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Simulation Study of Fuel Cell in Matlab/Simulink Environment

Sumit Kumar Maitra[1],
[1]Department of Electrical
&Computer Engineering
Wachemo University,
Hossana, Ethiopia
Email ID:
sumit.maitra@gmail.com,

Shailesh Kumar Gupta[2]
Department of Electrical and
Electronic Engg.
Raj Kumar Goel Institute of
Technology, Ghaziabad, U.P.
India Email ID:
skg26fee@rkgit.edu.in

Umakanta Choudhury[3]
Department of Electrical and
Electronic Engg.
Raj Kumar Goel Institute of
Technology, Ghaziabad, U.P.
India
Email ID:
ukchofee@rkgit.edu.in
,

Ravindra Kumar Yadav[4]
[4]Department of Electronics and Communication Engg.,
Raj Kumar Goel Institute of Technology, Ghaziabad, U.P. India
drrkyfec@rkgit.edu.in

Abstract

The entire earth is now in a poor state as a result of several issues relating to non-renewable energy sources. To meet the problems posed by the energy contingency Fuel Cells have the potential to meet more of the world's fuel requirements while still meeting sustainability standards. A fuel cell is an energy source that converts chemical energy into electrical energy by using hydrogen and oxygen as fuel. Fuel cell technology has a wide range of uses, including FCEVs, military applications, main or secondary sources of energy in many remote locations, and powering a variety of electronic devices. This paper uses matlab to model and simulate a Proton Exchange Membrane Fuel Cell (PEMFC)-based power generation device.

Keywords: Fuel cell, Proton Exchange Membrane Fuel Cell, Simulation

1. Introduction

A fuel cell is an electrochemical cell that uses an electrochemical reaction to produce electrical energy from fuel. To keep the reactions that produce energy going, these cells need a constant supply of fuel and an oxidising agent (usually oxygen). As a result, before the supply of fuel and oxygen is cut off, these cells will continue to produce electricity. Fuel cells are safe, silent, and effective electrochemical devices [1]. In 1839, an English chemist named William Grove patented the fuel cell. Grove also invented the wet-cell battery. They have no moving parts and can run indefinitely as long as fuel is available. In any case, fuel cell systems have cut emissions significantly as compared to traditional technologies [2]. There had been no significant investigation or review since then, when NASA started intensive fuel cell testing in the 1960s. NASA conducted a thorough investigation and research in order to improve the Alkaline Fuel Cell (AFC) for a space programme (Gemini, Apollo, and space lap) [3]. According to B. Laoun [4], there are two ways to estimating fuel cell (FC) efficiency using the polarisation curve. The first is focused on physical modelling of heat and mass transfer, while the second is based on a semi-empirical equation that is used as a black box in FC. There are various types of fuel cells depending on the electrolyte used. Phosphoric Acid Fuel Fuel Cell (PAFC), Solid Oxide Fuel Cell (SOFC), Molten Carbonate Fuel Cell (MCFC), and Proton Exchange Membrane Fuel Cell (PEMFC) are only a few of them Table 1 compares the different types of fuel cells, their characteristics and functions.

Criteria	**PEMFC**	**PAFC**	**MCFC**	**SOFC**
Operating Temperature	$< 220\ ^{0}F$	~ 400 ^{0}F	~ 1250 ^{0}F	~ 1800 ^{0}F
Operating Pressure	1-5 atm	1-8 atm	1-3 atm	1-13 atm
Fuel	H_2	H_2	H_2, CO_2, CH_4	H_2, CO_2, CH_4, NH_3
Construction Material	Graphite Carbon	Graphite Carbon	Ni and Stainless	Ceramics and Metals
Cooling Medium	Water	Boiling water	Excess air	Excess air

Table I. Comparisons of Fuel Cell

2. Working of Fuel Cell

A cathode, anode, and electrolyte make up a fuel cell, which is identical to an electrochemical cell. The electrolyte in these cells allows protons to travel around. A fuel cell can use the reaction between hydrogen and oxygen to produce electricity. This kind of cell was used in the Apollo space programme and served two purposes: as a source of fuel and as a source of drinking water.
This fuel cell worked by transferring hydrogen and oxygen via carbon electrodes into a condensed sodium hydroxide solution. The following is a formula for the cell reaction:

Positive Cell Reaction: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

Negative Cell Reaction: $2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$

Final Net Reaction: $2H_2 + O_2 \rightarrow 2H_2O$

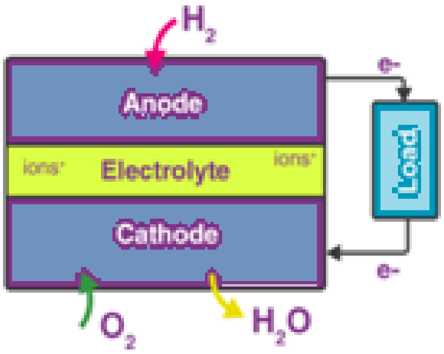

Figure 1. Block Diagram of fuel cell

This electrochemical reaction, however, has a slow reaction rate. A catalyst, such as platinum or palladium, is used to solve this issue. Before being inserted into the electrodes, the catalyst is finely separated to maximise the usable surface area. Figure 1 dipicts the fuel cell's block diagram.

The above-mentioned fuel cell has 70 percent efficiency in the production of electricity, while thermal power plants have a 40 percent efficiency. Since the generation of electric current in a thermal power plant requires the conversion of water into steam and the use of that steam to spin a turbine, there is a significant difference in performance. Fuel cells, on the other hand, have a medium for converting chemical energy into electrical energy directly.

3. Classification of Fuel Cells

Fuel cells come in a variety of shapes and sizes, despite the fact that they all function in the same way. In this part, we'll look at a few of these fuel cell forms.

3.1 Polymer Electrolyte Membrane (PEM) Fuel Cell

a. Proton exchange membrane fuel cells (or PEMFCs) are another name for these cells.
b. These cells work in a temperature range of 50 to 100 degrees Celsius.
c. Polymer membrane, bipolar panels and a catalyst, electrodes, and make up a standard PEM fuel cell.
d. Despite their environmentally sustainable uses in shipping, PEMFCs can also be used for portable and stationary power generation.
e. A polymer with the ability to conduct protons is used as the electrolyte in PEMFCs.

3.2 Phosphoric Acid Fuel Cell

a. As a means to channel the H+, these fuel cells utilse phosphoric acid as an electrolyte.
b. The temperatures work for these cells are between 150 and 200 degrees Celsius.
c. The non-conductive aspect of phosphoric acid forces electrons to pass to the cathode from an external circuit.
d. The electrolyte's acidic composition causes the elements in these cells to corrode or oxidise with time.

3.3 Solid Acid Fuel Cell

a. The electrolyte in these fuel cells is a solid acid substance, and the solid acids' molecular configurations are ordered at low temperatures.
b. A phase transition will happen at higher temperatures, resulting in a significant rise in conductivity.
c. $CsHSO_4$ (cesium hydrogen sulphate) and CsH_2PO_4 (cesium dihydrogen phosphate respectively) are two examples of strong acids.

3.4 Alkaline Fuel Cell

a. In the Apollo space programme, this was the fuel cell that was used as the main source of energy.
b. An aqueous alkaline solution is used to saturate a porous matrix in such cells, and then separates the electrodes.
c. These cells' working temperatures are very mild approximately 90 degreeC.
d. These cells are extremely efficient. They still provide heat and water in addition to electricity.

3.5 Solid Oxide Fuel Cell

a. a. Solid oxide or ceramic electrolytes are used in such cells like yttria-stabilized zirconia.
b. b. These fuel cells are both highly effective (approrx 85 percent) and inexpensive.
c. c. These cells' working temperatures are very high. standard operating temperatures range of 800 and 1000 degreeC.
d. Because of their high working temperatures, such cells are limited to stationary uses.

3.6 Molten Carbonate Fuel Cell

a. Lithium potassium carbonate salt is used as an electrolyte in these cells.
b. At high temperatures, this salt becomes molten, allowing carbonate ions to float about.
c. These fuel cells, like SOFCs, have a reasonably high working temperature of 650o.
d. Because of the high working temperature and the presence of the carbonate electrolyte, the anode and cathode of this cell are prone to corrosion.

4. Features of PEMFC

1. A proton exchange membrane fuel cell is a basic structure that consists of a cathode, an

anode, and a conducting medium in between. This works in the same way as traditional fuel cells, except the electrolyte and electrodes are all porous membranes.

2. In fuel cells, a polymer may be used as an ion exchange membrane electrolyte. Those membranes are excellent protons conductors. Pure water is generated as a byproduct in this form of fuel cell.
3. The electrolyte, which is a proton-conducting medium polymer, is the main distinction between PEM fuel cells and other fuel cells. The conducting polymer's mobile ion is H+. The electrolyte is an anion-conducting polymer with catalysed porous electrodes on both ends.

5. Identified Problem Statement

Rising fuel costs, as well as the pace at which fossil fuels are being depleted, as well as the emissions issues that come with them, have provided a worldwide push toward renewable energy sources. Nonrenewable energy supplies have been commonly considered for general use due to the success and reliability of combustion engines. However, rising fuel costs, as well as a strong emphasis on reducing global and local emissions, have prompted a greater focus on the production of alternative energy sources for use in other area.

6. Applications of PEMFC

Membrane is the central component of the PEM fuel cell, as previously said. The polymeric membrane serves three functions in PEM fuel cells: charge carrier for protons, separator of reactant gases, and electrical insulator to prevent electrons from flowing through the membrane (because of electron repelling and negative charge from SO_3). DuPont produced a perfluorosulfonic acid dubbed "Nafion" in the 1970s that increased the membrane's basic conductivity by two orders of magnitude while also extending its lifespan by four orders of magnitude. This quickly became the industry standard for PEMFC and remains so to this day. Advanced perfluorosulfonic acid membranes alongwith shorter side chains and a higher ratio value of SO_3H to CF_2 groups were developed by Dow Chemical Company and Asahi Chemical Company [5]. This Nafion membrane is made up of a copolymer of fluoro 3,6-dioxo 4,6-octane sulfonic acid and polytetrafluorethylene (PTFE). The Teflon backbone gives the membrane its hydrophobic appearance, and hydrophilic sulfonic acid groups (HSO3) have been chemically grafted into the backbone. These ionic groups also allowed the polymer to absorb a considerable volume of water, resulting in hydration of the polymer. Thus, the degree of hydration and thickness of a suitable proton exchange membrane influence its consistency, which plays an important role in determining its suitability for use in a fuel cell [12].

7. Modelling of Fuel Cell

7.1 Static Model: The static model represents the fuel cell's static nature, i.e. the amount of the voltage of static fuel cell as a function of the FC's static current.

$$V_{st} = E_{cell} - b.\log(a.I_{st}) - r.I_{st} - m.\exp(n.I_{st})$$

Here E_{cell} = voltage fuel cell at a current of zero amp i.e. perfect output cell potent

V_{st} = static voltage in fuel cell

I_{st} = static current in fuel cell

a, b, r, m, and n are empirical parameters of fuel cell.

7.2 Dynamic Model: The control algorithm for fuel cell systems is designed and tested using a dynamic model. This is focused on the fact that minor current variations cause small changes in cell voltage. The model is only true for minor variations in current around a given steady point, since it is built on the premise that the fuel cell is a linear device for small current signal variations.

Dynamic model is used to design and test fuel cell systems control algorithm. This is based on the fact that slight current variations cause small changes in the cell voltage. The model is only valid for minor variations in current around a set stable point; this is based on the assumption that the fuel cell is a linear system for small current signal variations. Based on ideal voltage at normal temperature and pressure, activation polarisation as a function of current density, temperature and oxygen concentration, and ohmic polarisation as a function of temperature and current density, an expression for the actual voltage is created.

Mathematical formula for the voltage electrochemical model of a fuel cell is given by [13]

$$V_{fc} = E_{cell} - V_{act} - V_{con} - V_{ohmic}$$

V_{fc} =True value of output cell potential

E_{cell}=Cell’s thermodynamic perfect output potential

V_{act} = activation overvoltage,

V_{ohmic} is ohmic overvoltage and V_{con} = concentration overvoltage.

8. Matlab Simulation and Result

Figure 3 represnts the Matlab/simulink model of fullcell while figure 4 shows simulation block diagram of power generation based on a Fuel cell. Figure 5 shows the output voltage of single cell and figure 6 shows the results of output load voltage vs load current of fuel cell.

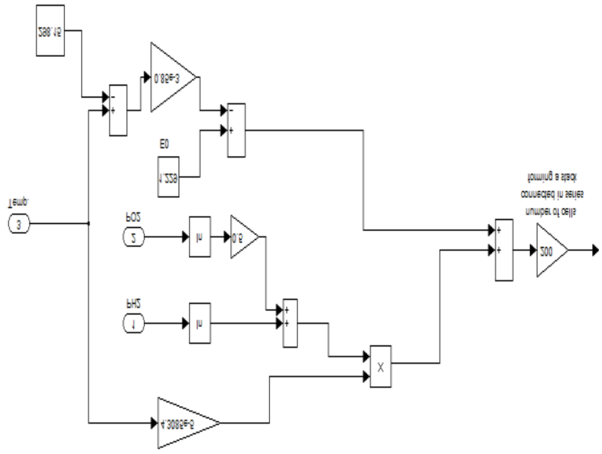

Figure 3. Matlab/simulink model

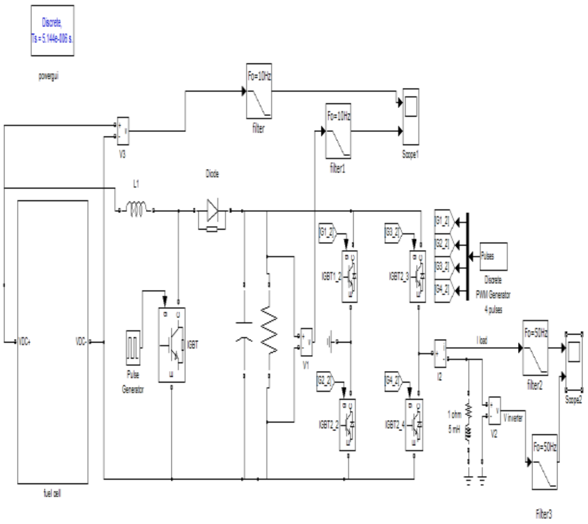

Figure 4. Simulation block diagram of power generation based on a Fuel cell

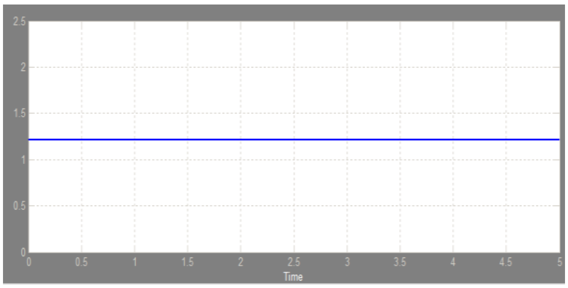

Figure 5. Output voltage of single cell

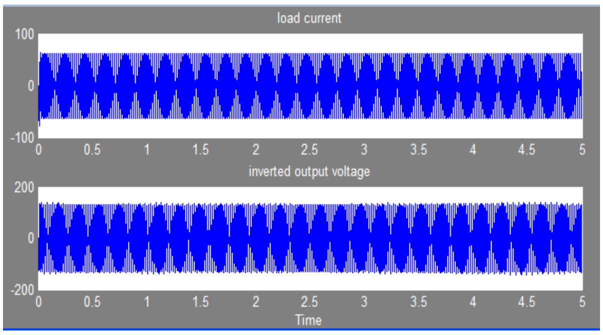

Figure 6. Output load voltage vs load current of fuel cell

9. Conclusion

The results of modelling and simulation are presented in this paper. The proton exchange membrane fuel cell is one of the most promising fuel cells for mobility and small stationary applications. Less pollution, higher efficiency, and low maintenance are all advantages of fuel cells. MATLAB simulink was used to analyse the static and dynamic features of the PEMFC.

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