Performance Analysis of Air Breathing Proton Exchange Membrane Fuel Cell Stack (PEMFCS) At Different Operating Condition

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Abstract: The answer for an emission free power source in future is in the form of fuel cells which combine hydrogen and oxygen producing electricity and a harmless by product-water. A proton exchange membrane (PEM) fuel cell is ideal for automotive applications. A single cell cannot supply the essential power for any application. Hence PEM fuel cell stacks are used. The effect of different operating parameters namely: type of convection, type of draught, hydrogen flow rate, hydrogen inlet pressure, ambient temperature and humidity, hydrogen humidity, cell orientation on the performance of air breathing PEM fuel cell stack was analyzed using a computerized fuel cell test station. Then, the fuel cell stack was subjected to different load conditions. It was found that the stack performs very poorly at full capacity (runs only for 30 min. but runs for 3 hours at 50% capacity). Hence, a detailed study was undertaken to maximize the duration of the stack’s performance at peak load.

Keywords: Convection, Draught, Fuel cell stack, Fuel cell test station, Humidity.

1. INTRODUCTION

In recent times, the emerging trends has been increasing concern nearby acid emissions, carbon dioxide, and other air excellence substances, which requires renewable technologies. PEM Fuel Cells are the most adaptable type of fuel cells presently in fabrication. Maximum power for an assumed load or capacity of fuel cell is yielded as they are very light mass, have a high power density, and they are qualified for many applications, such as transport, portable power application and stationary power. PEM fuel cell performance depends upon the different operating conditions like a humid, cell temperature, membrane dehydration, drying flooding, etc. The result of temperature on the inlet gas arrangement is predominantly tough in the range from 1 to 3 atm. Changes in operating pressure have a large impact on the inlet gas arrangement and hence on fuel cell performance [1]. Water level and humidification must be monitored by maintaining low pressure and by selecting low operating conditions. If a stack operated at a partial load at the most of the time, the nominal cell voltage does not provide higher operating efficiency and it also affects the
fuel cell performance due to the methods of electrode manufacture and level of humidification [2-3]. Flow profile is the major factor for the increasing the fuel cell performance. The cross current flow is better than compared other flow profiles because of the better distribution of the reactant gas over the electrode surface also this flow field improves the cell potential and electrical power [4]. The performance of PEMFC is getting lower when the design reason is decreased due to the rising in temperature and its limited non-uniform delivery. This superior temperature will weaken proton transportation capability of the membrane thus dropping the performance [5]. In a humidified normal condition, inconsistency of different flow direction is not affecting the performance of PEM fuel cell also maximum current density on stable cell voltage depends on the middle of outlet region of the cell in the active layer of the electrode. The counter-flow mode is a better density distribution with humidified normal condition compared co-flow mode [6]. The execution of the different models, different sizes, different materials of PEMFCs, shows the effects of variations in the performance of the cells.

2. EXPERIMENTAL PROCEDURE

The fuel test station (850 e) used for the performance study was imported from Scribner Associates Inc. USA [7-8]. The software FUEL CELL is necessary to operate the test station. The software is used to control the flow rate of different gases namely: hydrogen, oxygen and nitrogen. The temperature at inlet of all three gases can also be set. The output current can be controlled electronically using an in built load bank All the experiments were conducted on an imported PEMFC, which is shown in Fig. 1. A detailed description of all experiments done along with the data [Table-1] and the information obtained by analyzing the data is the specifications of (Proton Exchange Membrane fuel cell stack (PEMFC) no of cells 18, power - out put 100W, voltage 10V, current 10A and fuel hydrogen.

Table no: i

| Trial | Hydrogen flow rate | Hydrogen inlet pressure | Ambient conditions |
|-------|--------------------|-------------------------|--------------------|
| 1     | 2 lpm              | 2 bar                   | RC(25°C and 67%rh) |
| 2     | 2 lpm              | 2-4 bar                 | RC                 |

3. RESULTS AND DISCUSSION

3.1. Study of variation in performance of PEMFC stack due to various operating parameters:

Effect of natural and forced convection on performance of PEMFC stack. First, the PEMFC stack was made to run without any fans and then 2 fans at top and 2 fans at bottom were added and experiments were conducted by taking power from stack itself and also externally. From the data obtained, it is known that the stack performs very poorly in case of natural convection because of lack of air for electrochemical reaction as well as cooling purposes as
air cannot overcome the friction losses in the ducts in natural convection. When the fans are powered from stack itself, it performs quite satisfactorily up to 120 mA/cm$^2$ after which the output voltage decreases (due to concentration losses) forcing the fans to operate at lower rpm, which in turn deprives the stack of much needed air which causes a dramatic drop in performance of the stack. But in the case of externally powered fans, the stack gives best performance (88.5 W) and works at higher current density.

Effect of forced and induced draught on performance of PEMFC stack. In forced draught, the fans operate with air which is at room temperature but in induced draught, fans operate with air which has absorbed heat from the PEMFC stack and is lighter there by making the fans move a greater volume of air than forced draught. In induced draught there is obstruction to air flow at inlet of fans and hence the performance of stack is slightly lower than forced draught. Effect of different hydrogen flow rates on performance of PEMFC stack. First, the mass flow rate of hydrogen required for the electrochemical reactions to take place in the stack such that it delivers a nominal current of 10 A was calculated by using the equation

$$\text{H}_2 \text { mass flow rate} = \frac{(I \times \text{MW} \times N)}{(2 \times F \times D)} \tag{1}$$

Where, $I$ = Current (A), $\text{MW}$ = Molecular weight of hydrogen, $N$ = No. of cells in stack, $F$ = Faraday’s constant $D$ = density of hydrogen;

$$\text{H}_2 \text { mass flow rate} = \frac{(10 \times 0.002 \times 18)}{(2 \times 96495 \times 0.09)} = 1.244 \text { lpm}$$

But in practice, hydrogen distribution in the cell active area is not uniform. Hence hydrogen with a stoichiometric ratio of more than 1.2 is always given as input to the stack. Using a stoichiometric ratio of 1.5, we get $\text{H}_2$ mass flow rate = 2 lpm. Using a stoichiometric ratio of 2.5, we get $\text{H}_2$ mass flow rate = 3 lpm. It can be deduced that a stoichiometric ratio of 1.5 itself provides the necessary hydrogen molecules required for electro-chemical reaction to take place all over the cells’ active area and any further increase in flow rate causes no significant effect on the performance but merely leads to wastage of fuel [fig.2 & 3].

Effect of hydrogen inlet pressure on performance of PEMFC stack, the hydrogen inlet pressure was first determined by trial and error method. The inlet pressure was gradually increased and hydrogen was obtained at the outlet of fuel cell only at 2 bar. In this experiment, optimization of the pressure was done. The experiment was conducted at 3 different pressures: 2 bar, 3 bar and 4 bar. Best performance was seen in the case of 3 bar hydrogen inlet pressure.
But on further increase in pressure, the performance drops back to 2 bar level. It can be due to huge pressure difference between anode and cathode [fig.4].

Effect of ambient temperature and humidity on performance of PEMFC stack. Four different combinations were analyzed. They are: 1. Low temperature, low humidity (20 °C and 40% RH), 2. Low temperature, high humidity (20°C and 80% RH), 3. High temperature, low humidity (50°C and 40% RH), 4. High temperature, high humidity (50 °C and 80% RH). It can be seen that ambient temperature plays a dominant role in the performance of the stack. Lower ambient temperature gives best results as coolant air can absorb more heat from the stack. When the ambient temperature is high, heat transfer due to natural convection does not take place effectively because of low temperature difference between cell and surroundings. The coolant air itself is at elevated temperature and hence does not absorb heat from the stack effectively. Hence forced convection also fails. As temperature increases, the stack gets dehydrated due to evaporation of water molecules thereby obstructing the flow of positive ions across the membrane [fig.5]. The performances of PEMFC stack at various load conditions. In practice, the load on a PEMFC stack continuously varies and hence the performance of the stack was analyzed at different load conditions. The experiment was conducted at 5 different load conditions. They are: 3.5 A, 4 A, 4.5 A, 5.5 A and 7 A. A stack is said to perform satisfactorily if it runs continuously for 3 hours without any significant drop in output. Hence the experiment was conducted for 3 hours. The stack performs satisfactorily for the test period of 3 hours only at 3.5A and on increasing the load the duration of performance drops significantly each time. AS the temperature of the stack was also measured, we can observe a correlation between increase in cell temperature and decrease in performance. By observing the temperature-time graph, we can deduce that the threshold temperature of the PEMFC stack is 65°C. It can be inferred that the fans used here are able to effectively remove heat produced at part load.

Measure the voltage and temperature of individual cells in the PEMFC stack at part load. The stack was run at part load because of stable performance at that load. A multimeter was used to measure the voltage across each cell and a thermocouple was used to measure the temperature of each cell. The readings were taken from left to right and vice versa and finally the average of the two was. The readings were taken every 15 min for 3 hours. All the 18 cells give almost the same voltage except cell nos. 2, 7 and 8 shown in [fig. 6]. This can be due to manufacturing defect or due to some blockage present. Highest temperature is recorded at the middle as heat conduction to the end plates is ineffective as shown in [fig. 7]. But the increase in temperature in the middle portion does not affect the performance of the particular cells as
the temperature lies well below the threshold temperature. Temperature rise is almost uniform throughout the stack though the actual temperatures may differ. This can be due to effective heat removal by forced convection and ineffective conduction.

![Fig. 6 Effect of individual cell (Voltage)](image1)

![Fig. 7 Effect of individual cell (Temperature)](image2)

Variation in performance of PEMFC stack at peak load due to cell orientation as shown in fig. 8. This experiment was done using 2 different sets of fans to record the variation in performance of stack due to fan size and rpm. It can be observed that the stack gives high power and works longer when type 1 fan is used. This can be due to the fact that it works at a higher 4500 rpm. The stack was kept vertically first and then horizontally and the experiment was conducted. In both the cases, the stack used 4 fans powered by the stack itself. It is observed that the stack performs better and longer when kept vertically. This can be due to the effect of natural convection acting along the cathode ducts which helps in heat removal. This is absent in the case of a horizontal stack. It can be deduced that natural convection plays a small but significant role in heat removal from the stack. Gravity effect on air when stack is kept vertically does not cause any significant effect. The PEMFC stack was kept in a humidity chamber to maintain the different ambient temperatures and humidities. Five different combinations were analyzed as shown in fig. 9. They are: 1. Low temperature, low humidity (20 °C and 40% RH), 2. Low temperature, high humidity (20°C and 80% RH), 3. Room temperature, high humidity (25 °C and 70% RH) and 4. Room temperature, room humidity (25°C and 60% RH). It can be seen that ambient temperature plays a dominant role in the performance of the stack. Lower ambient temperature gives best results as coolant air can absorb more heat from the stack. Higher humidity prevents dehydration of the membrane thereby making it possible for the stack to work longer. When the fans are externally powered, they have constant power supply and hence the stack gives a better performance than when they are powered by the stack itself. The variation in performance of PEMFC stack at peak load due to hydrogen inlet pressure as shown in fig. 10. Hydrogen was first fed at 2 bar pressure to the stack and 7A current was drawn from it. Then the experiment was done with hydrogen inlet pressure of 3 bar. This can be due to better hydrogen availability for the rapidly happening electrochemical reactions in the stack. It is seen that the temperature rise is
greater at 3 bar pressure. It can be due to deflection of the membrane due to greater pressure difference across it leading to reduction of effective area of cathode ducts which reduces the amount of coolant air the stack receives. As the temperature rise is rapid above the threshold temperature, the stack performs only for a short period of time.

This experiment was done to test the hypothesis that humidified fuel given to PEMFC stack it performs better as the membrane gets humidified. The hydrogen fuel was sent to the humidifier in the fuel cell test station where different anode dew point temperatures viz. 30 °C, 45°C and 60°C were maintained and the output was given to the stack. The experiments were conducted and the data were plotted as shown in fig. 11. The hydrogen coming out has more water molecules than the other cases but it is also hot which raises the temperature of the stack also. Hence the effect of humidity is negated by the high temperature of the fuel necessary for good humidification.

**Fig. 8 Effect of cell orientation**

**Fig. 9 Effect of ambient conditions**

**Fig. 10 Effect of hydrogen inlet pressure (peak load)**

**Fig. 11 Effect of humidified hydrogen**

4. **CONCLUSIONS**

The study of various operating parameters convection 11.59 times better power output in case of forced convection. Better performance (2.16 W higher) by forced draught. Hydrogen flow
rates no significant effect. Hydrogen inlet pressure highest power output of 70.425 W at 3 bar pressure. Ambient conditions highest power output of 75.192 W at low temperature (20°C) and high humidity (80% RH). The study of performance of the PEMFC stack at different load conditions yielded the following results: The stack runs satisfactorily at 50% capacity for 3 hours and the stack runs for only 30 minutes at 100% capacity. Cell orientation, the stack works longer by 6 minutes in vertical position. Hydrogen inlet pressure, the stack works longer by 3 min at 2 bar pressure. Ambient conditions, the stack works at low temperature (20°C) and high humidity (80% RH).

5. REFERENCES

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