Effect of Voltage & Operation Temperature on Performance of Self-Humidified PEM Fuel Cell Stack

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Abstract

The Proton Exchange Membrane Fuel Cell (PEMFC) is a promising candidate as zero-emission alternative power source for transport & stationary application due to its high efficiency ,low temperature operation ,high power density ,quick start –up and system robustness.

In this paper, under the condition of steady state and flow in cell is considered to be laminar, the performance of 300w &100w PEMFC stack has been studied.300w fuel cell is compact &100w fuel cell is openable. This cell is self-humidified. Series of polarisation curves with different loading of voltage have been studied. various values of voltage, current density, power density &related temperature have been recorded using lab VIEW software. For this class of fuel cell, optimal operating temperature is found to be 75 0 c at 0.3v loading.the results obtained would lead to improvements in the design of fuel cell.

Keywords: PEMFC, power density, laminar flow, optimal temperature.

1. Introduction

Proton exchange membrane (PEM) fuel cells are electrochemical devices that directly convert the energy from the chemical reaction into electricity. Useful features such as high power density, simple, safe construction and fast start-up make those particularly suitable for home appliance, vehicles and transportation tools [1] Generally, A PEMFC has a working temperature from 60 to 100 °C and an efficiency of about 50 %, such that the remaining 50 % is waste heat. The waste heat must be discharged efficiently from the fuel cell to protect the proton exchange membrane [2].

It is well known that the operating temperature has a significant influence on PEM fuel cell performance. The increase in the operating temperature is beneficial to fuel cell performance since it increases reaction rate and higher mass transfer rate but usually lowers cell ohmic resistance arising from the higher ionic conductivity of the electrolyte membrane [1]. Useful mathematical models can provide powerful tools for the analysis and optimization of fuel cell performance [3].

In the early 1990s, the pioneering work on PEM fuel cell model development was done by Bernardi et al. [4], and Springer et al. [5] who formulated one-dimensional and isothermal models for the gas-diffusion layer, active catalyst layer and ion-exchange membrane.

Fuel cells in the range of 1 W-100 kW sizes are being considered for near term service in several remote and mobile applications where they provide quiet operation, high reliability, potentially high energy density and ultra-low emissions. In recent years, research and development in fuel cells and fuel cell systems have accelerated, and although significant improvements in polymer electrolyte membrane fuel cell technology has been achieved over the past decade, the performance, stability, and reliability for today's fuel cell technology is not sufficient to replace internal combustion engines. On the other hand, the cost of fuel cell systems is still too high for them to become viable commercial products. A number of fundamental problems must be overcome to improve their performance and reduce their cost [1-8].

Fuel cell is an electrochemical device that generates electricity, similar to batteries, but which can be continuously fuelled. Under certain pressure, hydrogen (H2) is supplied into a porous conductive electrode (the anode). H2 spreads through the electrode until it reaches the catalytic layer of the anode, where it reacts, separating protons and electrons. The H+ protons flow through the electrolyte (a solid membrane), and the electrons pass through an external electrical circuit, producing electrical energy. On the other side of the fuel cell, oxygen (O2) spreads through the cathode and reaches its catalytic layer. On this layer, O2, H+ protons, and electrons produce liquid water and residual heat as sub-products. [15]

The polarization behaviour of a fuel cell exhibit similar voltage/current relationships and it's the result of three types of phenomena: electrode kinetics, ohmic losses, and transport limitations. The activation polarization loss is dominant at low current densities and is present when the rate of the electrochemical reaction at the electrode surface is controlled by sluggish electrode kinetics. The processes involving adsorption of reactant species, transfer of electrons across the double layer, desorption of product species, the number and distribution of active sites, and the nature of the electrode surface can all contribute to activation polarization. Ohmic losses vary directly with current, increasing over the entire range of current density. These are due to the resistance to the flow of protons in the electrolyte membrane and resistance to flow of electrons through the stack materials, electrode materials, electrode backing, interconnects current collector plates and constant resistance between various interfaces. The ohmic losses can be reduced by using thinner electrolyte membranes with proper humidification, better conductivity cell stack materials, design of the flow field and current collection plates and by reducing contact resistances at various interfaces. The concentration polarization losses occur due to the mass transport limitation to reactants/products to or from the electro active sites. These voltage losses occur over the entire range of current density, but become prominent especially at high currents, when it is difficult to provide enough reactant flow to the reaction sites. The mass transport voltage losses can be reduced by making the gas distribution over the electrode surfaces more uniform, higher porosity of the backing layer without losing conductivity, or a right combination of the hydrophobic and hydrophilic properties of materials used to construct electrode layer for efficient water removal [3, 12-22]. Water management represents one of the main critical and design issues of PEM fuel cells because the membrane hydration in a PEM fuel cell determines its performance and its durability. If the membrane is not properly hydrated, it exhibits higher ionic resistance and can even be irreversibly damaged in extreme cases.[23]

In this work, the effect of various voltages loading on the performance of 300w &100w fuel cell stack is studied. Data has been collected &polarization curves have been obtained. This cell is self-humidified so it's effect on the performance has not been studied. Purge is also attached at the end of the cell. In this work, the voltages of the individual cells have been monitored in order to detect possible voltage drops, as if only the stack voltage is monitored, the breakdown of a single cell in a large stack is difficult to detect.[11]

2. EXPERIMENTAL SET UP

In the modelling of the fuel cell the following assumptions were made: the cell operates under steady-state condition, isothermal boundary conditions were used for external walls, flow in the cell is considered to be assumed to be ideal gas mixtures, and the electrode is assumed to be an isotropic and homogenous porous medium. It was assumed that the fuel was hydrogen at the anode side, diffuses through the porous gas diffusion layers and come in contact with the catalyst layer. At this layer, it forms hydrogen ions and electrons. The hydrogen ions diffuse through the polymer electrolyte membrane at the centre while the electrons flow through the gas diffusion layer to the current collectors and into the electric load attached.

The electrochemical reactions are:

At the anode: $2H_2 \rightarrow 4H^+ + 4e^-$ (HOR)

At the cathode: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ (ORR)

Total Cell Reaction: $2H_2 + O_2 \rightarrow 2H_2O$ + Heat +Electricity

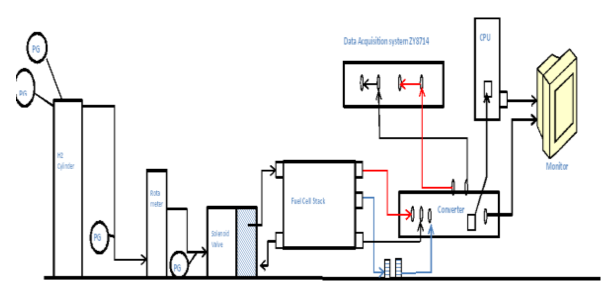

Fig.1 shows a scheme of the experimental arrangement

It consist of 300w (FCS-B300)&100w (FCS-B100) fuel cell stack with 61&24 individual cells manufactured by horizon fuel cell technology. These cells areself-humidified. The supply of air to the cathode is handled by a blower &hydrogen is stored in a high pressure tank at up to 100Kpa.As soon as the operational stack temperature reaches max. Stack temperature limit, the blower starts so as to maintain the temp.of the stack within range. Pure hydrogen &air are fed to the fuel cell stack. Purge valves is used to assist the removal of excess hydrogen from the valve so as to avoid the heating of the stack.

In this instrumentation, 300w cell is compact (can't remove individual cell)&100 w is open able. The system is fully instrumented to measure various operating parameters .Acomputer based control &data acquisition system, based on LAB View software developed application collects &multiplexes the respective signals &feeds them into the PC responsible for overall system control.

Purging is given at every 10sec.hydrogen flow rate is maintained at 2.8L/min. there are 3 blower attached to each stack whose air flow is maintained through the controller. The fuel cell stack performance is evaluated at different fuel cell voltage. As the voltage arevarying, the current & temp.is also varying. We have measured individual cell voltage on 100W FC stack by using multimeter.

Table 1 Physical parameters and properties

Channel length (mm)	100
Channel width (mm)	1
Channel height (mm)	0.8
Membrane thickness (mm)	0.036
Catalyst layer thickness (mm)	0.012
Anode diffusion layer thickness (mm)	0.21
Cathode diffusion layer thickness (mm)	0.12

3. Result & Discussion

3.1 Characteristic Performance of 300w fuel cell.

For this fuel cell, voltage loading of 20v to 36 v is given.The data of current, power, temperature has been given in table no.2. to no. 5.the polarization curve has been plotted .the polarization curve indicate that the fuel cell stack performance was improved with increasing voltage from 20v to 36v.as the voltage will increase, power also increases &temperature increases,but there is decline in current .As the temp.moves towards 60oc, the current falls down, the blower starts so as to maintain temp.of stack within 50-60^{0}c.

The increase in the fuel cell stack performance between 20 to 40 0C, in terms of the measured voltage, can be explained by the increase in the gas diffusivity and membrane conductivity at higher temperatures and to the increase of the exchange current density with the increase of the operation temperature, which reduces the activation losses. The gas diffusivity improves with increased fuel cell temperature; therefore, the fuel cell stack performance is improved at higher temperatures. Therefore, the kinetics reaction is improved by the high temperatures [24].

However, if the operation temperature is high enough, the membrane conductivity decreases because of the reduction in the relative humidity of the reactant gases and the water content in the membrane. Therefore, the fuel cell performance was worse when the fuel cell stack temperature was increased to 60ºC. As the temperature increases, there will be a greater rate of water evaporation. When the temperature reaches a critical temperature where the amount of evaporated water exceeds the amount of produced water, the membrane will start to dry out [25-28].all the data has been recorded after the steady state has been reached.

Table no. 2 performance of 300W stack at 20V Loading

Stack voltage V	Stack current A	Stack temperature	Stack power
20.96	18.97	45.6	397.61
20.96	17.34	37.8	363.44
20.96	15.71	31.64	329.28
20.96	14.89	50.39	312.09
20.96	14.08	55.3	295.11
20.96	13.67	59.2	286.52
20.96	12.85	57.3	269.33

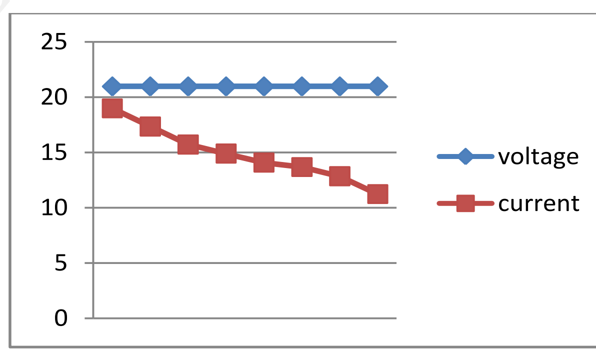

Figure no.2 polarisation curve for 300W stack at 20v Loading

Table no.3 performance of 300W FC at 25V loading

Stack voltage (V)	Stack current (A)	Stack temperature (¡æ)	Stack power
25.67	5.91	33.19	151.82
25.67	16.12	36.17	413.74
25.67	18.57	44.05	476.6
25.52	17.34	51.16	442.45
25.52	16.93	56.85	432.04
25.52	16.12	60.08	411.21
25.52	15.71	62.41	400.8
25.52	15.3	63.7	390.39
25.52	14.89	64.34	379.98

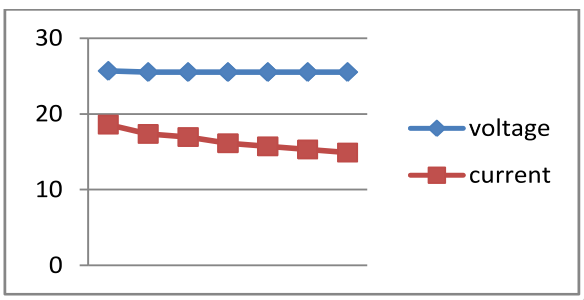

Figure no.3 polarisation curve for 300W stack at 25v loading

Table no. 4 performance of 300W stack at 30V Loading

Stack voltageV	Stack current A	Stack temperature	Stack power
30.2	15.3	55.3	462.06
30.2	14.29	58.01	431.55
30.2	13.12	61.5	396.22
30.2	12.37	62.28	373.57
30.2	11.20	60.73	338.24
30.2	10.39	59.2	313.77
30.2	9.45	57.3	285.39

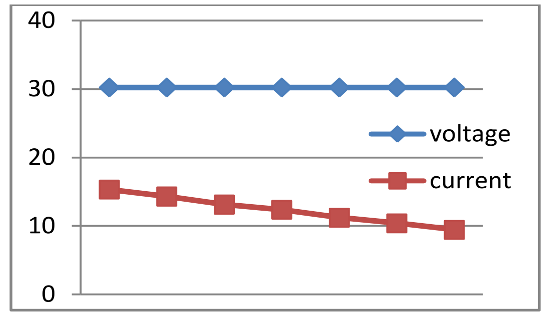

Figure no.4 polarisation curve for 300 W stacks at 30 v loading

Table no. 5 performance of 300 W stacks at 36 V loading

Stack voltage V	Stack current A	Stack temperatur e	Stack power
36.5	9.99	45.6	364.63
36.5	9.18	37.8	335.07
36.5	8.36	31.64	305.14
36.5	7.95	50.39	290.17
36.5	7.14	28.93	260.61

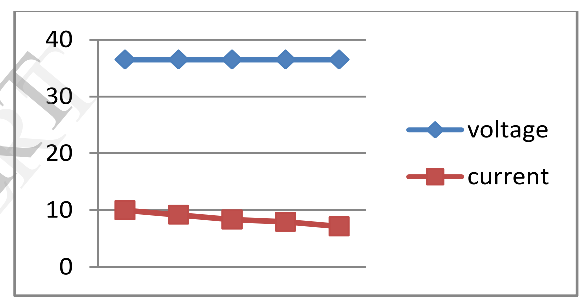

Figure no.5 polarisation curve for 300W stack at 36 v loading

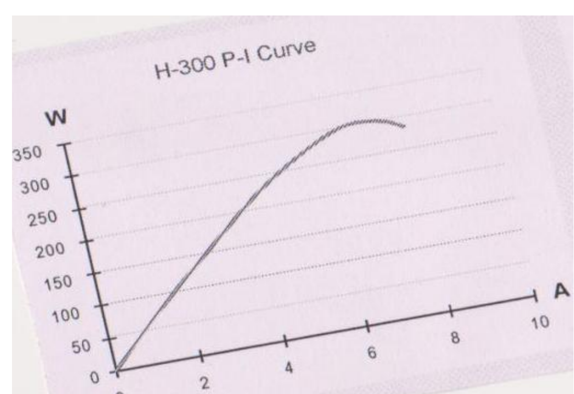

Figure no.6 power curve for 300W

3.2 Characteristic performance of 100w fuel cell

This fuel cell is openable. Voltage loading from 5v to18 v has been given to this cell.data has been recorded &polarisation curve has been obtained.as this stack is openable, it takes time to produce power of 100w.

Data of performance of 100w is given below.

Table no. 6 performance of 100W stack at 6V Loading

Stack voltage V	Stack current A	Stack temperature	Stack power
6.52	16.52	50	107.77
6.52	15.71	42.24	102.45
6.52	15.3	39.4	99.79
6.52	14.89	28.28	94.79
6.52	14.48	27.89	89.92
6.52	13.10	30.22	85.41

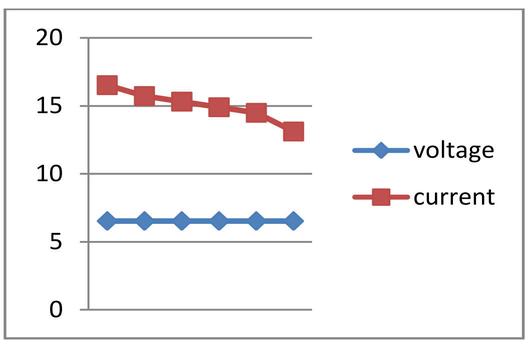

Figure no.7 polarisation curve for 100W stack at 6V loading

Table no. 7 performance of 100 W stacks at 11 V loading

Stack voltage v	Stack current	Stack temperature	Stack power
11.07	9.59	47.54	106.17
11.07	9.18	46.77	101.65
11.07	8.77	46.25	97.13
11.07	8.36	49.87	92.61
11.07	7.95	50.51	88.09
11.07	6.73	45.99	74.53

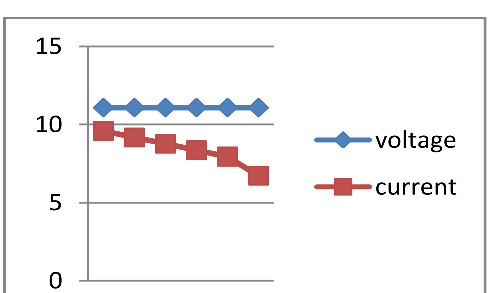

Figure no.8 polarisation curve for 100W stack at11V loading

Table no.8 performance of 100W stack at 15 V loading

Stack voltage V	Stack current A	Stack temperature	Stack power
16.1	7.14	38.24	114.9
15.94	6.73	40.43	107.28
15.94	5.91	35.13	94.27
15.78	5.1	34.75	80.46
15.78	4.28	34.62	67.53

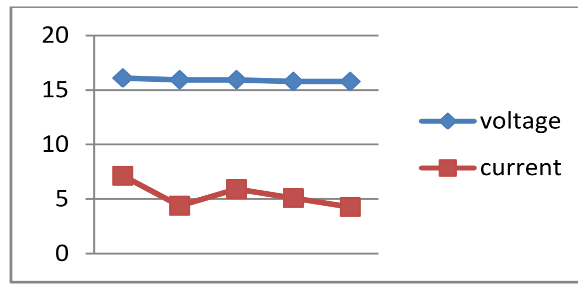

Figure no.9 polarisation curve for 100W stack at 15 V loading

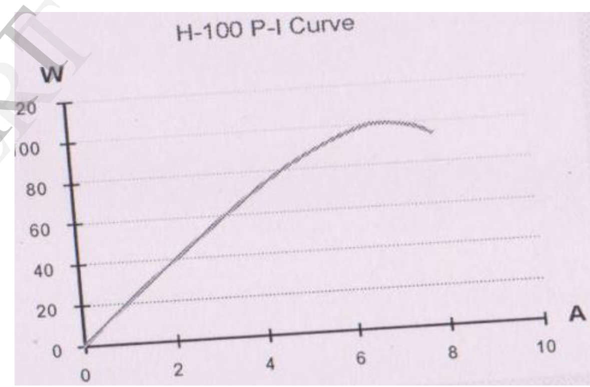

Figure no.10 power curve for 100W

3.3 Monitoring the individual cell voltage

This work is carried out on 100w open circuit fuel cell. The individual cell voltages at an operation temperature of 650c &with the different loading of current have been obtained.

Since all cells in a stack are electrically connected in series, the reliability of a stack depends on a satisfactory operation of all individual cells. Monitoring of only the stack voltage makes it difficult to distinguish the accumulation of slight deteriorations in all cells from the breakdown of a single cell. A single cell might have failed due to the blocking of channels or reaction sites by excess of water, due to overheating by temporarily insufficient cooling or due to mechanical failure of the membrane.

Figure shows the individual cell voltages at three polarization levels of the fuel cell stack at operation temperatures of 70ºC. When the stack is working at 3 A, the distribution of the individual cell voltages is practically uniform. At 7 A the distribution of the individual cell voltages is less uniform, the voltage of the firsts and lasts cells are lower than the voltage of the internal cells. At 12 A, the distribution of the individual cell voltages is similar than at 7 A, but the mean voltage is lower as the fuel cell stack is operating in the mass transfer control zone. For given operation temperatures, with the increase of current, the water production rate increases proportionally. The higher rates of water production can cause flooding in some cells and the uneven distribution of the individual cell voltages observed at high currents.

The voltage changes found previously in the individual cells at the different operating conditions can be attributed to different phenomena occurring throughout the stack, such as dehydration of the membranes or flooding of the gas diffusion electrodes, depending on the operation and humidification temperatures, and on the applied current. These phenomena cause a slight deterioration in every cell. Therefore, the monitoring of only the stack voltage makes it difficult to distinguish the accumulation of slight deteriorations in all cells from the breakdown of a single cell. [29]

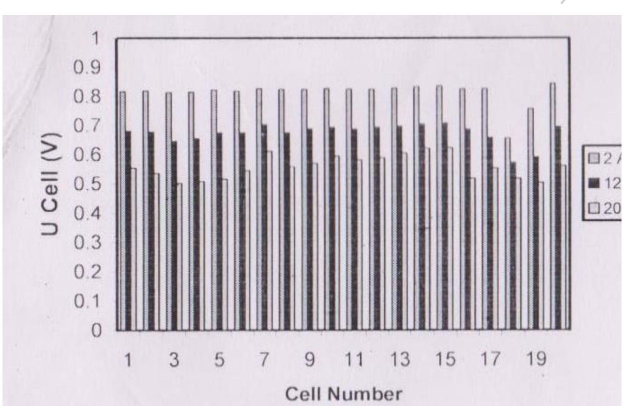

Figure no.11 individual cell voltages at operation temperature of 700c at different currents of 2A,12A,20A.

3.4 Optimal Operating Parameter.

In this section, we determined the optimal operating conditions for the developed mode.At the flow rate of 3.0 L/min.,loading voltage of 5v in 100w FC stack (as 300w is compact, optimisation can't be done on that),it has been found out that after 1800s (30 min),steady state has been reached,the current density is max.---.at 65 0c.After that it has started to drop out. This will assist in determining the best values of the operating parameters for the fuel cell system at the chosen levels of the operating voltage. Figure12 depicts the optimal search graph for temperature examined for this model. This shows the optimal current density obtained at temperatures of 750c at 0.3v operating cell voltage. .

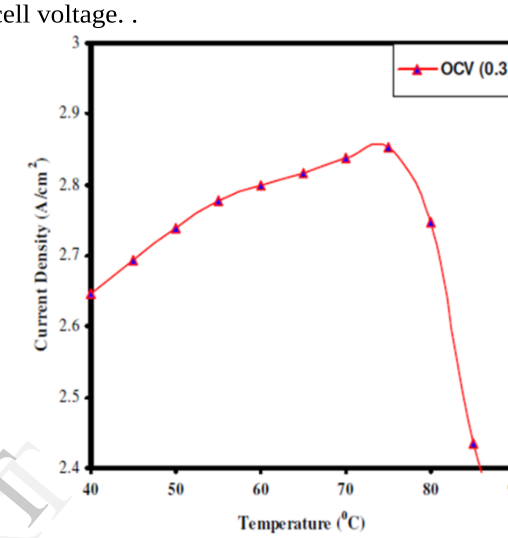

Figure no.12 Optimal Search Graph For Temperature

4. Conclusion

In this work, the effect of the voltage loading &temperature variance on the performance of a 300 W & 100WPEM fuel cell stack has been studied. As both the cells are self-humidified, polarization curves of the fuel cell stack showed that the fuel cell performance was improved with increase temperature from 30ºC to 60ºC &voltage loading of 20v to36v for 300W &5v to 16 v for 100W. At higher temperatures, the performance of the fuel cell stack decreases as the membranes can be dried. This causes a decrease on the mean stack voltage and an uneven distribution of the individual cell voltages.

The effect of the voltage loading on the fuel cell stack performance depends on the operation temperature.in this we have found out optimal working condition.

Acknowledgement

This work is supported by All India Council of Technical Education (grant no.8023/RID/Pvt (II policy) 2011-2012.the authors are thankful to sudhir sarawat from horizon fuel cell technology &Dr. R.P.Ugwekar for their kind support.

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