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Modeling and Simulation of a Fuel Cell based System for Residential Applications

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ABSTRACT

Fuel cell based power generation systems have gained tremendous interest in the near future, due to its reliability and high conversion efficiency. Among the different types of fuel cells, PEM fuel cells are gaining more importance due to its fast start up time and low operating temperature. This paper presents the modeling and simulation of a fuel cell based system which can be used for residential applications. The polarization curve and the power curve of a stack of 65 fuel cells is plotted by using MATLAB. Simulation is done in the MATLAB-SIMULINK environment and the results are also discussed.

Keywords

DC-DC converter, PEM fuel cell.

1. INTRODUCTION

Renewable Energy is considered to be one of the most promising alternatives for the growing energy demand in response to depletion of fossil fuels and undesired global warming issue. The high price of fossil fuels and their increasing demand have prompted every nation to think of renewable energy sources such as solar, wind, fuel cells etc. Among these alternative energy sources, fuel cells serve as a clean and excellent solution to reduce the dependency on fossil fuels and to meet the ever increasing energy demand [1].

Fuel cells are electrochemical devices which convert chemical energy of a fuel directly to electric energy, without any moving parts. Fuel cells are gaining importance due to their low maintenance, low temperature operation, high power density, high efficiency and reliability. A single fuel cell has an open circuit voltage of 0.8-1.2 V. To get higher operating temperatures, fuel cells can be arranged in cascaded series and parallel forms.

Fuel cells have a wide range of applications from transportation to distributed power generation and also from residential power to portable power. The most important application area of the fuel cell is in automotives. Some of the automotives powered by fuel cells include buses, boats, bicycles, planes etc... Currently hybrid vehicles are made with fuel cell technology. Fuel cells are also used in consumer products such as cell phones, vacuum cleaners and computers. They are also suitable for stand-alone and grid-connected applications [2].

Fuel Cells are classified primarily by the kind of electrolyte they employ. The classification denotes the type of chemical reactions taking place inside the cell, the catalysts selected, the operating temperature range and the fuels used. In the literatures there are mainly five types of fuel cell technologies such as Solid Oxide fuel cell, Direct Methanol fuel cell, Polymer Electrolyte Membrane (PEM) fuel cell, Phosphoric acid fuel cell, and Molten Carbonate fuel cell. Of all the types, PEM fuel cells have become an attractive option due to their fast start up time, low operating temperature range (50-100° C), high power density and long stack life.

The block diagram of a fuel cell based system is shown in Fig.1. A fuel cell power supply system consists of a stack of fuel cells, a DC-DC converter, an inverter and the load. A DC-DC converter is used to interface the fuel cell output with the inverter. This paper presents the simulation results of the system shown in Figure.1.

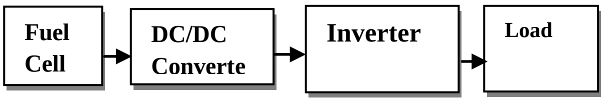

Figure 1: Block Diagram of a fuel cell based system

2. WORKING PRINCIPLE OF PEM FUEL CELLS

PEM fuel cell is an electrochemical cell which generates electricity as long as fuel and oxidants are supplied continuously. It consists of an anode and a cathode separated by an electrolytic membrane. Hydrated hydrogen gas is supplied at the anode and oxygen is supplied at the cathode. A proton exchange membrane is used as the electrolyte with a layer of platinum as the catalyst. At the anode, hydrogen gas is ionized into positively charged hydrogen ions and negatively charged electrons as shown in Figure 2 [3].

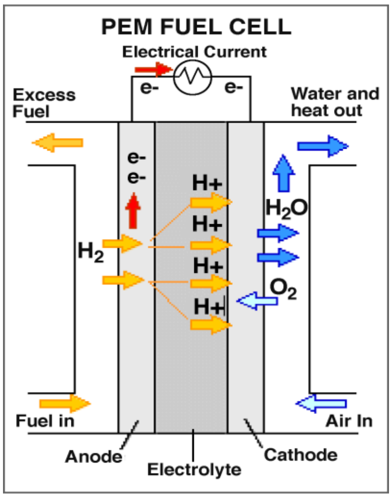

Figure 2: Working principle of a PEM fuel cell

The proton exchange membrane permits only the hydrogen ions to pass through the membrane and the electrons flow through the external circuit producing current flow. At the cathode hydrogen ions, electrons in the external circuit and the supplied oxygen combine to form water. The reactions at the cathode and the overall cell reaction is as follows:

At the anode: $2H_2 \rightarrow 4H^+ + 4e^-$

At the cathode: $O_2 + 4H^+ + e^- \rightarrow 2H_2O$

Overall Cell Reaction: $2H_2 + O_2 \rightarrow 2H_2O$ + Electricity + heat

3. MATHEMATICAL MODELLING OF PEM FUEL CELLS

Modelling of a fuel cell is useful for the fuel cell developers so that they can produce better design developments and more efficient fuel cells. A good model of a fuel cell should be able to predict the performance of a fuel cell under all operating conditions. Some of the parameters that have to be considered in selecting a fuel cell are the system temperature, fuel and oxidant temperature, fuel and oxidant pressures, and the weight fraction of each reactants.

The performance of a fuel cell is characterized by the polarization curve, which is a plot of fuel cell voltage versus load current which is shown in Figure.3[4]

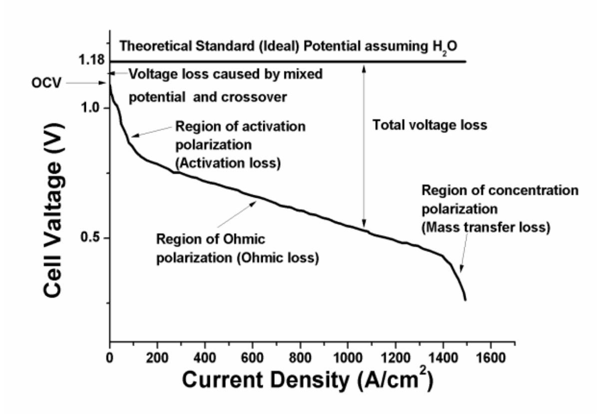

Figure 3: Polarization curve of a fuel cell

The polarization curve is affected by several factors such as cathode pressure, reactant partial pressures, cell temperature and membrane humidity. The polarization curve is plotted by using the Tafel equation [5],[6] and is given by:

$$V_{dc\text{-}stack} = V_{open} - V_{ohmic} - V_{activation} - V_{concentration} \quad (1)$$

Where V_{open} is called the Nernst voltage or reversible voltage that exists at no load condition for a given temperature and pressure and is given by:

$$V_{open} = N_o . [V_o + (RT/2F). \ln (P_{H2} \sqrt{Po_2} / P_{H2o} \sqrt{P_O})] \quad (2)$$

V_{ohmic} is the resistive voltage loss due to the resistance of the non ideal diodes and connections and the resistance to proton flow in the PEM and is given by:

$$V_{ohmic} = I_{dc} R_{FC} \quad (3)$$

$V_{activation}$ is the voltage loss due to the activation losses due to the rate of reactions taking place on the surface of the electrodes, and is given by:

$$V_{activation} = N_o . (RT/2\alpha F) \ln (I_{dc} / I_o) \quad (4)$$

$V_{concentration}$ is the voltage loss due to mass transport losses and is given as:

$$V_{concentration} = -c. \ln (1- (I_{dc} / I_{lim})) \quad (5)$$

In (1):

N_o	cell number;
V_o	open cell voltage;
R	Universal gas constant;
T	Temperature of the fuel cell stack;
F	Faraday's Constant;
PH2	Hydrogen partial pressure;
PH2O	Water partial pressure;
PO	oxygen partial pressure;
α	Charge transfer coefficient of the electrodes;
Idc	Current of the fuel cell stack;
ILim	limiting current;
Io	exchange current of fuel cell stack;
c	empirical coefficient for concentration voltage.

4. FULL BRIDGE DC-DC CONVERTER

DC-DC converter is an integral part of a fuel cell power conditioning unit. Switched mode DC-DC converters convert one DC voltage to another by storing the input energy temporarily and then releasing that energy to the output at different voltage. The storage may be in either magnetic field storage components such as inductors and transformers or electric field storage components such as capacitors. This conversion method is more efficient than linear voltage regulation.

In this paper, we have used a full bridge DC-DC converter for the regulation of output voltage. This converter provides isolation between converter input and output voltage. A 50 Hz transformer is used to provide dc isolation. The transformer size and weight vary inversely with frequency. So now the transformer operates at the switching frequency of the converter in the range of several hundred kHz. The transformer size will be reduced dramatically by these high frequencies. Figure.4[7] shows the schematic of a full bridge DC-DC converter.

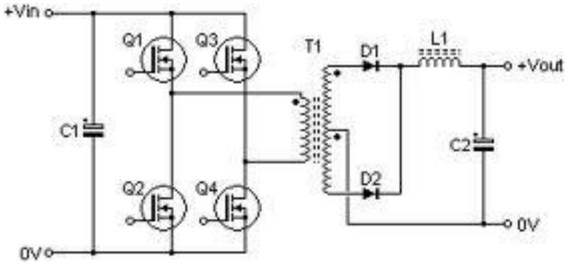

Figure 4: Schematic of a full bridge DC-DC converter

5. WORKING PRINCIPLE OF FULL BRIDGE DC-DC CONVERTER

The full bridge DC-DC converter works in the boost mode, which steps up the output voltage of the fuel cell to the voltage required by the load.

A full bridge DC-DC converter consists of a H bridge inverter at the input side, a transformer at the center for isolation and a full wave rectifier at the output side. When switches Q1 and Q4 of the inverter are on, the input voltage is fed to the primary of the transformer. It is scaled by a factor n, which is the turns ratio of the transformer. This secondary voltage is rectified at the other end of the transformer by the rectifier. The same process will be repeated at the next half switching cycle with the point that primary applied voltage will be negative but rectified at the other end of the inverter. The turns ratio is properly selected based on the input voltage and output voltage of the converter.

6. SIMULATION RESULTS

An m- file program for the static model of a fuel cell was written in the MATLAB to plot the polarization curve and power curve for a stack of 65 fuel cells connected in series. Figure.5 shows the polarization curve and Figure.6 shows the power curve.

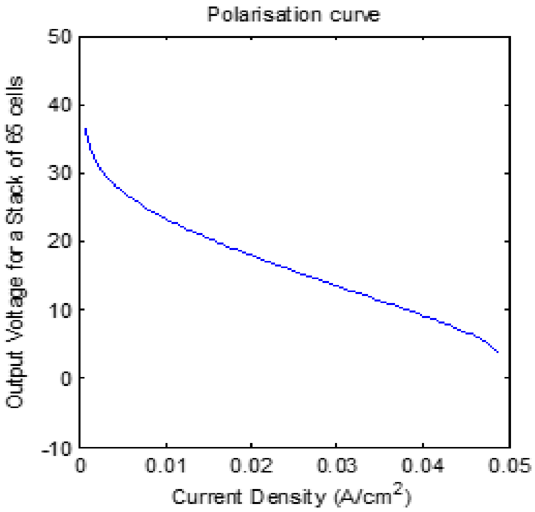

Figure 5: Polarisation curve of a stack of 65 fuel cells

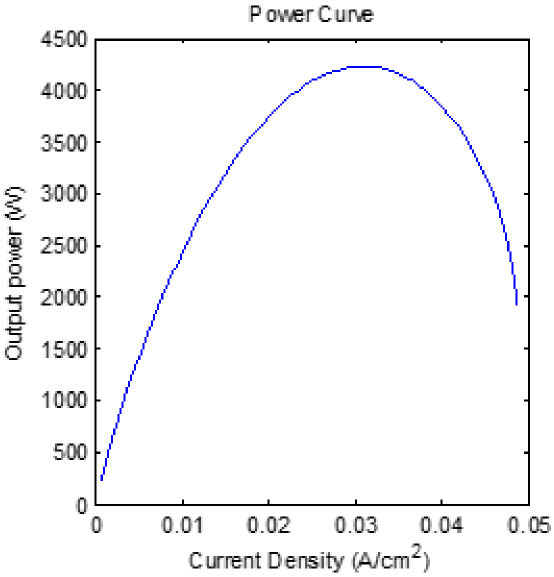

Figure 6: Power curve of a stack of 65 fuel cells

Simulation was carried out in MATLAB-SIMULINK environment and the complete simulation model is shown in Fig.7. First stage includes the DC-DC converter with the input source as fuel cell and the second stage includes a single phase H-bridge inverter which feeds the single phase ac supply to the load.

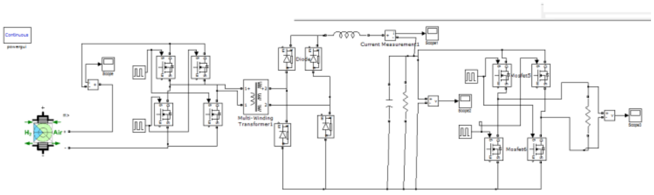

Figure 7: Matlab model of the entire system

7. FULL BRIDGE DC-DC CONVERTER MODEL

The full bridge DC-DC converter model in Matlab is shown in Figure 8. The output of the full bridge inverter is filtered to give a dc output voltage of 300 V. This dc output voltage of 300V is shown in Figure 9.

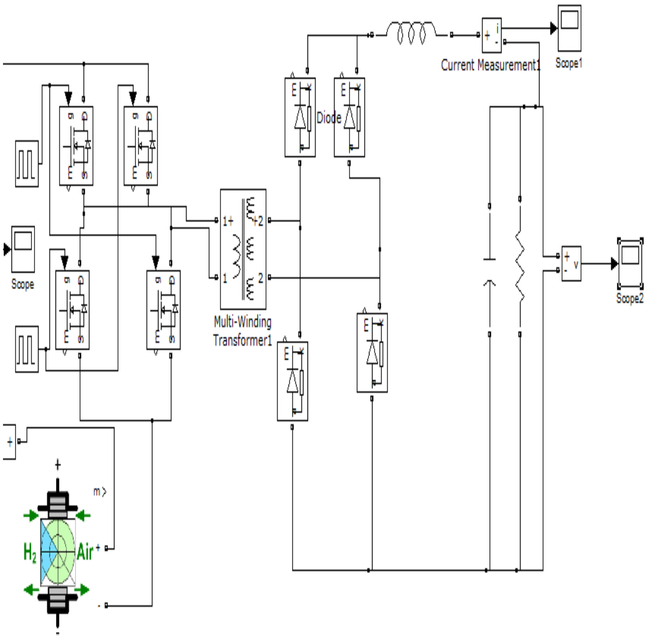

Figure 8: Full Bridge Converter model

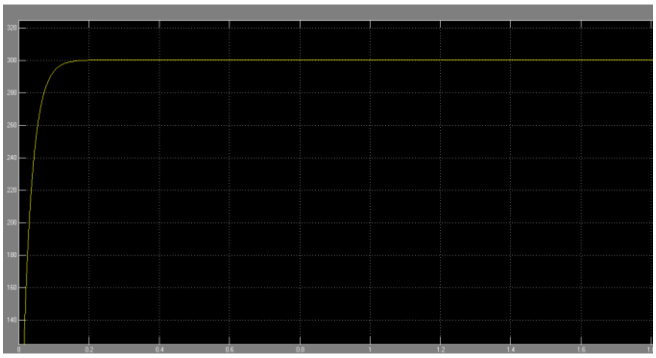

Figure 9: Converter output voltage of 300V

This output voltage is fed to a single phase inverter which feeds the load. Figure.10 shows the single phase ac waveform obtained at the output of the inverter.

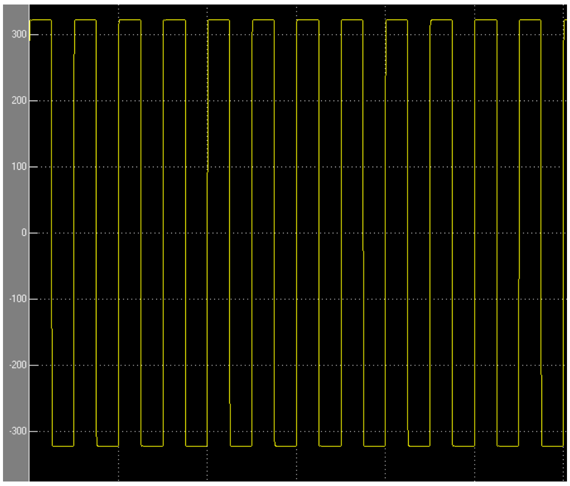

Figure10:Single phase inverter output wave form

8. CONCLUSION

The static modeling and simulation of a fuel cell based power generation system is discussed here. Among the renewable energy sources, fuel cells are widely used for residential applications due to their noise free operation and good reliability.

Fuel cells can be used in grid connected systems to supply supplemental power or as emergency power supply system in case of critical conditions. Advancements in power electronics have added more features to this power supply system.

A great deal of research has been done on fuel cells even though it has got some disadvantages such as high cost due to expensive materials like platinum and safety concerns regarding the use of hydrogen.

9. REFERENCES

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