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SIMULATION OF FUEL CELL ELECTROLYTE THICKNESS AND AREA ON OHMIC LOSSES USING MATLAB

A.H. Butar-Butar[1], M. Irwanto[2], M. Masri[3], H. Alam[4], Shahira M. A[5]

[1]Department of Electrical Engineering, universitas Negeri Medan (UNIMED), Medan, Indonesia
[2,3,4] Department of Electrical Engineering, Institut Teknologi Medan (ITM), Medan, Indonesia
[1,2,3,4,5]School of Electrical System Engineering,
Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia,

Abstract – This project is done to study the effect of fuel cell electrolyte thickness and area on the ohmic losses by using MATLAB software. The type of fuel cell that involve in this project is polymer electrolyte membrane (PEM) fuel cell due to the availability in market nowadays. The ohmic losses of the fuel cell was obtained from the simulation. This project involving the simulation of 2D simulation.. The data that have been used for the 2D simulation is based on the datasheet of H-100 FCS-C100 fuel cell. The parameter that related to the simulation is current density, electrolyte thickness and fuel cell area. The simulation will show the relationship between the fuel cell characteristic and the ohmic losses. The analysis from the result, will indicates the best electrolyte thickness and fuel cell in order to increase the performance of fuel cell.

I. INTRODUCTION

The increasing in a population growth in Malaysia day by day have affects the demanding in electricity usages. The natural sources have not enough to support the power generation anymore. Hence, Malaysia has introduced from Four to Five Fuel Diversification Strategy in 2002, renewable energy was considered as the fifth fuel for the new alternative source [1]. Besides, the renewable energy has been one of the options to the people nowadays because there are low pollution emissions, energy efficient and unlimited supply compare to non-renewable energy.

One of the renewable energy power sources for the future is fuel cell and the most popular fuel cell is Polymer Electrolyte Membrane (PEM) Fuel Cell. It use hydrogen as a fuel, it also can use another type of fuel from hydrogen to ethanol and convert to biomass-derived materials.

The three basic components that consist in the fuel cell are anode, cathode and electrolyte. It works when there is a chemical reaction occurs inside the fuel cell that will convert the fuel into electricity. At the anode side the hydrogen are oxidised and the oxygen will be reduced at the cathode side.

This project presents to observe the effect of the active area and thickness of the electrolyte in PEM fuel cell and to prove the statements that the ohmic losses of PEM fuel cell depends on the active areas and the thickness of the electrolyte.

Every material has its own natural resistance that will disturb and reduce the performance of charged flow through the fuel cell. In fuel cell, all the components that can contribute to those resistance including the anode and cathode terminals, electrolyte, bipolar plates and gas diffusion layer. The decreasing of the voltage due to this resistance is called ohmic losses which will affect the fuel cell performance.

An electrolyte is a proton conductive membrane which is the main source of ohmic losses in PEM fuel cell. The common ways to reduce the losses and improve the performance of the fuel cell by decreased the resistance of the electrolyte. The resistance can be decreased by reducing its area and propose a high conductivity materials to make it well connected to each other. But, there is the limitations for the thickness of the electrolyte, where the electrolyte cannot be too thin in order avoid the shorting of one electrode to another that can lead to physical robustness.

Fuel cell is one of the electrochemical energy conversion devices that works by converting the chemical energy to electrical energy through the chemical reaction. The chemical reactions involve the positively charged hydrogen ions with oxygen or another oxidising agent. Fuel cell have three basic components consists of anode, cathode and electrolyte membrane that will carried the positively charged hydrogen ions to the cathode. The basic operations of the PEM fuel cell are shown in Figure 1.1 [3].

At first, the hydrogen fuel are oxidised at anode by split into electrons and positively charged hydrogen. Then, proton is transported from the anode to cathode by electrolyte, while the electrons are flown to the cathode through the external circuit that will produces direct current electricity. At the cathode side, the oxygen will be reduced and combined with the electrons and positively charged hydrogen to produced heat and water. The chemical reaction at the anode and cathode are shown in Equation 1.1 [3].

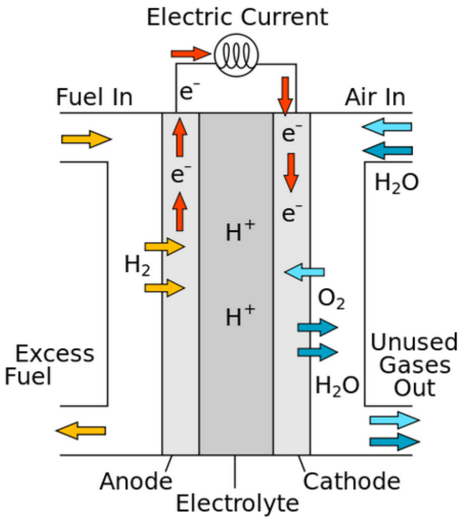

Figure 1.1: The basic operation of fuel cell [3].

$$\begin{aligned}&Anode:\ H_2 \rightarrow 2H^+ + 2e^-\\&Cathode:\ \frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O\\&Overall:\ H_2 + \frac{1}{2}O_2 \rightarrow H_2O + electrical\ energy + waste\ heat\end{aligned} \quad (1.1)$$

II. METHODOLOGY

2.1 Simulation of ohmic losses vs. current density

The procedures to simulate the ohmic losses vs. current density as shown based on the Figure 2.1 and the coding below.

1. A data input of fuel cell consists of current, area, thickness, conductivity and resistance which stated below that created in M-File MATLAB.

i=0.7;
% Current density (A/cm^2)
A=100;
% Fuel cell area (cm^2)
L=0.0050;
% Electrolyte thickness (cm)
Sigma=0.1;
% Conductivity (Ω/cm)
R_elec=0.005;
% Electrical resistance (Ω)

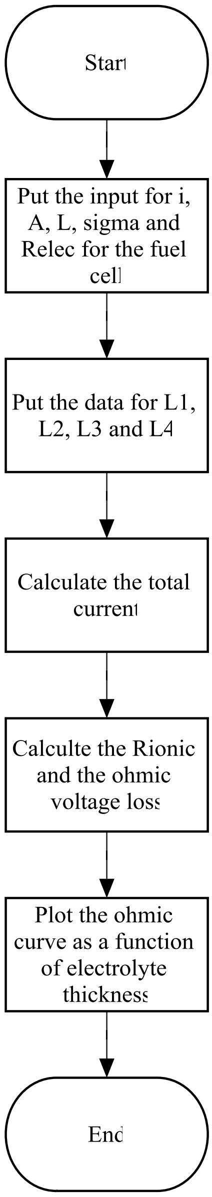

Figure 2.1: The flowchart of the simulation of electrolyte thickness.

2. A data input for the electrolyte thickness of L1, L2, L3 and L4.
i=0:0.01:1;
% Current range
L1=0.0025;
% Electrolyte thickness of 25μm

L2=0.0050;
% Electrolyte thickness of 50μm
L3=0.01;
% Electrolyte thickness of 100μm
L4=0.015;
% Electrolyte thickness of 150μm

3. Calculate the total current
   I=i*A;
4. Calculate the ionis resistance and the ohmic voltage loss
   R_ionic1=L1/(sigma*A);
   V_ohm1=I.*(R_elec+R_ionic1);
   R_ionic2=L2/(sigma*A);
   V_ohm2=I.*(R_elec+R_ionic2);
   R_ionic3=L3/(sigma*A);
   V_ohm3=I.*(R_elec+R_ionic3);
   R_ionic4=L4/(sigma*A);
   V_ohm4=I.*(R_elec+R_ionic4);

5. Plot the ohmic loss as a function of electrolyte thickness
   figure1=figure('Color',[1 1 1]);
   hdlp = plot(i,V_ohm1,i,V_ohm2,i,V_ohm3,i,V_ohm4);
   title('Ohmic Loss as a Function of Electrolyte Thickness','FontSize',14, 'FontWeight', 'Bold')
   xlabel('Current Density (A/cm^2) ', 'FontSize',12, 'FontWeight', 'Bold');
   ylabel('Ohmic Loss (V) ', 'FontSize',12, 'FontWeight', 'Bold');
   legend('L1=0.0025', 'L2=0.0050', ' L3=0.01', ' L4=0.015');
   set(hdlp, 'LineWidth',1.5);
   grid on;

2.2 Simulation of ohmic losses vs. fuel cell area

The procedures to simulate the ohmic losses vs. fuel cell area as shown based on the Figure 2.2 and the coding below.

1. A data input of fuel cell consists of current, area and resistance which stated below that created in M-File MATLAB.
   i=0.7;
   % Current density (A/cm^2) A1=16;
   % Area 1 (cm^2)

   R1=0.05;
   % Resistance 1 (Ω)
   A2=49;
   % Area 2 (cm^2)
   R2=0.02;
   % Resistance 2 (Ω)

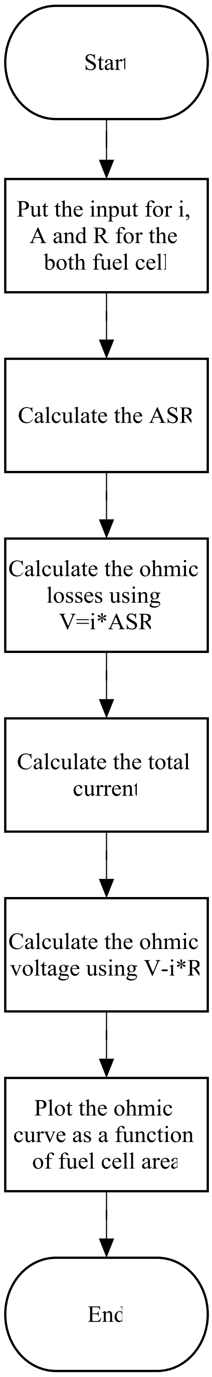

Figure 2.2: The flowchart of the simulation of fuel cell area.

2. Calculate the area specific resistance (ASR) of the fuel cell
   ASR = R*A;

3. Calculate the ohmic voltage losses
   V_ohm = i*ASR;

4. Calculate the total current
   I = i*A;

5. Calculate the ohmic voltage loss
   V_ohm = I.*R1;

6. Plot the ohmic losses as a function of fuel cell area
```
figure1=figure('Color',[1 1 1]);
hdlp = plot(A,V_ohm);
title('Ohmic Loss as a Function of Fuel Cell Area', 'FontSize',14, 'FontWeight', 'Bold')
xlabel('Fuel Cell Area (cm^2) ', 'FontSize',12, 'FontWeight', 'Bold');
ylabel('Ohmic Loss (V) ', 'FontSize',12, 'FontWeight', 'Bold');
set(hdlp, 'LineWidth',1.5);
grid on;
```

2.3 Analysis result of 2D graph

After the simulation in MATLAB, the graph by varying this two characteristic of electrolyte have been obtained which by varying the fuel cell area and varying the electrolyte thickness.

The first graph is obtained from the simulation of the fuel cell area. The graph is plot with the ohmic loss in the Y-axis and the current density in the X-axis by using four different thickness of the electrolyte.

The second graph is obtained from the simulation of electrolyte thickness. The graph is plot the ohmic losses at Y-axis as a function of the fuel cell area at 16cm^2 at the X-axis.

The result from the simulation will described the relationship between the characteristic of the fuel cell with the ohmic losses. The analysis also determine whether the increasing on those value will give the impact on the fuel cell performance and what the required size for the fuel cell in order to minimize the losses.

III. RESULT AND DISCUSSION

The result from the 2D simulation have divided into two part, the simulation on effect of the electrolyte thickness on the ohmic losses and the simulation on the effect of the fuel cell area on the ohmic losses.

3.1 Effect of the Electrolyte Thickness on the Ohmic Losses

As shown in Figure 3.1, the current density is directly proportional to the ohmic loss. Besides, it shows that as the electrolyte thickness increase, the ohmic loss and current density are increase.

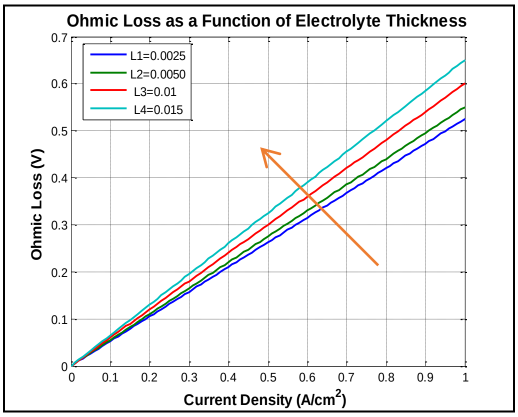

Figure 3.1: Ohmic loss as a function of electrolyte thickness.

Based on the theory, the ohmic losses increase due to the resistance in the electrolyte when the electrolyte when the electron flow through from anode to cathode. From the formulation of Equation 3.1. As the thickness of the electrolyte is increase, the resistance of the electrolyte will increase with the increasing of the ohmic voltage.

$$R = \frac{L}{\delta A} \tag{3.1}$$

Hence, it necessary to use thinner electrolyte to reduce the value of resistance while reduce the distance of the electron flow with the short length.

From the previous research paper state that the largest source for the ohmic losses in PEM fuel cell is electrolyte which act as proton conductive membrane. The resistance from that electrically conductive component and the contact resistance at the interfaces will affect the increasing in ohmic losses. As the ohmic losses reached maximum, that will be indicator to the high contact resistance due to the surface oxidation of the components or the stack not installed properly.

The ohmic losses also being an indicator for the water management because any problem will the gives a bad impact to the operation of fuel cell. The several parameter that related to the water management are current density, cell temperature and the gases flow rate and humidity.

3.2 Effect of the Electrolyte Area on the Ohmic Losses

As shown in Figure 3.2, the ohmic loss is directly proportional to the fuel cell area. The graph shows that as the fuel cell area increase, the ohmic loss will increase.

The increasing in the area of the electrolyte will increase the fuel cell active area part. The active area of the fuel cell is where the hydrogen is being supplied and convert the electron into the electricity. The ohmic losses is due to the resistance for flow the electrons through the electrodes.

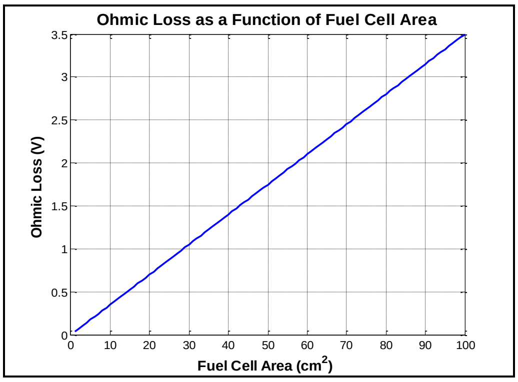

Figure 3.2: Ohmic loss as a function of fuel cell area for 16cm^2.

Even, the smaller active area will give the lowest ohmic loss but the size of the fuel cell is depends on the application. The smaller active area will have slow charge transfer, more efficient current collecting lower cost of machining and manufacturing and total less in dimension and weight.

In the other hand, the decreasing of the size of the active area will cause the decrease in power output of the cell. The decrease in power caused by the drop in cell operating temperature. The exothermic reaction can generated more heat in cell operation in larger area to increase the cell performance. The active area is important for the fuel cell performance because the electrochemical reaction are occur in the active area.

IV. CONCLUSION

The result from the 2D simulation as analyses in the previous chapter. For the first simulation, it shows that the ohmic losses are increase due to the increasing of the current density and the electrolyte thickness.

For the second simulation, the graph that resulted simulation shows that the ohmic losses of the fuel cell are increase as the fuel cell area increase. As the conclusion, the ohmic losses can be decrease by decreasing the size of the fuel cell area and the thickness of the electrolyte.

However, there are many factor that related to the fuel cell performance such as operating condition involving pressure, temperature, reactant gases and other parameter. The changing on each of the operating parameter must suitable with the application requirement because the changing may affect the fuel cell and other system performance. Based on this study, the performance of the fuel cell can be improve as the ohmic losses of the fuel cell decrease.

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