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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)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2015

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

ACKNOWLEDGEMENT

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].

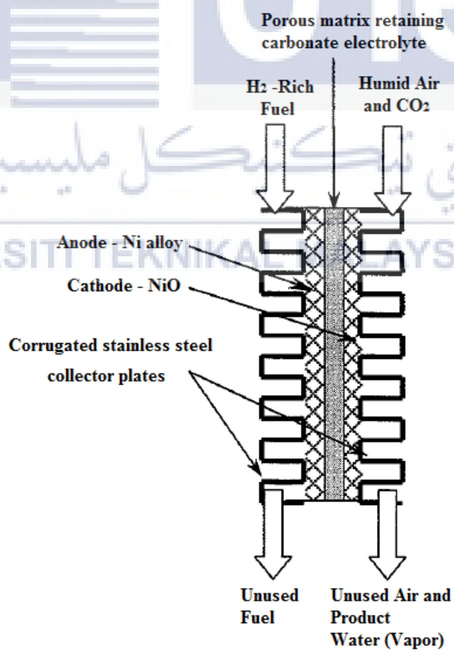


Figure 2.1: Schematic illustration of MCFC unit cell [2]

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].

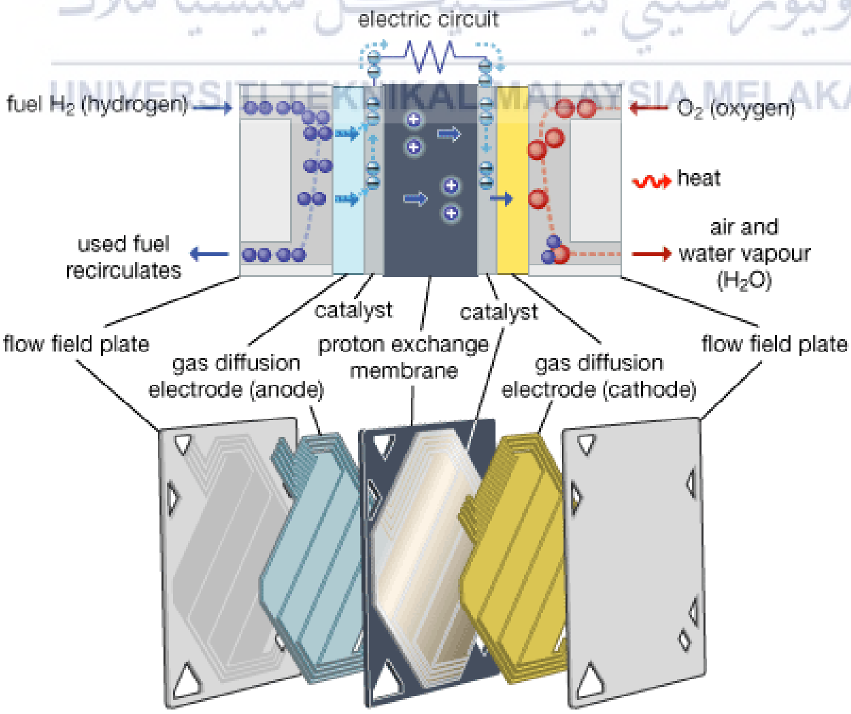


Figure 2.2: Simplified diagram of PEM fuel cell [7]

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

NetCon humidifier control data acquisition system and temperature control system integration program. Integral PID algorithm software is used to control the humidifier speed. Dehydration of fuel cell membrane which can cause the reduction of battery performance and service life need to be prevented. The humidifier outlet gas humidity will increase when the humidifier temperature increase. Authors in [9] and [10] are stated that the flooding phenomenon needs to be avoided by controlling the humidification system of the fuel cell.

Jeon D.H. in [11] wrote on the effect of humidity of the cathode (RHC) on the performance and the uniformity of PEM fuel cells. Computerized fluid dynamic (CFD) simulation is used to see the effect with various level of cathode inlet humidity. Level of cathode inlet humidity is varying at dry, 20%, 45%, 60%, 80%, and100%. It shows that the dry cathode inlet humidity operation of PEM fuel cell could produce a voltage loss at high current density and non-uniform temperature distribution compared to high cathode inlet humidity operation. However, excessively of high cathode inlet humidity may result in non-uniformity problem caused by water flooding.

The PEM fuel cell of flooding condition has been diagnosed by Dotelli, G. in [12]. From this paper, it is stated that the ohmic resistance estimation was used as an indicator together with the dc voltage measurement to detect the fuel cell flooding condition. The three phase and single phase inverter ripples was emulated as an electronic load. From this paper experiment, it is exposed that the ohmic resistance and DC voltage can be used in a model based diagnostic algorithm to indirectly recognise the excessive water inside membrane of fuel cell stack. By increasing the input gas relative humidity over saturation valued, the fuel cell flooding was obtained.

2.3.2 Temperature effect on PEM Fuel Cell

PEM fuel cell is divided into two types, which is open cathode and closed cathode. The open cathode used fan that take air from the surrounding as a coolant for the fuel cell. Meanwhile, for closed cathode, the oxygen or compress air can be used as a coolant the temperature of the fuel cell. Other than that, closed cathode also used water cooling system or also known liquid coolant. Besides that, there is many other type of liquid coolant that can be used for closed cathode fuel cell. Refer to Kim J. in [13], three-dimensional simulation software was used to see the effect of coolant type of ethylene glycol (EG) and water on pressure and velocity distribution of proton exchange membrane fuel cell (PEMFC). Closed cathode of PEM fuel cell was used in this paper. Refer to Luis A.M. in [14] it stated that the fuel cell performance is influenced by the water content in the membrane; the conductivity of the membrane is proportional to its water content. The drying condition can occurs due to the effect of rise temperature that cause the amount of water removed more than water produced through the chemical reaction.

According to [15], the authors claimed about the effect temperature on the performance of PEM fuel cell stack on dead end mode. According to the paper, it states that the performance of the PEM fuel cell stack is depending on the operation and humidification temperature. The results of both temperatures are represented by the polarization curve. If the humidification temperature is increase, the water content in membrane will start flooding. The flooding will cause the fuel cell stack performance to deteriorate. The performance of the fuel cell can be improved if the operation and the humidification temperature are design perfectly. The water content, gas diffusivity, membrane conductivity, activation losses and current exchange activity are the problems to be tackling in PEM fuel cell.

Authors in [16] explained about the transient characteristics of PEM fuel cell based on fuel cell temperature. The performance of the PEM fuel cell is being observed by conducting the current distribution measurement system experiments and current distribution measurement gasket. For current distribution measurement system experiment, the cell temperature, reactant gas flow rate and back pressure are being controlled. That system is controlled by the application software of LabViewTM. The temperature that been analyse is at the range from 303 Kelvin to 363 Kelvin of the PEM fuel cell. Results prove that when fuel cell temperature is lower than or equal to humidification temperature, local current along the channel decreases, while local current increases when fuel cell temperature is higher 20K than humidification temperature and vice versa.

Strahl S. in [17] presented on the performance improvement by temperature control of an open cathode PEM fuel cell system. The combines of experimental analysis and theoretical studies of temperature effects on the performance of an open-cathode, selfhumidified PEM fuel cell system for the design of optimization strategies are done in the paper. This experiment is covered on the open cathode of 100W PEM fuel cell. Temperature is controlled via a cooling fan, which is a DC electronic motor with a voltage limit using the PI controller. In this paper, the author varied the temperature of the PEM fuel cell at the range 35ºC to 64ºC. The simulation results with the presented thermal and performance models under operation with the designed extreme seeking controller show promising results in terms of optimal temperature control.

2.3.3 Signal Processing Technique

There is a few type of signal analysis technique. In this experiment, periodogram is used as the signal analysis technique. According to [18], the authors claimed about the detection of heart blocks in electrocardiogram (ECG) signals by spectrum and time frequency analysis. The signal analysis techniques are represented by the periodogram power spectrum. The periodogram power spectrum technique is represented the distribution power signal over frequency. Analysis of ECG variation has been done using the signal analysis techniques. Periodogram power spectrum is combined by the computed MatLab software so that the pre-processing analysis can be done. Result shows that the differential of normal ECG signal and heart block subject can be differing by using periodogram technique.

Zhou Q. explained on the analysis of EEG data using an adaptive periodogram technique in [19]. The time-frequency analysis method for EEG data processing using a periodogram technique is used to estimate time duration of a coherent signal. Periodogram is locally maximized when it is computed over an interval that effectively contains the majority of a signal. The periodogram technique is applied to EEG data of two seizure events. The periodogram have a good frequency resolution and also reveals coherent structure that is lost in the short-time Fourier transform.

2.4 Summary of Review

The PEM fuel cell is known as the best fuel cell types among the other types of fuel cell [6]. However, the characteristics of PEM fuel cell can be affected by a few parameters such as humidity and temperature. Fouquet N. in [8] explained on the real time model based monitoring of a PEM fuel cell flooding and drying out using the evolution of resistances that inspired by Randles model. The model shows that the method is reliable monitoring system for the flooding and drying condition. Besides that, Chen D. in [9] discusses on the humidification system of fuel cell. The simulation and modelling of the membrane humidifier have been analyse and results show that excess of humidity will cause the water blockage of flow channel, porous electrode and backing layer of it. On top of that, the humidification control system on PEM fuel cell has been implemented by Chui J. in [10]. Integral PID software is used to control the humidifier system, hence, it prove that the dehydration of fuel cell membrane which can cause the reduction of battery performance and service life of fuel cell. Thus, humidification system should be installed at the PEM fuel cell. The effect of the cathode inlet humidity on the performance and uniformity of PEM fuel cells is being explained by Jeon D.H. in [11], where the method of varying the humidity of fuel cell to dry, 20%, 45%, 60%, 80%, and100% of humidity using the CFD simulation system. The dry cathode inlet humidity produces a voltage loss at high current density and non-uniform temperature distribution, however excessively of high cathode inlet humidity may result in non-uniformity problem caused by water flooding. The PEM fuel cell of flooding condition has been diagnosed by Dotelli, G. in [12]. The ohmic resistance estimation was used as an indicator together with the dc voltage measurement to detect the fuel cell flooding condition. It is proved that by increasing the input gas relative humidity over saturation valued, the fuel cell flooding was obtained.

Coolant system for fuel cell is closely related to the temperature of fuel cell. There are many type of coolant that can be used for open cathode and close cathode fuel cell in order to maintain the temperature. Kim J. in [13] observed the coolant type of ECG and liquid coolant on the effect of closed cathode PEM fuel cell. The three-dimensional simulation software has been used to observe it. Refer to Luis A.M. in [14] it stated that the fuel cell performance is influenced by the water content in the membrane and the conductivity of the membrane is proportional to its water content. Page M.P. [15] observed the performance of PEM fuel cell that being affected by temperature. Method of blocking the water and hydrogen from being purge is used. Results proved that the water content, gas diffusivity, membrane conductivity, activation losses and current exchange activity are the problems to be tackling in PEM fuel cell, so that the excess inadequate of water can be avoided. Characteristic of PEM fuel cell is analyse using the current distribution measurement experiment by Sun H. [16]. The temperature that been analyse is at the range from 303 Kelvin to 363 Kelvin. Results prove that when fuel cell temperature is lower than or equal to humidification temperature, local current along the channel decreases. In addition, the performance improvement by temperature control of an open cathode PEM fuel cell system is presented by Strahl. S in [17]. Temperature is controlled at 35ºC to 64ºC by PI controller. Result shows performance of fuel cell is improved by optimal temperature control.

Signal processing technique is used as one of method in analysing the performance of PEM fuel cell. Periodogram is represented the distribution power signal over frequency [18]. Saad N.M. in [18] analyse the ECG using periodogram and combined it with MatLab, meanwhile, Zhou Q. in [19] analyse the EEG using periodogram. Therefore the results show that, periodogram signal can differentiate the normal or abnormal condition.

2.5 Summary

For this chapter, there are four sections that have been discussed. Section 2.2 explained more on the theoretical background of fuel cell which includes the types of the fuel cell. They are molten carbonate fuel cell, proton exchange membrane fuel cell and the phosphoric acid fuel cell. Furthermore, Section 2.3 discussed more the review of previous paper works that is related to this project. Related previous works covered on the temperature effect, humidity effect and signal analysis technique. Lastly, the summary and discussion of the review have been included in Section 2.4.

CHAPTER 3

DESIGN METHODOLOGY

3.1 Introduction

Chapter 3 explains the design methodology in which is divided into seven sections including introductory and summary of this chapter. Section 3.2 will discuss on the project flowchart of this project. Next, Section 3.3 will focus on the experimental set up for humidity and temperature experiment in this project. Besides that, Section 3.4 explains the testing and measurement of humidity experiment. In addition, testing and measurement of temperature experiment will be discussed in Section 3.5. Lastly, the data analysis of the project will be explained more in Section 3.6.

3.2 Project Flowchart

The project methodology of this project is representing in term of a flowchart as in Figure 3.1. This project will start with the literature review where all the information and previous works that related to this project will be studied. Next, the experimental set up of humidity and temperature will be done. Testing and measurement of both experiments will be conducted and the data obtained from the testing and measurement will be analysed. Data analysis will be divided into two parts which are performance characteristics analysis and the signal processing analysis. In addition, the report writing will be continued as soon as the data analysis is completed.

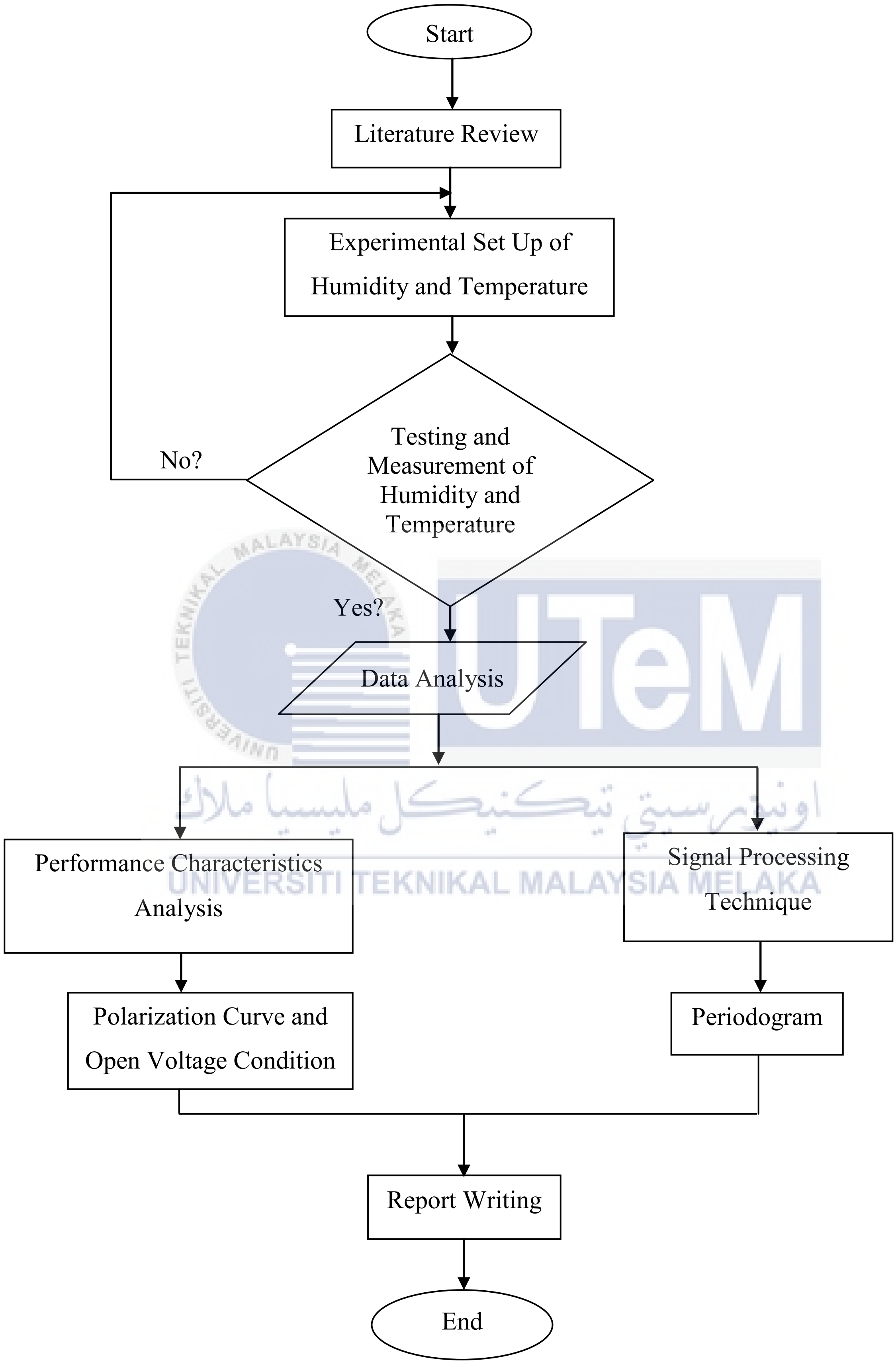


Figure 3.1: The flowchart of the methodology

i. Literature Review on PEM Fuel Cell

The literature review on the PEM fuel cell is an important stage of this project. The basic principles of the PEM fuel cell will be review in this stage. The concept of thermodynamic on fuel cell is being discussed in this part. Besides that, the type of the fuel cell will be discussed further in the literature reviews. In addition, the review will be covered on the works that been done previously on the effect of humidity and temperature towards the PEM fuel cell. Besides that, the signal processing technique of periodogram is discussed in this part.

ii. Experimental Set Up of Humidity and Temperature

The experimental set up is covered on how the project will be conducted before testing and measurement will be done. There are two experimental set up need to be set up which is the humidity experiment and temperature experiment. For humidity experiment, there are a few equipment needs which are the set of PEM fuel cell, oscilloscope, DC load, DC supply, humidifier, humidity sensor and cooler fan. Meanwhile, for the temperature experiment, hot gun and humidifier will be used to run the experiment.

iii. Testing and Measurement of Humidity and Temperature

Humidity and temperature is tested on the PEM fuel cell in order to investigate the effect of both parameters towards the performance of PEM fuel cell. In addition, the measurement of both parameters is taken using the oscilloscope and DC load. At the DC load, the current will be varied, and the data are captured by the oscilloscope.

iv. Data Analysis

Data analysis is divided into two parts. First part is the performance characteristics analysis and the second part is the signal analysis technique. The polarization curve is obtained through the performance characteristics analysis. Meanwhile the signal analysis technique can be obtained using periodogram analysis. The results captured by the oscilloscope will be documented in a table through the Microsoft Excel and the periodogram analysis will be obtained by simulation from the MatLab software.

3.3 Experimental Set Up of 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 cooling fan act as the cooler system is supplied by DC power supply that supplies 11.6V to 13V to the cooler. The PEM fuel cell is directly attached with the controller to control the purging and purge valve to release the water and hydrogen waste from the stack. Table 3.1 shows the specification of the H-2000 PEM fuel cell used in this experiment.

Table 3.1: Specification of the H-2000 of PEM Fuel Cell [20]

Number of cells	48 cells
Rated power	2000W
Performance	28.8 V @70A
Input valve voltage	12V
Cooling fan voltage	12V
Purging valve voltage	12V
Efficiency of stack	40% @ 28.8V
Maximum stack temperature	65^{o}C
Reactants	Hydrogen and Air

In this project, the experimental set up systems will be divided into two parts which are humidity and temperature. These systems will be connected to the fuel cell system to test the effect of both parameters towards the fuel cell system. The fuel cell system consists of a few components which are fuel cell stack, fuel cell controller, purge valve, DC supply, DC load and oscilloscope.

3.4 Testing and Measurement of Humidity

Figure 3.2 shows the experimental set up for the humidity experiment. The components used in this experiment are H_2 pressure regulator, distilled water tank, H_2 box, humidity sensor, data logger, and the PEM fuel cell system.

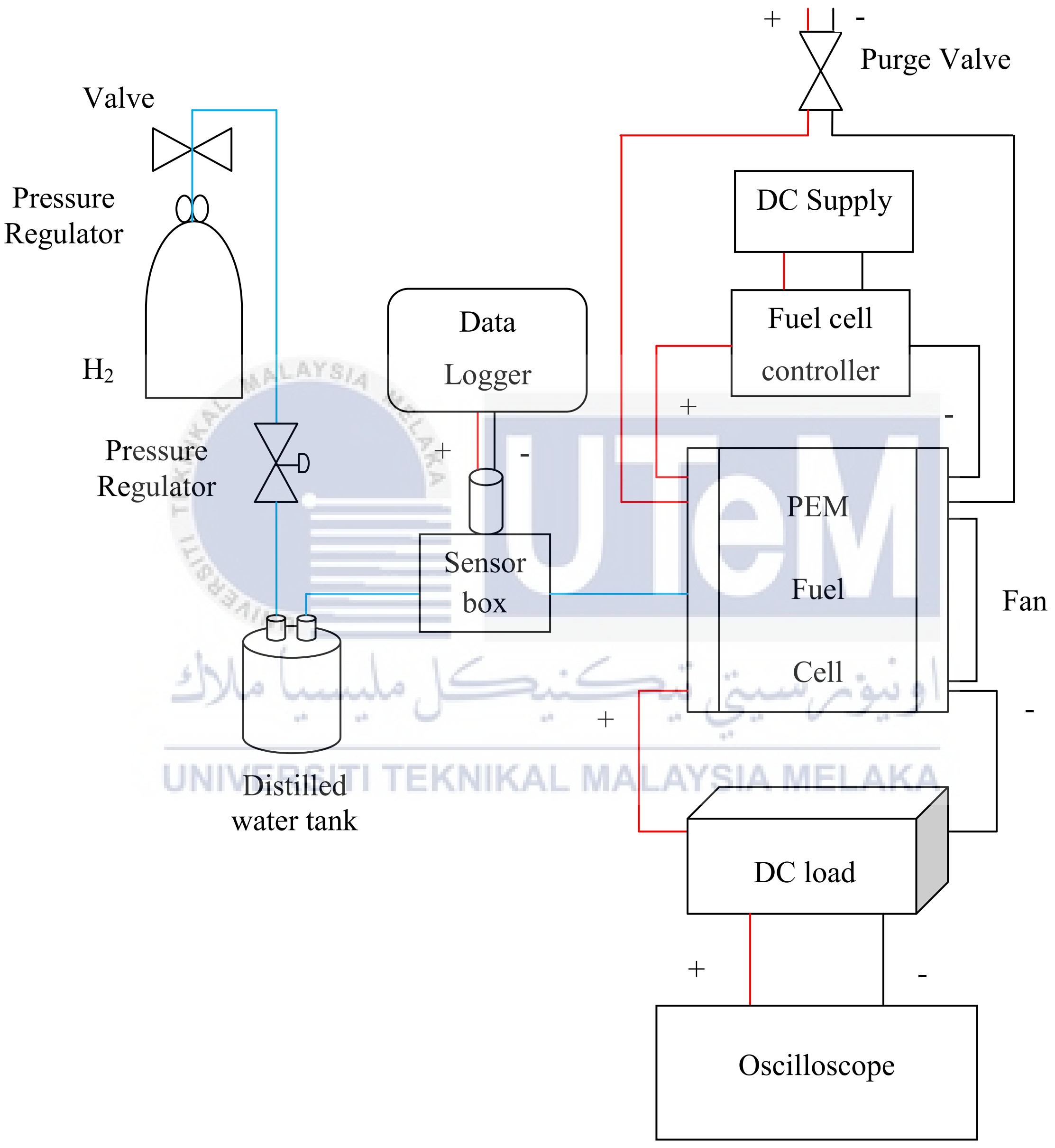


Figure 3.2: Schematic drawing for the humidity experiment

The humidity will be varied to 0% and 80% of humidity for current from 0A up to 36A for each of humidity percentage. The humidity will be limited up to 80% of humidity to prevent from the excess of water condition. Based on the review from the previous works, too much of humidity can lead to the flooding condition at the cathode side of the fuel cell [12]. Flooding condition can cause the performance of the fuel cell to decrease and thus, it can damage it. Figure 3.3 shows the testing and measurement for humidity experiment that has been installed.

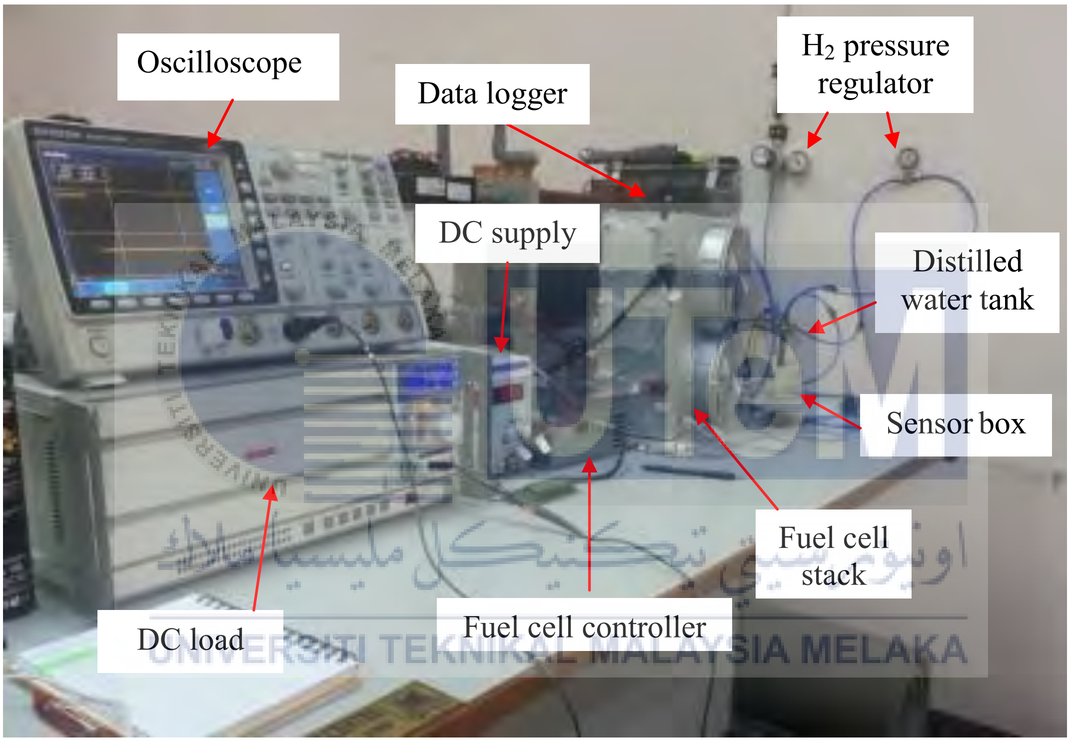


Figure 3.3: Testing and measurement for humidity experiment

For this experiment, the hydrogen is flowing from the hydrogen tank to the pressure regulator. Pressure regulator is used to regulate hydrogen pressure entering the system. The pressure of the hydrogen is regulated at 0.2 Bar. Hydrogen will then flow through the distilled water tank that shows in Figure 3.4.

Figure 3.4: Connection of humidity system

When hydrogen enters the distilled water tank, the humidity will produced inside it. Next, the humidity of the distilled water will flow through the sensor box. Humidity sensor is plug in into the sensor box so that it can sense the humidity percentage. The humidity value that detected by the humidity sensor will be sent to the data logger. Therefore, all the data sent by the sensor will be recorded into the data logger. Thus, from the data logger, the percentage of humidity can be monitor and controlled. Figure 3.5 shows the data logger used for this experiment. Data logger is specifically shows the percentage of the ambient temperature and the percentage of the hydrogen humidity inside the distilled water tank.

Figure 3.5: The data logger that connected to the humidity sensor

After that, the hydrogen will flow to the fuel cell stack and then it will flow through the fuel cell controller. The fuel cell controller received the voltage supply from the DC supply. The DC supply is regulated at 12.6V to keep the fuel cell controller running. Fuel cell controller will control the purging of hydrogen and water from the fuel cell stack. For this experiment, the load current will be varied by the DC load. Oscilloscope will captured all the signal of the fuel cell and also recorded all the reading of voltage of the fuel cell.

3.5 Testing and Measurement of Temperature

Figure 3.6 illustrate on the experimental set up for temperature experiment. H_2 pressure regulator, hot gun, humidifier, fan, fuel cell stack, fuel cell controller, purge valve, DC supply, DC load, and oscilloscope are the equipments used to run the temperature experiment.

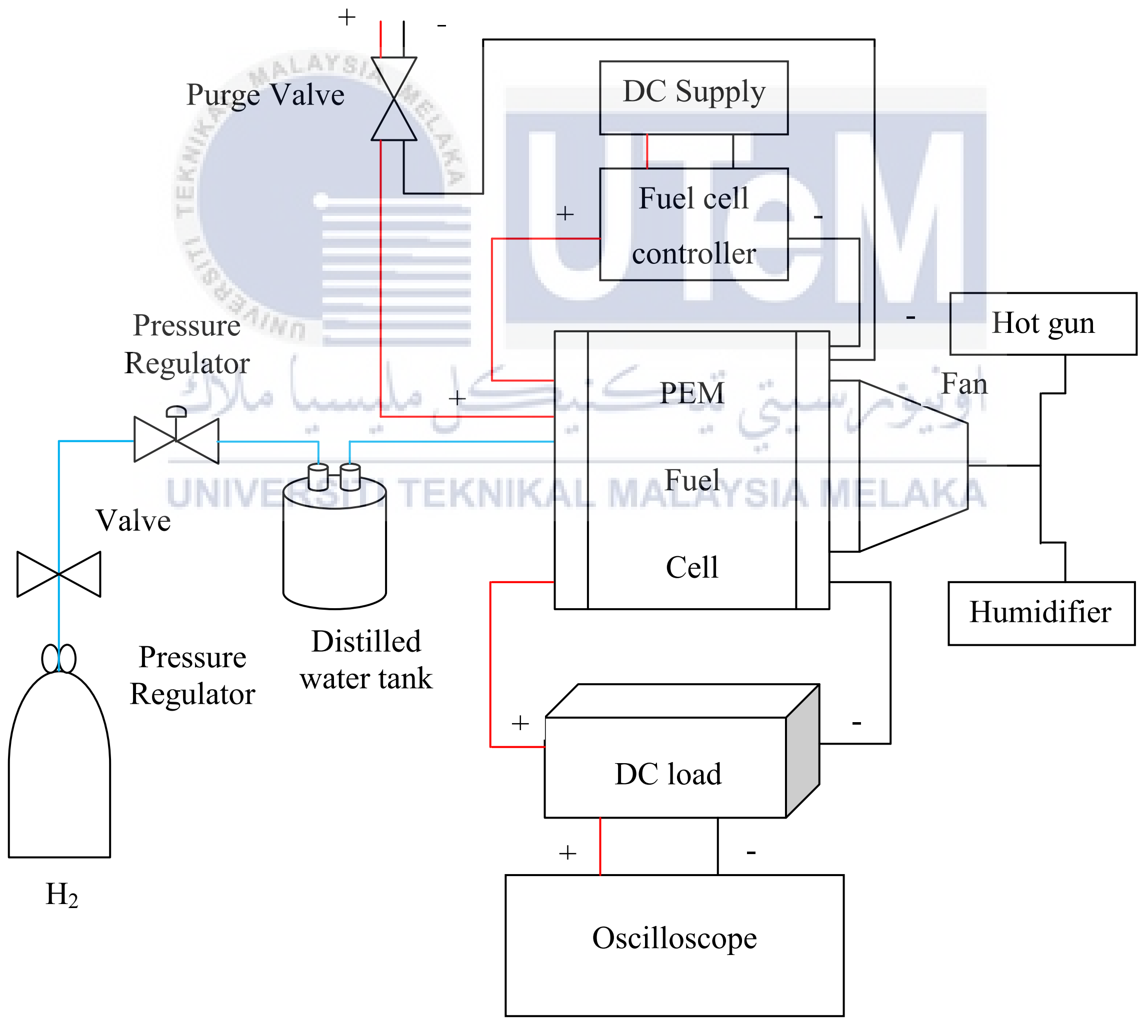


Figure 3.6: Schematic drawing for temperature experiment

Hot gun will be used to increase the temperature, while the humidifier is used to cool down the temperature. These two equipments are used to vary the temperature in order to achieve the required temperature values. The hydrogen will flow to the fuel cell stack through the fan. Fan is used to flow the hydrogen into the fuel cell stack. Temperatures are recorded at the screen panel at the fuel cell controller. In order to heat up the temperature, hot gun will be switch on. Temperature above 25ºC is considered as high temperature, because the nominal temperature is at 25ºC. Temperature below the nominal value is achieved by switching on the humidifier until the desired temperature is obtained. Figure 3.7 show the testing and measurement for the temperature experiment that has been installed.

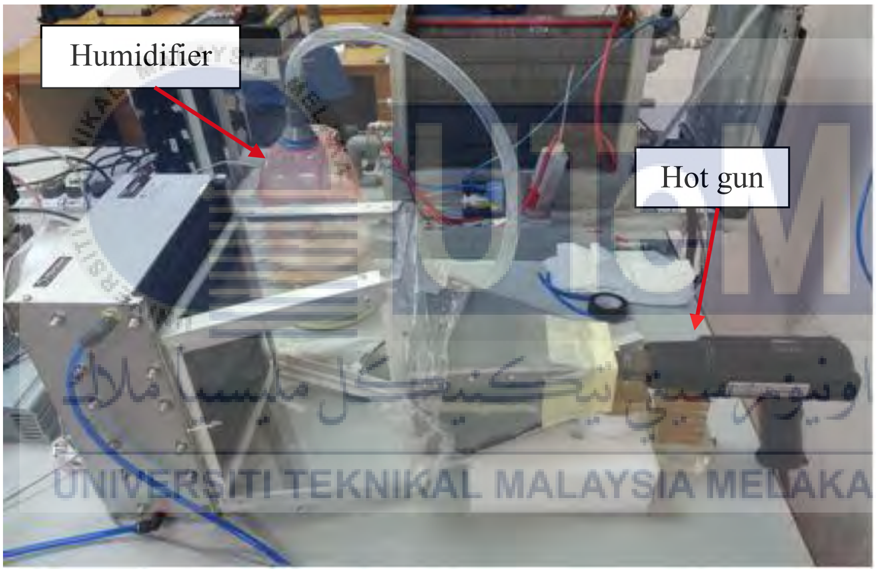


Figure 3.7: Testing and measurement for the temperature experiment

The humidifier speeds can the control by adjusting the knob and same goes to the hot gun. The hydrogen with certain temperature will flow through the fuel cell system. The testing and results will be obtained by the fuel cell system. The results are captured and recorded by the oscilloscope.

The temperature will be varied to 20ºC, 25ºC, 30ºC, 35ºC and 40ºC. Therefore, for each temperature, the current will be varied to 0A, 3A, 6A, 9A, 12A, 15A and 18 A using the DC load. Figure 3.8 shows the temperature Liquid Crystal Display (LCD) display that connected to fuel cell controller and displayed the temperature of the fuel cell. As a precaution step, the maximum temperature is limited up to 40 ºC and load current maximum at 18 A is chosen. This is due to the increasing of the load current will increase the temperature, so if temperature is too high, the performance of the fuel cell will drop. Furthermore, high temperature could lead to the drying condition on the cathode side. If the membrane is drying, the chemical reaction between hydrogen and oxygen will not occur. Drying could also cause the fuel cell to be damaged.

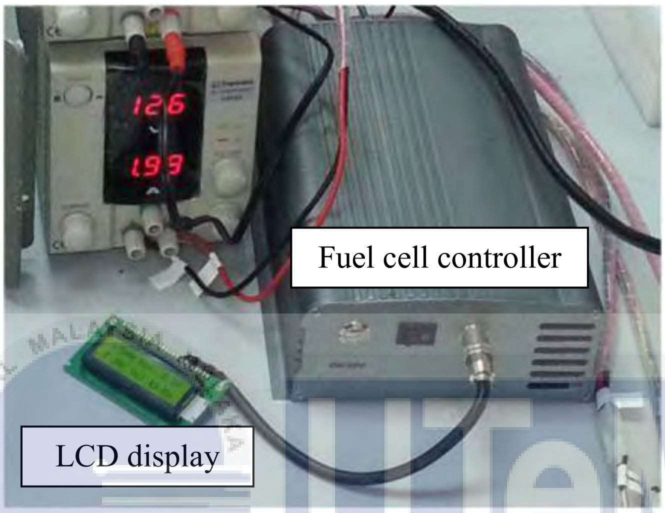


Figure 3.8: LCD display which connected to fuel cell controller

3.6 Data Analysis

Data analysis is divided into two categories, which is performance characteristic analysis and signal processing techniques. Both categories are used to analyse the data obtained from the testing and measurement of the experiment.

3.6.1 Performance Characteristics Analysis

Through the performance characteristics analysis, the polarization curve can be obtained. The data that have been collected from the testing and measurement process are sorted into the table as presented in Chapter 4, so that the changes of the data can be analysed. From that, polarization curve of IV curve and IP curve are plotted.

3.6.2 Signal Processing Technique (Periodogram)

Periodogram can be obtained by stimulate the specific coding using the MatLab simulation software. The coding will be consists the part of clearing, sampling frequency, resampling frequency, periodogram equation, plotting of the figure of its, equation of root means square voltage (V_{RMS}), direct current voltage (V_{DC}) and alternating current voltage (V_{AC}) and lastly the figure from the equation of its. Periodogram can be defined in Equation 3.1.

$$S_v(f) = \left| \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} v(t) e^{-j2\pi f t} dt \right|^2 \quad (3.1)$$

$S_v(f)$ can be defined as periodogram in the frequency domain and V(t) is the voltage waveform. Thus, the V_{RMS} can be calculated as in Equation 3.2.

$$V_{rms}(t) = \sqrt{\int_{-\frac{fmax}{2}}^{\frac{fmax}{2}} S_v(f) df} \quad (3.2)$$

Where $f_{max}/2$ is the maximum frequency of interest and $S_v(f)$ is periodogram. (V_{DC}) can be defined as in Equation 3.3.

$$V_{DC}(t) = \sqrt{\int_{-\frac{\Delta f}{2}}^{\frac{\Delta f}{2}} S_v(f) df} \quad (3.3)$$

Where Δf/2 is define as power system frequency. Meanwhile, Equation 3.4 shows the (V_{AC}).

$$V_{AC}(t) = \sqrt{V_{rms}(t)^2 - V_{DC}(t)^2} \quad (3.4)$$

Figure 3.9 shows the coding of the periodogram based on the Equation 3.2 to Equation 3.24.

```
clear all;
clc;
close all;

Fs0=500;
Fs=10;


load('h801516.mat');

%-------------------------------------------------------resample graph--
------------------%%

Nsample=length(h801516);
x=h801516(1:Nsample);

time1=([0:1/Fs:(Nsample-1)/Fs]);
%-------------------------------------------------------periodogram---%%
xb=h801516;
N=length(xb);

xa=smooth(xb,100);

x0=resample(xa,Fs,Fs0);

N0=length(x0);
x1=x0(10:N0-10);
Na=length(x1);


% Y1=fft(x1);
Y1=fft(xb);
[Ny,Nx]=size(Y1)
Y1=Y1.*conj(Y1)/Ny/Ny;

% freq=[0:Fs0/N:(Ny-1)*Fs/Ny];
freq=[0:Fs/Ny:(Ny-1)*Fs/Ny];
time=([0:1/Fs:(Na-1)/Fs]);


figure(1);plot(xa);grid;ylabel('Voltage
(V)','Fontsize',24);xlabel('Number of sample','Fontsize',24);title('Fuel
Cell','Fontsize',24); .....................%rough signal.........
% figure(2);plot(x1);grid;ylabel('Voltage
(V)','Fontsize',24);xlabel('Time(sec)','Fontsize',24);title('Fuel
Cell','Fontsize',24); ..........................%resample signal........
%
figure(3);plot(Y1);grid;ylabel('Amplitude','Fontsize',24);xlabel('Frequen
cy(Hz)','Fontsize',24);title('Periodogram','Fontsize',24);
........................%periodogram not over freq.....

figure(4);plot(time,x1);grid;ylabel('Voltage
(V)','Fontsize',24);xlabel('Time(sec)','Fontsize',24);title('Fuel
Cell','Fontsize',24);
figure(5);plot(freq,Y1);grid;ylabel('Amplitude','Fontsize',24);xlabel('Fr
equency(Hz)','Fontsize',24);title('Periodogram','Fontsize',24);


    y(1:Ny)=Y1(1:Ny);
    % looking for end point for DC
```

```
    m=1;
    for k=2:Ny-2
        if (y(k)<=y(k+1))
            a(m)=k;
            m=m+1;
        end
    end
    Nend=a(1);
      % looking for start point for DC
     m=1;
    for k=1:Ny-2
        if (y(Ny-k)<=y(Ny-k-1))
            a(m)=Ny-k;
            m=m+1;
        end

    Nstart=a(1);

    Vdc=(sum(Y1(Nstart:Ny))+sum(Y1(1:Nend)))^0.5;
    Vrms=sum(Y1(1:Ny))^0.5;
    Vac=(Vrms^2-Vdc^2)^0.5;

%      Vdc=(sum(y(Nstart:Ny))+sum(y(1:Nend)))^0.5;
%      Vrms=sum(Y1(1:Ny))^0.5;
%      Vac=(Vrms^2-Vdc^2)^0.5;

%
% time2=[Ny/2/Fs:1/Fs:(Nx-Ny/2)/Fs];
%  figure(5);plot(time2,Vrms(Ny/2:Nx-
Ny/2));grid;ylabel('Voltage(V)','fontsize',10);xlabel('time(h)','fontsize
',10);title('Instantaneous RMS Voltage,Vrms(t)','fontsize',10);
%  figure(6);plot(time2,Vdc(Ny/2:Nx-
Ny/2));grid;ylabel('Voltage(V)','fontsize',10);xlabel('time(h)','fontsize
',10);title('Instantaneous DC Voltage,VDC(t)','fontsize',10);
%  figure(7);plot(time2,Vac(Ny/2:Nx-
Ny/2));grid;ylabel('Voltage(V)','fontsize',10);xlabel('time(h)','fontsize
',10); title('Instantaneous AC Voltage,VAC(t)','fontsize',10);
%
figure(6);plot(time,Vrms);grid;ylabel('Voltage(V)','fontsize',10);xlabel(
'time(sec)','fontsize',10);title('Instantaneous RMS
Voltage,Vrms(t)','fontsize',10);
%
figure(7);plot(time,Vdc);grid;ylabel('Voltage(V)','fontsize',10);xlabel('
time(sec)','fontsize',10);title('Instantaneous DC
Voltage,VDC(t)','fontsize',10);
%
figure(8);plot(time,Vac);grid;ylabel('Voltage(V)','fontsize',10);xlabel('
time(sec)','fontsize',10); title('Instantaneous AC
Voltage,VAC(t)','fontsize',10);

VRMS=Vrms
VDC=Vdc
VAC=Vac

% VRMS=Vrms(Ny/2)
% VDC=Vdc(Ny/2)
% VAC=Vac(Ny/2)
```

Figure 3.9: The coding of the periodogram

3.7 Summary

For this chapter, there are five sections that have been discussed. Section 3.2 has discussed on the project flowchart for this project. However, Section 3.3 focused on the experimental set up for humidity and temperature experiment in this project. Besides that, Section 3.4 explained on the testing and measurement of humidity experiment. On the other hand, testing and measurement of temperature experiment has been discussed in Section 3.5. Lastly, the data analysis of the project has been elaborate more in Section 3.6.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

Chapter 4 is about the results and discussion in which is divided into four sections including introductory and summary of this chapter. Section 4.2 will discuss on the results obtained by the DC load bank and analysis of this experiment. On the other hand, Section 4.3 will focus on the results using the periodogram technique and analysis of it.

4.2 Results of Performance Characteristics Analysis

Results from the performance characteristic analysis are divided into two parts which is humidity and temperature. The results are represents in polarization curve and open voltage condition. The humidity part will be split into two which 0% humidity and 80% humidity. However, for temperature, it consists of temperature with load result and results in no load condition.

4.2.1 Results of Humidity (Polarization Curve and Open Voltage Condition)

Results for humidity effect towards the performance of PEM fuel cell is represented by the polarization curve of current versus voltage (IV) and current versus power (IP), and by the open voltage condition for humidity. Table 4.1 shows the results voltage and power against current for 0% humidity and Table 4.2 shows voltage and power against current for 80% humidity. According to these results, it shows that the difference between experiment 1 (EXP1) and experiment 2 (EXP2) is mostly about 0.1V. Hence, it is proved that the results are valid because the difference is too small. From these voltages from both experiments, the average voltage is calculated to obtain the mean results from the experiment. However, the results from the EXP1 are chosen to calculate the values of the power of this experiment. The results of voltage and power from both tables are used to build the polarization curve and open voltage condition.

Table 4.1: Results for voltage and power against current (0% humidity)

Current (A)	0% Humidity				
	EXP 1 (Voltage)	EXP2 (Voltage)	Voltage Different (V)	AVG (Voltage)	Power (W)
0	43.70	43.80	0.1V	43.75	0.00
1	38.90	39.00	0.1V	38.95	38.95
2	37.90	37.80	0.1V	37.85	75.70
3	37.40	37.40	0.1V	37.40	112.20
4	37.00	36.90	0.1V	36.95	147.80
5	36.50	36.60	0.1V	36.55	182.75
6	36.30	36.40	0.1V	36.35	218.10
7	36.10	36.10	0.1V	36.10	252.70
8	35.80	35.80	0.1V	35.80	286.40
9	35.60	35.60	0.1V	35.60	320.40
10	35.30	35.40	0.1V	35.35	353.50
11	35.00	35.10	0.1V	35.05	385.55
12	34.70	34.80	0.1V	34.75	417.00
13	34.50	34.50	0.1V	34.50	448.50
14	34.30	34.30	0.1V	34.30	480.20
15	33.90	34.00	0.1V	33.95	509.25
16	33.80	33.80	0.1V	33.80	540.80
17	33.50	33.60	0.1V	33.55	570.35
18	33.30	33.30	0.1V	33.30	599.40
19	33.10	33.10	0.1V	33.10	628.90
20	32.90	32.90	0.1V	32.90	658.00
21	32.60	32.60	0.1V	32.60	684.60
22	32.30	32.30	0.1V	32.30	710.60
23	32.10	32.10	0.1V	32.10	738.30
24	31.80	31.80	0.1V	31.80	763.20
25	31.70	31.70	0.1V	31.70	792.50
26	31.50	31.40	0.1V	31.45	817.70
27	31.30	31.30	0.1V	31.30	845.10
28	31.20	31.20	0.1V	31.20	873.60
29	31.00	31.00	0.1V	31.00	899.00
30	30.90	30.90	0.1V	30.90	927.00
31	30.70	30.70	0.1V	30.70	951.70
32	30.60	30.60	0.1V	30.60	979.20

33	30.30	30.40	0.1V	30.35	1001.55
34	30.20	30.20	0.1V	30.20	1026.80
35	30.10	30.00	0.1V	30.05	1051.75
36	29.90	29.90	0.1V	29.90	1076.40

Table 4.2: Results for voltage and power against current (80% humidity)

Current (A)	80% Humidity				
	EXP 1 (Voltage)	EXP2 (Voltage)	Voltage Different (V)	AVG (Voltage)	Power (W)
0	46.30	46.00	0.3V	46.15	0.00
1	41.50	41.40	0.1V	41.45	41.45
2	40.10	40.10	0.0V	40.10	80.20
3	39.10	39.20	0.1V	39.15	117.45
4	38.00	37.90	0.1V	37.95	151.80
5	37.60	37.40	0.2V	37.50	187.50
6	37.00	37.00	0.0V	37.00	222.00
7	36.70	36.60	0.1V	36.65	256.55
8	36.50	36.50	0.0V	36.50	292.00
9	36.40	36.20	0.2V	36.30	326.70
10	36.00	35.90	0.1V	35.95	359.50
11	35.70	35.70	0.0V	35.70	392.70
12	35.30	35.40	0.1V	35.35	424.20
13	35.10	35.20	0.1V	35.15	456.95
14	34.90	35.00	0.1V	34.95	489.30
15	34.80	34.70	0.1V	34.75	521.25
16	34.60	34.40	0.1V	34.50	552.00
17	34.20	34.30	0.1V	34.25	582.25
18	34.00	34.10	0.1V	34.05	612.90
19	33.80	33.90	0.1V	33.85	643.15
20	33.60	33.70	0.1V	33.65	673.00
21	33.60	33.50	0.1V	33.55	704.55
22	33.40	33.20	0.2V	33.30	732.60
23	33.10	33.20	0.1V	33.15	762.45
24	33.00	32.90	0.1V	32.95	790.80
25	32.80	32.90	0.1V	32.85	821.25
26	32.60	32.70	0.1V	32.65	848.90
27	32.50	32.60	0.1V	32.55	878.85
28	32.30	32.40	0.1V	32.35	905.80
29	32.30	32.20	0.1V	32.25	935.25
30	31.90	32.00	0.1V	31.95	958.50
31	31.80	31.70	0.1V	31.75	984.25

32	31.60	31.60	0.0V	31.60	1011.20
33	31.50	31.50	0.0V	31.50	1039.50
34	31.20	31.30	0.1V	31.25	1062.50
35	31.10	31.00	0.1V	31.05	1086.75
36	31.00	30.80	0.2V	30.90	1112.40

The polarization curve is illustrated Figure 4.1. It shows the relationship of the voltage and current that measured on the 2000W of PEM fuel cell from Horizon Fuel Cell Technologies under 0% of humidity and 80% of humidity. The values of voltage are taken from Table 4.1 and Table 4.2 to build the polarization curve of IV. It shows that as the load current increase in the fuel cell, the voltage of the fuel cell is decreasing. This is due to the humidity range of the PEM fuel cell. As the load current increase, the wetting content of the membrane to do the chemical reaction is decreased, so the voltage generate is decreased. The performance of the fuel cell is depending on the voltage of the fuel cell. The curve reached the highest peak at the zero load current condition; this is at 43.7V for 0% of humidity and 46.3V for 80% of humidity. The difference between these results is about 5.95%. However, at load current 36A, the IV curve for humidity reached its lowest peak condition. Lowest peak for 0% humidity is 29.9V and for 80% humidity is 31.0V. The difference between these results is about 3.68%. Therefore, the difference voltage of highest peak is greater than the lowest peak, however, it still proved that by increasing the humidity, the voltage can be increase, and the performance of PEM fuel cell can be improved.

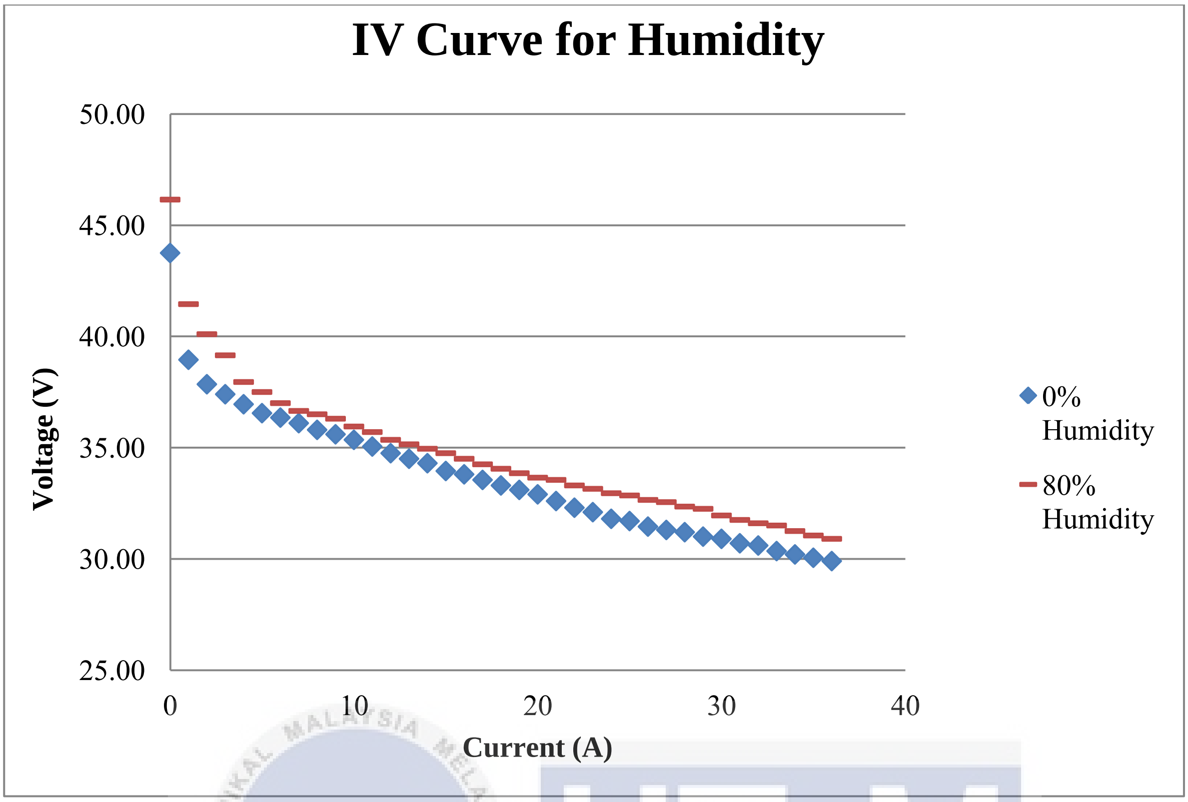


Figure 4.1: Polarization curve of IV for humidity

On the other hand, Figure 4.2 shows the polarization curve of IP for humidity. The values of the power are taken from the Table 4.1 for 0% humidity and from Table 4.2 for 80% humidity. According to the figure, the powers of the PEM fuel cell for the humidity experiment show an increment as the load currents are increased. The curve reached the highest peak at the load current of 36A condition; this is at 1076.4W for 0% of humidity and 1112.4W for 80% of humidity. The difference between these results is about 3.34%. In addition, at load current 1A, the IP curve for humidity reached its lowest peak condition. Lowest peak for 0% humidity is 38.95W and for 80% humidity is 41.45W. The difference between these results is about 6.42%. Therefore, the difference power of lowest peak is greater than the lowest peak, however, it still proved that by increasing the humidity, the power can be increase, and the performance of PEM fuel cell can be improved.

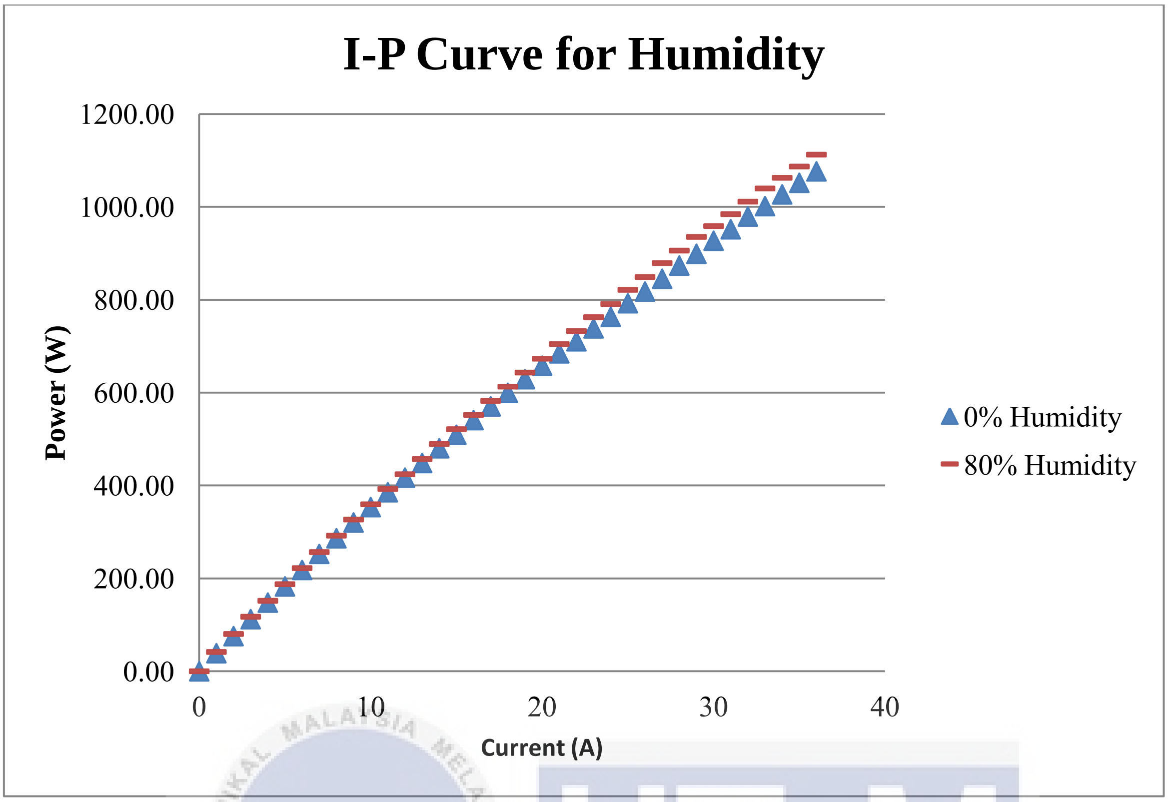


Figure 4.2: Polarization curve of IP for humidity

Figure 4.3 shows the graph effect of humidity towards the performance of PEM fuel cell at open voltage condition. The values of voltage at 0A from the Table 4.1 and Table 4.2 are taken to produce the open voltage condition for humidity. Open voltage condition curve is the result of the humidity at an ideal condition which is at 0A of load current. All the losses can be produced inside the PEM fuel cell is neglected. The graph shows that the voltage of fuel cell will increased when the humidity is increased. The voltage is at 43.7V during the 0% humidity and at 46.3V during 80% humidity of 2000W PEM fuel cell. Therefore, the performance of the PEM fuel cell will increase to 5.95% when the humidity increased from 0% to 80% humidity. Furthermore, the protons can only conduct at the wet membrane to do the chemical reaction. Therefore, when the humidity percentage is increased, the water inside the membrane of PEM fuel cell is increased so the voltage that can be generated will be increased.

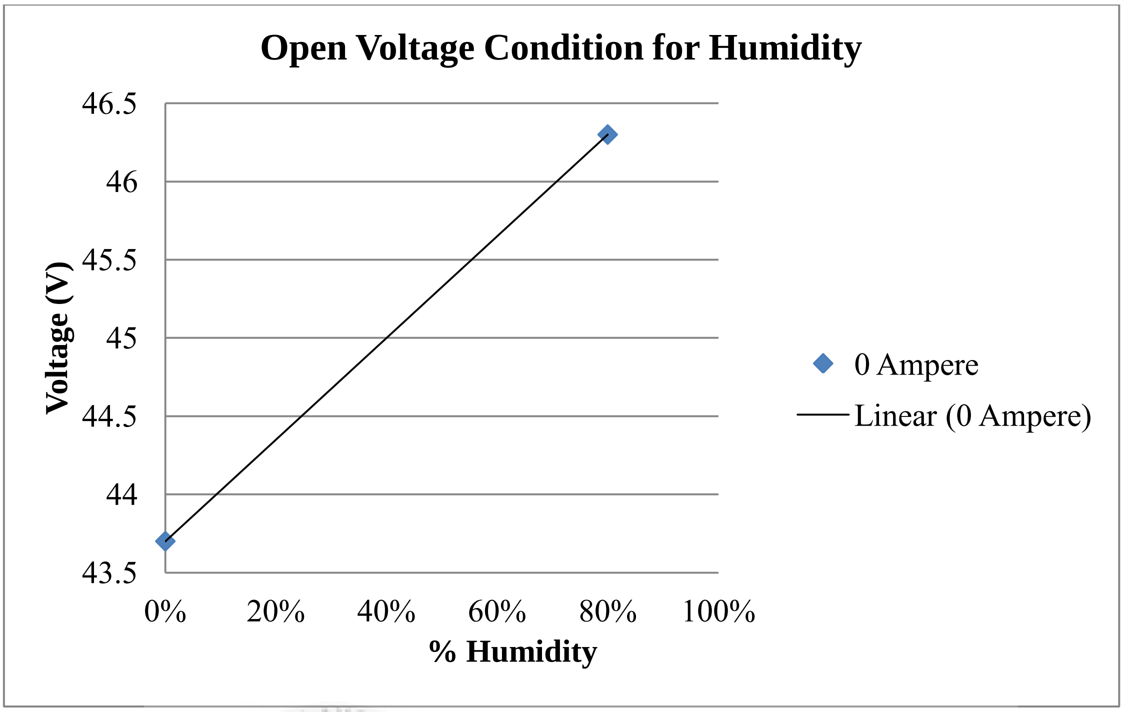


Figure 4.3: Open voltage condition for humidity

4.2.2 Results of Temperature (Polarization Curve and Open Voltage Condition)

Polarization curve is being used to represent the results for the temperature effect towards the performance of PEM fuel cell. Table 4.3 shows the results voltage and power against current for temperature of 20ºC, 25ºC, 30ºC, 35ºC and 40ºC. According to these results, it shows that the difference between EXP1 and EXP2 is about 0.1V. Hence, it is proved that the results are valid because the difference is too small. From these voltages from both experiments, the average voltage is calculated to obtain the mean results from the experiment. However, the results from the EXP1 are chosen to calculate the values of the power of this experiment. The results of voltage and power from both tables are used to build the polarization curve and open voltage condition. From this table, the polarization curve for the temperature is created in Figure 4.4.

Table 4.3: Results of voltage and power for temperature recorded by the DC load

Temperature		Current (I)						
		0	3	6	9	12	15	18
20 ºC	Exp 1 (V)	45.10	37.80	36.60	35.00	34.60	34.10	32.60
	Exp 2 (V)	45.20	37.70	36.70	35.10	34.70	34.20	32.70
	Exp 1 - Exp 2 (V)	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	Average (V)	45.15	37.75	36.65	35.05	34.65	34.15	32.65
	Power (W)	0.00	113.25	219.90	315.45	415.80	512.25	587.70
25 ºC	Exp 1 (V)	45.30	37.80	36.70	35.30	34.80	34.30	33.00
	Exp 2 (V)	45.40	37.90	36.90	35.40	34.90	34.30	33.00
	Exp 1 - Exp 2 (V)	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	Average (V)	45.35	37.85	36.80	35.35	34.85	34.30	33.00
	Power (W)	0.00	113.55	220.80	318.15	418.20	514.50	594.00
30 ºC	Exp 1 (V)	45.50	38.00	36.90	35.40	34.80	34.30	33.40
	Exp 2 (V)	45.50	37.90	36.80	35.40	34.90	34.20	33.30
	Exp 1 - Exp 2 (V)	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	Average (V)	45.50	37.95	36.85	35.40	34.85	34.25	33.35
	Power (W)	0.00	113.85	221.10	318.60	418.20	513.75	600.30
35 ºC	Exp 1 (V)	45.70	38.20	37.00	35.50	35.00	34.30	33.60
	Exp 2 (V)	45.80	38.10	37.00	35.40	35.10	34.40	33.70
	Exp 1 - Exp 2 (V)	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	Average (V)	45.75	38.15	37.00	35.45	35.05	34.35	33.65
	Power (W)	0.00	114.45	222.00	319.05	420.60	515.25	605.70
40 ºC	Exp 1 (V)	45.90	39.00	37.10	35.60	35.30	34.50	33.90
	Exp 2 (V)	45.80	43.00	37.10	35.70	35.30	34.60	34.00
	Exp 1 - Exp 2 (V)	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	Average (V)	45.85	41.00	37.10	35.65	35.30	34.55	33.95
	Power (W)	0.00	123.00	222.60	320.85	423.60	518.25	611.10

Figure 4.4 shows the polarization curve of current against voltage for temperature. The results consists of five temperature that have been varied which is 20ºC, 25ºC, 30ºC, 35ºC and 40ºC for load currents 0A, 3A, 6A, 9A, 12A, 15A and 18A. The graph indicates that the voltages are decreased when the load current is increased. However, the values of the voltage increases as the temperature are increasing. In addition, the curve reached the highest peak at the zero load current condition; this is at and 45.1V for 20ºC , 45.3V for 25ºC, 45.5V for 30ºC, 45.7V for 35ºC and 45.9V for 40ºC. The difference between these results is about 0.2V. However, at load current 18A, the IV curve for humidity reached its lowest peak condition. Lowest peak for temperature 32.6V for 20ºC , 33.0V for 25ºC, 33.4V for 30ºC, 33.6V for 35ºC and 33.9V for 40ºC. Therefore, the average difference of these voltages is 0.325V for each temperature.

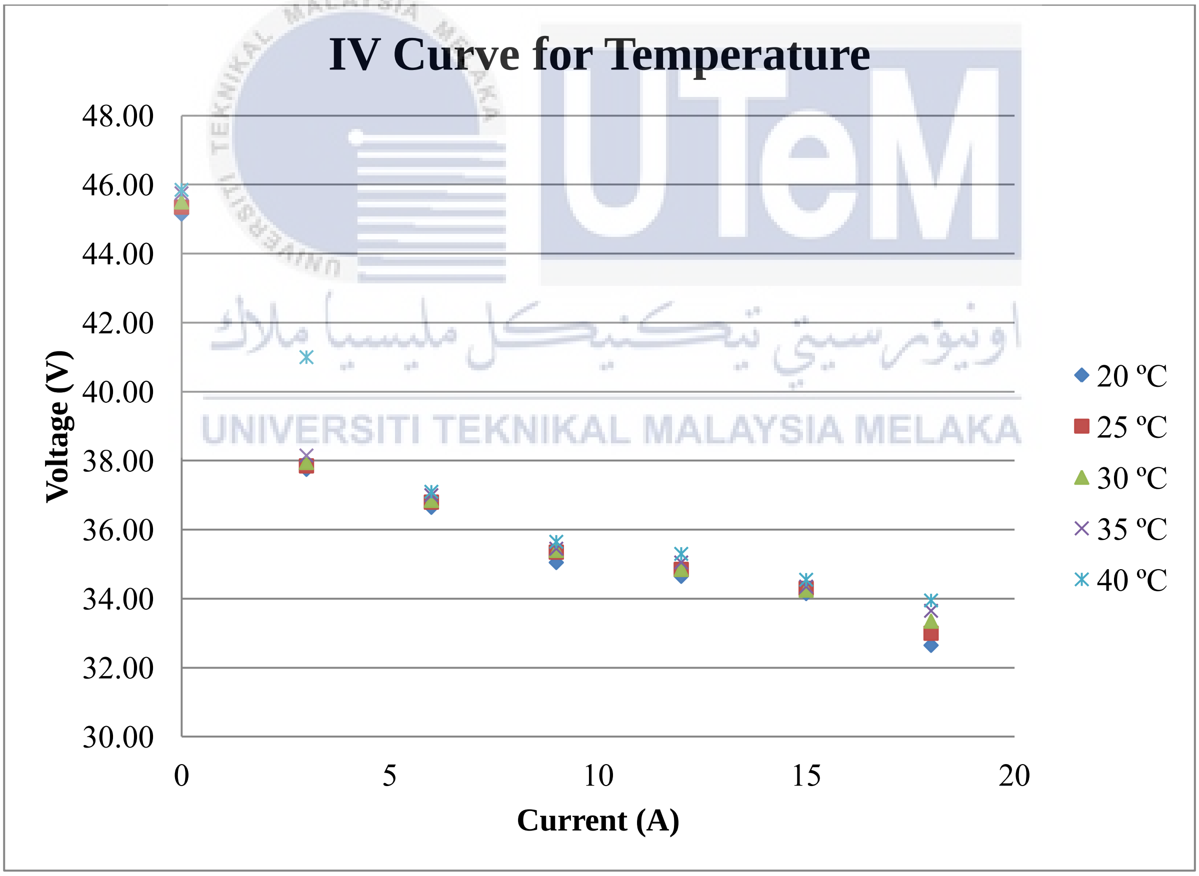


Figure 4.4: Polarization curve of IV for temperature

On the other hand, Figure 4.5 shows the polarization curve of IP for various temperatures value towards the performance of PEM fuel cell. The values of the power are taken from the Table 4.3 for temperature of 20ºC, 25ºC, 30ºC, 35ºC and 40ºC for load currents 0A, 3A, 6A, 9A, 12A, 15A and 18A. According this figure, the power of the PEM fuel cell for the temperature experiment showed an increment as the load current is increased. In addition, at 0A of load current, the IP curve for temperature reached its lowest peak condition. Lowest peak for temperature is 0W for 20ºC, 25ºC, 30ºC, 35ºC and 40ºC. The curve reached the highest peak at the load current of 18A condition are 587.7W for 20ºC , 594.0W for 25ºC, 600.3W for 30ºC, 605.7W for 35ºC and 611.1W for 40ºC. The average difference between these results is about 5.85V for each temperature. Therefore, it is proved that the performance characteristic of the fuel cell escalate as the temperature is adjusted at the specific values.

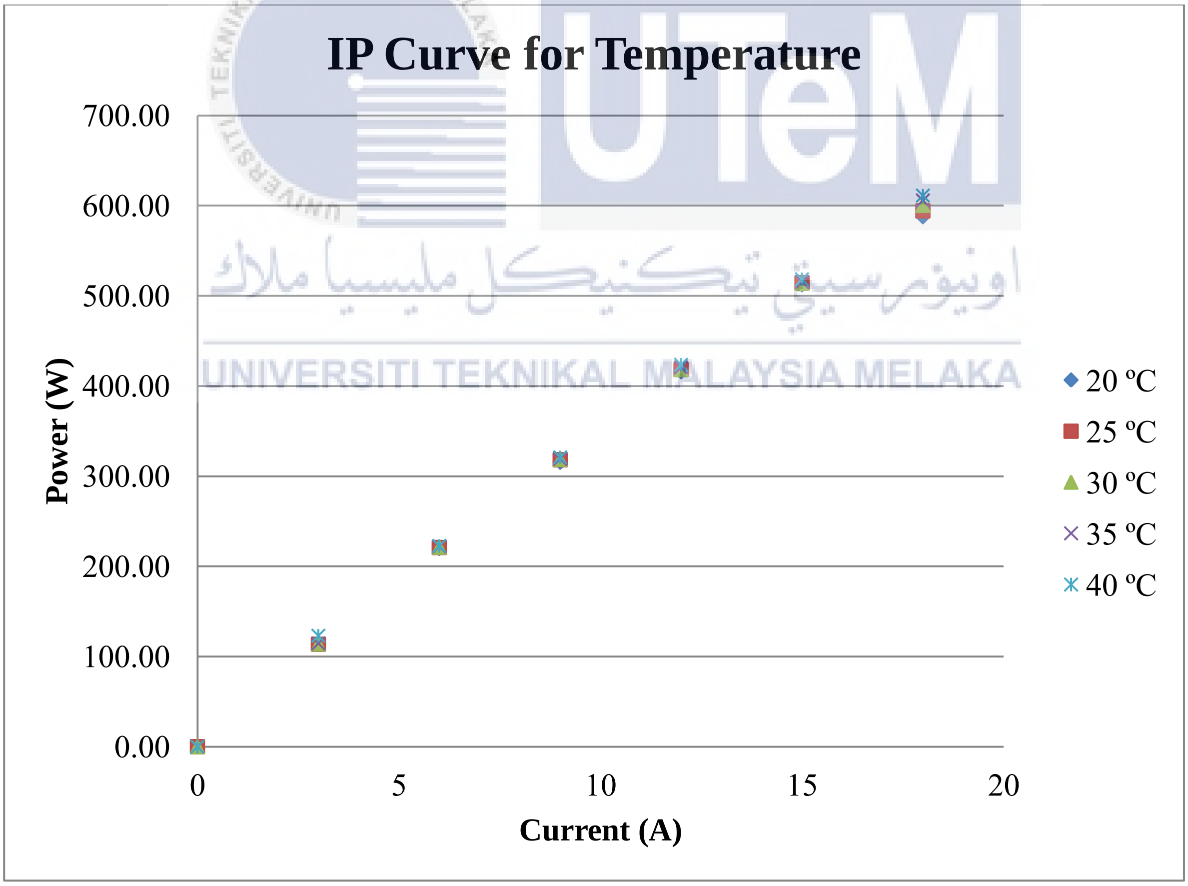


Figure 4.5: Polarization curve of IP for temperature

The effect of temperature toward the performance of thermodynamic potential of PEM fuel cell at open voltage condition is indicated at Figure 4.6. Open voltage condition curve is the result of the temperature at an ideal condition which is at 0A of load current. All the losses produced inside the PEM fuel cell are neglected. Figure 4.6 shows that the voltage of PEM fuel cell will increased when the temperature is increased. In addition, it indicate that the voltage of PEM fuel cell are 45.1V for 20ºC , 45.3V for 25ºC, 45.5V for 30ºC, 45.7V for 35ºC and 45.9V for 40ºC. The results proved that the increase of temperature result the increase of voltage generate for the fuel cell. Due to some reason of the fuel cell itself, the increment of the temperature and voltage is not too linear. Hence, the rising of the temperature of fuel cell cause the water reaction inside the fuel cell to be evaporated faster. Due to the evaporation, the membrane of the dries up more as the temperature increase. The protons can only conduct at the wet membrane to do the chemical reaction. At excessive high temperature inside the membrane can give the negative effect to the fuel cell. Increase the temperature can increase the performance of the fuel cell; however excessive temperature will dries up of the membrane.

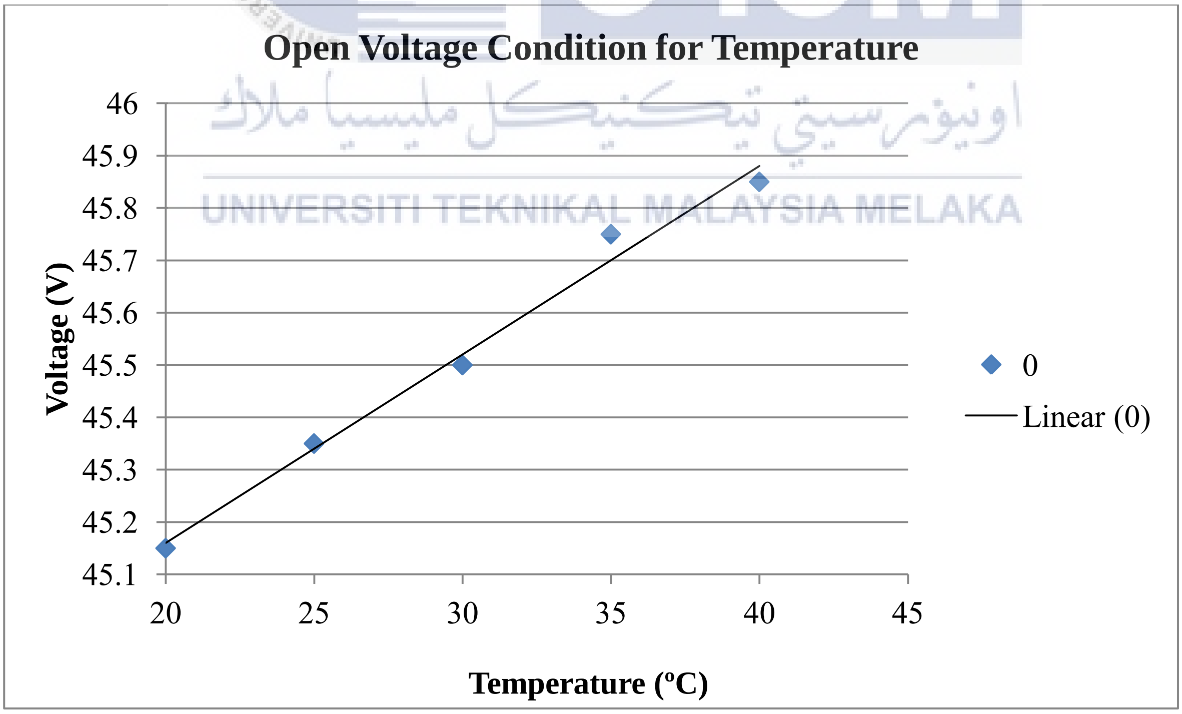


Figure 4.6: Open voltage condition for temperature

4.3 Results of Signal Processing Technique

The experiment on H-2000 PEM fuel cell from Horizon Fuel Cell Technologies, the periodogram technique is being used. The periodogram technique is used to conduct the micro monitoring of the PEM fuel cell based on the effect of humidity and temperature.

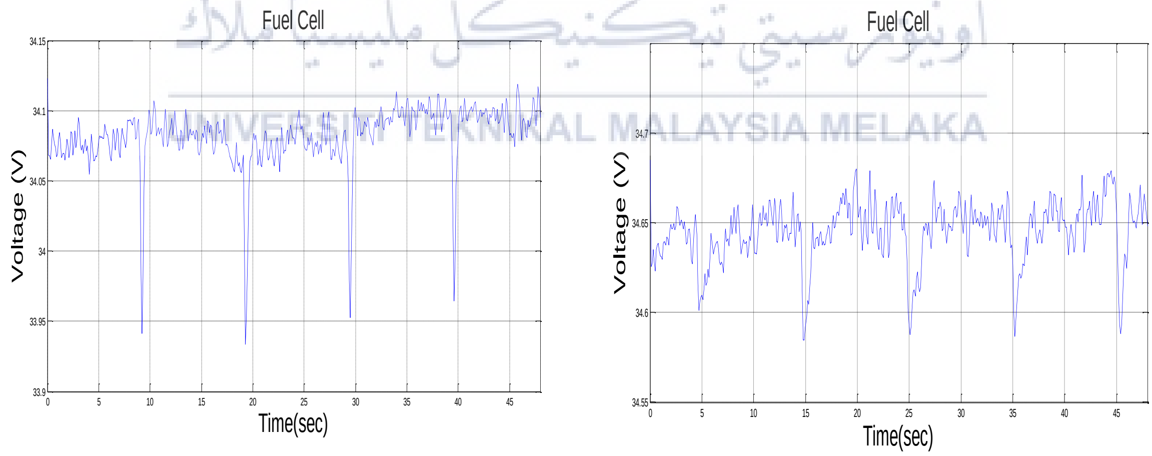
4.3.1 Results of Humidity (Periodogram)

The periodogram technique indicated the characteristic behaviour of PEM fuel cell based on the effect of humidity. The results expressed in rough signal that shows the relationship between voltage against time and in periodogram signal that show the relationship between the frequency and amplitude. The rough signals represent the V_{RMS} of the PEM fuel cell. Meanwhile, the periodogram signal represented the V_{DC} for the PEM fuel cell. Table 4.4 shows the results of $V_{RMS,}$ V_{DC} and V_{AC} for 0% and 80% humidity. According to the table, the V_{RMS} and V_{DC} at 0% humidity for range 15A to 35A is less than the V_{RMS} and V_{DC} at 80% humidity. However, the V_{AC} for 0% and 80% humidity are not constant due to the difference of V_{RMS} and V_{DC} as stated in Equation 3.4.

Table 4.4: Results of $V_{RMS,}$ V_{DC} and V_{AC} for 0% and 80% humidity

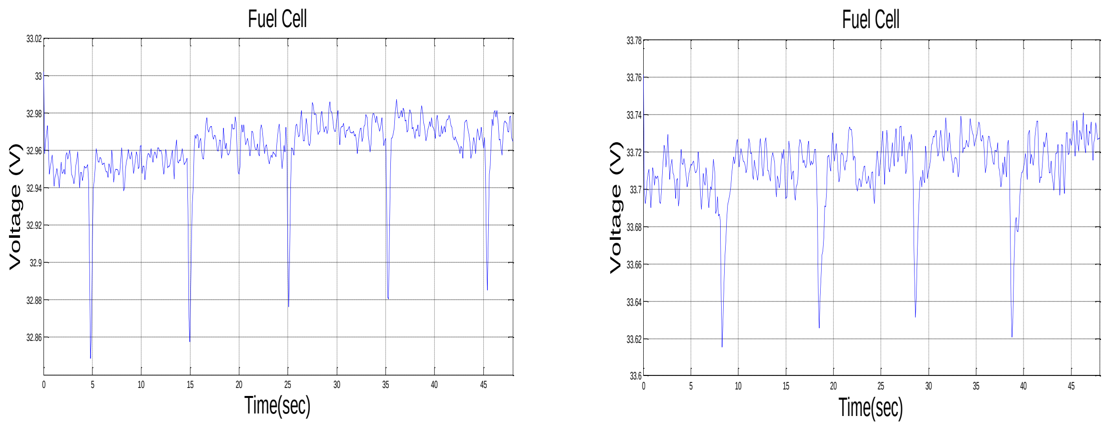
Humidity	Current (A)	Voltage (V)		
		V_{RMS}	V_{DC}	V_{AC}
0%	15	34.12	34.10	1.08
	20	32.99	32.98	0.58
	25	31.72	31.69	1.47
	30	30.92	30.89	1.43
	35	30.04	29.96	2.12
80%	15	34.68	34.67	0.84
	20	33.74	33.73	0.62
	25	32.87	32.85	1.20
	30	32.07	32.03	1.58
	35	31.08	31.06	1.17

According to Figure 4.7 to Figures 4.9, the voltages are decreasing because of the purging factors that exist from the 2000W PEM fuel cell. From the observation during the experiment and also from the signal in the figures, it shows that the purging took every ten second to purge the waste of hydrogen and water from the fuel cell stack. Figure 4.7 shows rough signals at 15 A for 0% humidity and 80% humidity. Based on the signals, it indicates that the voltage of the fuel cell is increase as the humidity percentage is increase. The voltage at 0% humidity is 34.12V, and the voltage is increase at the 80% humidity which is 34.68V. Therefore, there is about 1.64% increment for the voltage as the humidity is increased. On the other hand, Figure 4.8 shows the rough signals at 20 A for 0% humidity and 80% humidity. At 0% humidity, the voltage is 32.99V and at 80% humidity, the voltage is 33.74V. There is slightly increment at 2.27% of performance voltage. From Furthermore, Figure 4.9 shows the rough signals at 25 A. the voltage difference between both humidity percentages are is 3.63%, where the voltage at 0% humidity is 31.72V and at 80% humidity is 32.87V. It shows that the performance voltage is increase as the humidity is increase. It is prove that the characteristics behaviour of the PEM fuel cell could be influenced by the parameter of humidity. The other rough signal can be referred to the Appendix A, where it shows the signal for 30 A and 35A.



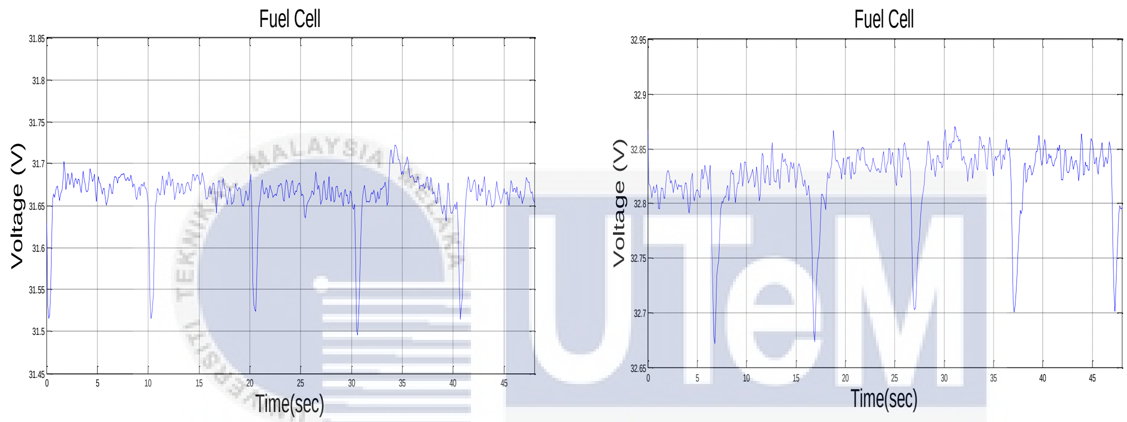
(a) (b)

Figure 4.7: Rough signal for 15A: (a) 0% Humidity (b) 80% Humidity



(a) (b)

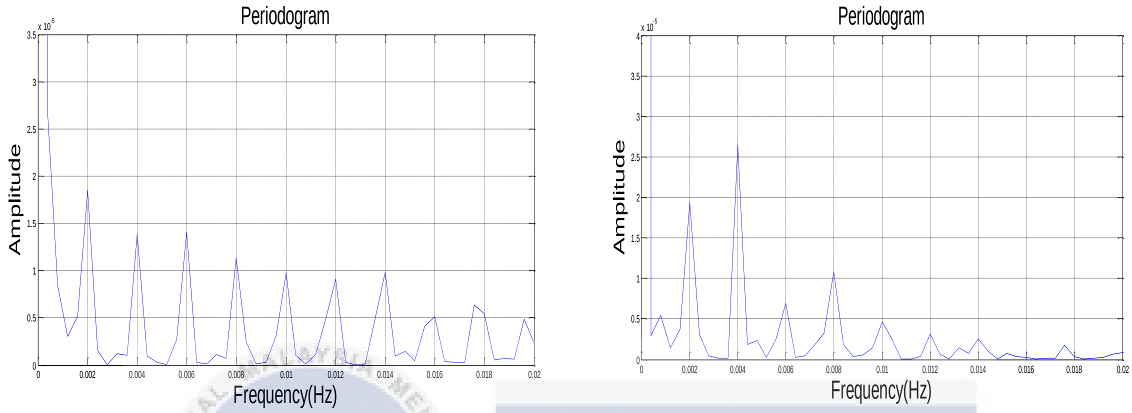
Figure 4.8: Rough signal for 20A: (a) 0% Humidity (b) 80% Humidity



(a) (b)

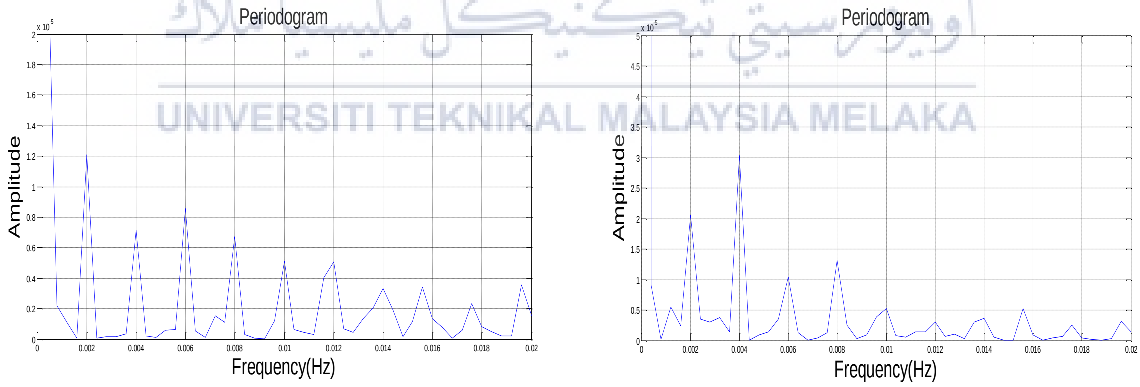
Figure 4.9: Rough signal for 25A: (a) 0% Humidity (b) 80% Humidity

Figure 4.10 to Figure 4.12 represent the periodogram signal of humidity at 15A, 20A and 25A. It shows the micro monitoring signal of voltage that obtained from the oscilloscope and combined with the MatLab simulation. The x-axis represents the frequency and y-axis represents the amplitude of the signal. The frequency is varied constantly at 0.02Hz. The amplitude at 0Hz indicates the V_{DC} of the experiment. The results of V_{DC} of each load currents are recorded in Table 4.5 for both 0% and 80% of the humidity. Even though PEM fuel cell carried the direct current voltage, but there are interruption signal in it. From the periodogram signal, the values of the V_{AC} can be observed so that micro monitoring of it can be done. The amplitude of the signal considered as the V_{AC} that exist inside the fuel cell. The amplitude other than at 0Hz in the figures can be considered as the interruption signal that occurs in the PEM fuel cell during the humidity experiment. The values of the signal varied as the values of humidity and load current being varied. The amplitude of the interruption signal is not consistent. Furthermore, it showed that the interruption signals show an increment as the signal nearer to 0Hz signal. These interruption signals will affect the performance of the PEM fuel cell.



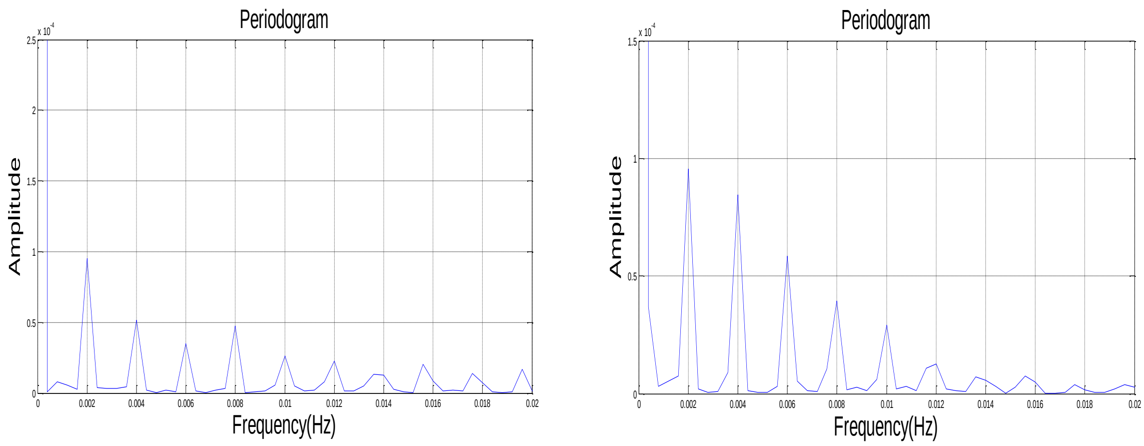
(a) (b)

Figure 4.10: Periodogram signal for 15A: (a) 0% Humidity (b) 80% Humidity



(a) (b)

Figure 4.11: Periodogram signal for 20A: (a) 0% Humidity (b) 80% Humidity



(a) (b)

Figure 4.12: Periodogram signal for 25A: (a) 0% Humidity (b) 80% Humidity

Table 4.5 shows the frequency values for 0% and 80% humidity results obtained by the periodogram signal. These frequency values are obtained from the periodogram signal shown at Figure 4.10 to Figure 4.12. The frequency is taken at each 0.002Hz of the signal. At each frequency, the peak values of the amplitude are recorded into the table. The amplitude of the V_{AC} is not consistent; however at the end of the frequency, the voltages are decreasing. On the other hand, the amplitude of V_{AC} indicates the interruption signal of PEM fuel cell even though the PEM fuel cell signals are carried by $V_{DC.}$ However, the interruption signal of VAC is just a small values but it is still exist in it.

Table 4.5: Frequency values for 0% and 80% humidity results obtained by the periodogram signal

Humidity	Current (A)	Frequency (HZ)										
		0	0.002	0.004	0.006	0.008	0.01	0.012	0.014	0.016	0.018	0.02
0%	15	1163.0	1.85E-05	1.39E-05	1.41E-05	1.14E-05	9.78E-06	9.10E-06	9.82E-06	5.11E-06	5.46E-06	2.30E-06
	20	1088.0	1.21E-05	7.16E-06	8.56E-06	6.71E-06	5.12E-06	5.09E-06	3.32E-06	1.35E-06	8.17E-07	1.59E-06
	25	1004.0	9.52E-05	5.13E-05	3.51E-05	4.75E-05	2.62E-05	2.25E-05	1.24E-05	8.40E-06	7.65E-06	1.71E-06
	30	954.0	2.21E-05	4.44E-05	5.72E-05	4.64E-05	2.46E-05	1.82E-05	1.14E-05	5.74E-06	8.14E-06	2.04E-06
	35	897.9	2.93E-05	2.86E-05	4.23E-05	2.24E-05	3.06E-05	1.52E-05	5.85E-06	7.76E-06	3.55E-06	1.88E-06
80%	15	1202.0	1.94E-05	2.65E-05	6.92E-06	1.08E-06	4.62E-06	3.11E-06	2.50E-06	2.58E-06	3.83E-06	8.66E-06
	20	1138.0	2.06E-05	3.03E-05	1.04E-05	1.31E-05	5.25E-06	3.04E-06	3.66E-06	8.81E-07	4.89E-07	1.38E-06
	25	1079.0	9.54E-05	8.46E-05	5.86E-05	3.96E-05	2.92E-05	1.28E-05	5.75E-06	5.10E-06	1.67E-06	2.72E-06
	30	1026.0	7.96E-05	1.22E-04	6.95E-05	3.51E-05	2.12E-05	1.23E-05	6.14E-06	4.43E-06	2.84E-06	1.82E-06
	35	964.6	2.98E-05	2.20E-05	1.66E-05	1.87E-05	9.85E-06	2.80E-06	1.62E-06	2.41E-06	6.40E-07	3.29E-07

4.3.2 Results of Temperature (Periodogram)

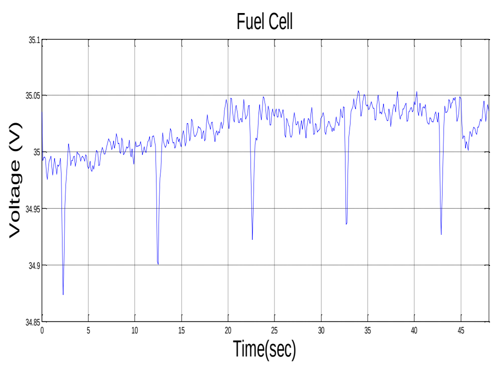
The periodogram technique indicated the characteristic behaviour of PEM fuel cell based on the effect of temperature. Temperature issue is closely related to the drying condition in which insufficient of water inside the membrane of the fuel cell stack. Drying condition could lead the fuel cell to lack of water to make the chemical reaction of hydrogen and water to produce the electricity. Thus, if the insufficient of water occurs, the membrane can easily damage. Table 4.6 shows the V_{RMS}, V_{DC} and V_{AC} values for temperature at various temperatures. It shows that the V_{RMS} and V_{DC} are increased as the temperatures of the PEM fuel cell are increased. However, the V_{AC} for 20ºC, 25ºC, 30ºC, 35ºC and 40ºC are not constant due to the difference of V_{RMS} and V_{DC} as stated in Equation 3.4. If the difference voltages between V_{RMS} and V_{DC} are higher, thus the V_{AC} will be higher and vice versa. Temperature of 40ºC indicates the highest voltage performance; meanwhile temperature of 20ºC indicates the lowest voltage of the PEM fuel cell.

Table 4.6: V_{RMS}, V_{DC} and V_{AC} values for temperature

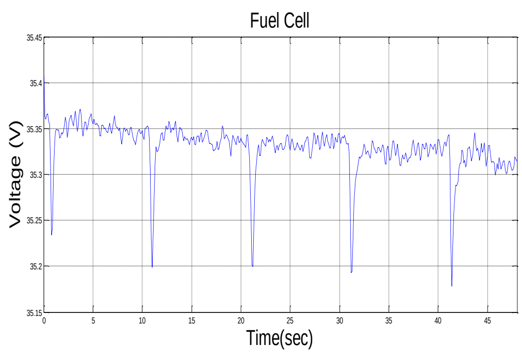
Temperature	Current (A)	Voltage (V)		
		V_{RMS}	V_{DC}	V_{AC}
20ºC	3	37.74	37.70	1.82
	9	35.05	35.04	0.71
	12	34.62	34.60	1.24
	15	34.16	34.09	2.21
	18	32.70	32.66	1.51
25ºC	3	37.81	37.78	1.61
	9	35.37	35.36	1.02
	12	34.74	34.70	1.69
	15	35.08	35.07	0.78
	18	32.99	32.97	1.16
30ºC	3	38.04	38.03	1.02
	9	35.43	35.43	0.53
	12	34.82	34.81	0.66
	15	34.35	34.32	1.39
	18	33.34	33.33	0.75
35ºC	3	38.15	38.14	0.65
	9	35.45	35.43	1.30
	12	35.08	35.07	0.78
	15	34.41	34.39	1.02
	18	33.67	33.63	1.63

	3	38.83	38.28	6.54
	9	35.53	35.52	0.62
40ºC	12	35.29	35.27	1.18
	15	34.55	34.53	1.30
	18	34.00	33.99	1.00

The results expressed in rough signal that shows the relationship between voltage against time and in periodogram signal that show the relationship between the frequency and amplitude. Figure 4.13 to Figure 4.15 show the results of temperature experimental at 9A, 12A and 18A at various temperature values. Purging is occurred every ten seconds and it can be proves by these figures. The voltage will be drop every time the purging occurred. The voltage of the PEM fuel is increase as the temperature is increased. From the figures, the peak value is the V_{RMS} values for this experiment. As the current is varied at 9A, the performance voltage is keep increase from 35.05V at 20ºC to 35.53V at 40ºC. It is slightly 1.37% increment of voltage when the temperature is increase. As the temperature increase, the voltage will increase. This shows that the performance of the PEM fuel cell can be improved by arising the temperature. However, the increment of the temperature should be control, because when the temperature exceeds a certain value, the performance characteristics of the fuel cell could be declined due to the drying condition. So, for this experiment, due to the precautions step, the temperatures are limited to 40ºC to prevent the fuel cell to damage. By referring to the manual of H-2000 PEM fuel cell from Horizon Fuel Cell Technologies, the temperature should operated below 65ºC only, otherwise it will distract the performance behaviour of the fuel cell.



(a)



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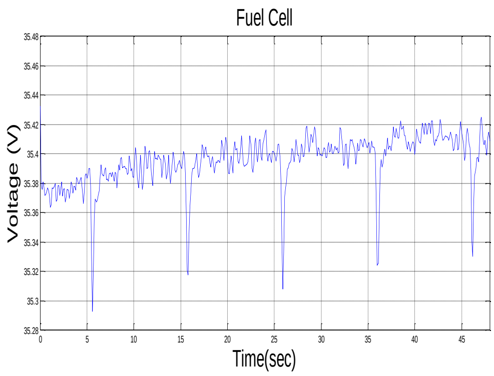

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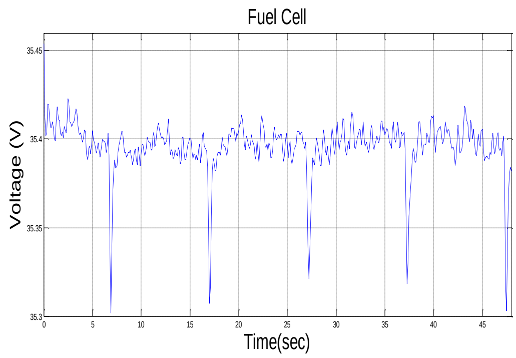

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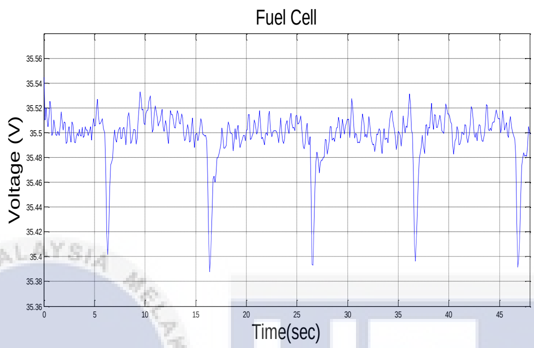
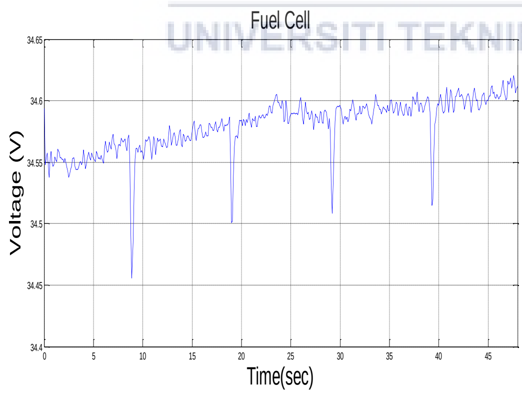
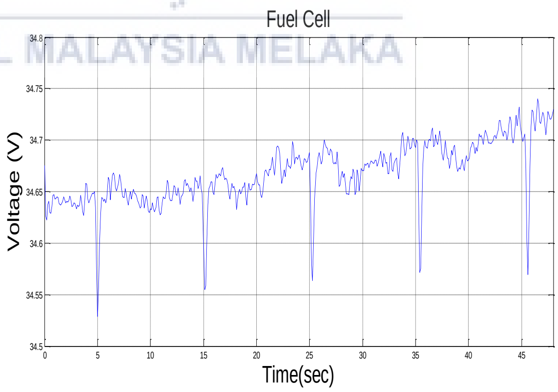


(e)

Figure 4.13: Rough signal for 9A: (a) 20ºC temperature (b) 25ºC temperature (c) 30ºC temperature (d) 35ºC temperature (e) 40ºC temperature



(a)



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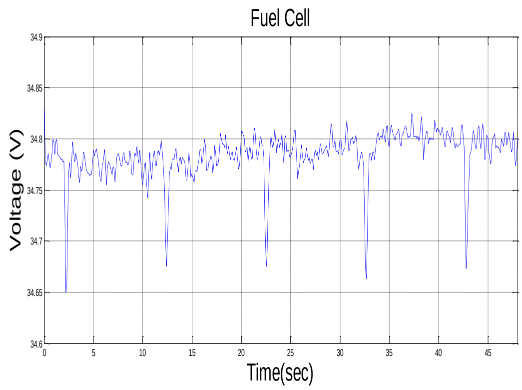

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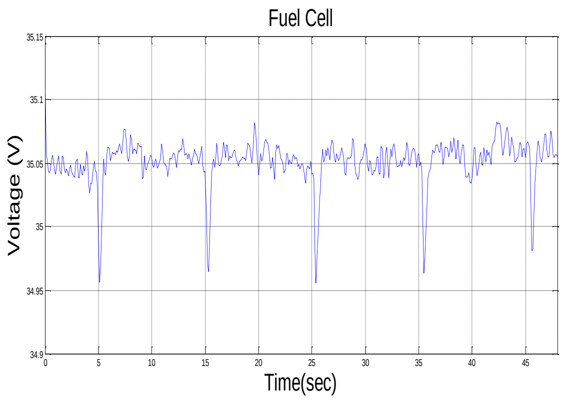

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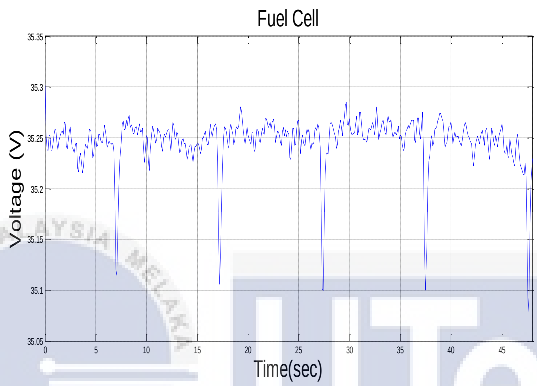
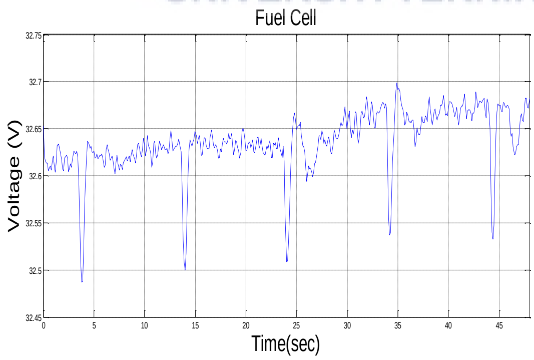
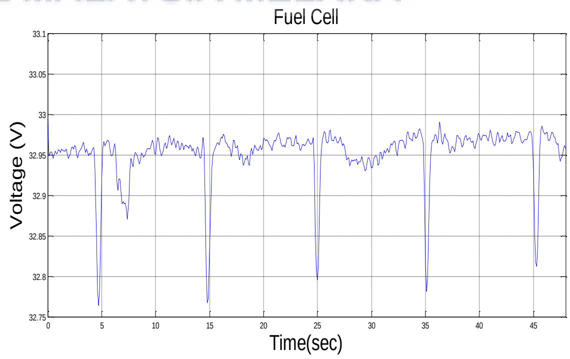


(e)

Figure 4.14: Rough signal for 12A: (a) 20ºC temperature (b) 25ºC temperature (c) 30ºC temperature (d) 35ºC temperature (e) 40ºC temperature



(a)



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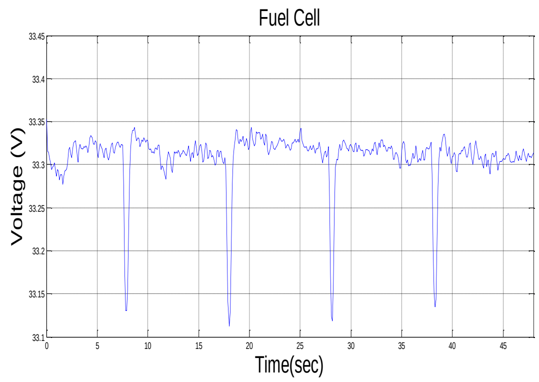

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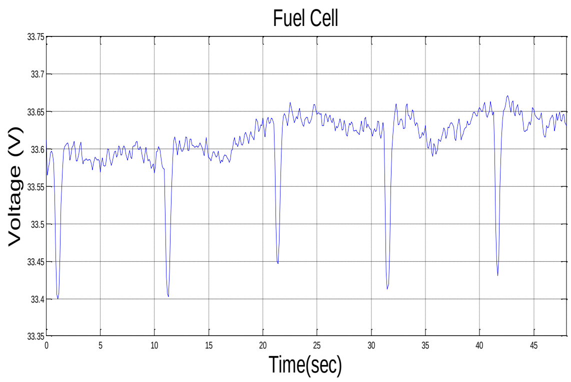

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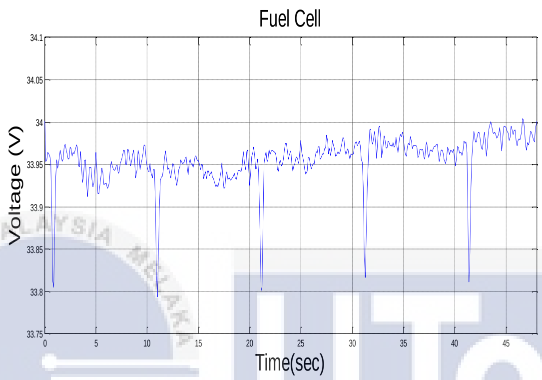


(e)

Figure 4.15: Rough signal for 18A: (a) 20ºC temperature (b) 25ºC temperature (c) 30ºC temperature (d) 35ºC temperature (e) 40ºC temperature

Figure 4.16, Figure 4.17 and Figure 4.18 show periodogram signal for various temperatures and at certain load current values. Values V_{DC} can be expressed in the periodogram signal at 0Hz. Besides, the value of V_{AC} represented by the amplitude at the others frequency. V_{AC} depends of the difference of the V_{RMS} and V_{DC} of the PEM fuel cell. It can be higher if the difference is huge and can be lower if the difference is narrower. However, the V_{AC} is not the good signal because it represented the distortions that occur inside the PEM fuel cell. Even though the values is not high, but from the periodogram, it can show that at certain frequency what values of distortion it can occurs, so the control of the condition can be determined. The values of the amplitude can be change due to load current and temperature being set for the experiment. These conditions proved that temperature give a big impact towards the characteristics behaviour of the PEM fuel cell.

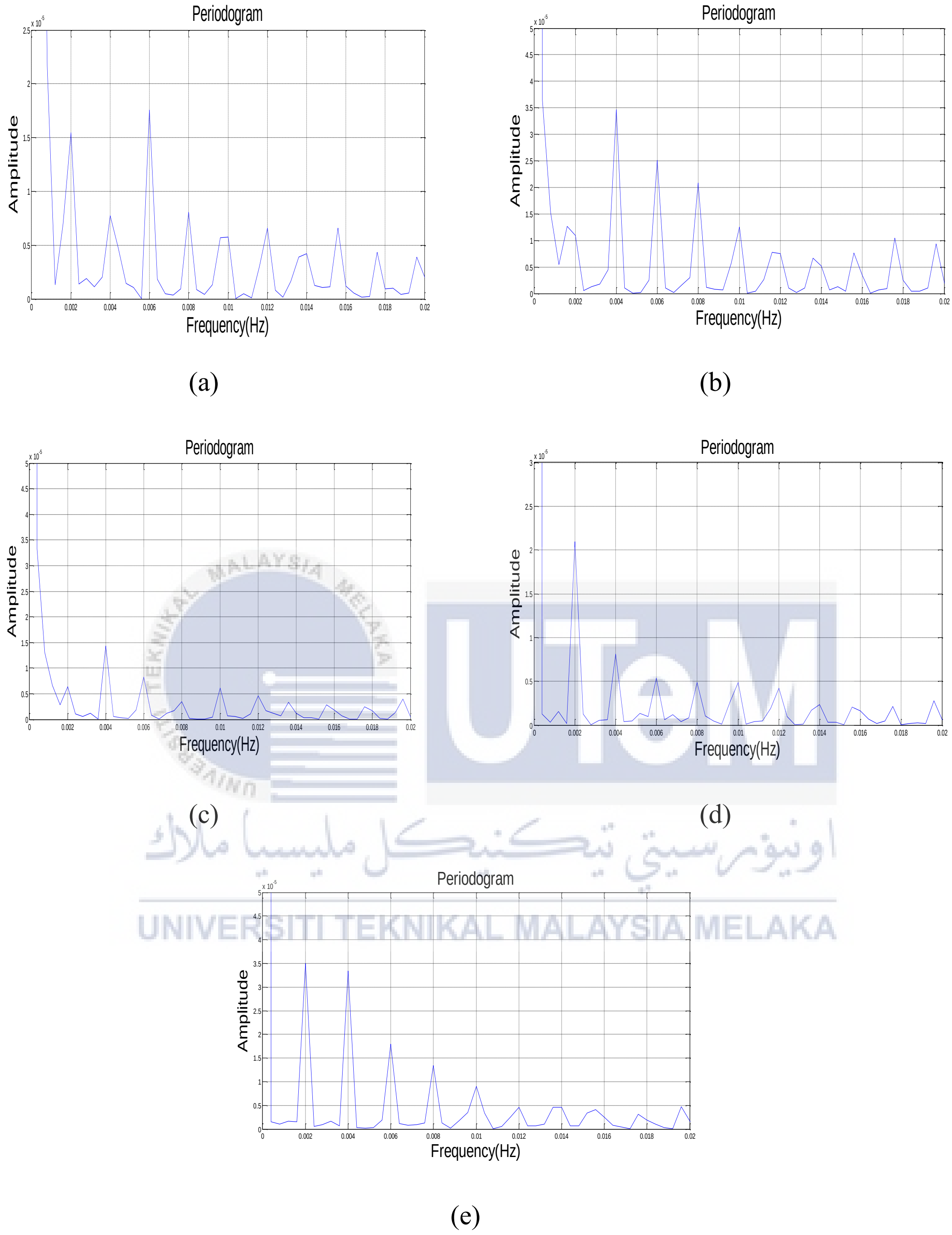
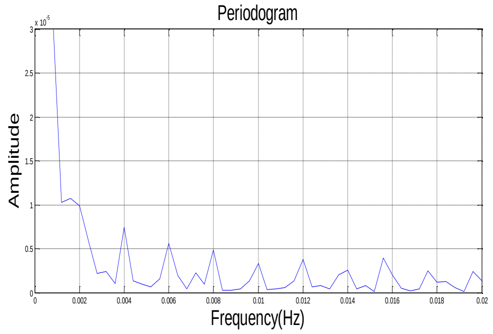
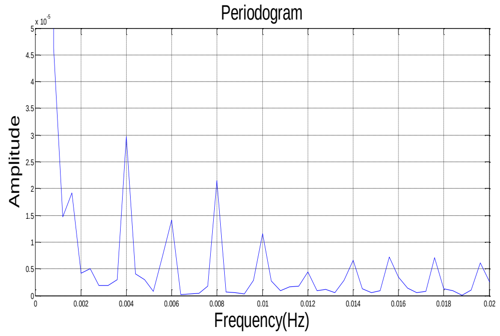


Figure 4.16: Periodogram signal for 9A: (a) 20ºC temperature (b) 25ºC temperature (c) 30ºC temperature (d) 35ºC temperature (e) 40ºC temperature



(a)



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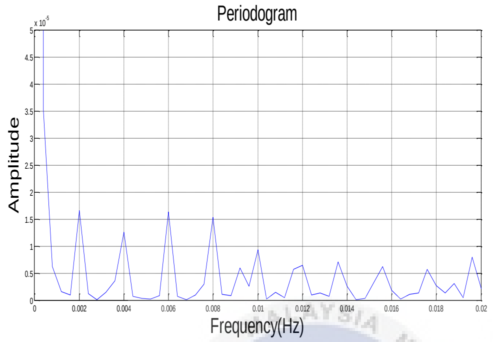
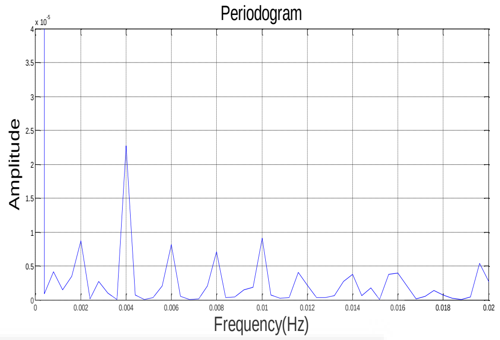


(c)



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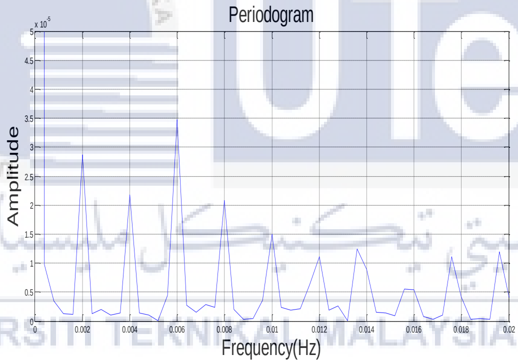
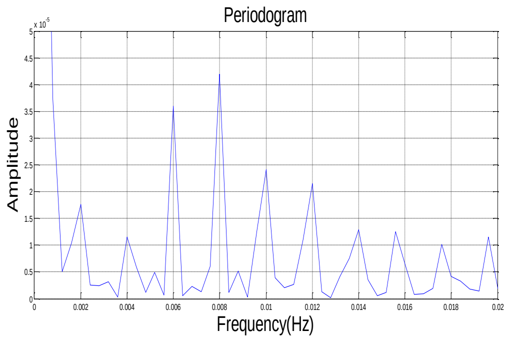
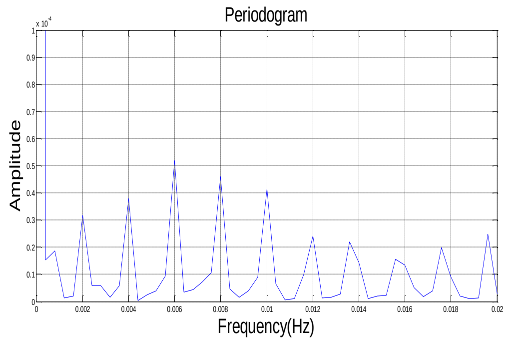


(e)

Figure 4.17: Periodogram signal for 12A: (a) 20ºC temperature (b) 25ºC temperature (c) 30ºC temperature (d) 35ºC temperature (e) 40ºC temperature



(a)



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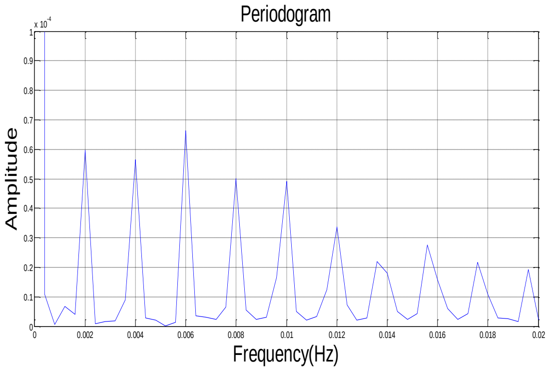

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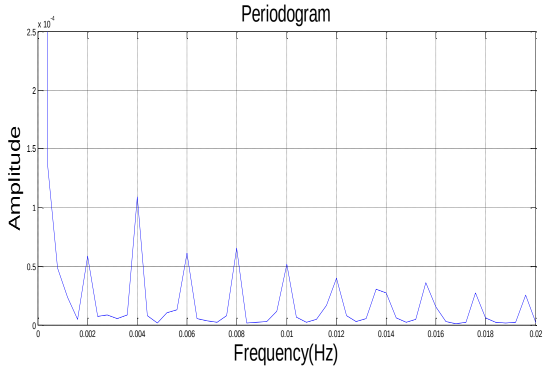

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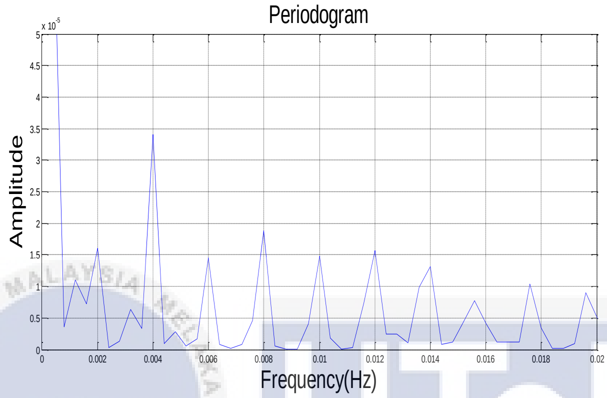


(e)

Figure 4.18: Periodogram signal for 18A: (a) 20ºC temperature (b) 25ºC temperature (c) 30ºC temperature (d) 35ºC temperature (e) 40ºC temperature

Table 4.7 shows the frequency values for 0% and 80% humidity results obtained from the periodogram signal. These frequency values are obtained from the periodogram signal shown at Figure 4.10 to Figure 4.12. The frequency is taken at each 0.002Hz of the signal. At each frequency, the peak values of the amplitude are recorded into the Table 4.7. The amplitude of the V_{AC} is not consistent; however at the end of the frequency, the voltages are decreasing. V_{AC} represents the signal that interrupts the performance of the PEM fuel cell. However, the interruption signal of VAC is just a small values but it is still exist in it.

Table 4.7: Results frequency at various temperatures for current 3A, 9A, 12A, 15A and 18A

Temperature	Current (A)	Frequency (Hz)										
		0	0.002	0.004	0.006	0.008	0.01	0.012	0.014	0.016	0.018	0.02
20˚C	3	1421	9.709E-05	5.840E-05	5.278E-05	2.565E-02	5.660E-06	1.625E-05	8.756E-06	2.235E-06	1.690E-06	3.019E-06
	9	1228	1.547E-05	7.747E-06	1.761E-05	8.089E-06	5.727E-06	6.567E-06	4.219E-06	1.163E-06	9.282E-07	2.003E-06
	12	1197	9.869E-06	7.435E-06	5.635E-06	4.860E-06	3.313E-06	3.751E-06	2.552E-06	2.050E-06	1.151E-06	1.343E-06
	15	1162	4.875E-05	2.587E-05	2.260E-05	9.052E-05	5.014E-06	8.490E-06	1.824E-06	4.679E-06	1.685E-06	1.709E-06
	18	1067	1.769E-05	1.148E-05	3.592E-05	4.190E-05	2.412E-05	2.146E-05	1.293E-05	6.507E-06	4.214E-06	1.967E-06
25˚C	3	1427	7.233E-05	5.384E-05	2.088E-05	2.05E-05	1.247E-05	1.298E-05	5.848E-05	9.901E-07	2.435E-06	1.638E-06
	9	1250	1.098E-05	3.467E-05	2.518E-05	2.087E-05	1.249E-05	7.568E-06	5.200E-06	3.491E-06	2.539E-06	2.022E-06
	12	1204	4.146E-06	2.972E-05	1.409E-05	2.153E-05	1.151E-05	4.444E-06	6.568E-06	3.430E-06	1.294E-06	2.645E-06
	15	1230	8.757E-06	2.275E-05	8.190E-06	7.107E-06	9.139E-06	2.154E-06	3.739E-06	3.996E-06	7.290E-07	2.671E-06
	18	1087	3.167E-05	3.796E-05	5.179E-05	4.592E-05	4.142E-05	2.421E-05	1.446E-05	1.341E-05	9.169E-06	3.014E-06
30˚C	3	1446	1.600E-04	8.562E-05	3.885E-05	2.671E-05	1.704E-05	1.136E-05	8.114E-06	7.465E-06	2.380E-06	8.993E-07
	9	1255	6.399E-06	1.431E-05	8.325E-06	3.466E-06	6.077E-06	4.629E-06	1.222E-06	1.848E-06	1.682E-06	4.771E-07
	12	1212	1.675E-05	1.259E-05	1.631E-05	1.535E-05	9.325E-06	6.474E-06	2.583E-06	1.836E-06	2.745E-06	2.148E-06

	15	1178	5.144E-06	2.071E-06	1.919E-05	2.434E-05	1.710E-05	1.004E-05	7.305E-06	4.211E-06	1.811E-06	2.416E-06
	18	1111	5.977E-05	5.660E-05	6.634E-05	5.004E-05	4.918E-05	3.363E-05	1.810E-05	1.578E-05	1.903E-05	2.311E-06
35˚C	3	1455	9.995E-05	4.429E-05	2.067E-05	1.330E-05	8.296E-06	3.828E-06	2.750E-06	2.340E-06	1.553E-06	3.036E-06
	9	1255	2.096E-05	8.108E-06	5.350E-06	4.834E-06	4.880E-06	4.245E-06	2.371E-06	1.611E-06	6.871E-08	6.030E-07
	12	1230	3.757E-06	2.275E-05	8.190E-06	7.107E-06	9.139E-06	2.154E-06	3.739E-06	3.996E-06	7.290E-07	2.671E-06
	15	1183	1.112E-05	2.608E-05	2.173E-05	1.095E-05	1.711E-05	1.333E-05	8.569E-06	7.244E-06	4.167E-06	6.489E-06
	18	1131	5.816E-05	1.093E-04	6.074E-05	6.531E-05	5.614E-05	3.939E-05	2.724E-05	1.558E-05	5.931E-06	2.275E-06
40˚C	3	1465	6.514E-05	3.342E-05	2.108E-05	7.697E-06	9.554E-06	7.991E-06	1.247E-06	1.039E-06	1.089E-06	1.102E-06
	9	1262	3.496E-05	3.336E-05	1.198E-05	1.347E-05	9.017E-05	4.582E-06	4.590E-06	2.497E-06	1.896E-06	1.600E-06
	12	1244	2.867E-05	2.181E-05	3.473E-05	2.080E-05	1.503E-05	1.116E-05	8.937E-06	5.437E-06	4.180E-06	4.230E-06
	15	1192	7.744E-06	3.996E-05	2.466E-05	1.562E-05	1.100E-05	1.552E-05	1.026E-05	4.746E-06	6.215E-06	3.787E-06
	18	1155	1.608E-05	3.403E-05	1.458E-05	1.879E-05	1.480E-05	1.569E-05	1.310E-05	4.270E-06	3.491E-06	5.071E-06

4.4 Summary

For this chapter, there are four sections that have been discussed including chapter introductory and summary. Section 4.2 explained on the results of performance characteristics analysis of humidity and temperature. Furthermore, Section 4.3 discussed the results of the signal processing technique for humidity and temperature.

CHAPTER 5

CONCLUSIONS

5.1 Conclusion

In a conclusion, analysis of humidity and temperature towards the performance of thermodynamic potential in PEM fuel cell has been performed successfully. The study on the effect of humidity and temperature towards the performance of PEM fuel cell has greatly achieved at the end of the experiment. In addition, the effect of humidity and temperature towards the performance of PEM fuel cell has been analysed. From the results and discussion, the voltage of the fuel cell is increase as the humidity percentage is increased, and same goes to the temperature. Hence, it was found that the humidity and temperature plays an important role towards the behaviour characteristics of PEM fuel cell and it need to be controlled so that the PEM fuel cell can be used in optimum. Besides that, by using the signal processing technique, the investigation on the signal identification of humidity and temperature using the changing behaviour in PEM fuel cell has been completely done. On top of that, the performance characteristic analysis and signal processing technique have been used to analyse the effect of the parameters and it is proved that using both technique, the analysis has been carried out perfectly. The signal identification is used to obtain the V_{RMS}, V_{DC} and V_{AC} of the PEM fuel cell, so that the monitoring system can be build in the future.

5.2 Recommendation

Based on the results and conclusion that have been made, it is recommended to continue the analysis of the result by using the spectrogram technique, so that micro monitoring on the characteristics behaviour of PEM fuel cell can be made more deeply. Besides that, it is also suggested to do the analysis on different parameters such as pressure, flow rate and others. In addition, from this experiment, the signal identification has been investigate, so from the results it is recommended to create the system monitoring hence from that application can be produced in the future.

REFERENCES

[1] M.R. Islam, R, Saidur. N.A. Rahim and K.H. Solangi, “Renewable Energy Research in Malaysia”, vol. 4, no.2, pp.69-72, 2 Dec 2009

[2] Ellis, M.W.; Spakovsky V., M.R.; Nelson, D.J., "Fuel cell systems: efficient, flexible energy conversion for the 21st century," *Proceedings of the IEEE*, vol.89, no.12, pp.1808-1818, Dec 2001

[3] *EG&G Technical Services Inc, Fuel Cell handbook* (Sixth ed., pp. 1-15). Science Application International Corporation.

[4] Laughton, M.A, "Fuel cells," Engineering Science and Education Journal, vol.11, no.1, pp.7-16, Feb 2002

[5] Ryan O.H., Cha S.W., Colella W. and Prinz F.B., “Fuel Cell Fundamentals”

[6] Moldrik, P.; Chvalek, R., “PEM fuel cells - The basic characteristics,” *Environment and Electrical Engineering (EEEIC), 10th International Conference on 2011*, pp.1- 4, 8-11 May 2011

[7] J. Larminie and A. Dicks, “Fuel Cell Systems Explained – Second Edition,” Wiley, Oxford, England, 2003.

[8] Fouquet N., “Real time model-based monitoring of a PEM fuel cell flooding and drying out,” *IEEE Vehicle Power and Propulsion Conference (VPPC), 2010*, pp.1-8, 1-3 Sept., 2010

[9] Chen D.; Peng, “Modelling and simulation of a PEM fuel cell humidification system,” *American Control Conference Proceedings of the 200*, vol.1, pp.822-827, 30 June – 2 July 2004

[10] Hui J.; Jie H., "Research of the humidity control system of PEM Fuel," *International Conference on Intelligent Systems and Knowledge Engineering (ISKE) 2010*, pp.548-551, 15-16 Nov. 2010

[11] Jeon D.H.; Kim K.N.; Baek S.M. and Nam J.H., "The effect of humidity of the cathode on the performance and the uniformity of PEM fuel cells*" International Journal of Hydrogen Energy 36 (2011),* 12 May – 2Aug. 2011

[12] Dotelli, G.; Ferrero, R.; Stampino, P.G.; Latorrata, S.; Toscani, S., "Diagnosis of PEM Fuel Cell Drying and Flooding Based on Power Converter Ripple, *IEEE Transactions on Instrumentation and Measurement*, vol.63, no.10, pp.2341,2348, Oct. 2014

[13] Kim J.; Goo Y.; Jang H.R., "Temperature related study on PEM fuel cell," *International Symposium on the 8th Russian-Korean Science and Technology, (KORUS 2004), 2004*, vol.1, pp.342-345, 26 June - 3July 2004

[14] Riascos, L.A.M.; Pereira, D.D., "Optimal temperature control in PEM fuel cells," *35th Annual Conference of IEEE Industrial Electronics, 2009. IECON*, pp.2778-2783, 3-5 Nov. 2009

[15] Page M. P. and Herranz V. P., "Effect of the Operation and Humidification Temperatures on the Performance of a PEM Fuel Cell Stack on Dead-End Mode" *International Journal of Electrochemical Science 2010,* 29 Oct. 2010 , 1 Feb. 2011

[16] Sun H.; Zhang G.; Guo L., "Transient Characteristics of PEMFC based on Fuel Cell Temperature," *Asia-Pacific Power and Energy Engineering Conference (APPEEC), 2010*, pp.1- 4, 28-31 March 2010

[17] Strahl S; Husar, A.; Puleston and P.; Riera, J., "Performance improvement by temperature control of an open-cathode PEM fuel cell system" *Fundamentals and Developments of Fuel Cells Conference 2013 (FDFC2013)*, vol. 14, no. 3, pp 466-478, June 2014

[18] Saad, N.M.; Abdullah, A.R.; Yin Fen Low, "Detection of Heart Blocks in ECG Signals by Spectrum and Time-Frequency Analysis," *4th Student Conference on Research and Development, 2006 (SCOReD 2006.)*, pp.61-65, 27-28 June 2006

[19] Zhou Q.; Brenneman M.; Morton J., "Analysis of EEG Data Using an Adaptive Periodogram Technique," *International Conference on Bio Medical Engineering and Informatics (BMEI 2008)*, vol.2, pp.353-357, 27-30 May 2008

[20] 2000W Fuel Cell Stack User Manual, *Horizon Fuel Cell Technologies*, 2013

APPENDIX A: ROUGH SIGNAL AND PERIODOGRAM SIGNAL FOR HUMIDITY

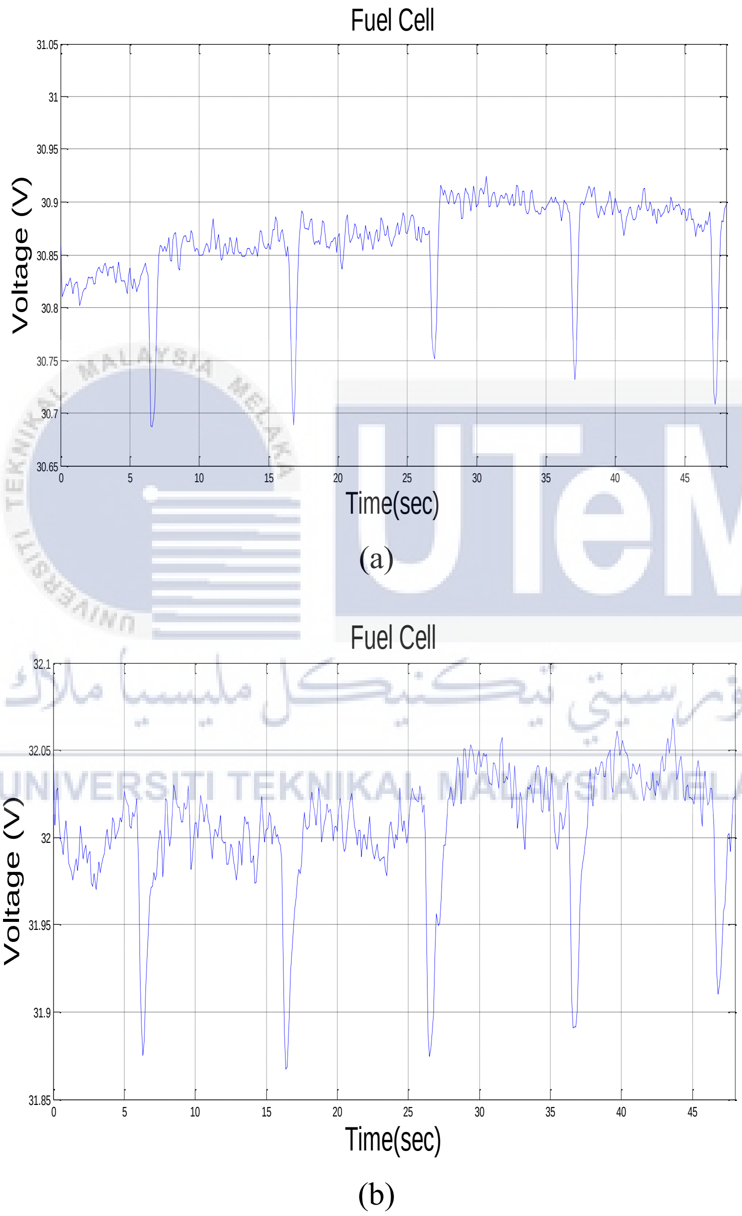
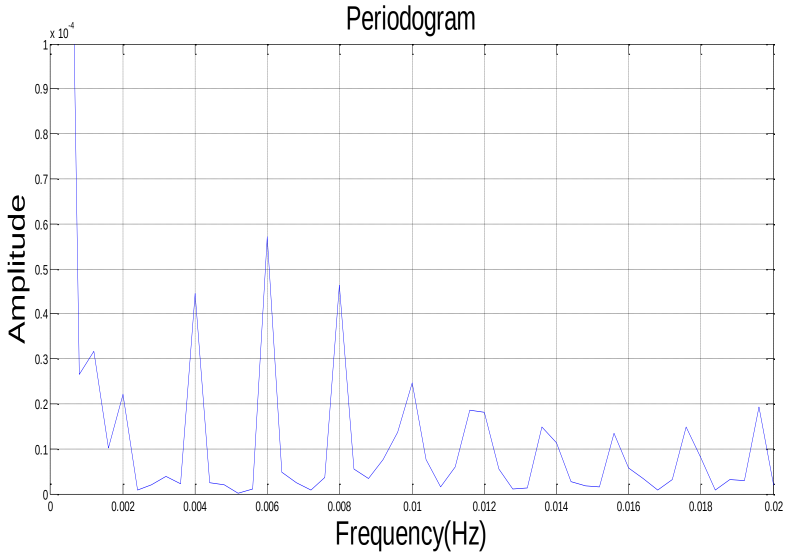


Figure A1: Rough signal for 30A: (a) 0% Humidity (b) 80% Humidity



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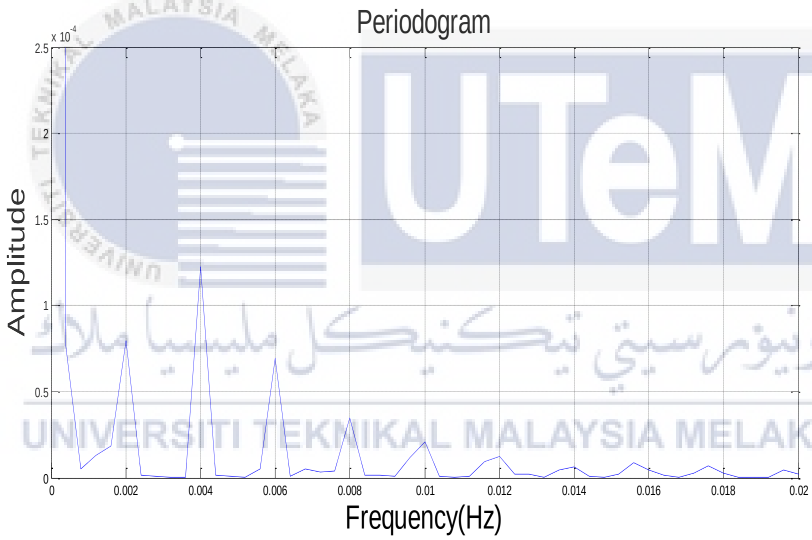
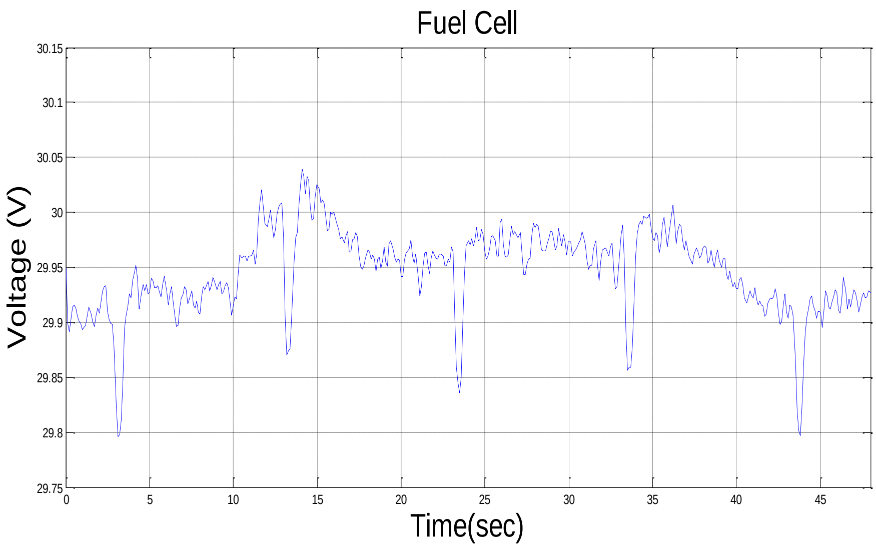
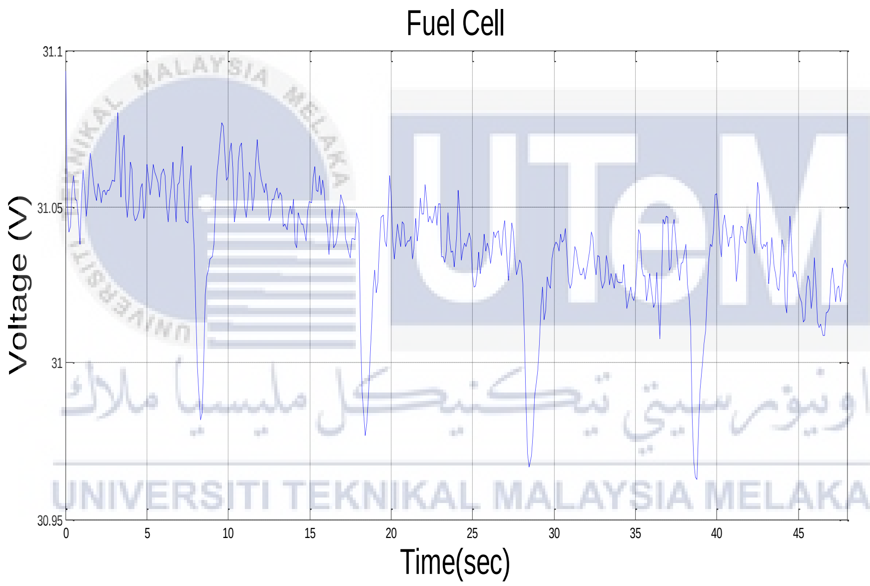


(b)

Figure A2: Periodogram signal for 30A: (a) 0% Humidity (b) 80% Humidity

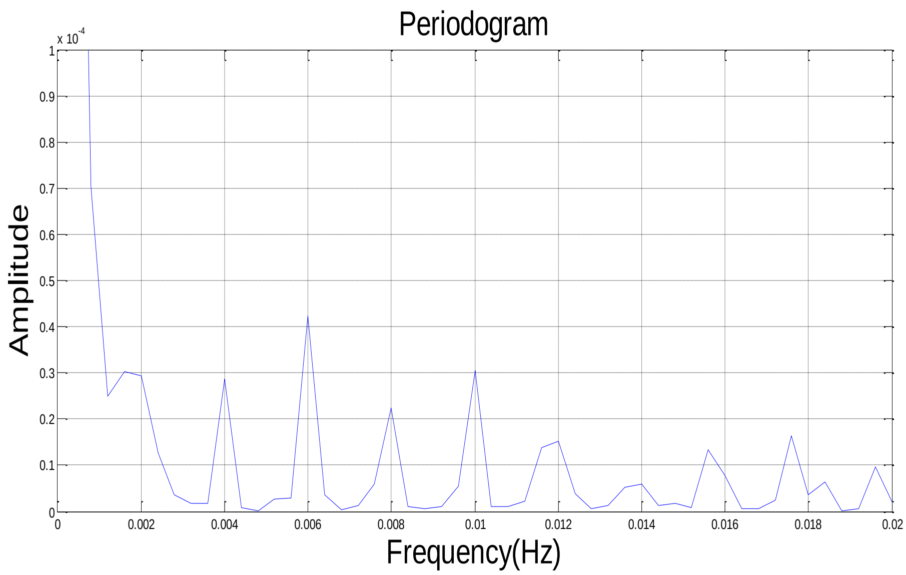


(a)

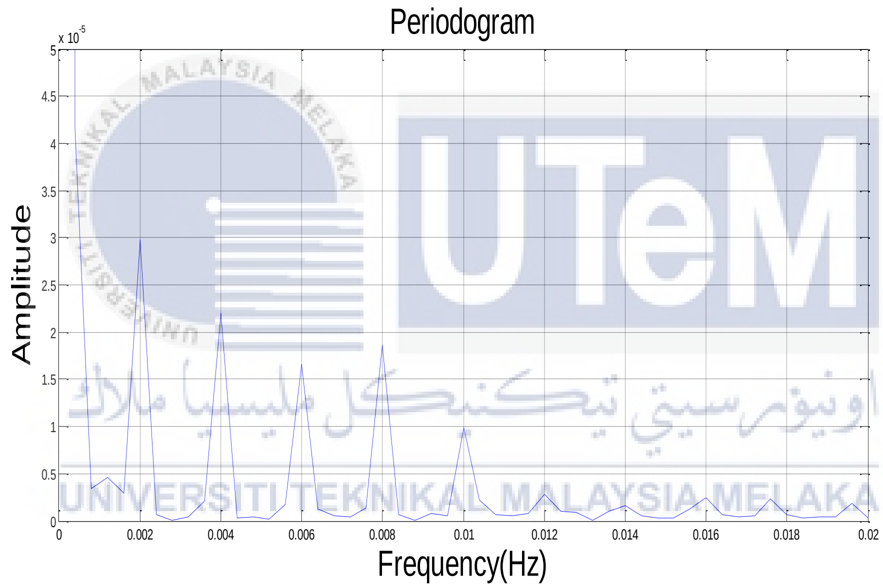


(b)

Figure A3: Rough signal for 35A: (a) 0% Humidity (b) 80% Humidity



(a)



(b)

Figure A4: Rough signal for 35A: (a) 0% Humidity (b) 80% Humidity

APPENDIX B: ROUGH SIGNAL AND PERIODOGRAM SIGNAL FOR TEMPERATURE

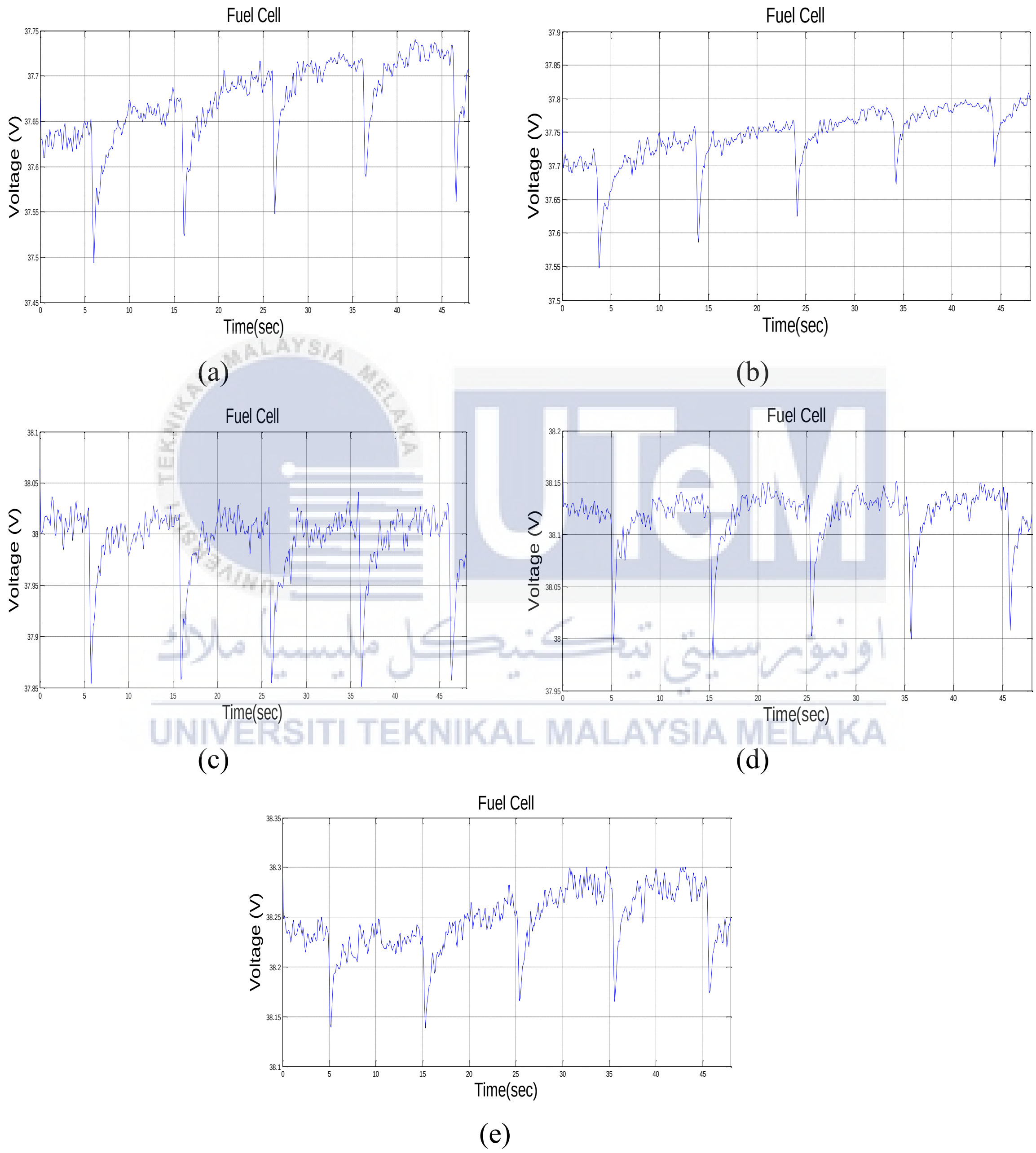


Figure B1: Rough signal for 3A: (a) 20ºC temperature (b) 25ºC temperature (c) 30ºC temperature (d) 35ºC temperature (e) 40ºC temperature

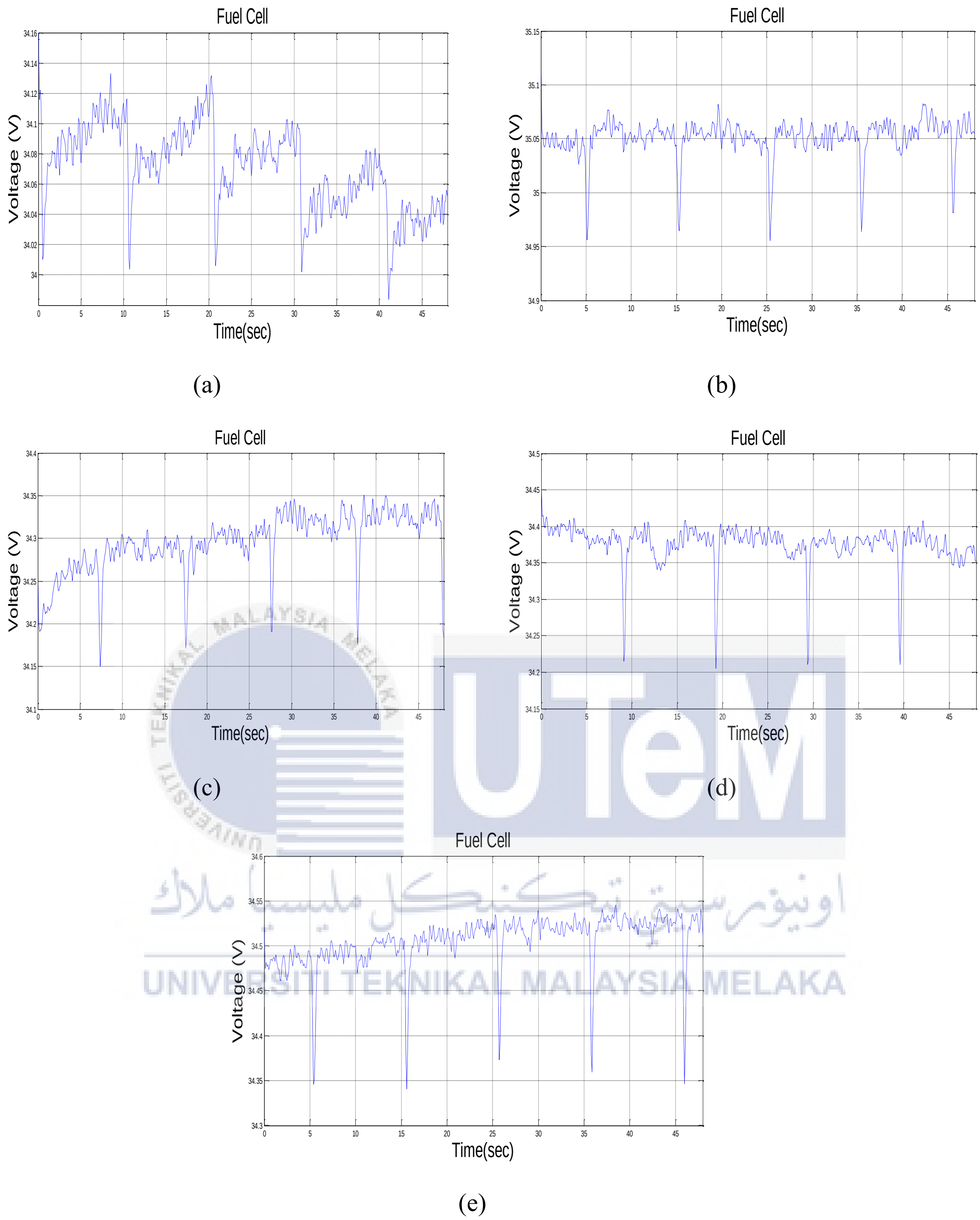
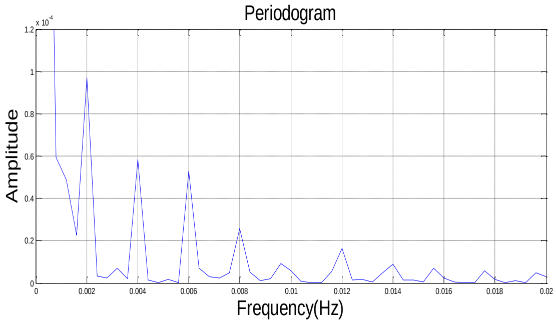
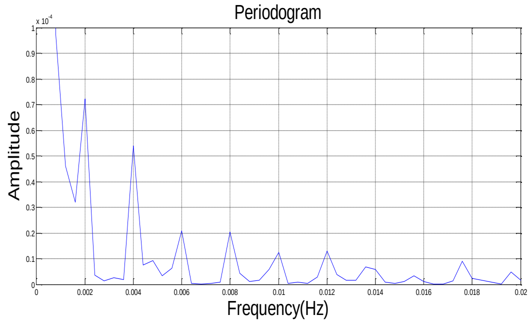


Figure B2: Rough signal for 15A: (a) 20ºC temperature (b) 25ºC temperature (c) 30ºC temperature (d) 35ºC temperature (e) 40ºC temperature



(a)



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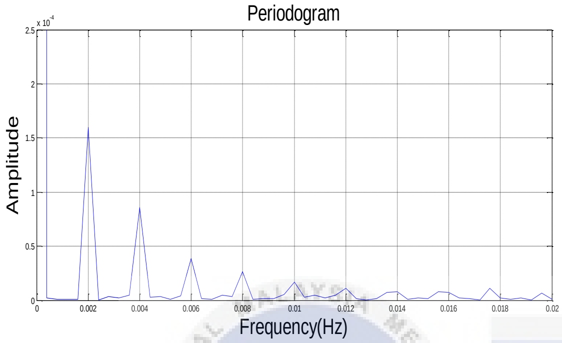

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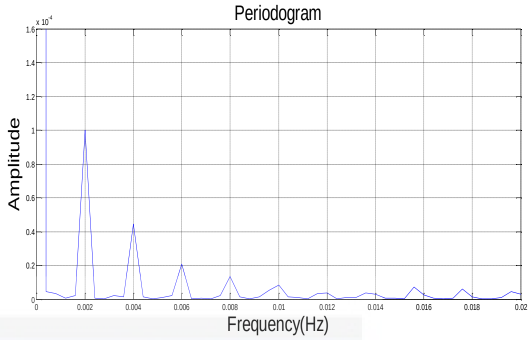

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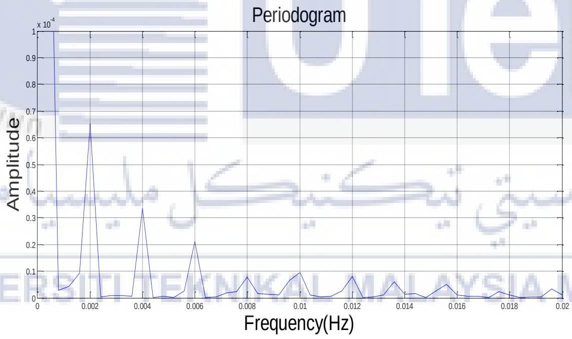
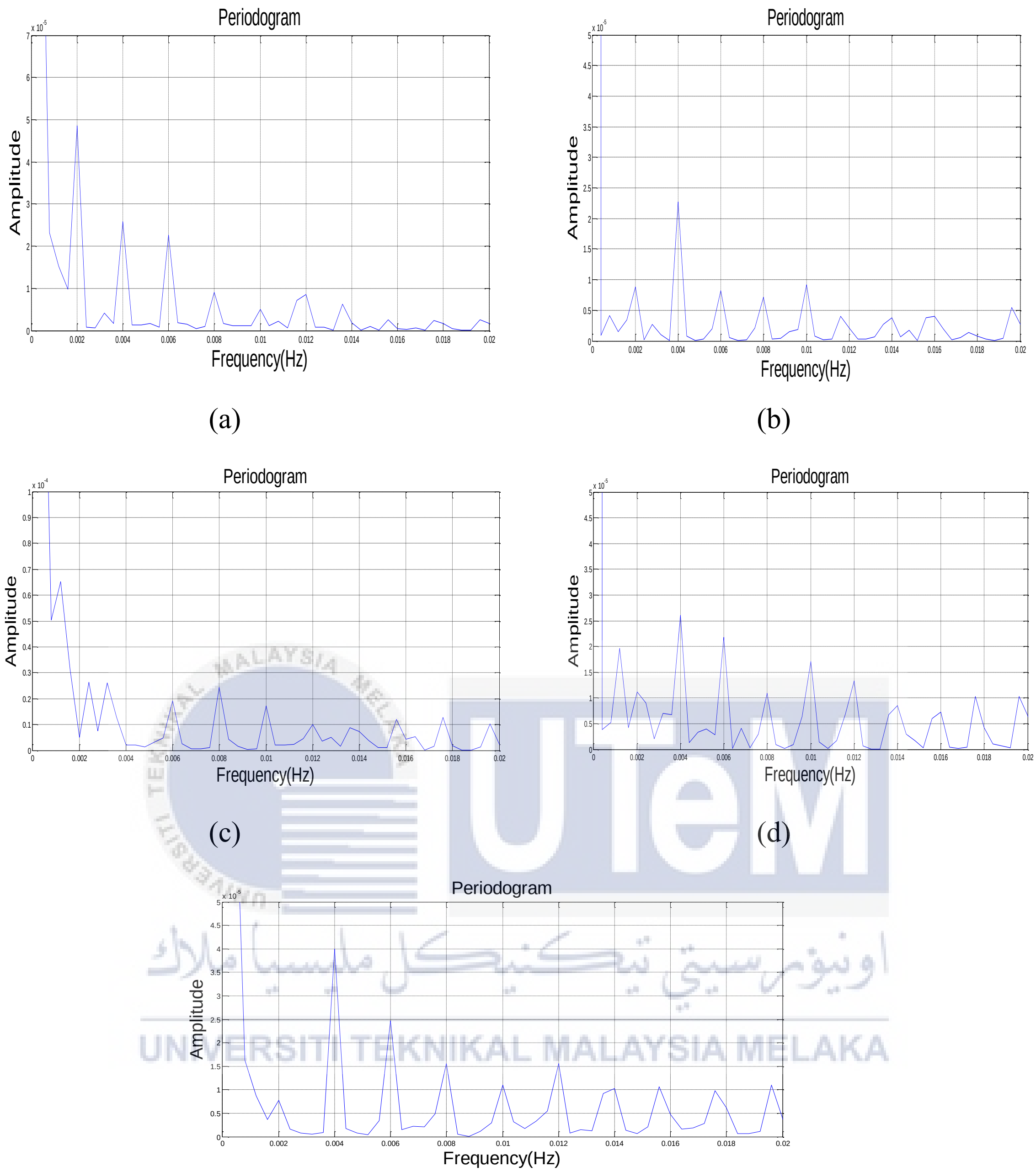


(e)

Figure B3: Periodogram signal for 3A: (a) 20ºC temperature (b) 25ºC temperature (c) 30ºC temperature (d) 35ºC temperature (e) 40ºC temperature



(e)

Figure B4: Periodogram signal for 15A: (a) 20ºC temperature (b) 25ºC temperature (c) 30ºC temperature (d) 35ºC temperature (e) 40ºC temperature