be fully investigated in order to develop the alternative sustainable PEMFC energy sources and to study the fundamental of fuel cell technology. The results of simulation and experimental will be compared.

Keywords: *Fuel cell; PEMFC; Efficiency of PEMFC; Simulation*

1. Introduction

Energy and air pollutions are the most seriously problems and it is not only affected to only one country but also affected to whole the world. Now a day, electrical power demands increase continuously and due to the limitation of fossil-fuel resources and environment concerns. It is very important to talk about new power sources in order to stop the global warming and reducing air pollutions. One of that is Fuel Cell technology. It uses hydrogen as the fuel. The fuel cell (FC) is an energy-conversion device that can produce electricity without harmful emissions. FC uses chemical reaction process to convert chemical energy directly into electrical energy. Fuel cell systems use hydrogen and oxygen as a fuel which fed into anode and cathode side of fuel cell. One of the various existing fuel cell systems is a proton exchange membrane fuel cell (PEMFC) and it is the most popular type of fuel cell for electrical power generation.

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Many types of PEMFC have been studied and analyzed the performance. There are two types of PEM fuel cell that were studied, single and stack cells. Also, mathematical model of PEMFC are made in order to study some of parameters that effected to both single and stack cells. Not only the PEMFC's parameters but also loads changed have been evaluated. In order to understand the behavior and characteristics of PEMFC performance, the mathematical model is developed [1]-[6].

Mathematical model and an experimental of 1.2 kW PEMFC is presented. Performance of PEM fuel cell is studied by varying load current in order to show the behavior and characteristics of the PEMFC under various operation conditions. The objectives of this research are to compare the model results with experimental results when there is load current changing under various operation conditions.

2. Theoryvand Research Methodology

Physical structure of PEMFC is very important to understand how its work. Figure 1 shows schematic of a single PEMFC. Hydrogen and air are fed to anode and cathode channels in the active fuel cell section, respectively.

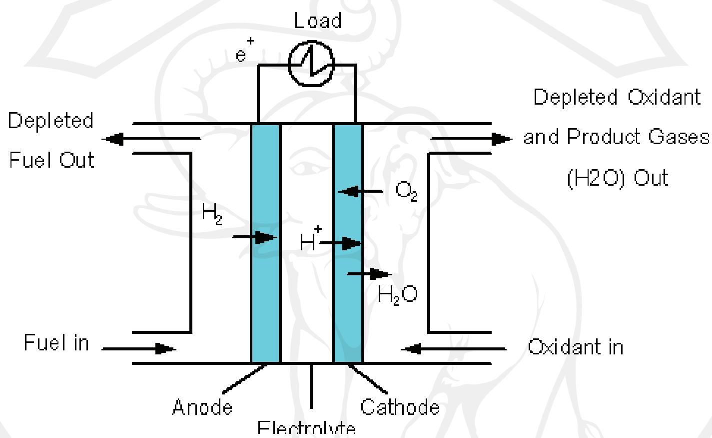


Fig. 1 Schematic diagram of a PEMFC [6].

PEMFC is constructed from a proton conducting polymer electrolyte membrane, usually a per fluorinated sulfuric acid polymer. The chemical reactions producing at the oxidation and reduction electrode of a PEMFC are shown in Equation (1) and (2) [5, 6]

Anode: $$H_2 \rightarrow 2H^+ + 2e^- \quad (1)$$

Cathode: $$(0.5)O_2 + 2H^+ + 2e^- \rightarrow H_2O \quad (2)$$

Mathematical model of PEMFC is developed based on energy, mass, and electrochemical equation. Some of parametric has been studied to evaluate PEMFC's performance. The PEMFC performance can be expressed *i-v* curve as shown in Figure 2. The characteristic of this curve depends on the output voltage and current density. The output voltage of the PEMFC depends on parameters which shown in physical equations. The result of the model will be compared to the experiment results. The output voltage of developing fuel cell is depending on the thermodynamically predicted fuel cell voltage output and three majors losses which occurred in fuel cell as following: Activation losses, Ohmic losses, and Concentration losses. Activation losses are loss due to electrochemical reaction. Ohmic losses occur due to ionic electronic condition. Concentration losses are losses due to mass transport.

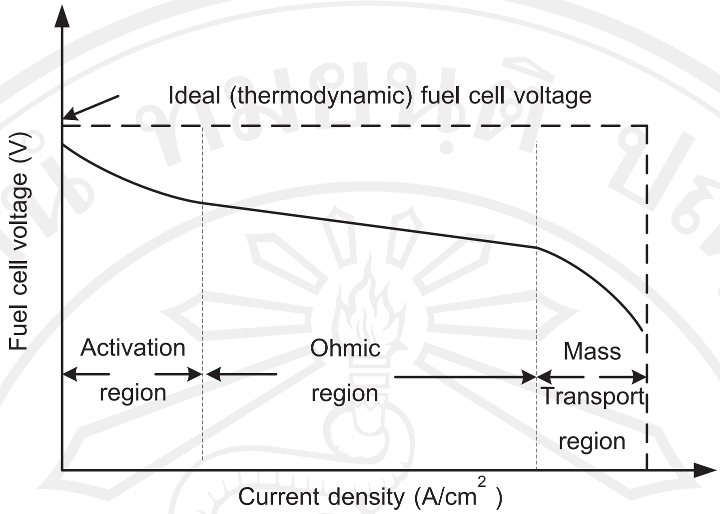


Fig. 2. *i-v* curve schematic of FC [6]

Then, the output voltage of PEMFC can be expressed in equation (3).

$$V = E_{thermo} - \Delta E_{act} - \Delta E_{ohmic} - \Delta E_{conc} \quad (3)$$

where V is the real output voltage of fuel cell. E_{thermo} is the thermodynamically predicted fuel cell voltage output. ΔE_{act} is the Activation loss due to reaction kinetics. ΔE_{ohmic} is the Ohmic loss from ionic and electronic condition. ΔE_{conc} is the concentration loss due to mass transport.

The result of chemical reactions inside a fuel cell is reversible single electrode potential, E_{thermo}, given by the Nernst equation as shown in equation (4).

$$E_{thermo} = E^{0}_{thermo} - \left[\left(\frac{RT}{nF}\right) ln\left(\frac{p_{H_2O}}{p_{H_2} \times \sqrt{p_{O_2}}}\right)\right] \quad (4)$$

where E^{0}_{thermo} is standard electrode potential, R is gas constant (8.3144 J/mol K), T is temperature in Kelvin scale, n is number of electrons per reacting ion or molecule, F is Faraday's constant (96,500 C/mol), p_{H_2O} is the partial pressure of water, p_{H_2} is partial pressure of hydrogen, and p_{O_2} is partial pressure of oxygen.

The activation loss (mostly affect in initial part of curve) due to reaction kinetics at an electrode of a PEMFC is shown in equation (5). This equation is commonly known as Tafel equation.

$$\Delta E_{act} = \left(\frac{RT}{\alpha F}\right) ln\left(\frac{i + i_{loss}}{i_o}\right) \quad (5)$$

where α is an activity coefficient, i_{loss} is a current loss, i_O is an exchange current density for reaction with constant value, and i is an applied current density. The ohmic losses (mostly apparent in the middle section of the curve) is resistance of ions flow in electrolyte and resistance of the flow of electrons through electrically conductive fuel cell components, R_{ohmic}. Ohmic losses (which include ionic, electronic, and contact resistance, Ωcm^2) can be calculated from current density as.

$$\Delta E_{ohmic} = i\left(R_{ohmic}\right) \quad (6)$$

The effect of concentration losses due to mass transport (most significant in the tail of *i-v* curve) is shown by equation (7).

$$\Delta E_{conc} = \left(\frac{RT}{n\,F}\right) ln\left(\frac{i_L}{i_L - i}\right) \tag{7}$$

where i_L is limiting current density with constant value and i is an applied current density.

Activation and concentration polarization can occur in both anode and cathode. The cell voltage, V_{cell} , is therefore:

$$V_{cell} = E_{thermo} - (\Delta E_{act} + \Delta E_{conc})_a - (\Delta E_{act} + \Delta E_{conc})_c - \Delta E_{ohmic} \tag{8}$$

Subscript a and c denote the anode and cathode sides of FC membrane, respectively. [6]

2.1 Single Cell Voltage

By substitution equations (4), (5), (6) and (7) into equation (8), a relationship between fuel cell potential and current density, called fuel cell polarization curve, is obtained the single cell output voltage:

$$\begin{aligned} V_{cell} = E_{thermo} &- \left(\frac{RT}{\alpha nF}\right) ln\left(\frac{i + i_{loss}}{i_{o,c}}\right) - \left(\frac{RT}{\alpha nF}\right) ln\left(\frac{i + i_{loss}}{i_{o,a}}\right) \\ &- \left(\frac{RT}{nF}\right) ln\left(\frac{i_{L,c}}{i_{L,c} - i}\right) - \left(\frac{RT}{nF}\right) ln\left(\frac{i_{L,a}}{i_{L,a} - i}\right) - i\left(R_{ohmic}\right) \end{aligned} \tag{9}$$

where $i_{o,a}$ and $i_{o,c}$ are the exchange current density for the reaction of the anode and cathode side, respectively. $i_{L,a}$ and $i_{L,c}$ are the limiting current density of the anode and cathode side, respectively. Equation (9) is the single cell voltage, which calculated by vary the current density, i .

2.2 Stack Cell Voltage

This section presents the various equations that are necessary for overall modeling of fuel cell system. The total stack cell voltage is calculated as follows.

$$V_{cell} = N\left\{\begin{aligned} &E_{thermo} - \left(\frac{RT}{\alpha nF}\right) ln\left(\frac{i + i_{loss}}{i_{o,c}}\right) - \left(\frac{RT}{\alpha nF}\right) ln\left(\frac{i + i_{loss}}{i_{o,a}}\right) \\ &- \left(\frac{RT}{nF}\right) ln\left(\frac{i_{L,c}}{i_{L,c} - i}\right) - \left(\frac{RT}{nF}\right) ln\left(\frac{i_{L,a}}{i_{L,a} - i}\right) - i\left(R_{ohmic}\right) \end{aligned}\right\} \tag{10}$$

where N is a number of cell. The parameters, such as i_o , α , T, and i_L, are studied to determine the effect of PEMFC performance. Those parameters were presented in. The PEMFC performance will be shown as *i-v* curve for a single cell.

3. Simulation Model

The mathematical model of PEMFC is developed based on the basis of the equations given in the previous section. Figure 3 shows the schematic of a PEMFC module in *MATLAB* with *Simulink*.

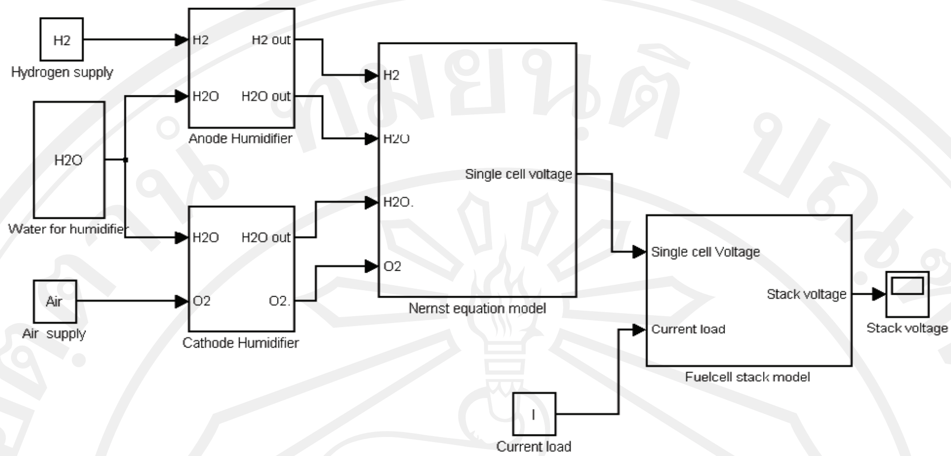


Figure. 3. The schematic of a PEMFC module.

4. Experimental Setup

The experiment is set up as show in figure 4.The experiment used PEMFC with 1.2 kW, 46 A (NexaTM Power Module User's Manual, model: MAN5100078). It consists of hydrogen tank, personal computer, PEMFC module, and electronic load.

Fig. 4. Experiment Setup Schematic

The experiments are tested at difference pressure operation and varied the current load in order to study the behavior and performance of PEMFC.

5. Simulation and Experiment Results

The experiment results show in figure 5 that indicates the output voltage of PEMFC with difference of pressure operation.

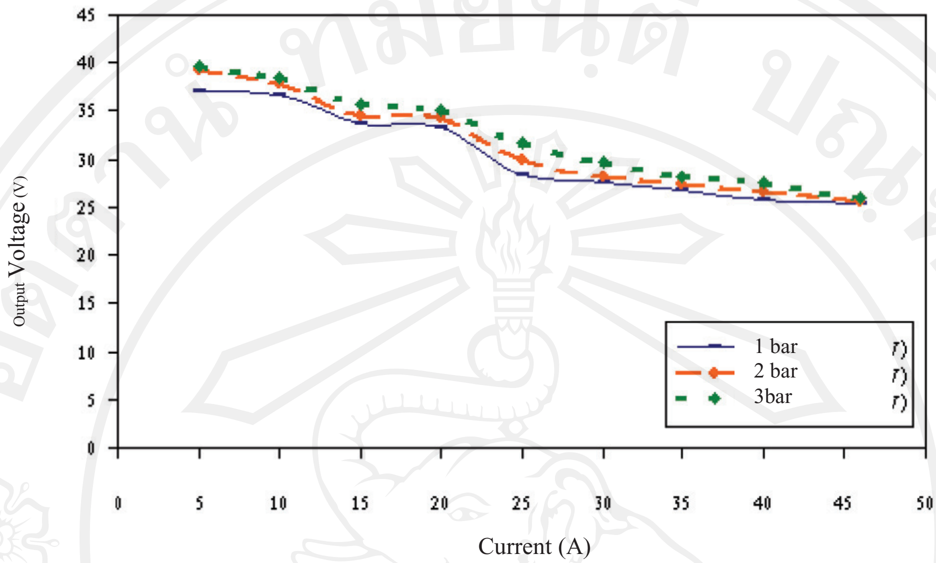
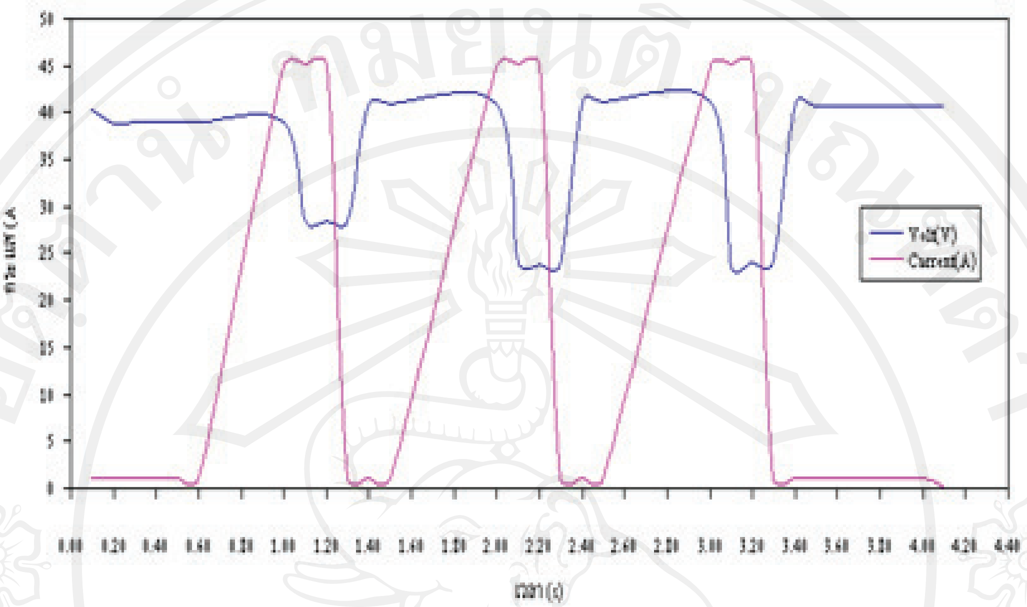


Fig 5. Output voltage of PEMFC with difference of gas pressure operation at 1, 2, and 3 bars

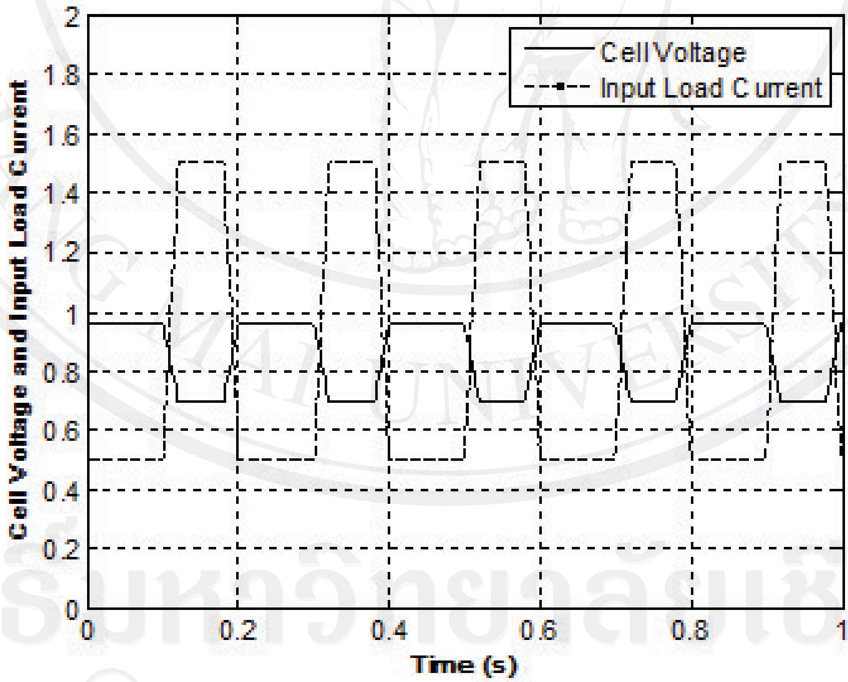
The experiment is taken at atmospheric pressure for air and changing the hydrogen pressure from 1 to 3 bars. The results show the output voltage of PEMFC trends to decrease when increased the load current from 5A to 45A for all difference pressure operation. Pressure operation was set up at 3 bars which gave higher output voltage. Figure 6(a) shows the fuel cell voltage when immediately changed the load current from 1A to 46A every 10 seconds. The load current increase sharply will cause the fuel cell voltage decrease. Figure 6(b) is the simulation results of a single cell. It shows the output voltage and current responses of PEMFC model with input load current. The simulation results take total simulated time about 1 second with 0.2 second per period.

Figure 7 shows the comparison of the output voltage of mathematical model and experimental. It shows that the output voltage from the model has little bit higher than the experiment. It is because of we keep some parameters in the model constantly but in the experiment there is some parameters will change when the operation temperature changed.

In Figure 8 is the comparison of power output of both model and experiment results. It shows that the output power of both model and experiment increased when increased the load current from 5A to 46A and the result has the same trend.



(a)



(b)

Fig. 6. The changing of load current and cell voltage.

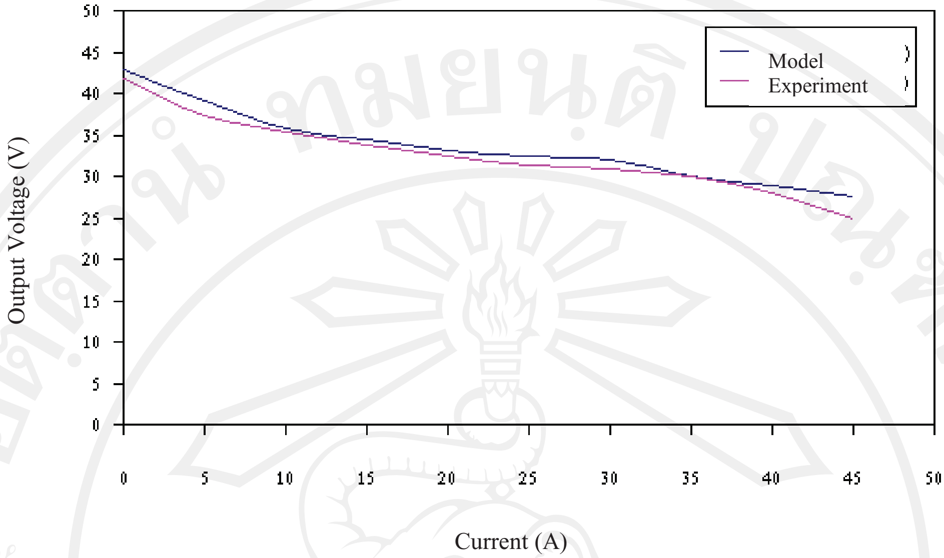


Fig. 7. The comparison of output voltage of mathematical model and experimental.

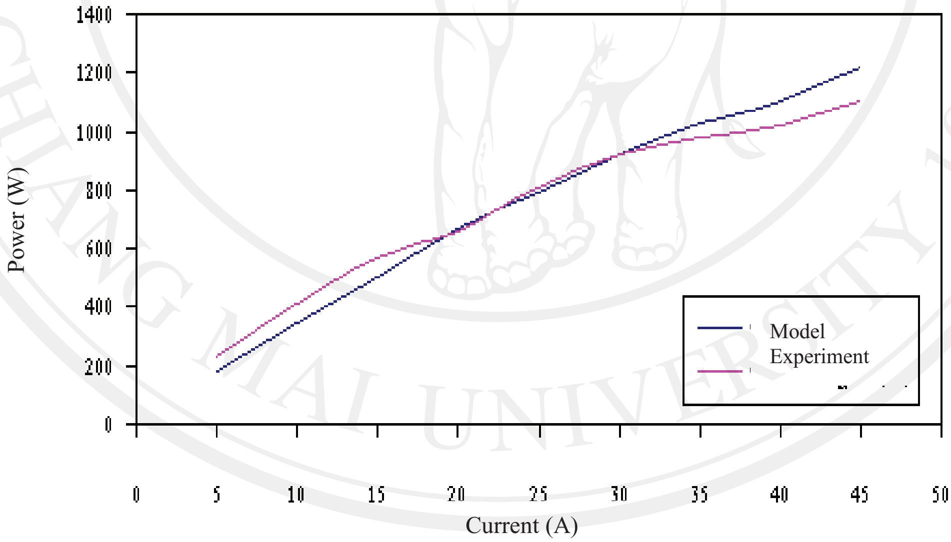


Fig. 8. The output power for both model and experiment results.

6. Conclusions

The study of PEMFC performance in this work show the hydrogen pressure has effected to the FC performance. The PEMFC's performance will increase when increased the pressure. The output voltage changed rapidly when the current load has been changed. Both results of mathematical model and experiment can be show the behavior of the PEMFC. The results are good agreement. The model of the study can be expressed the dynamic behavior of the PEMFC when there is load changing.

Acknowledgement

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References

[1] Cheng Wang, Zongqiang Mao, Fuyi Bao, Xiaoguang Li, and Xiaofeng Xie “Development and performance of 5 kW proton exchange membrane fuel cell stationary power system” International Journal of Hydrogen Energy ,vol. 30, pp.1031-1034,2005.

[2] Colleen Spiegel “PEM Fuel Cell Modeling and simulation Using MATLAB, Book, Elsevier Inc, 2008.

[3] Lin Wang, Attila Husar, Tianhong Zhou, and Hongtan Liu “A parametric study of PEM fuel cell performances” International Journal of Hydrogen Energy ,vol. 28, pp.1263-1272, 2003.

[4] Fang-Bor Weng, Ay Su, Guo-Bin Jung, Yen-Chiao Chiu, and Shih-Hung Chan “Numerical prediction of concentration and current distributions in PEMFC” Journal of Power Sources,vol. 145, July 18, pp.546-554, 2005.

[5] Sampath Yerramalla, Asad Davari, Ali Feliachi, and Tamal Biswas “Modeling and simulation of the dynamic behavior of a polymer electrolyte membrane fuel cell” Journal of Power Sources ,vol. 124, pp.104-113, June 11, 2003.

[6] Winai Chanpeng and Yottana Khunatorn, “Simulation of Dynamic Behavior of a Proton Exchange Membrane Fuel Cell”, Proceeding of International Conference on Green and Sustainable Innovation 2009.

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"The effect of the input load current changed to a 1.2 kW PEMFC performance",
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The effect of the input load current changed to a 1.2 kW PEMFC performance

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Abstract

This paper focuses on the performance and dynamic behavior of proton exchange membrane fuel cell (PEMFC) with 1.2 kW under varies of an input load current. The mathematical model of PEMFC is developed based on energy, mass, and electrochemical equation. The some parameters in the model are kept constant. The performance and dynamic behaviors of PEMFC are determined by applied the variety of input load current with different types of input load current, such as saw-tooth, step, step input with dead time, and multi-step input load current. The results of model are compared to the experimental results. The results of the model show that the output cell voltages are suddenly dropped when the input load current have been increased and output cell voltage increased when decreased the input load current. This mathematical model can predict the dynamic behavior of the PEMFC when the input load currents have been changed. The experimental setups use 1.2 kW of PEMFC with connected to electronic load device and can be operated the input load current from 0A to 500A. Hydrogen is used as a fuel at the anode side and air is used at the cathode side. The operating temperature is kept to be constant at room temperature. The experiments show that the output cell voltage is decreased when the input load current increased. There is some slightly different between the model and experiment results when compared at the same conditions. This is because of in the model we kept some parameter constant. The water generated during the process is tested under varying input load current from 1A to 30A. The dynamic behavior of the PEMFC under different types of input load current shows very well.

Keywords: Load current; PEMFC; Performance; Model of PEMFC; Dynamic behavior

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1. Introduction

Proton Exchange Membrane Fuel Cell (PEMFC) is an electrochemical energy converter that converts chemical energy of fuel directly into DC electricity. PEMFC uses hydrogen and oxygen or hydrogen and air as a fuel which feed into anode and cathode side of fuel cell as shown in Fig. 1

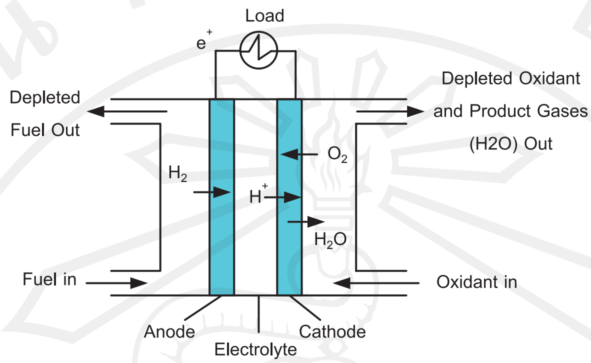

Fig. 1. Schematic diagram of a PEMFC [10].

PEMFC is constructed from a proton conducting polymer electrolyte membrane, usually a perfluorinated sulfonic acid polymer [2,4]. The chemical reactions producing at the oxidation and reduction electrode of a PEMFC are shown in Eqs.*(1)* and *(2) ;*

Anode: $$H_2 \rightleftarrows 2\,H^+ + 2\,e^- \qquad (1)$$
Cathode: $$(1/2)\,O_2 + 2\,H^+ + 2\,e^- \rightleftarrows H_2O \qquad (2)$$

Many researches and development of PEMFC have received much attention [1-10]. Some of them are pointed on mathematical model to study some of parameters that effected to both single and stack cells [3], [5-9]. Performance testing and application of PEMFC are evaluated in order to get optimize operation [1]. A phenomenon occurs inside fuel cell is very difficult to predict. Also, parameters that effected to PEM fuel cell performance are very hard to indicate. In order to understand the behavior and characteristics of PEMFC performance, the mathematical model is developed.

A mathematical model of PEM fuel cell is presented. Performance of PEM fuel cell is studied by changing some parameters in order to show the behavior and characteristics under various operation conditions. The objectives of this research are to study parametric which affect to PEMFC performance and develop the PEMFC model under various operation conditions by changing the input load currents.

Nomenclature

V	real output voltage of fuel cell
E_{thermo}	thermodynamically predicted fuel cell voltage output
ΔE_{act}	activation loss due to reaction kinetics
ΔE_{ohmic}	ohmic loss from ionic and electronic condition

ΔE_{conc}	concentration loss due to mass transport
E^{0}_{thermo}	standard electrode potential
R	gas constant (8.3144 J/mol K)
T	temperature in Kelvin scale
n	number of electrons per reacting ion or molecule
F	Faraday's constant (96,500 C/mol)
p_{H_2O}	partial pressure of water
p_{H_2}	partial pressure of hydrogen
p_{O_2}	partial pressure of oxygen
α	activity coefficient
i_{loss}	current loss
i_O	exchange current density for reaction with constant value
I	applied current density
R_{ohmic}	resistance of ions flow in electrolyte and resistance of the flow of electrons through electrically conductive fuel cell component
i_L	limiting current density with constant value

2. Theory and research methodology

A mathematical model of PEMFC is developed based on energy, mass, and electrochemical equation. Some of parametric have been studied to evaluate the effect of a PEMFC system performance. The PEMFC performance can be expressed *i-v* curve, which is shown in Fig. 2. The characteristic of this curve depends on output voltage and current density, which varies with parameters as shown in physical equations.

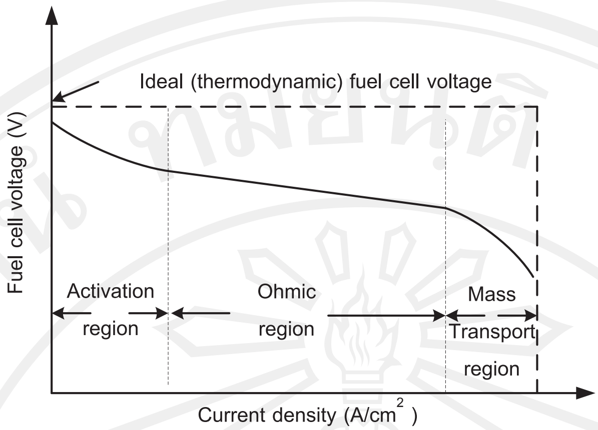

Fig. 2. *i-v* curve of PEMFC [10].

The output voltage of developing fuel cell is less than thermodynamically predicted voltage output due to irreversible losses. There are three major types of fuel cell loss, which occurred in fuel cell as follow: Activation losses are loss due to electrochemical reaction mostly affected in initial part of curve. Ohmic losses occur due to ionic electronic condition mostly apparent in the middle section of the curve. Concentration are losses due to mass transport was most significant in the tail of *i-v* curve. Each contains parameters, which depend on the physical dimensions of PEMFC. The output voltage of PEMFC can be written as Eq. *(3)* [2,4].

$$V = E_{thermo} - \Delta E_{act} - \Delta E_{ohmic} - \Delta E_{conc} \quad (3)$$

The output voltage of PEMFC depends on parameters that contain in three major losses which can be expressed in Eq. *(4)* through Eq. *(7)*. The result of chemical reactions inside a fuel cell is reversible single electrode potential, E_{thermo}, given by the Nernst equation as shown in Eq. *(4)*.

$$E_{thermo} = E^{0}_{thermo} - \left[\left(\frac{RT}{nF}\right) ln\left(\frac{p_{H_2O}}{p_{H_2} \times \sqrt{p_{O_2}}}\right)\right] \quad (4)$$

The activation losses are due to reaction kinetics at the electrodes of a PEMFC is shown in Eq. *(5)*. This equation is commonly known as Tafel equation.

$$\Delta E_{act} = \left(\frac{RT}{\alpha F}\right) ln\left(\frac{i + i_{loss}}{i_o}\right) \quad (5)$$

Ohmic resistant losses, (R_{ohmic}) which includes ionic, electronic, and contact resistance, Ωcm^2, can be calculated from current density as.

$$\Delta E_{ohmic} = i\left(R_{ohmic}\right) \quad (6)$$

$$\Delta E_{conc} = \left(\frac{RT}{nF}\right) ln\left(\frac{i_L}{i_L - i}\right) \quad (7)$$

The parameters, such as i_o , α , T, and i_L, are studied to determine the effect of PEMFC performance.

3. Simulation results

The simulation results shown in Fig.3. There are activation losses due to an exchange current density (i_o) of the 1.2 kW PEMFC, when the i_o was increased by 10 times causing the output cell voltage decrease about 12%.

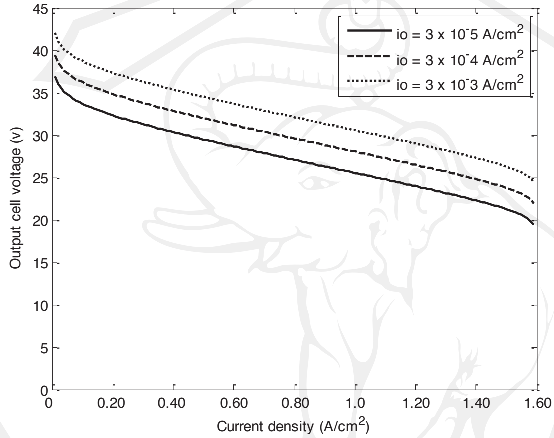

Fig. 3. The variation of exchange current density (i_o)..

Figure 4 shows the effect of vary the activity coefficient (α) by increase its from 0.5 to 0.9. The result of changing will cause the FC performance improved by 12% as shown in Fig. 4.

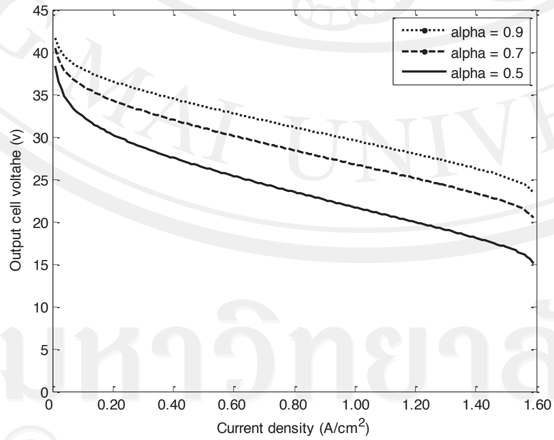

Fig. 4. The variation of activity coefficient.

Figure 5 shows the ohmic losses which are caused by resistance of ions flow in the electrolyte and resistance of flow of electrons through the electrically conductive fuel cell components. The increasing of ohmic loss by 33% will cause the FC performance decreased about 12%. Figure 6 shows the effect of limiting current density, i_L to the FC performance. Increasing of i_L by 6% will effect to FC performance decrease about 5% .

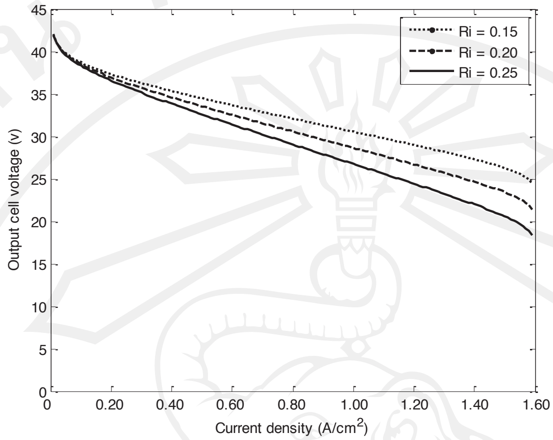

Fig. 5. The variation of resistance of ions flow in the electrolyte and resistance of the flow of electrons.

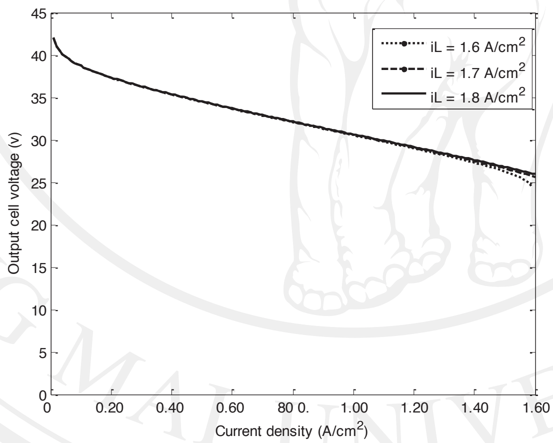

Fig. 6. The variation of the limiting current density in fuel cell.

Figure 7 shows the result of stack cell output voltage when the input load currents have been changed with step shape from 27A to 40A. It caused the output voltage of the PEMFC dropped as shown in Fig 7.

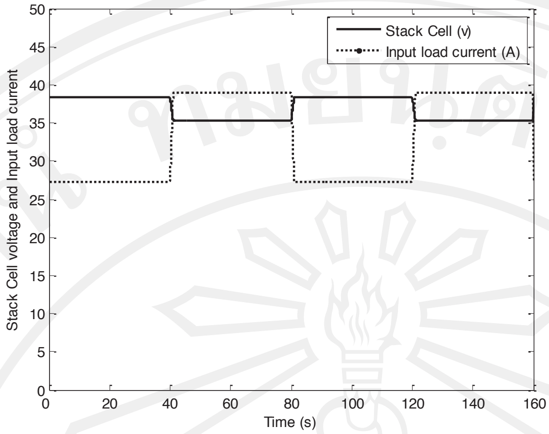

Fig. 7. Output voltage and current responses of step shape of input load current.

Figure 8 shows the output voltage and current responses of saw tooth shape of input load current. The input load current is slowly increased. It caused the output voltage of PEMFC gradually dropped and then, suddenly decreased the input load current caused the output voltage sharply increased. Figure 9 shows the output voltage and current responses of step shape of input load current with dead time.

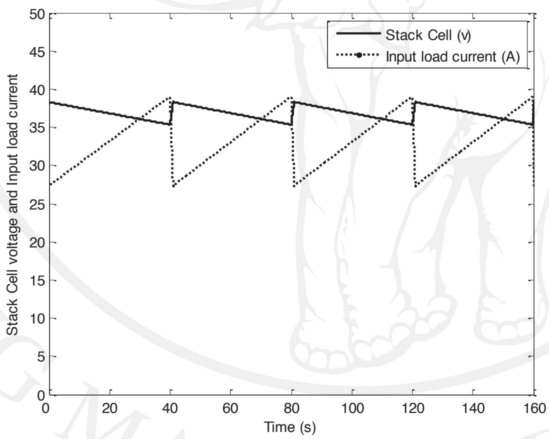

Fig. 8. Output voltage and current responses of saw tooth shape of input load current.

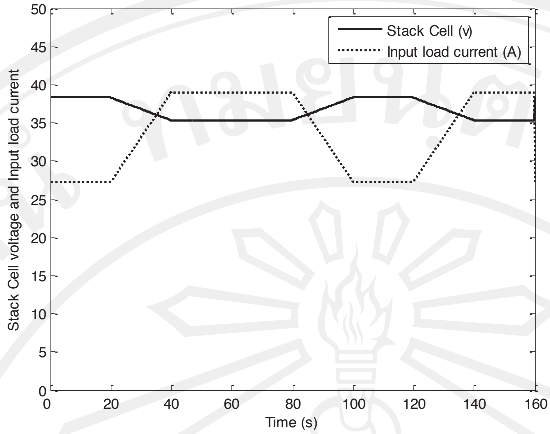

Fig. 9. Output voltage and current responses of step shape of input load current with dead time.

Figure 10 shows the output voltage and current responses of multi-step shape of input load current. The input load current is gradually increased caused the output voltage slowly decreased and then, increased the input load current suddenly. It caused the output voltage dropped.

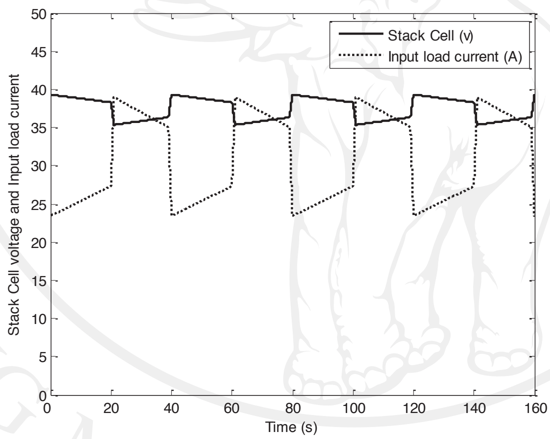

Fig. 10. Output voltage and current responses of multi-step shape of input load current.

Figure 11 shows the experimental devices, which consist of (1) Hydrogen tank (2) 1.2 kW PEMFC (3) Personal computer, and (4) Electronic load.

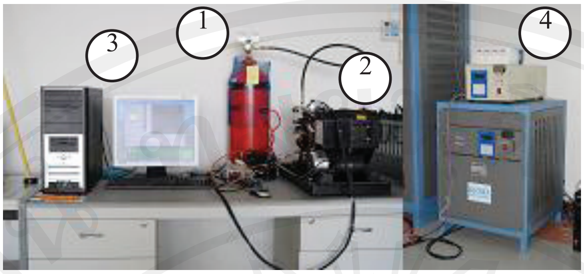

Fig. 11. Experimental device.

Figure 12 and 13 show the comparison of an experimental and model results of 1.2 kW PEMFC. Figure 12 shows the output voltage changed when the input load current has been changed from 1A to 5A with step shape. The result of both simulation and experiment results have the same trend but, there are some small different of the value during the input load current changed. The model result shows more rapidly changed when the input load current has been changed than the experiment result. Figure 13 shows the output voltage of both results under the changing of input load current from 5A to 30A. The simulation result shows the smooth line of decreasing and increasing of the output voltage when the input load current changed. In the other hand, the experimental result shows the output voltage decreased and increased as a ladder shape. Because the electronic load cannot be controlled smoothly to increase and decrease input load current.

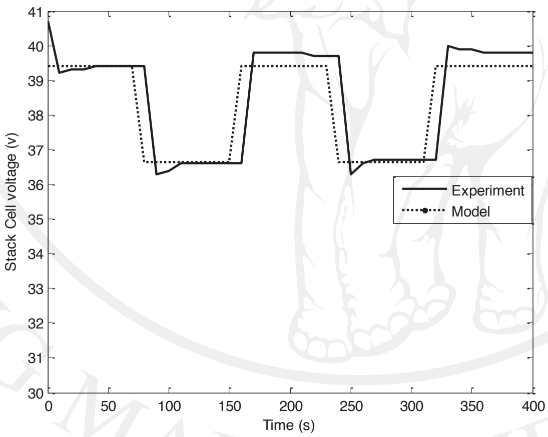

Fig. 12. The comparison of experiment and model results with step shape.

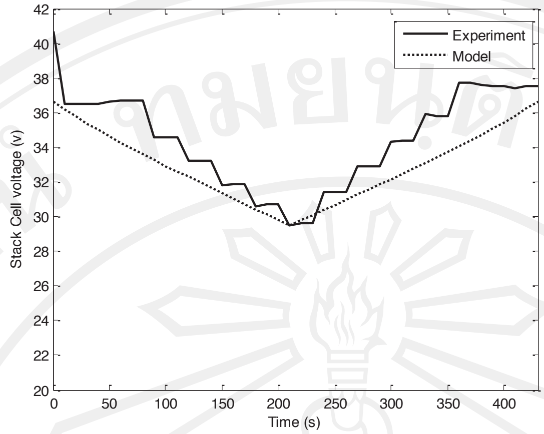

Fig. 13. The comparison of experiment and model results with triangle shape.

4. Conclusion

The mathematical model of the proton exchange membrane fuel cell (PEMFC) system is presented. The model is defined by parametrical equations that can predict the performance of fuel cell under various operations. The model results show some parameters affected to fuel cell performance. The input load current also affected to output voltage of fuel cell. The increasing and decreasing of input load current directly affected to the behaviour of fuel cell. The model has been validated to an experiment of 1.2 kW PEMFC. The model was developed in this paper. It can be used to study the behaviour of PEMFC under various operations. The input load current affected to PEMFC performance and performed characteristic behaviour of output voltage with different shape of input load current changed. This model can be also performing a detailed analysis of the effect of the PEMFC system using the developed model.

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References

[1] Cheng Wang, Zongqiang Mao, Fuyi Bao, Xiaoguang Li, and Xiaofeng Xie "Development and performance of 5 kW proton exchange membrane fuel cell stationary power system" International Journal of Hydrogen Energy 30, pp.1031-1034, 2005
[2] Colleen Spiegel "PEM Fuel Cell Modeling and simulation Using MATLAB, Book, Elsevier Inc, 2008
[3] Fang-Bor Weng, Ay Su, Guo-Bin Jung, Yen-Chiao Chiu, and Shih-Hung Chan "Numerical prediction of concentration and current distributions in PEMFC" Journal of Power Sources 145, pp.546-554, July 18, 2005
[4] Frano Barbir "PEM Fuel Cells: Theory and Practice" Book, Elsevier Academic Press, 2005
[5] Lin Wang, Attila Husar, Tianhong Zhou, and Hongtan Liu "A parametric study of PEM fuel cell performances" International Journal of Hydrogen Energy 28, pp.1263-1272, 2003
[6] Leonard J. Bonville, H. Russel Kunz, Ying Song, Anthony Mientek, Minkmas Williams, Albert Ching, and James M. Fenton "Development and demonstration of a higher temperature PEM fuel cell stack" Journal of Power Sources 144, pp.107-112, March 16, 2005
[7] M.T. Outeiro, R. Chibante, A.S. Carvalho, and A.T. de Almeida "A parameter optimized model of a Proton Exchange Membrane Fuel Cell including temperature effects" Journal of Power Sources, pp. 952-960, 2008
[8] Ronald K.A.M Mallant "PEMFC systems: the need for high temperature polymers as a consequence of PEMFC water and heat management" Journal of Power Sources 118, pp.424-429, 2003
[9] Sampath Yerramalla, Asad Davari, Ali Feliachi, and Tamal Biswas "Modeling and simulation of the dynamic behavior of a polymer electrolyte membrane fuel cell" Journal of Power Sources 124, pp.104-113, June 11, 2003
[10] Winai Chanpeng and Yottana Khunatorn "Simulation of Dynamic Behavior of a Proton Exchange Membrane Fuel Cell", International Conference on Green and Sustainable Innovation December 2 – 4, 2009, Chiang Rai, Thailand

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- Winai Chanpeng and Yottana Khunatorn, "Simulation of Dynamic Behavior of a Proton Exchange Membrane Fuel Cell", International Conference on Green and Sustainable Innovation 2009, December 2 – 4, 2009, Chiang Rai, Thailand

- Winai Chanpenga, Yottana Khunatorna and Boonyang Plangklang, "Model and Experiment Analysis of 1.2 kW PEMFC Electrification", 2nd International Science, Social-Science, Engineering and Energy Conference 2010: Engineering Science and Management, Procedia Engineering 8 (2011) 106–114

- Winai Chanpenga and Yottana Khunatorn, "The effect of the input load current changed to a 1.2 kW PEMFC performance", 9th Eco-Energy and Materials Science and Engineering Symposium, Energy Procedia 9 (2011) 316 – 325