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Proton Exchange Membrane Fuel Cell Design and Dynamic Modeling in MATLAB

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ABSTRACT
The alternatives to combustion engines in future will be fuel cells. The dynamic behavior of fuel cells for changing load conditions show poor voltage regulation. For improving the voltage regulation of PEM fuel cell, efficient control system should be designed. If the dynamic behavior of the fuel cell is known, the cost in designing the control system is greatly reduced .The behavior of the fuel cell for various load conditions and for changing pressure and temperature can be found by dynamically modeling the proton exchange membrane fuel cell.

I. INTRODUCTION

Global warming has increased in the past century due to the increased emission of carbon dioxide in to atmosphere [1]. Millions of years are taken by the fossil fuels to form and are the major causes of pollution in the world. Since they are non renewable sources of energy, they get depleted. In order have a pure and clean source of energy, fuel cells are used. They are the remedy for various pollution problems concerned with the environment [2].Fuel cells combine hydrogen and oxygen to produce electricity and water. Hence they are the most sustainable sources of electricity in future. The chemical energy is is converted to electrical energy directly by the fuel cell. Continuous supply of hydrogen and oxygen is required for the operation of fuel cell. The fuel cell is a static power conversion device and produce dc power as output. Water vapour which is a non pollutant is the only exhaust of the fuel cell if pure hydrogen is used as fuel.The efficiency of conversion is better as the chemical energy is directly converted to electricity without intermediate conversion. There are various types of fuel cell. They are phosphoric acid fuel cell, Alkaline fuel cell, Molten carbonate fuel cell, Solid oxide fuel cell and proton exchange membrane fuel cell. The automobile industries mainly use proton exchange membrane fuel cell because of their high efficiency. And they have very low noise because of the absence of stationery parts. Compared to other types of fuel cells, the operating temperature is also very low. The voltage regulation is very important in the vehicular application. Due to the characteristics of the polarization curve governed by the electrochemical reaction, the voltage regulation is poor. The simple equivalent electrical circuit which includes a capacitor because of the double-layer charging effect were previously reported[3].Later a PEM fuel cell model that included the development of catalytic overvoltage was proposed [4].By dynamically modeling the fuel cell, the response for various load conditions can be found. For dynamic changes in temperature and pressure, the fuel cell response can be found. Using this model, the controller can be designed with reduced cost.

II. PHYSICAL MODEL OF FUEL CELL

The fuel cell consists of three main parts. They are the anode, cathode and the electrolyte. A solid membrane of organic material that allows H^+ ions to pass through it is used as the electrolyte. Platinum is used as the electro chemical catalyst. Based on the type of electrolyte the fuel cells are classified. The hydrogen is given to the anode and oxygen is given to the cathode.

Anode: $2H_2 \rightarrow 4H^+ + 4e^-$ (1)

High pressurized hydrogen gas is given to the anode and when this passes through the catalyst layer the hydrogen gets splits in to hydrogen ions and electrons. The ions pass through the proton exchange membrane and the electrons flow through the external path and electricity is produced.

Cathode: $O_2 + 4e^- + 4H^+ \rightarrow 2H_2O$ (2)

On the cathode, oxygen is supplied where it combines with the electrons and ions to form water

Overall reaction: $2H_2 + O_2 \rightarrow 2H_2O + 4e^-$ (3)

The output voltage of single fuel cell is 0.7-0.8V.When fuel cells are combined together it forms the stack. Thus the desired voltage can be taken from the stack

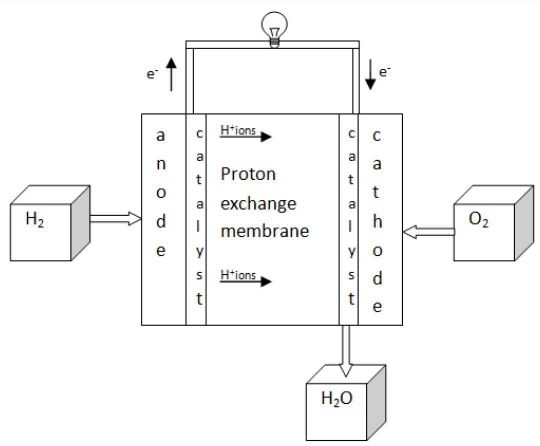

Figure1:Simplified representation of fuel cell

III. MODELLING

In order to obtain the performance of the fuel cell it is modeled dynamically. The output voltage of the PEM fuel cell is given by the following [5]

$$V_f = V_n - V_a - V_o - V_c \quad (4)$$

V_f	Fuel cell output voltage (V)
V_n	Nernst voltage (V)
V_a	Activation voltage loss (V)
V_o	Ohmic voltage loss (V)
V_c	Concentration voltage loss (V)

2.1 ACTIVATION LOSS:

The electron transfer process is limited by the activation energy. Inorder to emit adequate number of electrons specific amount of activation energy is required. This activation energy is supplied by the output of the cell resulting in activation loss.Efficient catalyst like platinum can be used to reduce this loss.

$$V_n = 1.229 + (T-298)(-2.302\times 10^{-4}) + 4.308\times 10^{-5}\, T \ln (PH_2 PO_2^{1/2}) \quad (5)$$

T	Temperature of operation (K)
PH_2	Partial pressure of hydrogen (bar)
PO_2	Partial pressure of oxygen (bar)

$$V_a = A \ln(i/i_o) \quad (6)$$

$$A = \frac{RT}{2\propto F} \quad (7)$$

i	Actual cell current density (A/cm^2)
i_0	Exchange current density (A/cm^2)
R	Universal Gas Constant (J/(mol*K))
$\propto$	Charge transfer coefficient
F	Faraday's Constant (C/mol)

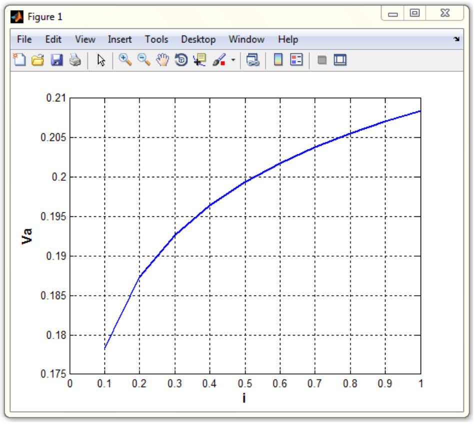

Figure 2: V_a with respect to current density

2.2 RESISTANCE LOSS:

In the case of large current there will be contribution from internal resistance which is due to resistance offered by the electrolyte and contact resistance between electrode and electrolyte. This loss can be reduced by using electrolyte of high conductivity.

$$V_o = i \times (R_e + R_p) \quad (8)$$

R_e	Resistance produced by the membrane to the flow of electrons (ohm)
R_p	Resistance produced by the membrane to proton flow (ohm)
I	Actual cell current density (A/cm^2)

$$R_p = \frac{L}{\sigma A} \quad (9)$$

L	Electrolyte thickness (cm)
σ	Conductivity (mho/cm)

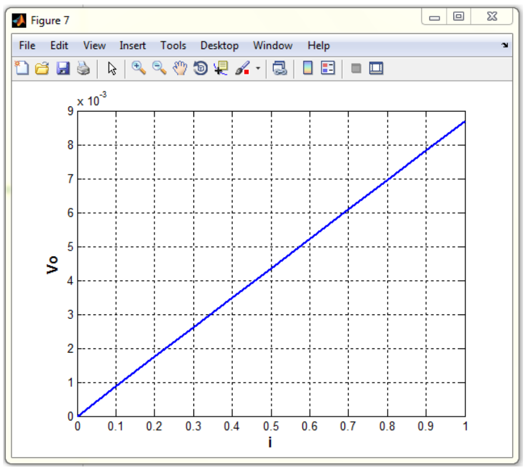

Figure 3: V_o with respect to current density

2.3 CONCENTRATION LOSS

This is due to the slow diffusion of reactants through the porous electrode and due to slow diffusion of ions in the electrolyte.This loss can be reduced by increasing conductivity of the electrolyte and the operating temperature of the cell.

$$V_c = -B\ln[1-(i/i_{max})] \quad (10)$$

B Parametric coefficient
i_{max} Maximum current density (A/cm^2)

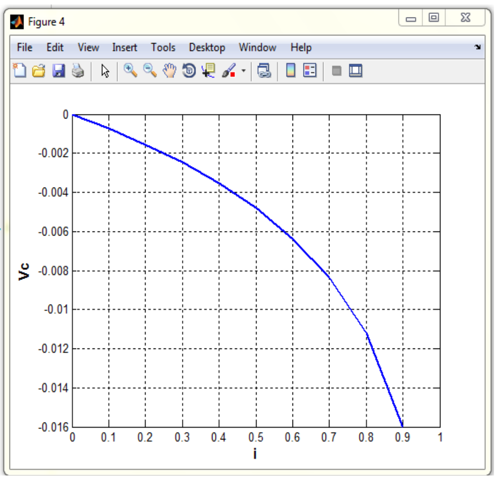

Figure 4: V_c with respect to current density

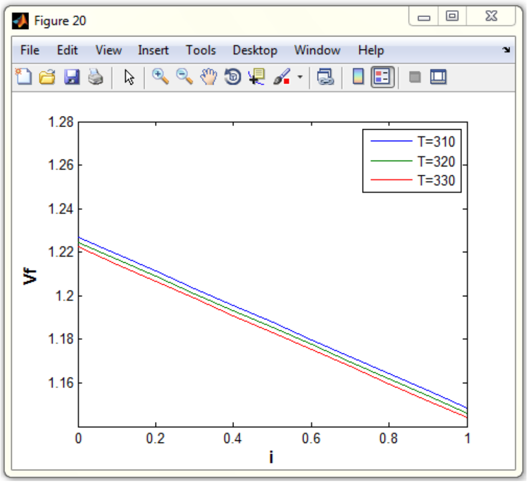

Figure 5: Response of the PEM fuel cell for changes in temperature

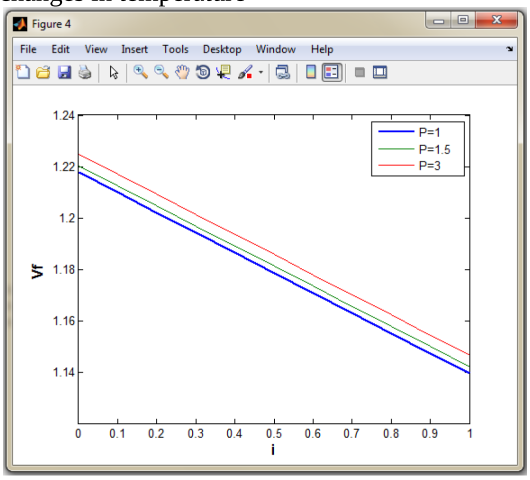

Figure 6:Response of the PEM fuel cell for changes in pressure

IV. CONCLUSION

Hence the dynamic response of the fuel cell for various load condition ,temperature and pressure are acquired with the help of dynamic model and implemented in MATLAB.This model of MATLAB is used for the calculation of system specfic parameters.This can be further used for real time data processing,testing different control strategies,for checking transient response of the system and for designing the controller of the fuel cell

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