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Performance Analysis of PEM Fuel Cell for different Atmospheric conditions

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Abstract:
The fuel cell is a promising green technology and it can be a vital solution for the many problems relating to the pollution like transportation electricity generation etc. However, the performance of the fuel cell is highly dependent on the ambient conditions and therefore their study for the better use of the fuel is very necessary. The losses in the fuel cell have a relationship with the pressure and temperature and this paper deals about the different types of losses in the fuel cell and how they vary with different parameters. These losses are depending on the operating temperature of fuel cell, partial pressure of hydrogen and oxygen, rate of reaction and many more factors. This paper analyses the performance of fuel cell vary with different parameters.

Keywords **:** *PEMFC, Losses, Nernst's Voltage*

I. INTRODUCTION

Fuel Cell is a quickly emerging technology in the energy sector, and it is a promising less carbon footprint technology. In the fuel cell chemical energy is directly covert into electrical energy with very high efficiency. There are different types of fuel cell present in the market, but proton exchange membrane fuel cell (PEMFC) is most suitable to be used for colossal number of applications[1].

In recent days, PEM fuel cell is highly used in vehicles, as a generator at remote area because of low weight, small size and low amount of fuel required as compare to IC engines. It is also used in combination with other renewable energy sources like Solar, Wind etc. [2], [3]. The fuel cell takes very small time to fill its fuel tank and it start quickly. That is the reason, why fuel cell is so popular in these days [4]–[7].

II. WORKING OF FUEL CELL

There are two electrodes present in the fuel cell, first one is anode and other is cathode. At anode, H_2 fuel is fed with high pressure through the distribution channel, and in the presence of Pt and porous carbon catalyst, this H_2 (presence in vapour form) breaks in two h+ ions and gives two free electrons (Equation 1) [5].

$$H_2 = 2H^+ + 2e^- \quad (1)$$

This H^+ ion flows through the proton exchange membrane from anode to cathode side and the free e^- are flow through the output circuit where load is connected and reached to cathode terminal [8]–[10].

At cathode terminal oxygen is fed from atmosphere with the help of channel. the free e^- & H^+ ion and O_2 are combine together and give water (H_2O) as a by-product.

$$2H^+ + 2e^- + ½\, O_2 = H_2O \quad (2)$$

III. LOSSES IN PEM FUEL CELL

In fuel cell, there are different type of losses but in this paper only three of them are discuss such as carbon loss, Activation loss, concentration loss ohmic loss and loss due to fuel cross over and internal current and many more.

A. Activation Losses:

This type of loss appears, when electrochemical reaction rate is very slow at the electrodes surface. This loss is totally depending on the rate of reaction at the both electrodes i.e. anode and cathode [4], [11], [12].

Activation loss in fuel cell is given by

$$E_{active} = -B \ln(i/i_0) \quad (3)$$

Where $B=-RT/anF$, i is current density, i_0 is exchange current density ($i>i_0$), a is the electrons transfer coefficient and n represent total moles of electron transferred for each mole of hydrogen in the reaction.

For simplification purpose the Activation losses can be simplified by using an offset value and a current dependent function which approximates the effects of the activation losses. The generalised and simplified version of the activation losses is

$$E_{active} = a + b*\log(i) \quad (4)$$

Where a is the offset value and the b is the logarithmic coefficient. Moreover, both of the coefficients have a dependency on the temperature, and they can be written as

$$a = a_o + a_1(T) \ \& \ b = b_o + b_1(T) \quad (5)$$

B. Concentration losses:

These losses originate because of the formation of concentration gradient that forms due to the high consumption of the fuel during the high flow of current [7], [13]. High current results in the heavy consumption of the fuels and that breaks the streamline circulation of fuels and therefore these losses are evident at higher currents. Also the pressure plays a very important role in the concentration losses at low pressure condition the losses tends to increase due to the fact that in low pressure conditions the formation of the gradients are much more easier and low pressure tends to lower down the reaction rate as there are fewer number of the reactants participating at the time of reactions. This loss develops due to the decrease in the concentration of the fuel or reactant at the electrodes surface, the reactants are consumed due to the reaction occurring in fuel cell. Different factors are responsible for the concentration losses in the fuel cell, such as slow dissociation of H_2 at anode and slow association of H^+, e^- and O_2 at cathode.

Given equation is used for calculating concentration loss in fuel cell

$$E_{conc} = (m*\exp(n*i))/P - 0.60073797*\log(1/P) \quad (6)$$

Where m is constant and depends on the temperature, n is a constant, i is current density, P is pressure.

C. Ohmic losses:

Ohmic loss appears due to the resistance offered by the electrolyte i.e. proton exchange membrane during transferring proton from anode to cathode side and also by electrodes when electrons flow from them [14]–[16]. The current flow through electrolyte and electrodes follow Ohm's law. The Ohmic losses are calculated by simple formulae

$$E_{ohmic} = i*(R) \quad (7)$$

Where I is current in fuel cell, R is resistance offer by electrolyte and electrodes.

The resistance R also depends upon the internal temperature of the fuel cell with a liner dependency as a normal resistance does.

Output terminal voltage of fuel cell:

Output terminal voltage is given by Nernst's voltage equation

$$E_{nernst} = 1.229 - 8.45\times10^{-4}((T - 298.15) + 4.31\times10^{-5} (T + 273.15) * \ln(pH2 * sqrt(pO2)) \quad (8)$$

The T is the temperature in Kelvin, pH2 is the partial pressure of hydrogen, pO_2 is partial pressure of oxygen.

When we consider the losses of fuel cell then output terminal voltage of cell is given by

$$E_{net} = E_{nernst} - E_{activation} - E_{conc} - E_{ohmic} \quad (9)$$

IV. SIMULATION MODEL

The model shown in figure 1 is primarily a numerical simulation model which aims to find and trace the characteristics of the fuel cell for different conditions and understand the basic behavior for the better practical uses of fuel cell. In the model we had make some basic assumptions and neglected some effects for the simplicity purpose. The double layer phenomenon and the thermal model of the fuel cell has been neglected for the sake of the simplicity. The model broadly focuses on the Nernst Potential obtained and the effects of the losses at different atmospheric conditions.

In the model we have assumed that the pressure of hydrogen will be constant as it will be produced in a reformer which is basically a closed container and therefore the pressure will be somewhat always be constant regardless of the altitude.

The pressure of the oxygen will be dependent on the altitude and will be governed by the function

$$P = ((1 - .000022557695*h))^{5.2561} \quad (10)$$

Where the h is the height in meters from the sea level.

The fuel cell current generated by the Fuel Cell Stack (I_s) is the summation of the current delivered to the peripherals and current delivered by the FC (I_{FC}). For the calculation of the I_s the formula was borrowed from a journal and it has been checked with the experimental data [17]–[19].

$$I_s = K_2 I_{FC}^2 + (1 + K_1) * I_{FC} + K_o \quad (11)$$

Where the K_o, K_1 & K_2 are the empirical constants.

The different internal parameters used in the model are given in table 1.

Table 1

Description	parameter	Value
Peripheral Consumption	$K_o(A)$	1.524
	K_1	-1.2080×10^{-3}
	$K_2(A^{-1})$	4.1180×10^{-4}
Activation Phenomenon	$a_o(V)$	0.1259
	$a_1(VK^{-1})$	1.1128×10^{-4}
	$b_o(V)$	5.087×10^{-3}
	$b_1(VK^{-1})$	1.4866×10^{-5}
Concentration Phenomenon	$m_o(V)$	8.250×10^{-4}
	$m_1(VK^{-1})$	-3.328×10^{-6}
	$n(A^{-1})$	4.5×10^{-2}
Ohmic Phenomenon	R_{ohm0}	8.959×10^{-4}
	R_{ohm1}	4.8479×10^{-6}

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V. RESULTS AND DISCUSSION

The graph of figure 2 shows us the Voltage and Current characteristics of the fuel cell for the various heights.

A sharp fall in the starting of the curve demonstrates the presence of the activation losses during the starting period, after that there is quite a linear curve which is primarily because of the dominance of the Ohmic losses. After that curve takes a sharp dip to turn zero gradually at the higher current levels. That is because of the dominance of the Concentration losses at the higher currents and they exponentially vary with the current.

From figure 2 we can see that there is a clear degradation in the V vs I characteristics as the height increases. Also, the maximum terminal voltage also drops severely with the increase in height primarily because the fact the pressure drops which decreases the number of reactants at the reaction surface. Moreover, the cut-off current decreases with the increase in the altitude primarily because of the fact that the losses mainly Concentration losses tend to increase with the altitude and that causes a decrease in the cut-off voltage.

Also, at the higher altitudes the Concentration losses start to dominate the curve much earlier relative to lower height that can be explained by the fact that with increase in the heights the pressure drops and at the lower pressure concentration gradients forms easily.

The graph of figure 3 shows the relationship between the terminal voltage of fuel cell with the variation in Altitude for the various current densities. From the graph we can easily conclude that there is a clear degradation in the terminal voltages for the increase in the altitude and that decrease is found to be linear in nature, and this pattern is recognizable for every current density. The slope of graph doesn't change much for lower amount of the current densities but for higher amount of current density the slope of the graph decreases much abruptly and the effect is much more easily recognizable. The reason for such change is that at higher currents concentration losses plays a more critical role and therefore the slope decreases further.

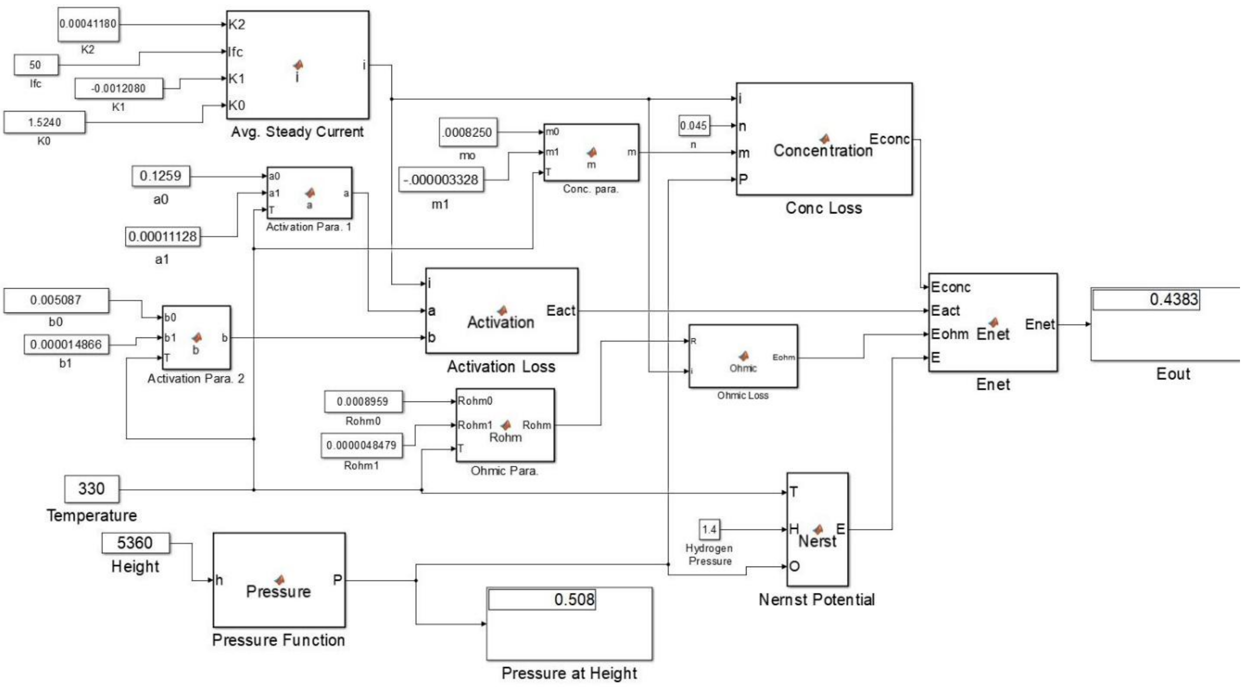

Fig. 2.Numerical simulation model a fuel cell

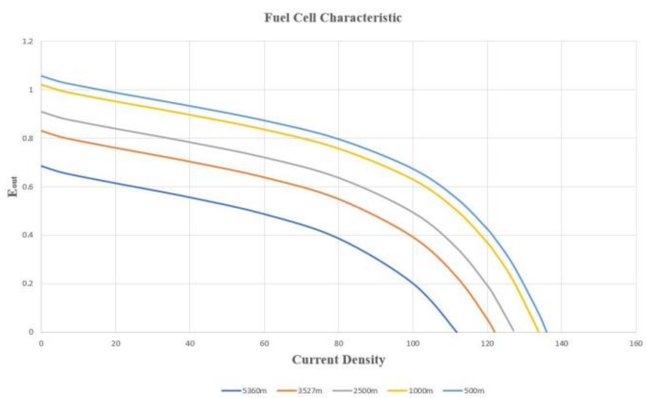

Fig. 2. Effect of Current Density at E_{out}

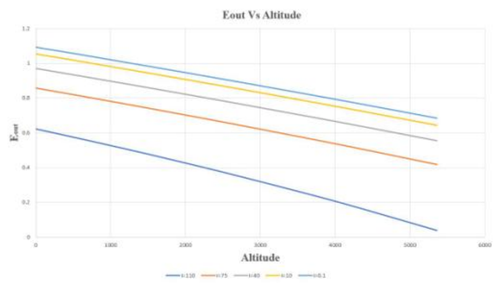

Fig. 3. Effect of Altitude & Variation at E_{out}

The graph of figure 4 shows the variation of the Power with the current density. From the graph we can see that there is linear relation between current density and power at starting but when current density increases more and more the relationship becomes exponential till maximum power is obtained. Now further increase in current density causes decrease in power. The fuel cell is used in its maximum power region which in our case lies in between the 60 to 80mA/cm^2 range. Also, the stable region for the operation of the fuel cell lies between 63 to 80mA/cm^2. That is primarily because the fact that if the power decreases in this part the voltage shall increase which will again increase the power and try to get back to the same old plot and it will maintain the stability. The power graph gives us the idea to where use the fuel cell to have maximum power with the optimal efficiency.

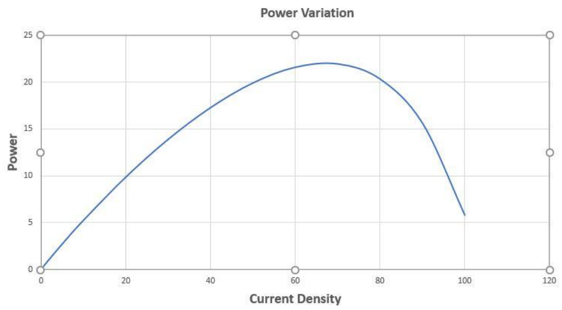

Fig. 4.The variation of the Power with the current density.

VI. Conclusion

In this paper a detailed performance analysis of PEM Fuel Cell for different atmospheric conditions is done. Variation of different parameters of a PEM fuel cell is shown in the results. There are different types of losses in fuel cell, but in this paper few of them are discuss because they are highly responsible for voltage drop at the output terminal of the fuel cell. These losses are depending on the different factors such as current density, partial pressure of fuel in stack, temperature and many more factors. This paper is very useful for studying the losses occurring in a fuel cell and their variation with different parameters.

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