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Open-Cathode Hydrogen Experimental of 5 watt Polymer Exchange Membrane Fuel Cell

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ABSTRACT

In this work, an analysis of an open-cathode hydrogen pressure based on experimental approach was conducted at Alternative Energy Research Centre, Faculty of Mechanical Engineering Universiti Teknologi MARA Shah Alam. The polymer electrolyte membrane (PEM) fuel cell is a custom-built device consisting of five membranes or cells. The aim is to observe the polarization curve of 5 watt PEM fuel cell. The experiment on the PEM fuel cell has been conducted for data collection and analysis. The performance of fuel cells was measured by varying the hydrogen supply (supplied at the anode side and the relative humidity. The outputs of PEM fuel cell were measured in net power, watt and stak voltage, volt where the curve was plotted. The result obtained from the experiment shows a similarity in the trend of the polarization characteristic curve.

Keywords: *proton exchange membrane fuel cell; open-cathode; hydrogen; polarization curve*

1. INTRODUCTION

The concept of fuel cell dates back to the early 1800s. Efficient and clean energy offered by fuel cell systems has perhaps initiated several producers of stationary and mobile applications of today to conduct a thorough development [1]. The PEM fuel cell systems can generate power from miliwatts (mW) up to kilowatts (kW) capacities, so it can cover a wide range of applications. The range of the power generation contributes a big advantage to this type of fuel cell as once the technology is advanced, the range can be applied to variety of applications [2]. In transportation and stationary application, PEM fuel cell could be the favorable power source due to its higher efficiency, lower temperature operation, higher power density, faster startup, and high system robustness [3]. A fuel cell can generate electricity by a chemical reaction. Every fuel cell has two electrodes, one positive (anode) and one negative (cathode). The reactions that produce electricity take place at the electrodes. Electrically charged particles from one electrode to the other carried by electrolyte in every fuel cell [4]. Hydrogen gas flows on to an electrode (anode), and with the help of catalyst, it is separated into electrons and hydrogen protons [4,5]. During the catalyst process, it will also speed up the chemical reactions at the electrode side. The protons and electrons will create electricity by the flowing of protons to the other electrode (cathode) through the electrolyte while the electrons flow through an external circuit. The combination of hydrogen protons and electrons with oxygen flowing through the cathode will produce water as the waste

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product of the fuel cell [5]. Figure 1 shows the schematic diagram of a proton-conducting fuel cell.

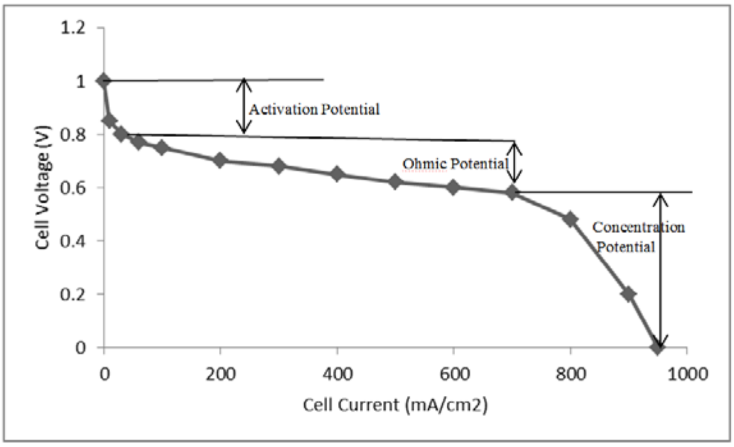

Figure 1: The polarization curve of fuel cell stack

The behavior of PEM fuel cell can be studied either under an open cathode or closed-cathode. A open cathode PEM fuel cell uses a fan to pull air through the cathode channels to deliver oxygen to the cathode catalyst layer and cool the stack [6]. Standard exergy sensitivity analysis powered by a 1kW open cathode PEM fuel cell has been studied to evaluate efficiency related to pressure and temperature variations [7]. Several researchers have carried out an investigation on an open cathode PEM fuel cell either in the temperature characteristic, pressure or the electrochemical impedance spectroscopy measurements [8-11]. The profiling of stack cooling of 3-cell PEM fuel cell was developed as a platform for thermal engineering studies [12]. There is a continuation from this work where [13] have conducted an experimental thermal analysis on air cooling for closed-cathode PEM fuel cell. Optimisation of air cooled of an open-cathode fuel cells was also have been studied by [14] to minimize the resistive losses and optimize the operating conditions. A 16 fuel cell stack was simulated and tested experimentally for compression test of open cathode PEM fuel cell [15]. This paper presents the polarization curve of five fuel cell stacks with 5 watt electric power output where in-depth observation and analysis based on load current was discussed. Analysis based on various hydrogen operating conditions as well as load conditions was also conducted and studied in this open-cathode experimental.

2. METHODOLOGY

In this work, the experimental set-up was done at Alternative Energy Research Centre (AERG), Faculty of Mechanical Engineering Universiti Teknologi MARA Shah Alam Selangor. The aim of this experiment is to analyze the characteristic of PEM fuel cell system by varying the hydrogen inputs as well as to obtain the polarization curve of an open-cathode with five cells stack. There were four sub-systems involved in this experimental set-up. The systems were the gas supply system, the flow rate systems, the humidifying system, and the electronic load system. The experimental study was conducted using a custom-built 5 watt fuel cell under an open-cathode operation. The hydrogen fuel was supplied from a hydrogen tank while the air was supplied from fan at the cathode side while the load current was applied

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to the fuel cell using a DC loader. The schematic diagram of the experimental apparatus used in this work is shown in Figure 2.

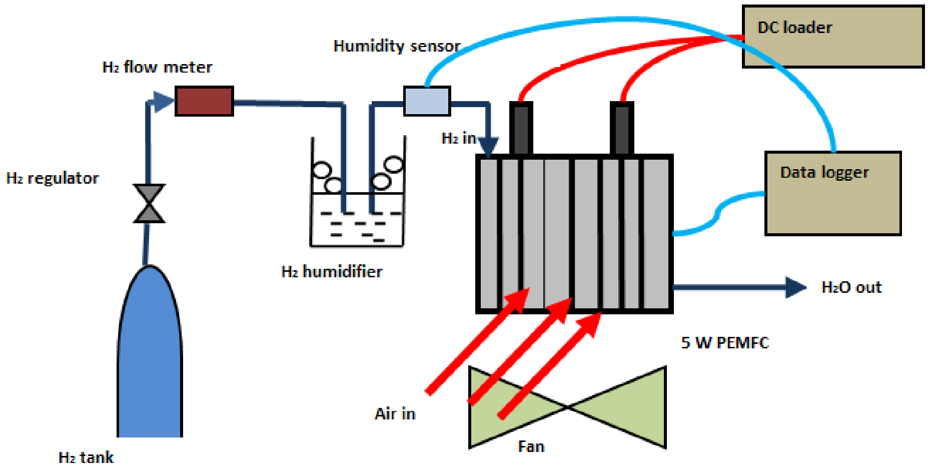

Figure 2: Illustration of the an open-cathode schematic diagram

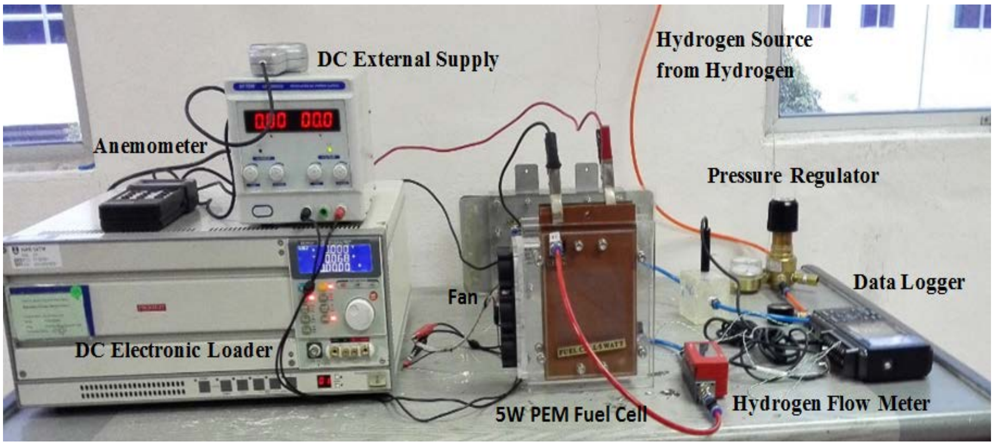

Figure 3: The experimental set-up for an open-cathode PEM fuel cell

Figure 3 shows the experimental set-up of open-cathode hydrogen which used the hydrogen gas tank, pressure relief valve, flowmeter, 5 watt PEM fuel cell, fan, DC power supply, DC loader, anemometer, and data logger. The 5 watt custom-built PEM fuel cell was used for this open-cathode experiment in order to analyse the characteristics of hydrogen variations in terms of net power and stack voltage. The construction of 5 watt PEM fuel cell can be seen in Figure 4 where the fuel cell stack consisted of five individual cells connected in series with two different flow field configurations which was a combination of convectional serpentine and inter-digitated flow field. The stack used an air fan for combined oxidant supply and cooling as in Figure 4. The flow channel layout was designed in such way in order to improve the stack performance by creating active transport reactant in close vicinity to the electrode.

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Figure 4: The 5 watt PEM fuel cell stack

2.1 Experimental set-up and procedures

The data that can be collected from an open-cathode experiment is the stack voltage (V) and the net power (W) of the 5 watt PEM fuel cell. This section explains the proceduces involved in this experiment:

a. Firstly, the experiment was set up as in Figure 3. All of the instruments and the subsystems; Hydrogen gas tank, pressure relief valve, flowmeter, 5 watt PEM fuel cell, fan, DC power supply, DC loader, and data logger were then connected.
b. The humidify hydrogen gas was collected in the humidity sensor. The humidity level (%) of the hydrogen gas displayed by the GRAPHTEC data logger was recorded.
c. Hydrogen was flowed into the anode of the stack fuel cell. It had been varied from 0.0 bar to 0.5 bar.
d. The pressure relief valve was used to control or limit the pressure from the hydrogen gas tank while flowmeter measured the flow of the hydrogen.
e. Oxygen was then flowed into an open cathode of the stack fuel cell by the fan. The oxygen gas supply came from the surrounding air at room temperature.
f. DC power supply was used to operate the fan. The higher the voltage from DC power supply the higher the speed rotation of the fan thus the higher the rate of oxygen supply. The maximum voltage that can be fed to the fan is 12V.
g. The voltage from DC power supply applied to the fan was fixed at 6.0 V. The velocity, flow, and temperature of the oxygen were measured by an anemometer.
h. The current or stack current (A) applied to the current collector of the fuel cell stack was then loaded by DC loader.
i. The load current had been increased from 0.0A up until 3.6A in order to deplete the stack voltage (V) of the fuel cell from the maximum voltage it can produce until no more stack voltage can be produced by the fuel cell (0.00V).
j. Starting from 0.0A load current, the measurements of the stack voltage (V) of the 5 watt PEM fuel cell were taken until the stack voltage becomes 0.00V in order for the data to be analyzed and studied.
k. The hydrogen and oxygen inside the fuel cell stack needed to be purged first before inserted with the new one in order to conduct the new experiment with different hydrogen pressure.
l. Lastly, data collection was kept for further analysis.

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3. RESULTS AND DISCUSSIONS

A custom-built 5 watt fuel cell stack was used during the experiment with ambient temperature of 297.15 K. An open-cathode circuit has a DC fan acts as air and cooling, as the hydrogen supply was varied. As the fuel cell stack had an open-cathode, only hydrogen supply was controlled by the pressure valve. Table 1 shows the details of PEM fuel cell specifications used in this open-cathode experiment.

Table 1: Speification of PEM fuel cell stack

Item	Specification
Cell number	5
Fuel	H_2/Air
Power	5 watt
Cooling type	Fan
Ambient temperature	297.15 Kelvin

Two sets of experiments were conducted to characterize an open-cathode fuel cell stack. The first experiment was to measure the load current operation at different operating pressures of applied hydrogen. Here, the pressure of hydrogen was varied from 0.1 to 0.5 bar in order to see the effect of it towards the stack voltage. The voltage-current characteristics of the PEM fuel cell was measured based from load current given by DC electronic loader and pressure of hydrogen applied to the fuel cell stack. This result is shown in Figure 5 due to variation in hydrogen operating points. It can be seen that, as the load current increased, the voltage also decreased. It behaves like an inverse from the ohm's law where voltage should be increasing proportionally with the current, but in this experiment the load current acted as a resistance to the PEM fuel cell. It shows that an increase in the pressure also increased the flow and thus improved the voltage of fuel cell.

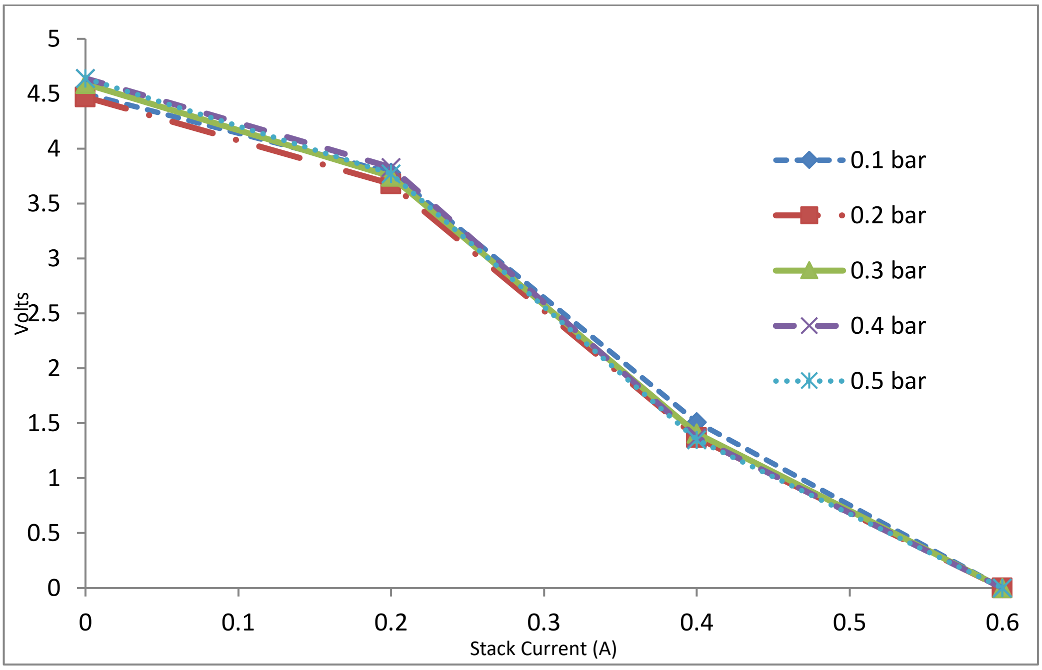

Figure 5: Hydrogen pressure of voltage versus load current

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The response of net power versus the load current can be seen in Figure 6. From the observation, the power increased with the load current at 0.6 A. Based on the result obtained in Figure 6, it shows that if the current increased, the power also will increase. The graph in Figure 6 shows several results from an open- cathode experiment based on the net power against the load characteristics. It shows a similarity in the trend for different operating pressures.

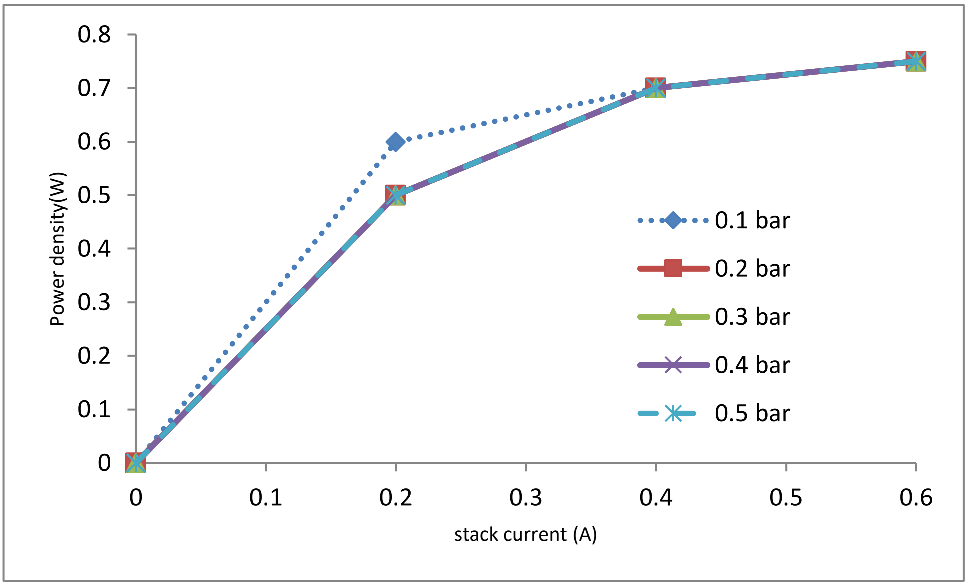

Figure 6: Hydrogen pressure of power versus load characteristics

The second experiment is based on relative humidity. Table 2 tabulates the details of operating parameters specifications during this experiment. Two types of parameters were compared to analyze the performance of fuel cell stack.

Table 2: The operating parameters

Item	Specification	
Air	9 V	12V
Air flow	1.305 cm/mm	1.540 cm/mm
Air velocity	1.50 m/s	1.68 m/s
Ambient temperature	297.15 K	296.15 K
Relative temperature	1.5%	78.4%

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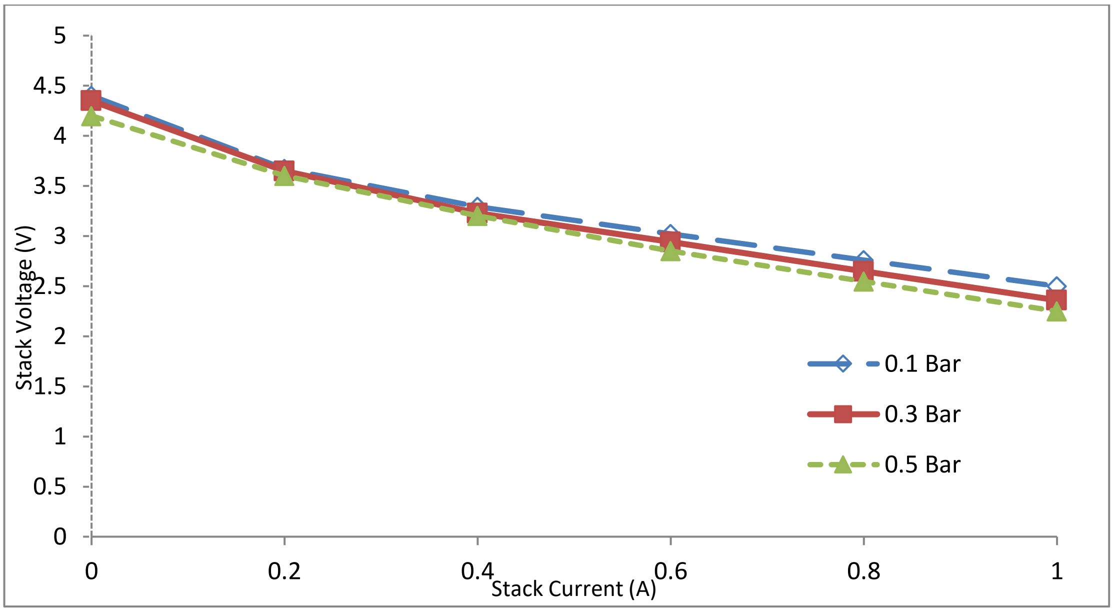

Figure 7: The relative humidity of hydrogen at 1.2%

The inlet of hydrogen varied beginning with a small percentage of relative humidity 1.2% to a higher percentage of relative humidity 78% to see the response of fuel cell stack. The response of relative humidity was studied as a stack voltage versus the load current as shown in Figure 7 and Figure 8. Based on the result obtained in Figure 7, it shows that if the current decreased, the current density of the fuel cell stack follow would also decrease. As shown in both graphs, it can be observed that there was no clear variation of the stack performance for the hydrogen pressures of 0.1, 0.3 and 0.5 bar. However, the trend of hydrogen pressure of 0.1 bar was slightly higher in performance as shown in Figure 7 compared to the trend of hydrogen pressure of 0.1 bar as in Figure 8 which was lower at the relative humidity of 78.4%.

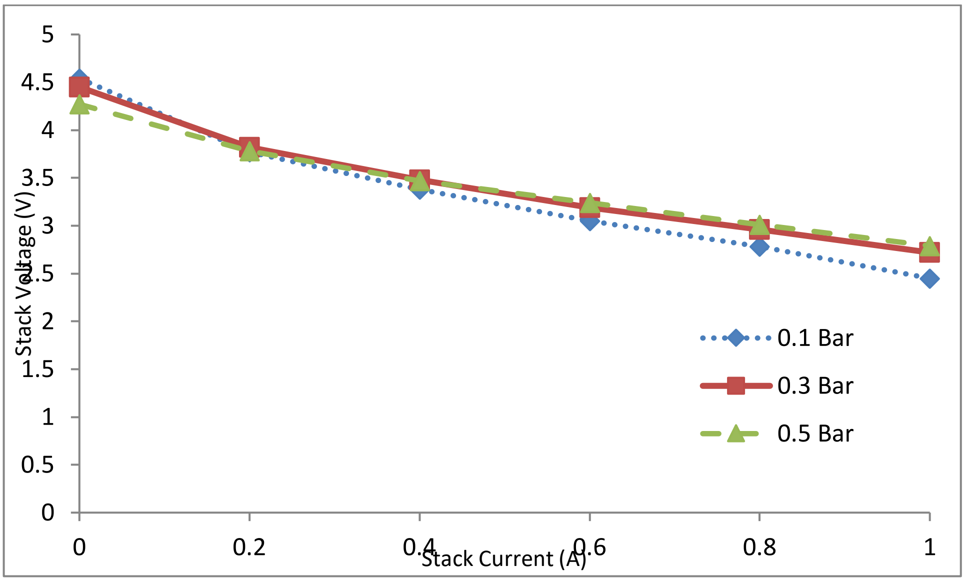

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Figure 8: The relative humidity of hydrogen at 78.4%

The performance of fuel cell stacks was affected by the flow rate of air through the cathode. The fuel cell stack was air cooled, which happened to be the main cooling mechanism in the air flow. The stack performance of relative humidity 78% is shown in Figure 8 where it shows a gap between 0.3 bar and 0.5 bar of pressure. This was due to lack of oxygen for the current reaction which indicated a drop in the performance of fuel cell.

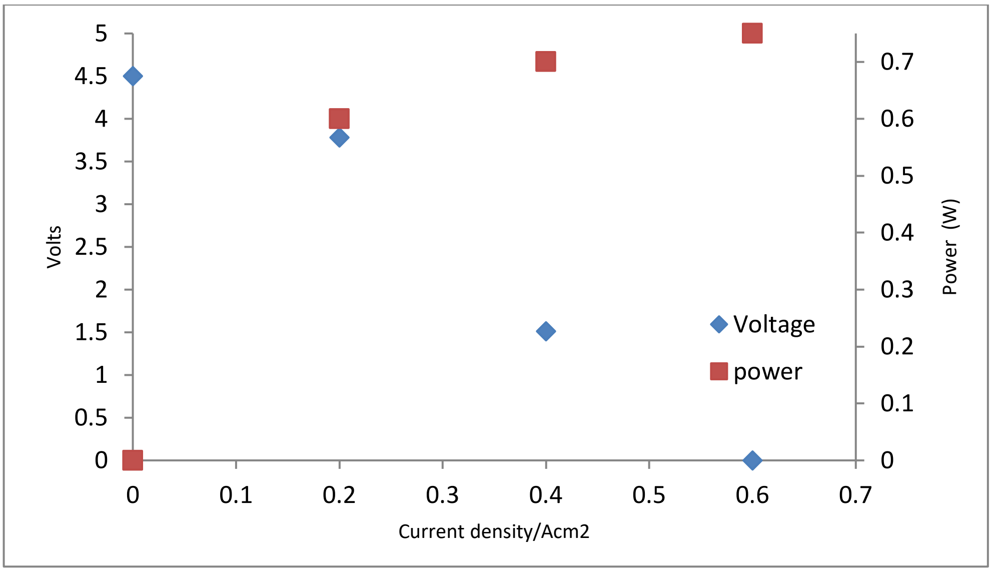

Figure 9: Polarization curve of open-cathode with five cells stack

The resulting polarization curve is shown in Figure 9 consisting of five cells stack at ambient temperature of 297.15 K. From the polarization curve it shows that the maximum power density was more than 0.7 W/cm2 at a cell voltage of 5 volt and a current density of 0.6 A/cm2. As we can see from the graphs above, the trend of the experimental result showed a similarity in the I-V characteristics of PEM fuel cell. The aim of this study is to provide a platform in physical investigation of 5 watt PEM fuel cell under an open-cathode hydrogen pressure. From the observation it can be found that when there is an increase in the air flow rate, the maximum load current values of the PEM fuel cell are proportional to the current load. It can be concluded that the higher the hydrogen supplied to the 5 watt fuel cell stack, the better the performance of the fuel cell will be.

4. CONCLUSIONS

This work has presented an open-cathode PEM fuel cell stacks based on two types of experiment. The purpose of this work is to demonstrate the effect of hydrogen and relative humidity in the stack which has a direct influence towards the overall performance of fuel cell. The operating current load in fuel cell stack is dynamic due to acceleration and deceleration of hydrogen pressure as well as the relative humidity. In this work, the polarization curve of fuel cell has been studied and observed. It shows a similarity of trend in the graph due to the polarization curve of fuel cell. According to the results, it can be concluded that the higher the the hydrogen supplied to the fuel cell, the better the

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performance of the fuel cell becomes. Overall, this experiment provides some new information and ideas about the state of health of fuel cell stacks in terms of their operation, pressure and performance.

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