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Stack temperature parameter analysis of proton exchange membrane fuel cell (PEMFC) using spectrogram

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Abstract: The uncertain condition in Proton Exchange Membrane Fuel Cell (PEMFC) affected by many factors either from the design characteristics itself or from the operating conditions. Unstable voltage in PEMFC occurs for every changes load demand and requires time to warm up before it reaches the stable voltage conditioned. An unstable power supply can damage the entire system and even put the life of an operator at risk as well as decreased its life time. This research required to analyses and extracts the PEMFC voltage signal under various stack temperature conditions and changed load demand. Time-frequency distribution (TFD) is presently used as technique to analyse the PEMFC voltage signal. The parameter of instantaneous direct current (V_{DC}), instantaneous root mean square (V_{RMS}), and instantaneous alternating current (V_{AC}) are extracted and from the spectrogram result. Such relationship between instantaneous V_{DC}, V_{RMS}, and V_{AC} parameter on every load demand at various stack temperature are discussed and summarized. Thus, this parameter estimation is significant to be used in development of system identification.

Key words: Signal; Frequency; Load demand; Instantaneous voltage

1. Introduction

Increasing energy demand in turn leads to an increase in greenhouse effect and increase in fuel prices (Baños et al., 2011). Therefore, this problem encourages utilizing renewable energy sources in more optimize. In addition, 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. About 14% of the total world's energy resources are produce from renewable energy (United Development Programme, 2011).

The performance of PEMFC voltage signal are affected by many factors either from PEMFC design characteristics itself or from the operating conditions. These factors will make the PEMFC in uncertain condition. All of the factors will lead to occurrence of various fatalities which could lead to damage of PEMFC stack.

More information regarding to change in PEMFC system parameter is required to determine the efficiency of the PEMFC (Bar-On et al., 2002). Apart from that, (Dhirde et al., 2010) mentioned that researchers should pay more attention to understand the PEMFC behaviour in order to gain the best performance characteristic. Therefore, the improvement of PEMFC is disturbed as there are various parameters and features of the PEMFC that have not yet to be discovered intensely especially on the power spectrum analysis.

A voltage generated from the PEMFC always in unstable condition (Chen and Zhou 2008). According (Tzamalis et al., 2011) on their researcher mentioned that PEMFC needs time to warm up before it reaches the stable voltage conditioned. However, this unstable voltage occurs for every load demand changes (Zhang et al., 2012). An unstable power supply can damage the entire system and even put the life of an operator at risk as well as decreased its life time (Onwubolu, 2005). This is hard for researchers to stable the PEMFC as it takes a lot of time and hydrogen fuel consumption. For that reason, a lot of researchers simply applied the DC/DC converter to maintain and balance the output voltage of PEMFC without profoundly analysed the actual problems that occur (Zhang et al., 2013b). Therefore, this research analysed the PEMFC voltage signal under various stack temperatures conditions and changed load demand. Apart from that, the parameters of PEMFC voltage signal such as V_{RMS}, V_{DC} and V_{AC} from time-frequency representation (TFR) are required to estimate.

2. Temperature analysis

Stack temperature is one of the factors that change the behaviour of PEMFC. The research on effect of temperature towards the performance of PEMFC stack on dead end mode stated that performance of PEMFC increased as the temperature

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is increased. This is due to the increase of gas diffusivity, membrane conductivity, current exchange activity as well as decrease of activation losses (Pérez-Page and Pérez-Herranz, 2011).

(Freire and Gonzalez, 2001) mention that increase in temperature will recover the back diffusion phenomena that result from cathode to anode water transport. However, step changed load researched that performed by (Yan et al., 2006) shows that PEMFC performance was worse as the stack reach critically high temperature. This is because the membrane conductivity decreases at high temperature and going to be dried.

On the other hand, (Riascos and Pereira, 2009) mentioned that drying or flooding phenomena to the membrane of PEMFC occurs if the stack temperature are too high or the internal are too wet. Therefore, temperature or thermal management in PEMFC is required in order to control the performance of PEMFC.

Previous researcher by (Asghari et al., 2010) has study the effect of temperature towards the PEMFC by using the electrochemical impedance spectroscopy (EIS) technique. It state that charge transfer resistance and mass transport resistance is decrease as the temperature is increase. This is due to increase in proton mobility which had subsequently led to the increase in the membrane conductivity (Yan et al. 2007b). Current interruption (CI) technique also been done by (Rubio et al., 2007) to estimate the flooding level of PEMFC in dynamic condition.

3. Signal processing analysis

There are a number of researchers have directly identify the PEMFC by using signal processing technique. Raw signal or time domain signal would only shows the time for disturbance or every change in that take place at the signal (Abidin et al., 2012a). Thus, signal processing analysis represents the time domain signal transform into either frequency domain or time-frequency representation (TFR) (Ahmad et al., 2014).

PEMFC of 1A and 10A load condition with inverter and DC/AC converter has been analysed previously using periodogram (Lima et al., 2007). Previous research (Shireen and Nene 2012) also made research on the periodogram from the PEMFC with and without the active filter circuit condition. In addition, effect of hydrogen inlet pressure on open voltage condition towards 30 Watt (W) PEMFC was analysed using periodogram by the previous researcher (Razali et al., 2015).

Spectrogram is one of the linear time-frequency distributions (TFD) where it is encouraged by the limitation of periodogram to cater non stationary signal (Hory et al. 2002). Previously, researchers have experimentally study the leakage current in high voltage insulators (Abidin et al., 2012b), battery characteristic analysis (Kasim et al., 2015), and bio-medical application (Mustafa et al., 2011). This spectrogram indicate a 3-Dimensional (3-D) graphic of the energy voltage with depend on frequency and time. Spectrogram can be defined as (Abdullah et al., 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 time-frequency distribution while $x(\tau)$ is the input signal or voltage waveform and $w(\tau - t)$ window of observation window. Thus, the instantaneous V_{RMS} can be calculated as in equation (2) while an instantaneous V_{DC} can be calculated as in equation (3) (Abdullah and Sha'ameri, 2008).

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

$$V_{DC}(t) = \sqrt{\int_{f1-\frac{\Delta f}{2}}^{f1+\frac{\Delta f}{2}} S_x(t,f) df} \quad (3)$$

Where f_{max} can be defined as the maximum frequency of interest,$_1$ is the fundamental frequency and Δf is defined as bandwidth. Meanwhile, equation (4) shows the instantaneous V_{AC} (Kasim et al. 2015).

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

The signal characteristic voltage of direct current (V_{DC}), voltage of root mean square (V_{RMS}), and voltage of alternating current (V_{AC}) parameter that extract from spectrogram are desired to be analysed in this experiment.

4. Methodology

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 1 shows the technical specification of the H-2000 PEMFC.

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. Fig. 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.

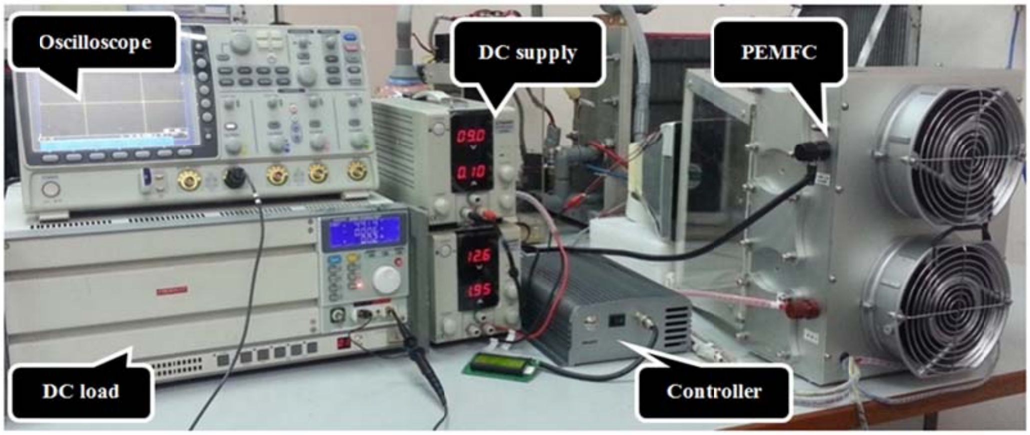

Fig. 1: Experimental setup of H-2000 PEMFC

Table 1: H-2000 open cathode PEMFC operation specifications

Parameter	Values
Reactants	Hydrogen and Air
Ambient temperature	30ºC
Max H_2 pressure	0.55 bar
H_2 supply pressures (gage)	Up to 0.55 bars
H_2 purity	≧99.995% H2
H_2 flow rate at max output	26 L/min
Stack dimension	30.3cm x 35cm x 18.3cm
Efficiency of stack	40% @ at full power
Performance	28.8V @ 70A

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5. Results and discussion

From this experiment, the signals information from 2KW PEMFC stack is generated by varying the operating condition of the system. The temperature stack variations towards the performance of PEMFC are investigated in this research by using a novel approach spectrogram technique. Afterward, the spectrogram are then generated the signal voltage and its parameters estimation of instantaneous V_{RMS}, V_{DC}, and V_{AC} of every load changes on various stack temperature conditions.

6. Time domain information analysis

Fig. 2 shows the raw signal voltage of PEMFC at25 ºC stack temperature with 3A load conditions. From the signal, voltage value of 20 ºC stack temperature is 37.72 Volt (V). The signal voltage for 25 ºC is increased by 0.21% for 37.8V. The signal voltage is then increased about 0.58% making it 38.02V for 30 ºC stack temperature.

There are slight decreases present in signal voltage. The purging of water vapour or excess water is cause of the voltage drop. 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. The raw signal of PEMFC are then analysed by using TFD technique.

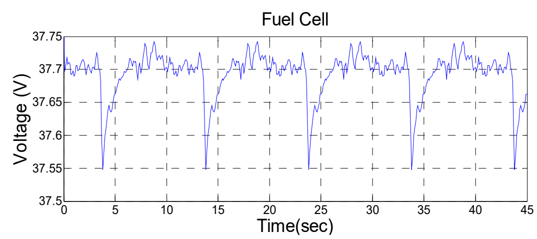


Fig. 2: Time domain information of 2KW PEMFC at 3A load demand with20ºC stack temperature

7. Time-frequency distribution analysis

Fig. 3 represents the spectrogram which indicated the magnitude information on the changing frequency content of a signal over time. 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. Ideal voltage states that a DC source has no frequency which is in 0 Hz frequency condition. However, result from spectrogram capable to detect the existence of frequency distortion from the PEMFC source.

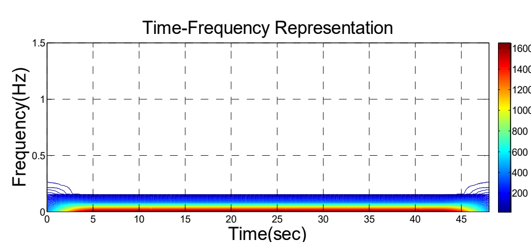


Fig. 3: Time-frequency representation from spectrogram technique

The spectrogram are then generated the signal voltage and its parameter estimation of instantaneous V_{RMS}, V_{DC}, and V_{AC} at every load changes for various stack temperature conditions.

Fig. 4 (b) (c) and (d) respectively shows some signal example of parameter estimation for V_{RMS}, V_{DC}, and V_{AC} at 25 ºC stack temperature with 15A load condition.

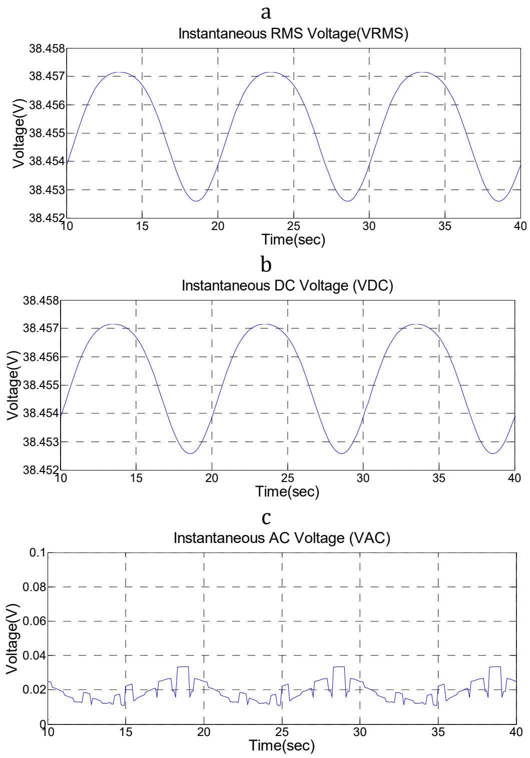


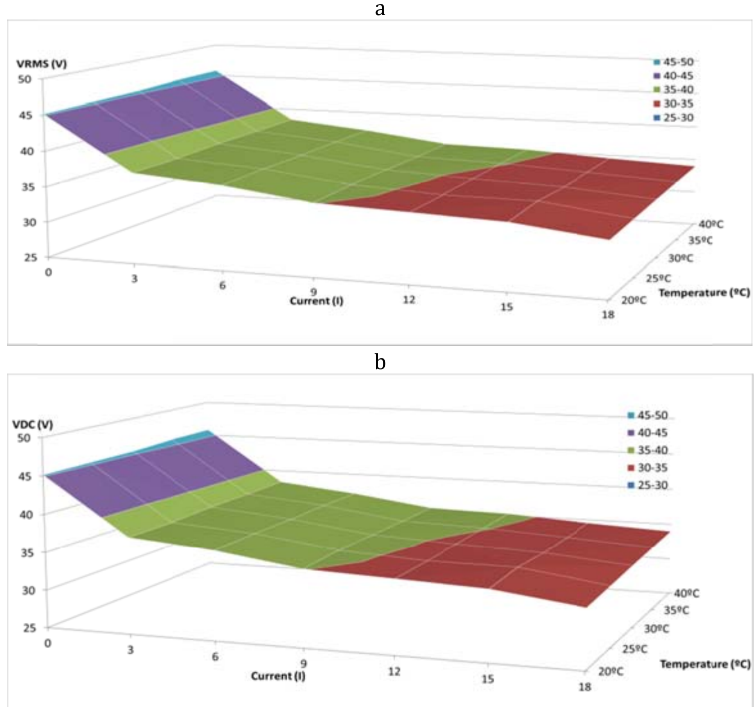
Fig. 4: Parameter identification for 2KW PEMFC at 25 ºC stack temperature with 15A load: a) instantaneous root mean square b) instantaneous direct current c) instantaneous alternate current

8. Parameter estimation

The signal characteristics of instantaneous V_{DC}, V_{RMS}, and V_{AC} are analysed. Therefore, the overall results of analysed parameter at various temperatures conditions are respectively shown in Fig. 5 (a) (b) and (c). It shows that signal voltage of V_{DC}, V_{RMS} decreased as the load demand is increased. It also indicated that the greater stack temperature contribute to higher signal voltage. Stack performance increases as the gas diffusivity and kinetic reactions is improve at high temperature. Spectrogram able to analysed the existence of V_{AC} signal from the DC sources. However, it shows that high distortion rate is present at high and low load demand areas. Low load demand with low temperature shows high distortion value. This is due to low stack temperature which causes the flooding phenomena will hinder the O_2 movement. This condition increases the mass transport losses and consequently decreases the PEMFC performance.

High load demand area also shows high distortion rate which previous researcher stated that large load resistance exist at high load demand. On high load demand area, rate of distortion at high temperature is greater compare to low temperature. High temperature and load demand require fast electrochemical reaction rate by inlet inflow and outflow rate. However, greater outflow rate will increased the rate of distortion at those conditions. Critical temperature will cause dried membrane and thus increase the performance resistance.

a



c

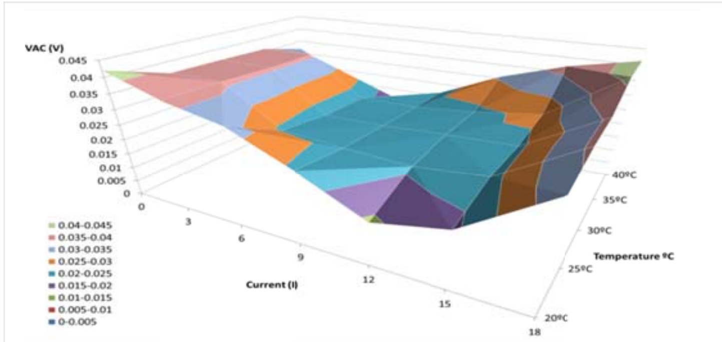


Fig. 5: A 3-D map rate of estimated for various temperature and load demand at: a) V_{RMS} parameter estimation b) V_{DC} parameter estimation c) V_{AC} parameter estimation

9. Conclusion

Spectrogram is one of the TFR techniques to cater non stationary signal. The signal characteristics of V_{DC}, V_{RMS}, and V_{AC} are analysed from this TFD. It shows that performance voltage of V_{DC}, V_{RMS} decreased as the load demand in PEMFC is increased. Spectrogram able to analysed the present of V_{AC} which cause the unstable voltage signal from the DC sources. Therefore, it detected the existence of frequency distortion on every temperature condition and load demand.

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