

# A Dynamic Modeling and Simulation of a Proton Exchange Membrane Fuel Cell Using MATLAB/SIMULINK

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**Abstract**—In order to investigate the output characteristic of a proton exchange membrane fuel cell (PEMFC) based on the electrical empirical model, a novel dynamic model of the PEMFC has been developed with MATLAB/Simulink, which is distinct from the models that have been published previously. The comprehensive results of simulation manifested that the model is effective and operational. This model will be very useful to optimize the structure design, improve the operation performance, and develop the real-time control system of PEMFC.

**Index Terms**—Dynamic model, dynamic simulation, proton exchange Membrane fuel cell (PEMFC).

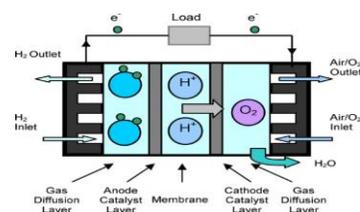
## 1. INTRODUCTION:

Fuel cells are set to become the power source of the future. The interest in fuel cells has increased during the past decade due to the fact that the use of fossil fuels for power has resulted in many negative consequences. Some of these include severe pollution, extensive mining of the world's resources, and political control and domination of countries that have extensive resources. A new power source is

needed that is energy efficient, has low pollutant emissions, and has an unlimited supply of fuel. Fuel cells are now closer to commercialization than ever, and they have the ability to fulfill all of the global power needs while meeting the efficacy and environmental expectations.

Mathematical Model for the performance and operation of a single polymer electrolyte membrane fuel cell which incorporates all these electrochemical processing occurring membrane electrolyte, cathode catalyst layer, electrode backing and flow channel[5]. Pem Output is based on Electrical empirical Model and Transient Electrical Response of PEMFC can be conducted and analyzed under various conditions. Mathematical Model of PEMFC is used to establish a simple effective model through which Transient Voltage, Power and efficiency with changing loads is analyzed.

## II. BASIC OPERATION OF PEMFC :



[4] Polymer Electrolyte Membrane Fuel Cell is a nonlinear, multiple-input and-output, strongly coupled, and large-delay dynamic system, the working process of which is accompanied with liquid/vapour/gas mixed flow transportation, heat conduction, and electrochemical dynamical reaction. Hydrogen and oxygen work as fuel and oxidant, and they need to be humidified before they are fed into the cell/stack. The positively charged protons diffuse from anode through one side of the membrane and migrate toward the cathode. The electrons pass from the anode to the cathode through an exterior circuit and provide electric power along the way; the by-product water is drained out with the gases. Platinum catalyst is used to speed up the electrochemical reaction on both anode and cathode. Hydrogen atoms are stripped of their electrons, or “ionized” at the anode. At the cathode, the electrons, hydrogen protons, and oxygen from the air combine to form water.

### III. MODELLING OF PEMFC :

#### 3.2.1 Mathematical Modeling of Polymer Electrolyte Membrane Fuel Cells

To simplify the analysis some assumptions are made below of them.

1. The stack is well designed so that all

cells perform similarly and can be lumped as a stack.

2. All gases obey the ideal gas law and are equably distributed.
3. Pure hydrogen gas is assumed to be supplied to the anode from a hydrogen tank and the inlet hydrogen flow and oxygen flow are assumed to have 100% relative humidity.
4. The temperatures of hydrogen inside the anode and oxygen inside the cathode are equal to the stack temperature.
5. Pressures in the gas flow channels are constant.
6. The only reaction product is liquid water.

The ideal standard potential of a hydrogen/oxygen fuel cell at standard state conditions (25°C and 1 atm) is 1.229V with liquid water product..

#### 3.2.2 Reversible Cell Voltage

The reversible cell voltage  $V_{\text{CELLreversible}}$ , is the maximum voltage that each cell in the stack can produce at a given temperature with the partial pressure of the reactants and products known. The reversible stack voltage is equal to the number of cells in the stack multiplied by the reversible voltage for each cell. The maximum cell voltage is derived from the maximum amount of energy that is available to

do useful work that is the change in Gibbs free energy per mole.

### 3.2.2.1 Activation loss

The activation loss of the fuel cell relates to the slowness of the reactions that take place on the surface of the electrodes. A proportion of the voltage generated is lost in driving the chemical reaction at the electrodes. It is called an activation loss because it relates to the activation energy required at both the anode and cathode of the fuel cell.

### 3.2.2.2 Ohmic Loss

The ohmic loss is due to the resistance of ions through the polymer electrolyte membrane and the resistance of imperfect electrodes. For a complete electrical circuit the membrane is required to conduct protons. An ideal membrane would freely conduct  $H^+$  ions. Some Polymer Electrolyte Membrane fuel cells have only a very small electrode resistance and it can be omitted from the model

### 3.2.2.3 Concentration Loss

A concentration loss relates to the reduction of the reactant's concentration in the gas channels. The fuel and oxidant are used at the surface of the electrodes. The incoming gas must then take the place of the used reactant. The concentration of the fuel and oxidant is reduced at the various points in the fuel cell gas channels and is less than the concentration at the

inlet value of the stack.

$$V_{con} = -B \times \ln\left(1 - \frac{I}{I_{max}}\right)$$

## IV. Mathematical model calculations

The output voltage of the single cell is given by (1) according to the Polymer Electrolyte Membrane Fuel Cell output characteristics empirical equation, which was developed by Amphlettetal and Kimetal.

$$V_{cell} = E_{Nernst} - V_{act} - V_{ohmic} - V_{con} \quad (3.1)$$

The activation loss of Polymer Electrolyte Membrane Fuel Cell is caused by the sluggish kinetics of the reactions taking place on the active surface of electrodes and it can be computed by the following equations.

$$V_{act} = \xi_1 + \xi_2 T + \xi_3 T [\ln(CO_2)] + \xi_4 T [\ln(i)]$$

$$\xi_1 = -\frac{\Delta G_c}{2F} - \frac{\Delta G}{\alpha_c nF}$$

$$\xi_2 = \frac{RT}{\alpha_c nF} \left\{ \ln \left[ nFAK_c^0 (C_{H^+})^{1-\alpha_c} (C_{H_2O})^{\alpha_c} \right] \right\}$$

$$\xi_3 = \frac{R(1-\alpha_c)}{\alpha_c nF}$$

$$\xi_4 = -\left( \frac{R}{2F} + \frac{R}{2F} \right)$$

$$C_{O_2} = \frac{P_{O_2}}{5.08 \times 10^6 \exp\left(\frac{-498}{T}\right)}$$

Different from the ohmic losses of the empirical equation that is already presented, in

this model, ohmic losses consist of the voltage drop that is caused by  $R_M$ , the equivalent membrane impedance, and the voltage drop that is caused by  $R_c$ , the contact resistances both between the membrane and electrodes as well as the electrodes and the bipolar plates. It is constant once the cell is fabricated. It can be shown as

$$V_{ohmic} = i R_{ohmic} = i (R_M + R_c).$$

The equivalent membrane impedance  $R_M$  can be expressed via Ohm's law

$$R_M = \frac{\gamma_M l}{A}$$

The resistivity  $\gamma_M$  of a NaF ion series proton exchange membrane can be calculated by

$$\gamma_M = \frac{181.6 \left[ 1 + 0.03 \left( \frac{i}{A} \right) + 0.062 \left( \frac{T}{303} \right)^2 \left( \frac{i}{A} \right)^{2.5} \right]}{\left[ \lambda - 0.634 - 3 \left( \frac{i}{A} \right) \right] \exp \left[ 4.18 \left\{ \left( \frac{T - 303}{T} \right) \right\} \right]}$$

Where  $\lambda$  is the water content of the membrane, a parameter relative humidity of gas anode.

In this model concentration losses are considered.

Concentration losses are caused by mass transportation, which, in turn affects the concentration of the hydrogen and oxygen at

high current density. This term is ignored in some models, perhaps because it is not desirable to operate the stack at regions where concentration losses are high (efficiency is low). However, if the stack operates at high current density, this term needs to be included. The concentration losses can be expressed as

$$V_{con} = B \ln \left( 1 - \frac{J}{J_{max}} \right)$$

$$V_{act} = \xi_1 + \xi_2 T + \xi_3 T \left[ \ln(CO_2) \ln(i) \right] \tag{3.8}$$

$$\xi_1 = -\frac{\Delta G_c}{2F} - \frac{\Delta G}{\alpha_c nF}$$

$$\xi_2 = \frac{RT}{\alpha_c nF} \left\{ \ln \left[ nFAK_c^0 (C_{H^+})^{1-\alpha_c} (C_{H_2O})^{\alpha_c} \right] \right\}$$

$$\xi_3 = \frac{R(1-\alpha_c)}{\alpha_c nF}$$

$$\xi_4 = -\left( \frac{R}{2F} + \frac{R}{2F} \right) \tag{3.9}$$

$$C_{O_2} = \frac{P_{O_2}}{5.08 \times 10^6 \exp \left( \frac{-498}{T} \right)}$$

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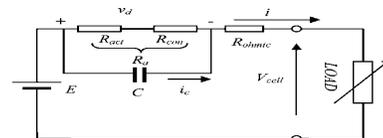
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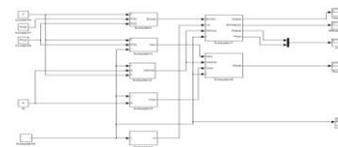
**V.EQUIVALENT CIRCUIT OF PEMF**

There exists a charge double layer in the Polymer Electrolyte Membrane Fuel Cell analyzed the charge double layer at the surface of the fuel cell cathode and gave a simple equivalent circuit model of the Polymer Electrolyte Membrane Fuel Cell in which an electrical capacitor can be considered as the layer of charge on or near the electrode electrolyte interface, which (3.9) store of electrical charge and energy, as shown below of them



*3.2 Equivalent circuit model of the PEMFC*

**VI. Dynamic Model Simulation:**



*Fig .3.3, Dynamic Model Simulation PEMFC diagram*

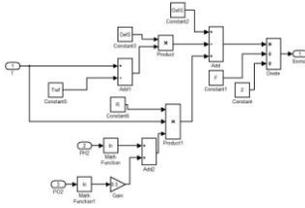


Fig ,3.4 PEMFC of electrode potential

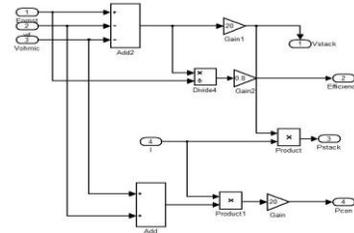


Fig ,3.8. PEMFC output power, effecency,voltage

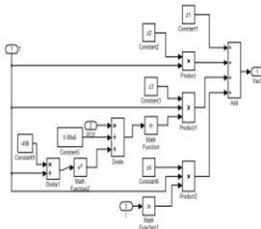


Fig 3.5.,PEMFC Activation losses

Fig , 3.9.PEMFC Resistance

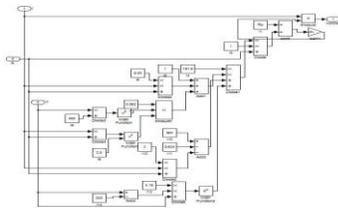


Fig ,3.6.PEMFC Ohmic losses

**Graphs:**

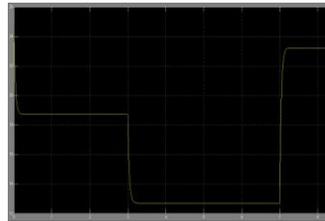


Fig , 3.10.Dynamic response of stack output voltage

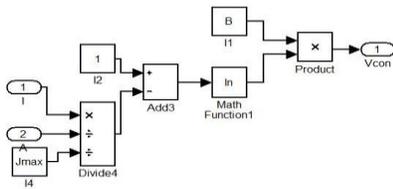


Fig , 3.7.PEMFC Concentration losses

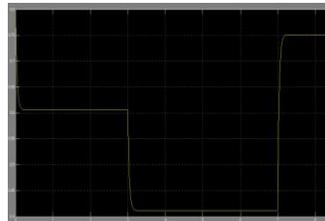


Fig.3.11, Dynamic response of stack efficiency

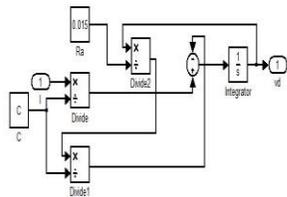


Fig , PEMFC Voltage drop

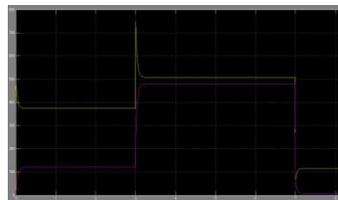
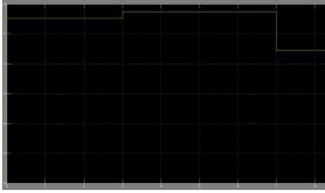


Fig ,3.12. Dynamic response of stack output power and consumed power.



Fig, 3.13. Dynamic response of stack equivalent resistance



Fig, 3.14. Dynamic response of current

## VII.CONCLUSION:

In this paper, a dynamic model of PEMFC, which has been implemented in MATLAB/Simulink environment, is proposed. A series of simulation and analyses is carried out, which includes the voltage, power, and efficiency of the PEMFC with changing load. Simulation results show that the model developed is valid and operable, and reflects the dynamic output characteristic of the PEMFC. The analyses demonstrate that the dynamic interaction effects within PEMFC are significant and necessary. It can also effectively predict and evaluate the performance of the fuel cell. Further improvement of the model would be helpful for the performance analysis, design optimization, and real-time control.

## VIII.REFERENCES:

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