A PEM Fuel Cell Inverter Based Distributed Generation Grid Connected System

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Abstract: In this paper, a fuel cell model and control concept is presented for a fuel cell system intended for grid connected operation. First the mathematical model of the fuel cell is described. Then, the power conditioning system, including the DC/DC and DC/AC converters, is presented and typical waveforms are shown from its simulation. And at last the fuel cell model and its interface to the grid are implemented in matlab- simulation.

Keywords: *PEM Fuel cell Modeling, PEM Fuel cell for resistive load, Grid connected Fuel cell.*

I. INTRODUCTION

A fuel cell is work like a battery in that it generates electricity from an electrochemical reaction. Batteries and fuel cells convert chemical energy into electrical energy and release heat and water. But The Difference is that in Battery we can store electricity and recharge using an external supply of electricity to drive the electrochemical reaction in the reverse direction.[1]

A fuel cell, on the other hand, uses an external supply of chemical energy and can run indefinitely, as long as it is supplied with a source of hydrogen and a source of oxygen (usually air). During oxidation, hydrogen atoms react with oxygen atoms to form water; in the process electrons are released and flow through an external circuit as an electric current.[1]

Fuel cells can produce only a few watts of electricity, right up to large power plants producing megawatts. All fuel cells are based on a central design using two electrodes separated by a solid or liquid electrolyte that carries electrically charged particles between them. A catalyst is used to increase the speed of the reactions at the electrodes. Fuel cell types are generally classified according to the nature of the electrolyte they use. Each type requires particular materials and fuels and is suitable for different applications.[1]

A fuel cell is an electrochemical device and it uses hydrogen as its fuel to produce protons, electrons, heat and a by product of water. There is a simple chemical reaction combustion of hydrogen and air i.e. oxygen.

This chemical reaction between hydrogen and oxygen produce electrons which can provide electricity through a simple connected circuit provided with a load. The area of contact between the electrolyte, the electrode and the hydrogen fuel is very small, due to this there is a high resistance between the electrodes in the electrolyte. These problems in a fuel cell have been corrected by proper designing of a flat plate electrodes and a small thickness of electrolyte between the electrodes which gives a maximum area of contact between the electrolyte, electrodes and hydrogen which helps in achieving maximum efficiency of the fuel cell.[1]

A fuel cell can produce electricity based on flow of hydrogen and oxygen. Its design is based on the simple arrangement of two electrodes placing opposite to the electrolyte.[1]

II. MATHEMATICAL MODEL OF A PEM FUEL CELL

A. Fuel Cell Working Model

The fundamental structure of a PEM fuel cell can be described electrodes (anode and cathode) separated by a solid membrane acting as an electrolyte (Fig.1). Hydrogen fuel flows through a network of channels to the anode, where it dissociates into protons that, in turn, flow through the membrane to the cathode and electrons that are collected as electrical current by an external circuit linking the two electrodes. The oxidant (air in this study) flows through a similar network of channels to the cathode where oxygen combines with the electrons in the external circuit and the protons flowing through the membrane, thus producing water.[2] The chemical reactions at the anode and cathode electrode of a PEM fuel cell are as follows:

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

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

Total cell reaction: $2H_2 + O_2 \rightarrow 2H_2O +$ Electricity+heat (3)

The products of this process are water, DC electricity and heat.

B. Fuel Cell Dynamic Model

The output stack voltage V is defined as a function of the stack current, reactant partial pressures, fuel cell temperature, and membrane humidity.[2] The potential difference between the anode and cathode is calculated using the Nernst's Equation and Ohm's law and can be written as follows:

$$V_{cell} = E_{cell} - V_{act} - V_{ohm} - V_{conc} \ \mathrm{V} \quad (4)$$

Nernst's equation:

$$E_{cell} = E_0 - 0.85 * 10^{-3}(T - 298.15) + \frac{RT}{2F}\ln(P_{H_2}P_{O_2}^{0.5}) \ \mathrm{V} \quad (5)$$

The relationship between molar gas flows through the valve is proportional to its partial pressure and can be expressed as,

$$\frac{q_{H_2}}{p_{H_2}} = \frac{k_{an}}{\sqrt{M_{H_2}}} = k_{H_2} \quad (6)$$

$$\frac{q_{H_2O}}{p_{H_2O}} = \frac{K_{an}}{\sqrt{M_{H_2O}}} = K_{H_2O} \quad (7)$$

Where,

qH2 : Molar flow of hydrogen
qH2O : Molar flow of water
PH2 : Partial pressure of hydrogen
PH2O : Partial pressure of water
PO2 : Partial pressure of oxygen

kH2 : Hydrogen valve molar constant
kH2O : Water valve molar constant
Kan : Anode valve molar constant
MH2 : Molar mass of hydrogen
MH2O: Molar mass of water

1. Activation voltage drop:

The equation given below is used to calculate the activation voltage drop in a fuel cell.

$$V_{act} = n_0 + (T - 298.15) * a * T * b * \ln(I)$$

$$= V_{act\,1} + V_{act\,2} \qquad (8)$$

Where $V_{act\,1} = (n_0 + (T - 298) * a)$ is the voltage drop affected only by the fuel cell internal temperature, while $V_{act\,2} = (T * b * \ln(I))$ is both current and temperature dependent.

2. Ohmic Loss:

The ohmic resistance of a PEM fuel cell consists of the resistance of polymer membrane, the conducting resistance between the membrane and electrodes, and the resistance of electrode.[2] The overall ohmic voltage drop can be expressed as,

$$V_{ohm} = I * R_{ohm} \qquad (9)$$

Where R_{ohm} is also a function of current and temperature.

$$R_{ohm} = K_{RI}\,I - K_{RT}\,T \qquad (10)$$

3. Concentration voltage drop:

During the reaction process, concentration gradients can be formed due to mass diffusions from the flow channels to the reaction sites (catalyst surfaces). At high current densities, slow transportation of reactants (products) to (from) the reaction sites is the main reason for the concentration voltage drop. The concentration over potential in the fuel cell is defined as,

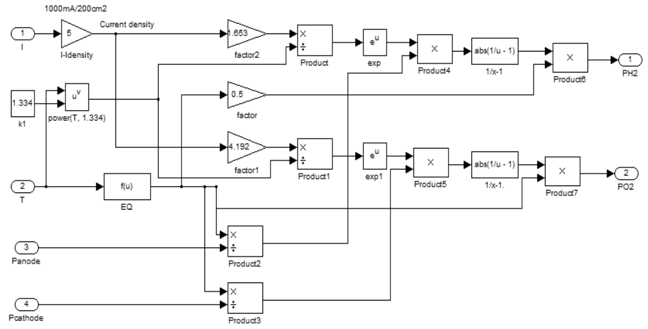
$$V_{conc} = \frac{-RT}{ZF}\ln\left(1 - \frac{I}{I_{limit}}\right) \qquad (11)$$

Table 1: Electrical Model Parameter Values for Fuel Cell

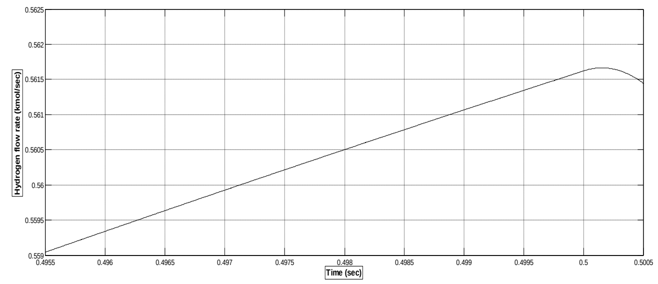
T	298 K
PH2	1.5 k mol/sec
PO2	1.0 k mol/sec
K1	1.335
F	96500 coulomb
R	0.082
Eo	1.229 V
C	4700 uF
Ract 1	1.2581 ohm
Ract 2	0.00112*(T-298) ohm
Rohm 0	0.2793 ohm
R Conc.	0.080312 ohm

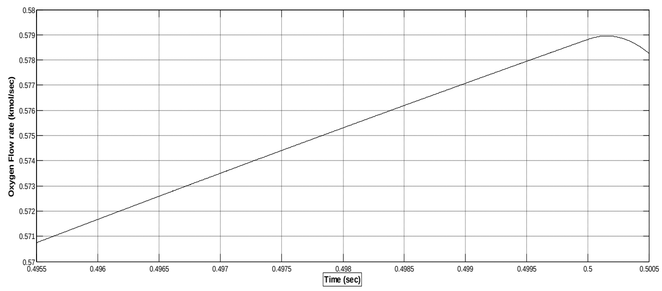
III. MATLAB SIMULATION AND RESULT OF PEM FUEL CELL

1. Flow of Hydrogen and Oxygen

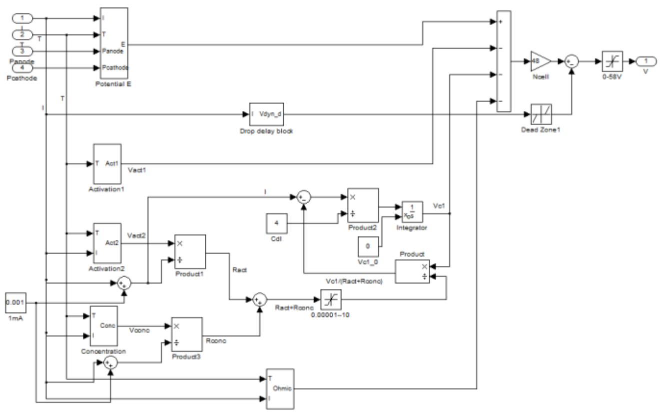


RESULT

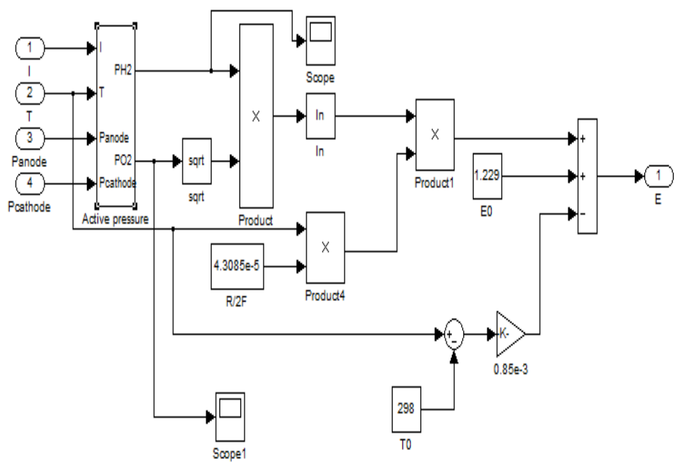




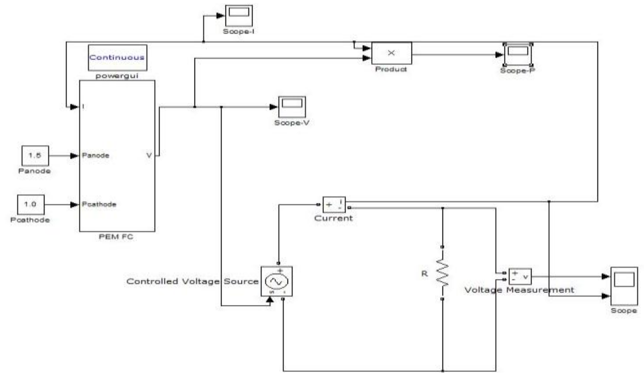
2. Simulation of Terminal Voltage



3. Simulation of Nernst Equation



4. Simulation of PEM Fuel Cell



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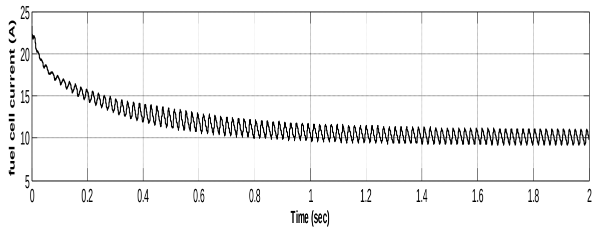
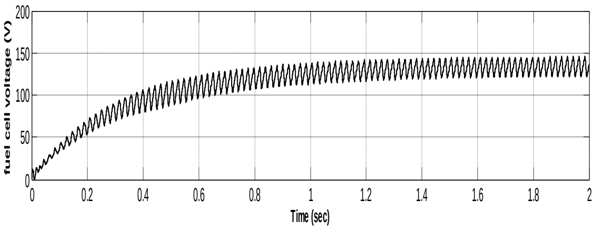
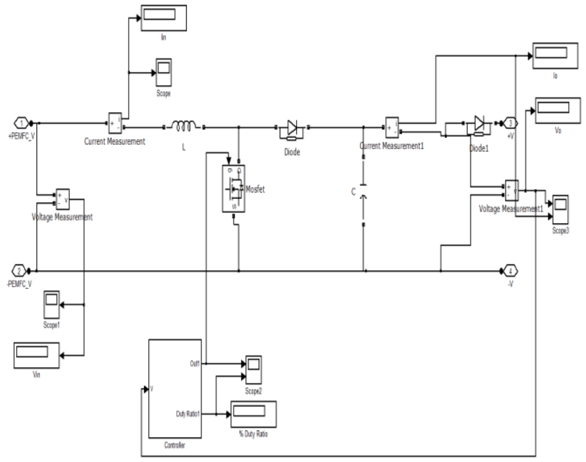




IV. SIMULATION AND RESULT OF PEM FUEL CELL FOR RESISTIVE LOAD

1. Simulation of Boost Converter



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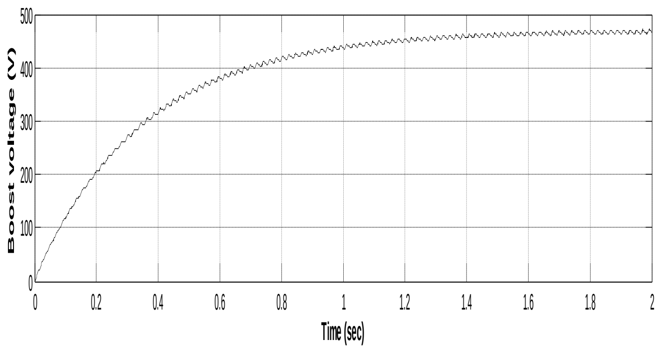
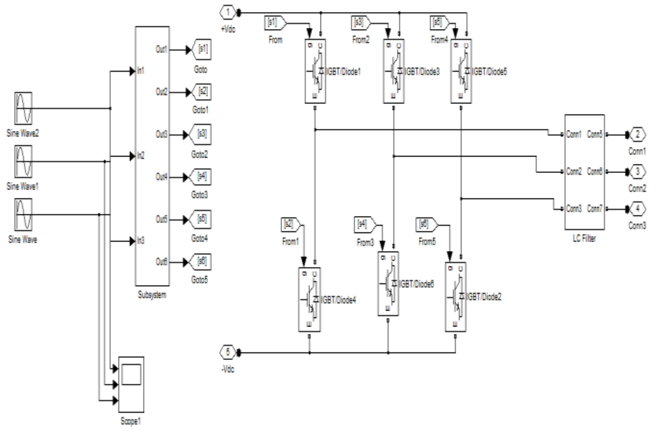
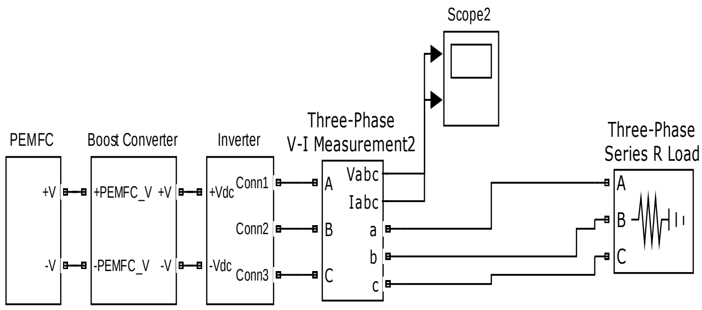


2. Simulation of Inverter



[3] Simulation of Inverter Based PEM Fuel Cell



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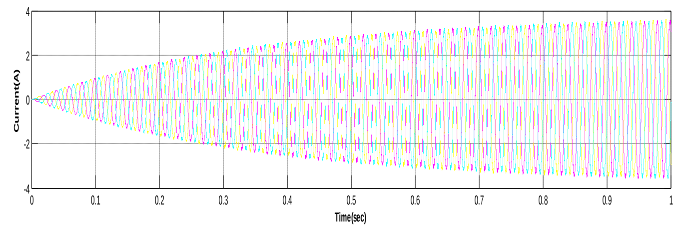
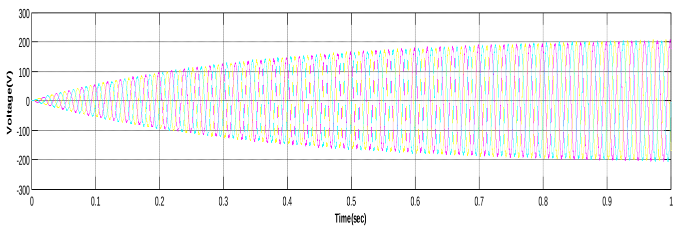
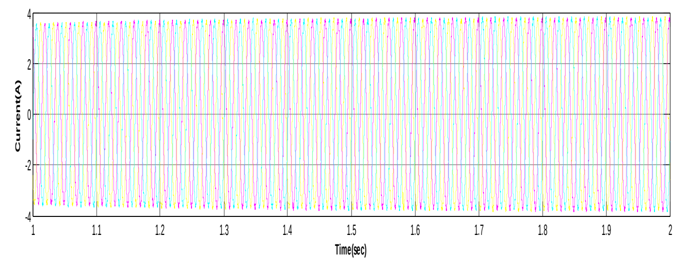
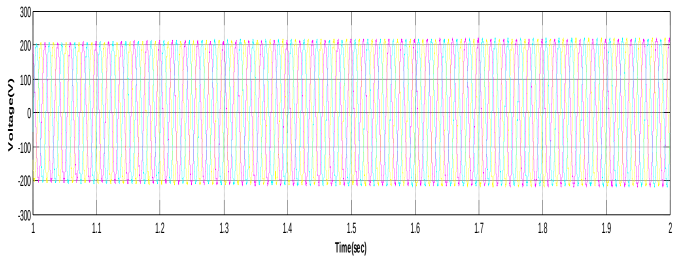
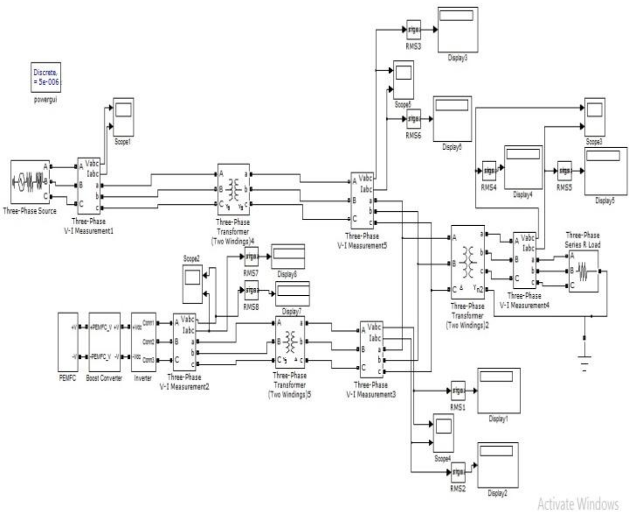








V. SIMULATION AND RESULT OF GRID CONNECTED INVERTER BASED PEM FUEL CELL FOR RESISTIVE LOAD



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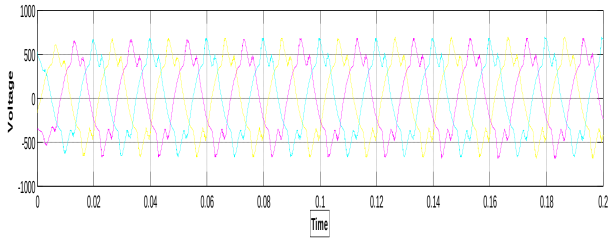

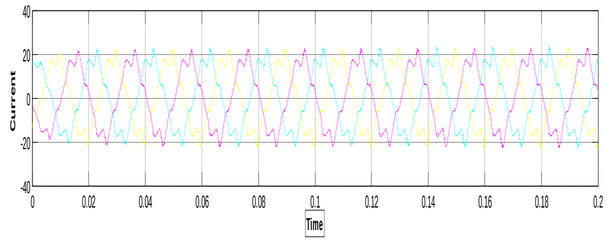

CONCLUSION

This paper deals with the dynamic simulation of a PEM Fuel cell generation system interfaced with the network through voltage source inverter. The dynamic performance of the PEM Fuel cell is studied. A Control strategy for the inverter switching signals has been discussed. In addition, the model for three phase inverter are simulated and verified by showing that it can be controlled. Simulation of PEM Fuel cell Model is performed for its operation both in grid connected and islanded mode.

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