Experimental Study to Analyze the Effect of Fan Speed on Energy Efficiency in Open Cathode Pem Fuel Cells

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Abstract: Open Cathode PEM Fuel Cells (OCPEMFCs) are widely used, performance OCPEMFCs is affected by operating conditions such as temperature, humidity, air flow rate. In this paper, an experimental investigation has been carried out on the effect of fan speed on stack performance and efficiency of energy that using commercially from OCPEMFCs system 1kW. During the experiment, temperature, voltage and current of stack will be monitored and recorded under various load level. It is referred that the optimal fan speed through the duty cycle setting can reduce auxiliary power consumption. The results are compared with the commercial system. The experimental results show that by loading a fuel cell gradually from 100 - 500W will produce the optimum duty cycle values of the fans were obtained, namely 20, 30, and 40% respectively. From the duty cycle value, the stack performance is still in a stable condition, it can be seen from the range of stack voltage during the experiment that still allowed with nominal voltage range. Meanwhile, a comparison of the stack power output between the fuel cell and the Company's and the Lab's system shows that the fuel cell and the Lab's system have a smaller difference of about 8 W.

1 INTRODUCTION

Fuel cells are a type of new renewable energy that can convert chemical energy into DC electricity through the reaction of hydrogen and oxygen gases(Mousavi & Mehrpooya, 2021)(Souleman et al., 2009). The fuel cell will generate electricity continuously as long as the supply of hydrogen gas to the anode channel and oxygen to the cathode channel is full. Fuel cells are becoming popular as an alternative energy source because they have high power density, zero-emissions, and low operating temperatures(Fernandez et al., 2020). There are several types of fuel cells, such as Solid Oxide Fuel Cells (SOFC), Direct Methanol Fuel Cells (DMFC), and Polymer Electrolyte Membrane or Proton Exchange Membrane (PEM) Fuel Cells. Of these types of fuel cells, in general they have several similarities, namely having an anode and cathode channels as a fuel supply. While the PEMFC type fuel cell has several advantages compared to other types such as fast dynamic response and low operating temperature(Pangaribowo et al., 2020)(Meng et al., 2022).

PEMFCs with open cathode technology (OCPEMFCs) have been widely used, especially in electronic devices that are portable applications because of their small shape and simple stack design(Ling et al., 2016)(Zhao et al., 2020)(Shahsavari et al., 2012). In OCPEMFCs, electric fans are used to provide oxygen supply from the surrounding air and control the stack temperature(Huang et al., 2014). The advantage of OCPEMPCs is their simple and lightweight fuel cell configuration. This is because several sub systems such as cooling, humidifier and inlet pressure control have been eliminated(Kurnia et al., 2021). However, the weakness of the open cathode type fuel cell is that the performance of the fuel cell is affected by the thermodynamic conditions of the surrounding environment and for a higher current density, the supply of reactants at the cathode may not be sufficient

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to produce an optimal electrochemical reaction and the heat generated by the reaction cannot be removed effectively(Baik & Yang, 2020). However, in recent years, the demand for OCPEMFCs as a source of stationary energy and portable applications is growing rapidly(Gopi et al., 2020).

The proton conductivity of the membrane is the main factor affecting OCPEMFCs performance, where the ionic conductivity depends on the amount of water content in the membrane, while the amount of water content is affected by flow rate, humidity and temperature(Zhang et al., 2008). Pei et al.(Pei et al., 2014) shows that high stack temperatures can cause evaporation of water in the membrane, causing dehydration of the membrane which results in decreased stack performance.

Sasmito et al.(Sasmito et al., 2010) have studied several factors that affect operating point and stack temperature such as fan power, single fan or fans in series, stack length, separate air-coolant channels. Meyer et al.(Meyer et al., 2015) showed that parasitic loads such as air blowers can affect stack performance and temperature distribution. For the purposes of energy efficiency, the effect of parasitic loads needs to be investigated further. Analysis of how much the minimum cooling air flow is needed to maintain the temperature when there is a change in load from the fuel cell, is a problem that needs to be answered.

From the problems above, this paper reports the results of an experimental investigation on the effect of fan speed on energy efficiency produced by OCPEMFCs with various power loads where the fan is used to maintain the stack temperature to be in permissible conditions. The net power output, stack temperature and energy efficiency produced experimentally (which is named as the Lab's system) will be compared with the company's system.

2 EXPERIMENTAL

2.1 Experimental Setup

The open cathode PEMFC used in this experiment is A commercially available fuel cell system (G-HFCS-1kW36V hydrogen fuel cell system produces 1000 W), which is named as the Company's system in this paper, and it consists of an electrical fan, an inlet valve, a purge valve and a control unit(Dr. Colleen Spiegel, 2019). The electrical fan used consists of two fans with a voltage specification of 12V and a current of 4.1A for each fan. Figure 1. is a schematic diagram of experimental setup.

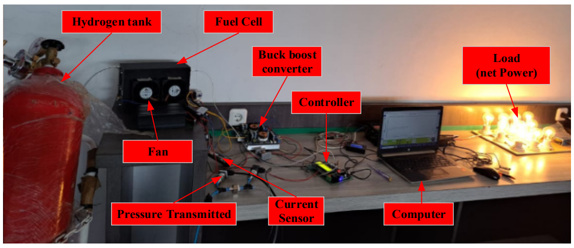

Figure 1: A Schematic of experimental setup.

The hydrogen pressure entering the anode side (stack inlet) is controlled by a pressure regulator at 5 psi and also a temperature sensor which is used to measure the stack temperature. In addition, there are voltage and shunt current sensors that are used to monitor the fuel cell voltage and current. The fuel cell power levels were applied using six light bulbs connected to the dimmer shield as various power loads. The microcontroller unit (MCU) is used to control the fan speed. using pulse width modulation signal and data acquisition sensors. All information is processed by the microcontroller and sent to the computer which is then processed and recorded using Visual Basic.net software.

Table 1: Specification of fuel cell system (G-HFCS 1kW36V) (Dr. Colleen Spiegel, 2019).

Description	Values
Nominal Power	1000W
Nominal Voltage	36V
Nominal Current	27.8A
DC voltage Range	32-55V
Hydrogen Pressure	0.004 – 0.006 MPa
Hydrogen Consumption	11.7 L/min (at nominal power)
Ambient temperature	-5 to +35^{o}C
Ambient Humidity	10% RH to 95%RH
Storage Ambient Temperature	-10 to 50^{o}C

2.2 Experiment Procedure

In this study, the fuel cell system was operated at various stack power outputs, ranging between 100 and 500 W. Fan speed was controlled by varying the duty cycle from 10-60% with a delay every minute on each stack power output, where the smaller the duty cycle, the lower the fan speed, which means the lower the power consumption. During operation, the value of voltage, current, temperature of stack and duty cycle will be recorded, while the pressure of hydrogen gas flowing into the anode channel is set to be constant at 5 psi.

To find the optimal fan duty cycle value, namely the fuel cell is given a certain load constantly, then the duty cycle value is increased at each step with an initial value of 10%, 20%, 30% to 60%. Furthermore, observing the stack temperature, the optimal duty cycle value is obtained if the stack temperature value has started to decrease but also considering the stack temperature value is still within the range of permitted conditions, namely below 50°C.

In efficiency analysis of the fuel cell system, the net power output (P_{net}) between our Lab's system was compared with that of the company's system, where P_{net} is the difference between the stack power output (P_{stack}) and the power consumption of the auxiliary components ($P_{auxiliary}$) (Bizon, 2014).

$$P_{net} = P_{stack} - P_{auxiliary} \quad (1)$$

For the operation fan speed, controller provides the supply voltage with pulse width modulation (PWM) under duty cycle setting. A duty cycle (D) is expressed as

$$D = t_{pulse} / t_{cycle} \quad (2)$$

Where t_{pulse} is the duration of the pulse width and t_{cycle} is the signal period (Brown, 1990).

3 RESULT AND DISCUSSIONS

Fig. 2 shows the variations in the temperature, voltage, and current of the OCPEMFC stack of the Company's system under various load levels, which auxiliary components of the Company's system like two electric fans that controlled by using built-in controller so the user cannot control its velocity. It can be seen that stack temperature and constant fan speed to keep stack temperature below 50°C.

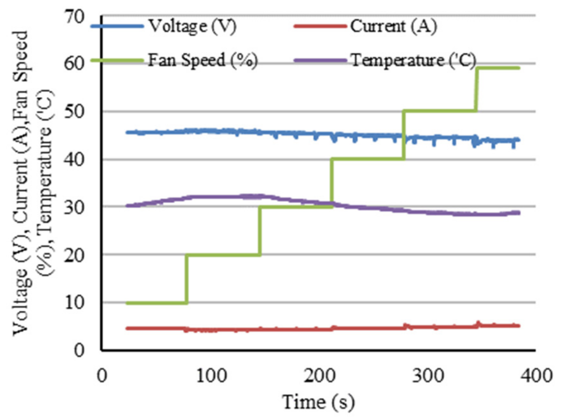

Figure 2: Distribution of temperature, voltage and current of company's System under variable speed fan.

The first experiment was the fuel cell was loaded with 100 W where variations in the temperature, current, and voltage of the OCPEMFC stack of the Lab's system as shown in Figure 3. When the duty cycle of the fan was 10%, the stack temperature increased from 30 - 33°C in about 1 minute. When the duty cycle changes to 20%, the stack temperature is maintained constant at 33°C and the stack voltage value is still maintained constant at 47 V. Next, when the duty cycle is 30%, the stack temperature drops, but the stack voltage also drops, this is due to there is an additional load due to the faster fan speed. From these results it can be stated that the optimal duty cycle value for a 100W load is 20%.

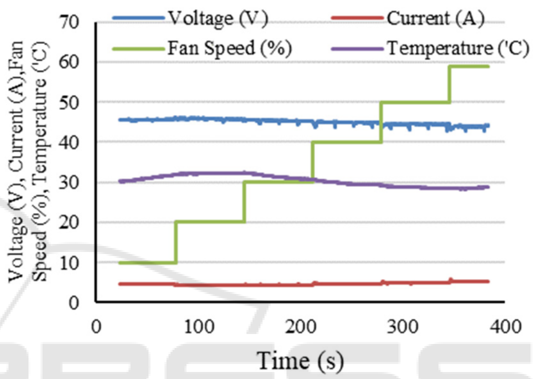

Figure 3: Distribution of temperature, voltage and current under variable speed fan with fuel cell loads 100W.

Figure 4 is the result of the fuel cell experiment with a load of 200W. From the figure it can be seen that when the duty cycle is less than 30%, the stack temperature rises from 31-37°C for 140 seconds. This phenomenon shows that the fan speed at a duty cycle below 30%, the stack temperature will continue to rise if it is operated for a long time and will cause a decrease in fuel cell performance and result in damage to the fuel cell membrane. When the duty cycle is 30%, the stack temperature starts to drop and at that time the stack voltage value is 45V. From this experiment it can be concluded that the optimal value of the duty cycle of the fan speed for a load of 200W is 30%.

When the fuel cell is loaded with 300W as shown in Figure 5, the stack temperature increases rapidly from 33-43°C for 120 seconds with duty cycle values of 10% and 20%. The stack temperature starts to drop at 30% duty cycle with a constant stack voltage of 40V. From these results, that the optimal duty cycle at 300W load is 30% and this is the same as at 200W load.

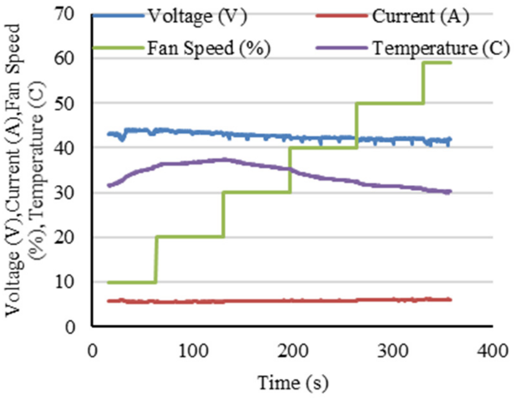

Figure 4: Distribution of temperature, voltage and current under variable speed fan with fuel cell loads 200W.

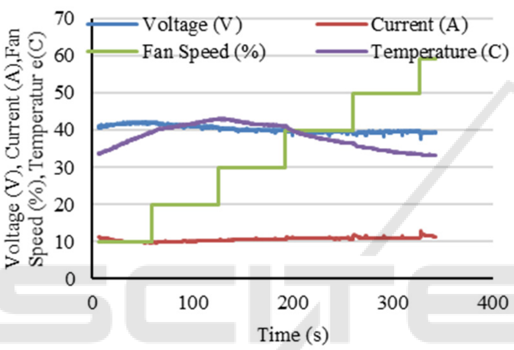

Figure 5: Distribution of temperature, voltage and current under variable speed fan with fuel cell loads 300W.

When the fuel cell is loaded with 400W, as shown in Figure 6, the stack temperature continues to rise when the duty cycle value is 10-30% with a value close to 45ºC, but when the duty cycle value is that the stack voltage constant value is around 40V. When the duty cycle is increased to 40%, the stack temperature drops, followed by the stack voltage to 38V. So that the optimal duty cycle value is obtained when the 400W load is 40%.

When the fuel cell is loaded with 500W as shown in Figure 7, the fuel cell experiences a transient with the stack voltage rising from 33V to a peak of 40V for 30 seconds. Besides that, the duty cycle of 10%, 20%, 30% is not able to reduce the stack temperature, as a result, the stack temperature continues to increase from 29 –44ºC. When the duty cycle is 40%, the stack temperature has decreased and the stack voltage has reached a steady state point of 38V even though the duty cycle value has been increased to 60%. From this experiment it shows that the optimal duty cycle value with a 500W load is 40% and this value is the same when the fuel cell load is 400W.

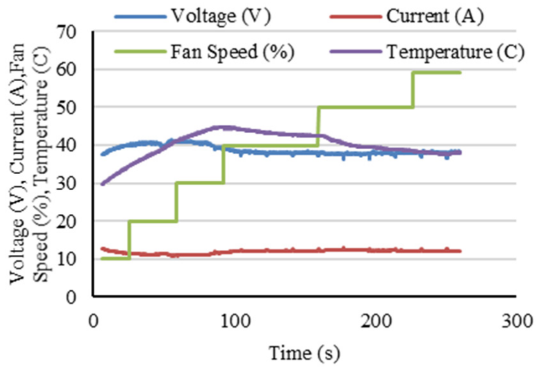

Figure 6: Distribution of temperature, voltage and current under variable speed fan with fuel cell loads 400W.

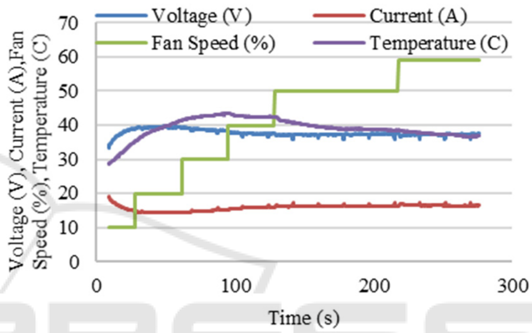

Figure 7. Distribution of temperature, voltage and current under variable speed fan with fuel cell loads 500W.

Based on the experimental results above, it shows that the stack temperature is very dependent on the fuel cell load, the greater the fuel cell load, the greater the stack temperature. In addition, the stack voltage at steady state conditions also decreases when the load increases (see Figure 8). Figure 8 also shows the stack voltage to be a momentary drop caused by purging activity. To increase fuel cell energy efficiency, apart from maintaining the internal condition of the fuel cell within the permitted area, it can also be done by optimizing the power used to supply electronic components such as electric fans which are used to support the performance of the fuel cell or it is called Auxiliary power consumption. As a result, the fan needs to control its speed, where the size of the speed is affected by the load from the fuel cell. Table 2 shows the conclusion of the results of the P_{stack} comparison of the fuel cell between the Lab's System and the Company's system during the experiment with a load of 100-500 W.

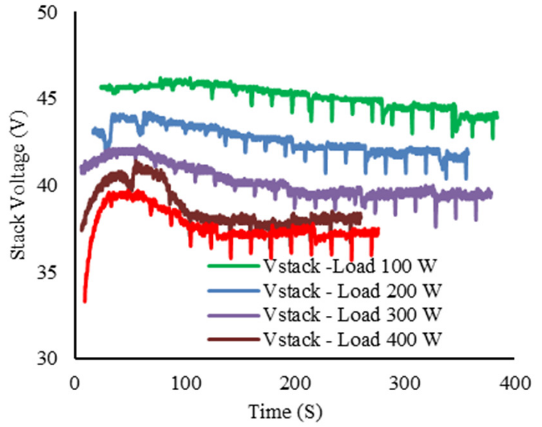

Figure 8: Comparison Stack Voltage under various load of fuel cell.

Table 2: Comparison P_{stack} fuel cell between Lab's System and Company's system.

Fuel cell loads (Watt)	P_{stack} of Lab's system (W)	P_{stack} of Company's system (W)	ΔP_{stack} (W)
100	196.08	204.78	8
200	243.96	252.66	8.2
300	420	428.7	8.7
400	462.38	471.08	8.9
500	610.5	619.2	9

4 CONCLUSIONS

Based on the experimental results of setting the fan speed manually at OCPEMFC 1000 watts with a load of 100-500W, it can be concluded that:

1. The stack temperature is affected by the load of the fuel cell. The greater the fuel cell load, the stack temperature will increase faster.
2. Providing a fuel cell load of 100-500W or only 50% of the maximum capacity of the fuel cell, the required duty cycle is no more than 40%.
3. The P_{stack} power stack comparison between the company's system and Lab's system is around 8W, which means that the Lab's system's fuel cell can minimize auxiliary power consumption by around 8W.

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REFERENCES

Baik, K. D., & Yang, S. H. (2020). Development of cathode cooling fins with a multi-hole structure for open-cathode polymer electrolyte membrane fuel cells. *Applied Energy*, *279*. https://doi.org/10.1016/j.apenergy.2020.115815

Bizon, N. (2014). Improving the PEMFC energy efficiency by optimizing the fueling rates based on extremum seeking algorithm. *International Journal of Hydrogen Energy*, *39*(20), 10641–10654. https://doi.org/10.1016/j.ijhydene.2014.04.194

Brown, M. (1990). How a Switching Power Supply Works. In *Practical Switching Power Supply Design*. https://doi.org/10.1016/b978-0-08-051454-3.50005-9

Dr. Colleen Spiegel. (2019). *Fuel Cell Store*. https://www.fuelcellstore.com/blog-section/how-to-predict-fuel-cell-performance

Fernandez, A. M. I., Kandidayeni, M., Boulon, L., & Chaoui, H. (2020). An Adaptive State Machine Based Energy Management Strategy for a Multi-Stack Fuel Cell Hybrid Electric Vehicle. *IEEE Transactions on Vehicular Technology*, *69*(1), 220–234. https://doi.org/10.1109/TVT.2019.2950558

Gopi, K. H., Nambi, A., & Rajalakshmi, N. (2020). Design and Development of Open Cathode PEM Fuel Cell – Flow Analysis Optimization by CFD. *Fuel Cells*, *20*(1), 33–39. https://doi.org/10.1002/fuce.201900124

Huang, Z. M., Su, A., Hsu, C. J., & Liu, Y. C. (2014). A high-efficiency, compact design of open-cathode type PEMFCs with a hydrogen generation system. *Fuel*, *122*, 76–81. https://doi.org/10.1016/j.fuel.2013.12.058

Kurnia, J. C., Chaedir, B. A., Sasmito, A. P., & Shamim, T. (2021). Progress on open cathode proton exchange membrane fuel cell: Performance, designs, challenges and future directions. *Applied Energy*, *283*. https://doi.org/10.1016/j.apenergy.2020.116359

Ling, C. Y., Cao, H., Chen, Y., Han, M., & Birgersson, E. (2016). Compact open cathode feed system for PEMFCs. *Applied Energy*, *164*, 670–675. https://doi.org/10.1016/j.apenergy.2015.12.012

Meng, K., Chen, B., Zhou, H., Shen, J., & Tu, Z. (2022). Experimental investigation on voltage response characteristics of hydrogen-oxygen proton exchange membrane fuel cells under gas starvation. *Energy Conversion and Management*, *268*(July), 115973. https://doi.org/10.1016/j.enconman.2022.115973

Meyer, Q., Himeur, A., Ashton, S., Curnick, O., Clague, R., Reisch, T., Adcock, P., Shearing, P. R., & Brett, D. J. L. (2015). System-level electro-thermal optimisation of air-cooled open-cathode polymer electrolyte fuel cells: Air blower parasitic load and schemes for dynamic operation. *International Journal of Hydrogen Energy*, *40*(46), 16760–16766. https://doi.org/10.1016/j.ijhydene.2015.07.040

Mousavi, S. A., & Mehrpooya, M. (2021). Fabrication of copper centered metal organic framework and nitrogen, sulfur dual doped graphene oxide composite as a novel electrocatalyst for oxygen reduction reaction. *Energy*, *214*. https://doi.org/10.1016/j.energy.2020.119053

Pangaribowo, T., Utomo, W. M., Bakar, A. A., & Khaerudini, D. S. (2020). Review on Fuzzy Strategies to Improve PEMFC Performance. *2020 2nd International Conference on Broadband Communications, Wireless Sensors and Powering, BCWSP 2020*, 53–58. https://doi.org/10.1109/BCWSP50066.2020.9249458

Pei, H., Shen, J., Cai, Y., Tu, Z., Wan, Z., Liu, Z., & Liu, W. (2014). Operation characteristics of air-cooled proton exchange membrane fuel cell stacks under ambient pressure. *Applied Thermal Engineering*, *63*(1), 227–233. https://doi.org/10.1016/j.applthermaleng.2013.11.012

Sasmito, A. P., Lum, K. W., Birgersson, E., & Mujumdar, A. S. (2010). Computational study of forced air-convection in open-cathode polymer electrolyte fuel cell stacks. *Journal of Power Sources*, *195*(17), 5550–5563. https://doi.org/10.1016/j.jpowsour.2010.02.083

Shahsavari, S., Desouza, A., Bahrami, M., & Kjeang, E. (2012). Thermal analysis of air-cooled PEM fuel cells. *International Journal of Hydrogen Energy*, *37*(23), 18261–18271. https://doi.org/10.1016/j.ijhydene.2012.09.075

Souleman, N. M., Tremblay, O., & Dessaint, L. A. (2009). A generic fuel cell model for the simulation of fuel cell power systems. *2009 IEEE Power and Energy Society General Meeting, PES '09*. https://doi.org/10.1109/PES.2009.5275853

Zhang, J., Tang, Y., Song, C., Xia, Z., Li, H., Wang, H., & Zhang, J. (2008). PEM fuel cell relative humidity (RH) and its effect on performance at high temperatures. *Electrochimica Acta*, *53*(16), 5315–5321. https://doi.org/10.1016/j.electacta.2008.02.074

Zhao, C., Xing, S., Chen, M., Liu, W., & Wang, H. (2020). Optimal design of cathode flow channel for air-cooled PEMFC with open cathode. *International Journal of Hydrogen Energy*, *45*(35), 17771–17781. https://doi.org/10.1016/j.ijhydene.2020.04.165