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HYDROGEN INLET PRESSURES PARAMETER ANALYSIS OF PROTON EXCHANGE MEMBRANE FUEL CELL (PEMFC) USING SPECTROGRAM

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ABSTRACT

Proton Exchange Membrane Fuel cell (PEMFC) generates electricity by electrochemical reaction of hydrogen gas and oxygen gas. Identification analysis is required to monitor the effect of fuel pressure towards the performance of PEMFC. Spectrogram capable to tracing changes in the phase behaviour of electrical operations as external parameters is varied. Spectrogram is one of the time-frequency distribution (TFD) analysis techniques as it indicate a 3-Dimensional (3-D) graphic of the energy voltage with depend on frequency and time. The use of this technique is provided in this paper within the scope of monitoring the signal changes in the various load change of a 2000 Watt (W) PEM fuel cell stack. The 99.99% purity of hydrogen inlet pressure is varied from 0.1 bar to 0.5 bar using pressure regulator. GW-Instek GDS-3254 oscilloscope captured the waveform signal with various load demand between 0Amp until 36Amp (A) current. Thus, Spectrogram generated the monitoring of signal voltage and its parameter estimation of voltage direct current (V_{DC}), voltage root means square (V_{RMS}), and voltage alternating current (V_{AC}) of every load changes on various pressure conditions. The voltage performance increases with rise in hydrogen inlet pressures and the spectrogram energy signal increases accordingly. The result shows that voltage performance of PEMFC increased as increased in hydrogen pressure. Therefore, the spectrogram technique has been proven useful and practical in identification parameter of various hydrogen inlet pressure of a PEM fuel cell stack.

Keywords: proton exchange membrane fuel cell, pressure, signals processing, spectrogram.

INTRODUCTION

Fossil fuel sources of electric are going to be exhausted as the rate of electrical demand increases per year (Figueiredo, De, Guillén, and F., 2014). High demand of electricity has forced power producers and researchers to produce more and better electricity supply. Fossil fuel sources of energy which course pollution, greenhouse effect and others global problems should be overcome by encouraging the renewable energy sources. Developments of renewable energy give big impact to the world as it unpolluted waste product besides its performance efficiency could compete with the existing fossil fuel sources.

Proton Exchange Membrane Fuel Cell (PEMFC) is a kind of renewable energy which is most recently introduced. PEMFC generates electricity through the electrochemical reaction without any internal combustion process take place (Ortiz-Rivera, Reyes-Hernandez, and Febo, 2007). This electrochemical occurs as Membrane Electrode Assembly (MEA) layer which innards of PEMFC sustain oxygen gas from cathode inlet and hydrogen gas as fuel from anode inlet. PEMFC provide higher energy density and a longer lasting system compared to a battery system (Ryan, Cha, Whitney, and Fritz, 2006).

However, the improvement of PEMFC disturbed because there are several parameters and characteristic of Fuel Cell which has not yet been studied deeply especially from power spectrum analysis. To overcome this problem, researchers should pay more attention to understand the PEMFC behaviour in order to get the best performance. Therefore, this research investigates the signal identification of various hydrogen inlet pressures on PEMFC by using spectrogram.

The performance characteristics of the PEMFC are affected by many factors either from PEMFC design characteristics itself or from the operating conditions. All of the factors will lead to occurrence of various fatalities such as flooding phenomena, drying phenomena, concentration losses, activation losses and mass transport losses which could lead to damage of PEMFC stack. Table-1 shows the distribution between design characteristics and operating conditions of PEMFC.

Table-1. Factors that affect the performance characteristics.

Design characteristics	Operating conditions
1.Active area of membrane	1. Temperature of stack
2.Thickness of membrane	2. Inlet temperature
3.Roughness of carbon graphite	3. Inlet Pressure
4.Flow channel design	4. Anode inlet flow rate
5.Number of cells	5. Inlet humidity
	6. Purging condition

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PEMFC INLET PRESSURE ANALYSIS

Previously, researchers have analysed the effect of pressure and temperature towards the thermodynamic potential of PEMFC (Gao, Blunier, and Miraoui, 2012), (Khiar, Razali, Ghani, and Chairul Imran Sutan, 2015). In paper of (Atan and Mohamed, 2014) monitoring the effects of varying hydrogen properties towards improvements to individual PEMFC power output stack. Increase of hydrogen pressure in anode inlet would decrease the effect of concentration lost and water vapour diffusivity (purge) (Mishra, Yang, and Pitchumani, 2005).

Identification analysis is important to monitor the factors that play a part in the changes of the performance characteristics. There are various techniques that have been used to identify the effect of fuel pressure towards the performance of PEMFC. In paper written by (Lin *et al.*, 2003) represent the effect of pressure at anode and cathode inlet between a variation of 1 to 3.72 atm by using polarization curve. Monitoring of various pressures condition towards the PEMFC by using Electrochemical Impedance Spectroscopy (EIS) have experimentally studied previously by (Andreasen, Jespersen, Schaltz, and Kaer, 2009). On the other hand, (Fontes, Turpin, and Astier, 2010) in their paper analysed the rough signal characteristics of dynamic PEMFC behaviour.

There are a number of researchers have monitoring the PEMFC by using signal processing technique. Time domain signal would only demonstrate the time for disturbance or any changes in phenomena that are likely to occur at the signal (Abidin, Zainal, *et al.*, 2012). The time domain waveform signal are then transform into the frequency domain waveform signal by using periodogram technique. Thus, periodogram technique represent the distribution of the waveform signal power over the frequency (Ahmad, Abdullah, Bahari, and Hassan, 2014).

Previously (Lima, Almeida, Mendes, and Cardoso, 2007) has analysed PEMFC of 1A and 10A load condition with inverter and DC/AC converter by using periodogram. Apart from that, in paper written by (Shireen and Nene, 2012) experimentally study the periodogram of fuel cell with and without the active filter circuit condition. Previous research also identify the effect of hydrogen inlet pressure on open voltage condition of 30 Watt (W) PEMFC by using periodogram (Razali, Abdullah, Mohamed, and Khiar, 2015). However, the limitation for this technique is it only suitable for stationary signals and does not provide time information (Konar, P., and Chattopadhyay, 2011).

Spectrogram technique is motivated by the limitation of periodogram to cater non stationary signal. There are a lot of researchers study the parameter identification and monitoring by using spectrogram technique such as monitoring the leakage current in high voltage insulators (Abidin, Abdullah, Norddin, and Aman, 2012), battery characteristic analysis (Kasim, Rahim, Selamat, Bahari, and Ramli, 2015), and bio-medic measurement (Mustafa, 2011).

Spectrogram is novel technique to investigate parameter identification of PEMFC performance. Thus, the wave signals generated by varying the supply of inlet hydrogen pressures on a 2KW PEMFC stack using the spectrogram technique are studied. The signal characteristic voltage of direct current (V_{DC}), voltage of root mean square (V_{RMS}), and voltage of alternating current (V_{AC}) parameter from spectrogram are desired to be identified in this research.

SPECTROGRAM

Spectrogram technique is one of the time-frequency distribution (TFD) analysis techniques which represent signal energy with respect to time and frequency. Spectrogram can be defined as (A. R. Abdullah, Zainal, and Aman, 2012) (Hlawatsch and Auge, 2013):

$$S_x(t,f) = \left| \int_{-\infty}^{\infty} x(\tau) w(\tau - t) e^{-j2\pi f \tau} d\tau \right|^2 \quad (1)$$

From equation (1), the $S_x(t,f)$ is a spectrogram in term of frequency and time domain while $x(\tau)$ is the input signal or voltage waveform and $w(\tau - t)$ window of observation window. Thus, the V_{RMS} can be calculated as in equation (2) while a V_{DC} can be calculated as in equation (3) (A. Abdullah and Sha'ameri, 2008).

$$V_{RMS}(t) = \sqrt{\int_0^{f_{max}} S_x(t,f) df} \quad (2)$$

$$V_{DC}(t) = \sqrt{\int_{-\frac{\Delta f}{2}}^{\frac{\Delta f}{2}} S_x(t,f) df} \quad (3)$$

Where f_{max} can be defined as the maximum frequency of interest and $\Delta f/2$ is define as power system frequency. Meanwhile, equation (4) shows the V_{AC} (Kasim *et al.*, 2015).

$$V_{AC}(t) = \sqrt{V_{rms}(t)^2 - V_{DC}(t)^2} \quad (4)$$

EXPERIMENTAL SETUP

Presently, this report represents the parameter identification of various hydrogen inlet pressures on fuel cell by using spectrogram. From this experiment, 48-cells open cathode H-2000 Horizon PEMFC stack with 2 kilo watt (KW) maximum power rating was used. On the anode inlet side, dry hydrogen gas (H_2) with 99.99% purity as well as non- humidified has been applied as fuel agent. For the meantime, cathode inlet side utilised air at ambient conditions considering this PEMFC is an open cathode type. Table-2 shows the technical specification of the H-2000 PEMFC.

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This experiment varied the hydrogen (H_2) pressures at anode inlet within 0.1, 0.2, 0.3, 0.4 and 0.5. Meanwhile air flow at the cathode side is not varied. The hydrogen pressure variation was obtained using a pressure regulator. For the development of this project, GW-Instek GDS-3254 oscilloscope was used to capture the waveform signal where the probe is connected to the current collector plates. Figure-1 shows the experimental setup of H-2000 PEMFC with oscilloscope and the pressure regulator to vary the pressure of the hydrogen (H_2) gas into the anode side.

On this experiment, dry hydrogen is used as a fuel supply to activate the PEMFC. Every data of various H_2 pressures are taken at a various load condition between 0Amp until 36Amp (A) current. As a precaution step, the maximum pressure that applied to the PEMFC to conduct this experiment is limit to 0.5 bar. This is required in order to prevent the MEA membrane of the inner part of PEMFC from leaks. PEMFC would definitely damage or its performance would be dropped if there is leakage in the MEA layer.

Table-2. H-2000 open cathode PEMFC operation specifications.

Parameter	Values
Reactants	Hydrogen and Air
Ambient temperature	30^{o}C
Max H_2 pressure	0.55 bar
H_2 supply pressures (gage)	Up to 0.55 bars
H_2 purity	≧99.995% dry H2
H_2 flow rate at max output	26 L/min
Stack dimension	30.3cm x 35cm x 18.3cm
Start-up time	≦30s at ambient temperature
Efficiency of stack	40% @ at full power
Performance	28.8V @ 70A

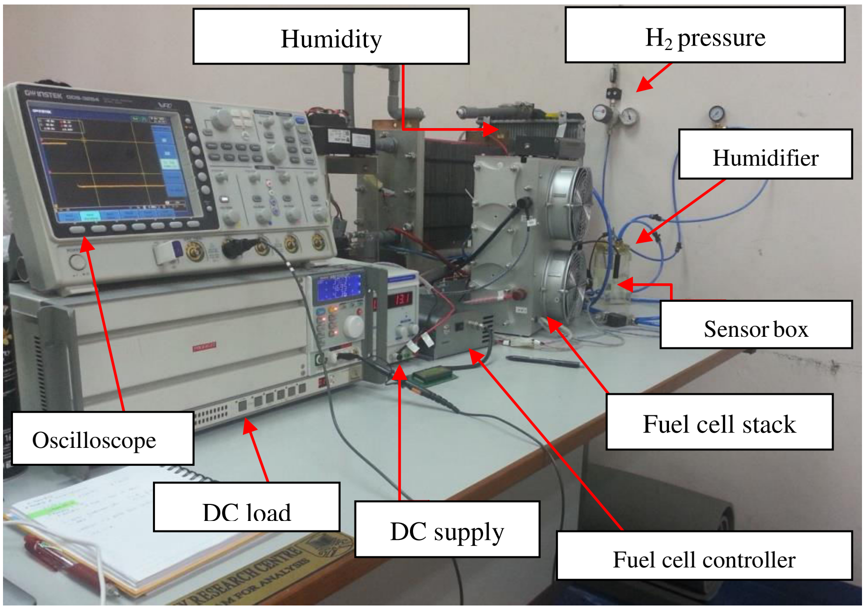

Figure-1. Experimental setup of H-2000 PEMFC.

RESULT AND DISCUSSIONS

Figure-2 shows the result of voltage signal in time for experimental of 2KW PEMFC at various hydrogen pressures for 21 A load condition. During the condition of 0.1 bar pressure, the signal voltage shows the value of 31.90 Volt (V). The signal voltage for 0.2 bar pressure is then increased for about 2.2% making it 32.60V. The signal voltage of 0.3 bar pressure has increased by 1.5% to 33.10V. Meanwhile, the signal voltage for 0.4 bar pressure is increased by 0.61% to 33.30V. The signal voltage for 0.5 bar pressure is then increased for about 0.9% making it 33.60V. The increment of voltage by 0.9% to 33.60V was registered as the hydrogen pressure is increased to 0.5 bar pressure.

These figures show existing of slight decreased on every signal voltage. This is due to the purging factor that present from the 2KW PEMFC. However, it has demonstrated a record voltages drop for only 0.1V to 0.2V. The time taken for the purging factor for these PEMFC is keep constant for about every 10 second.

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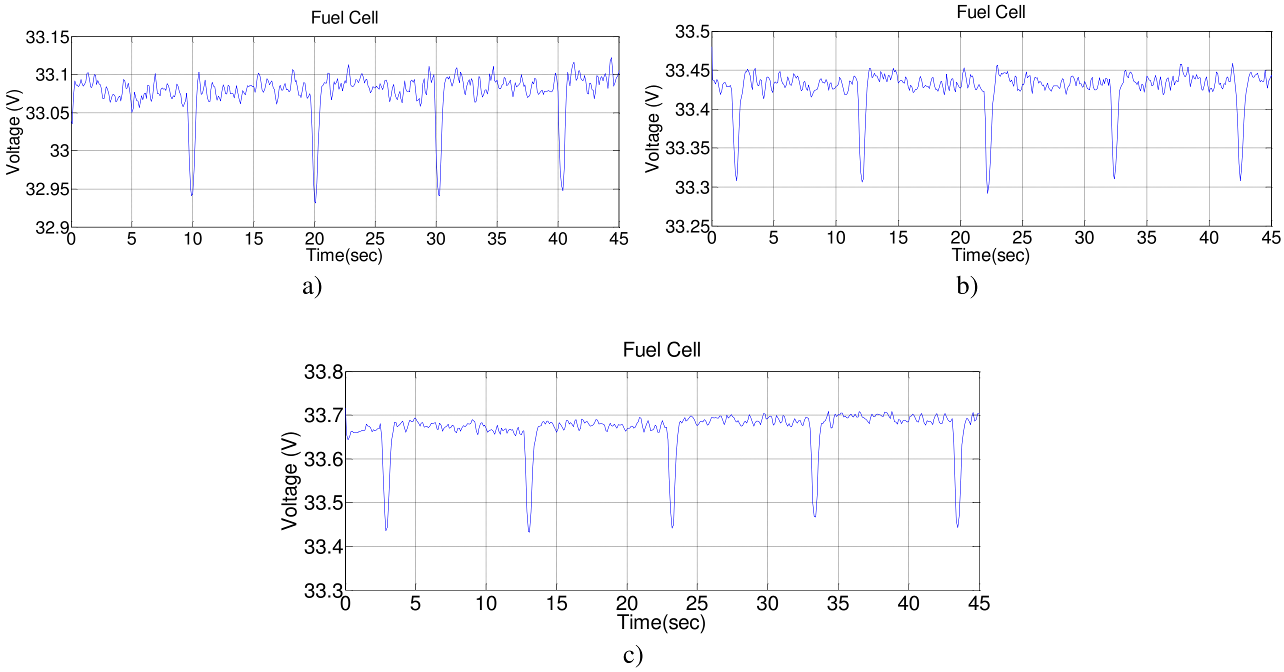

Figure-2. Signal voltage of 2KW PEMFC with different of hydrogen pressure at anode side of 21A load: a) 0.3 bar H_2 pressure b) 0.4 bar H_2 pressure c) 0.5 bar H_2 pressure.

Figure-3 shows the time-frequency representation of spectrogram. This spectrogram indicate a 3-Dimensional (3-D) graphic of the energy voltage with depend on frequency and time. Thus, spectrogram graph will provides information on the changing frequency content of a signal over time. The time resolution of the graph could be better if the window size is smaller. The window that has been used in this research is hanning window with 128 window size. However, the resolutions are decrease as the decrease in window size (Rosero, Cusidó, Garcia Espinosa, Ortega, and Romeral, 2007). The colour indicator represented the magnitude of energy voltage of the spectrogram. Red indicator represented highest amplitude value while blue indicator for the low amplitude value. It shows that the highest magnitude took place on the low frequency area.

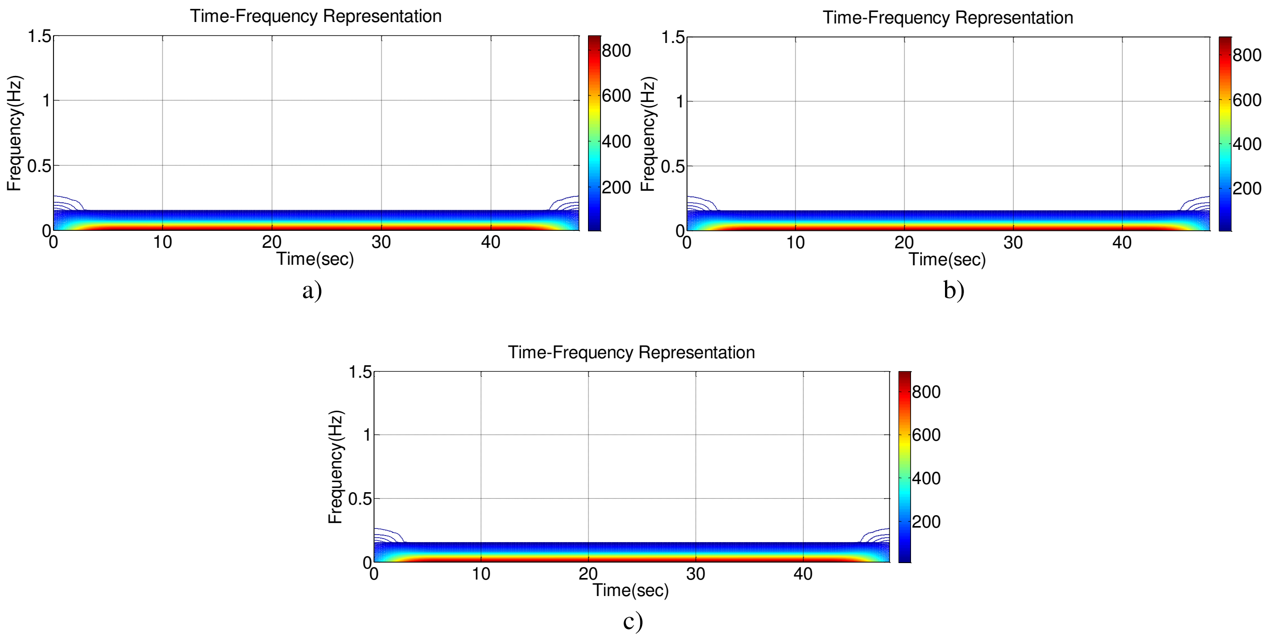

Figure-3. Time frequency representation of 2KW PEMFC with different of H_2 pressure at anode side of 21A load: a) 0.3 bar H_2 pressure b) 0.4 bar H_2 pressure c) 0.5 bar H_2 pressure.

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Afterward, the spectrogram are then generated the signal voltage and its parameter estimation of V_{RMS}, V_{DC}, and V_{AC} of every load changes on various pressure conditions. Figure-4, 5 and 6 respectively shows the signal voltage of V_{RMS}, V_{DC}, and V_{AC} for 21A load condition with various hydrogen pressures. It shows that the value of V_{DC} at 0.1 bar until 0.5 bar pressures respectively increased from 34.4401V, 35.1251V, 35.6903V, 36.0667V, to 36.3292V. Apart from that, the V_{RMS} value for 0.1 bar until 0.5 bar pressures respectively increased from 34.4405V, 35.1255V, 35.6907V, 36.0671V to 36.3299V. Therefore, the signal voltage is increased as the hydrogen pressure is increased. The zoomed graphs which represent the micro behaviour of the signal show the instability of the wave form. However the instability of the signals is only in small value which is around 0.001V to 0.004V.

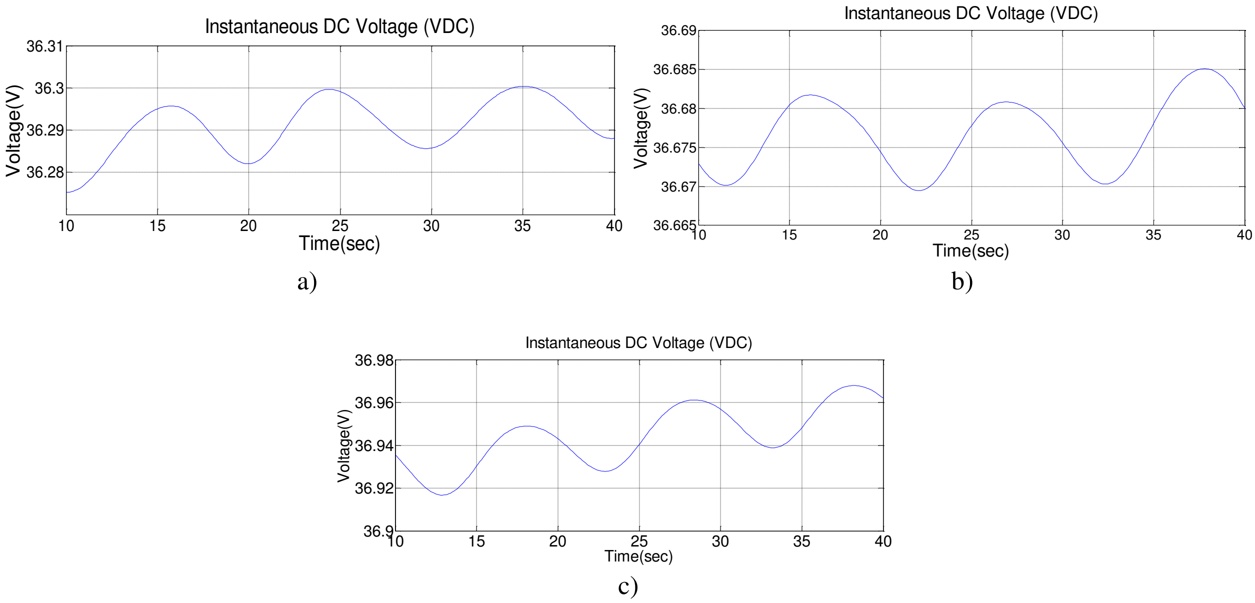

Figure-4. The signal voltage of direct current for 21A load: a) 0.3 bar H_2 pressure b) 0.4 bar H_2 pressure c) 0.5 bar H_2 pressure.

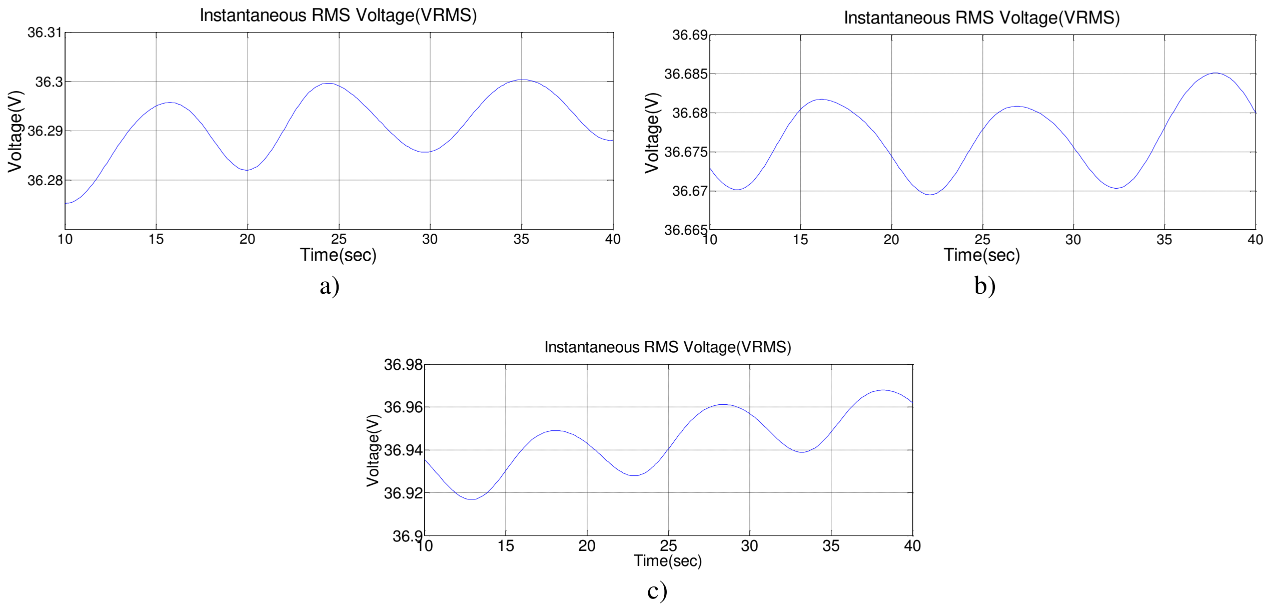

Figure-5. The signal voltage of root mean square for 21A load: a) 0.3 bar H_2 pressure b) 0.4 bar H_2 pressure c) 0.5 bar H_2 pressure.

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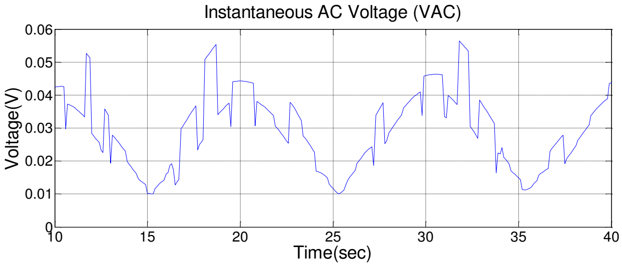
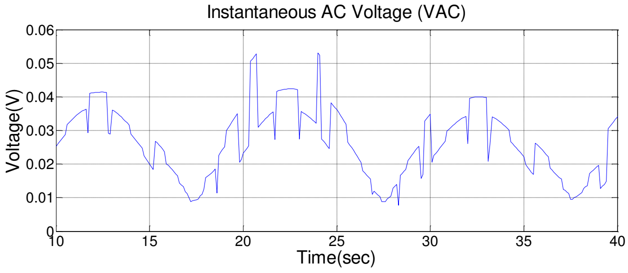
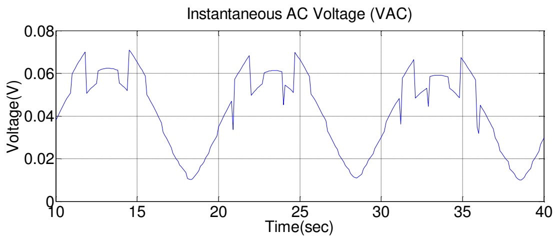


a)



b)



c)

Figure-6. The signal voltage of alternate current for 21A load: a) 0.3 bar H_2 pressure b) 0.4 bar H_2 pressure c) 0.5 bar H_2 pressure.

The signal characteristic of V_{DC}, V_{RMS}, and V_{AC} were identified. Hence, Figure 7, 8, and 9 respectively represent the overall results for estimated parameter of V_{RMS}, V_{DC}, and V_{AC} at various hydrogen pressure conditions. It shows that the voltages estimated of V_{RMS} and V_{DC} is decreased as the load demands are increased. This is due to existing of larger load resistance at increasing load demand (Benziger, Satterfield, Hogarth, Nehlsen, and Kevrekidis, 2006). Besides that, the value parameter estimated larger as the hydrogen pressure from the anode inlet is increased. Researchers declared that higher operating pressure of PEMFC could overcome the oxygen transfer limitation towards membrane (Zhang, Wu, and Zhang, 2013).

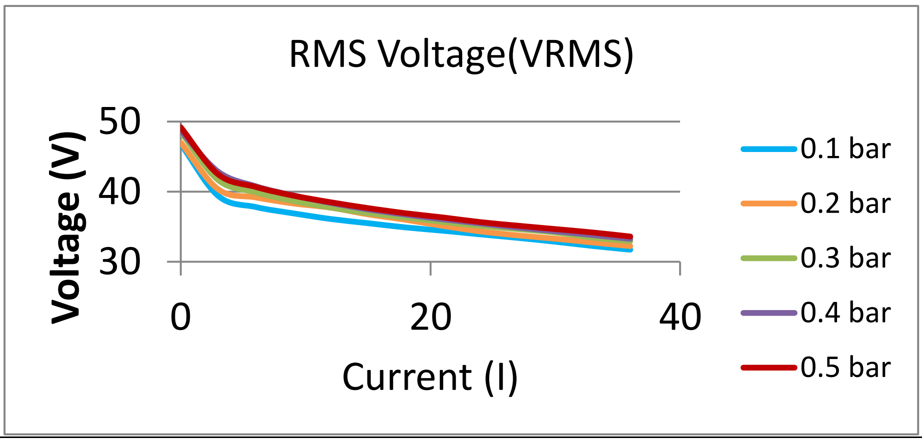


Figure-7. Estimated of V_{RMS} parameter at various hydrogen pressures.

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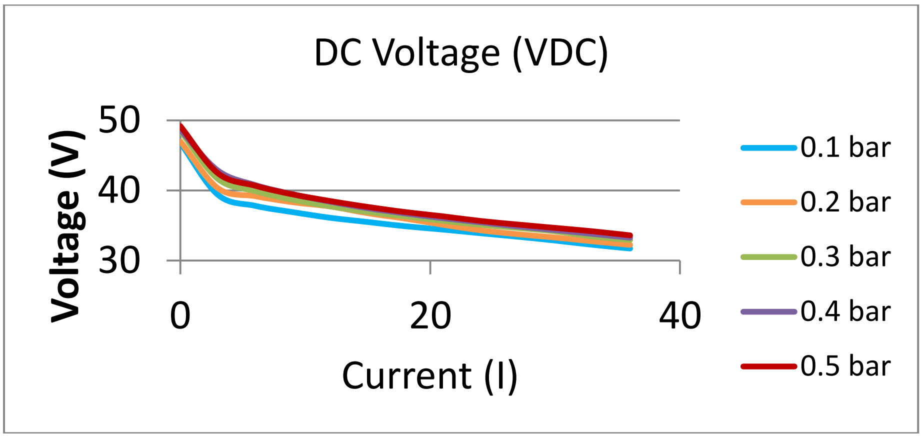
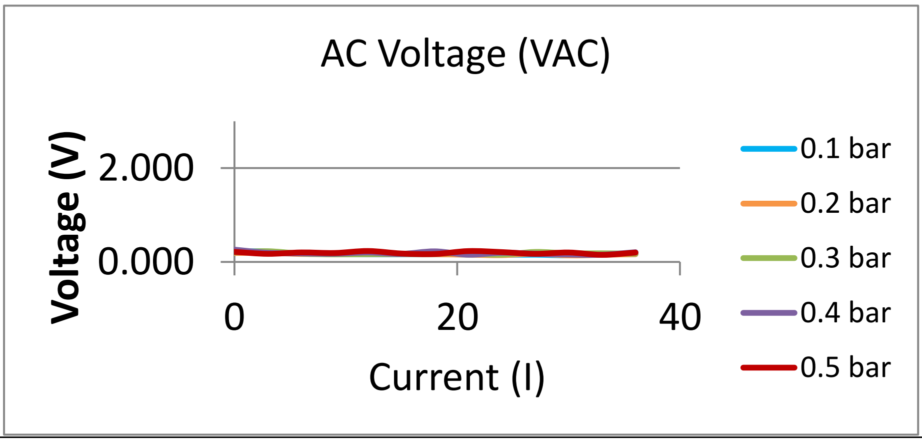


c)

Figure-8. Estimated of V_{DC} parameter at various hydrogen pressures.



c)

Figure-9. Estimated of V_{AC} parameter at various hydrogen pressures.

CONCLUSIONS

This experimental study been performed to analysed the variety of hydrogen pressures of PEM Fuel cell by using spectrogram. Thus, Spectrogram generated the signal voltage and its parameter estimation of V_{RMS}, V_{DC}, and V_{AC} of every load changes on various pressure conditions.

It indicated that signal estimation of V_{DC} and V_{RMS} changed as the hydrogen pressure is raised. Apart from that, it also shows that the value of V_{AC} distortion parameter that present in the PEMFC is changed as the hydrogen pressure is changed. Therefore, this experiment shows the relationship between the hydrogen pressures at the anode side toward the performance of PEMFC by using spectrogram. Consequently, the signal characteristics of various hydrogen pressures are well presented by using spectrogram method.

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