Innovative Systems Design and Engineering
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol.7, No.5, 2016

Stand alone PEM Fuel Cell Feeding Non-Linear, Linear and PMSM Load through HVDC Link

Dipesh Kumar Karmakar Laxman Dasari
M.Tech Student, EEE Department, GITAM University,Visakhapatnam, Andhra Pradesh-530045, INDIA

Abstract
In the present scenario, the Fuel cell (FC) plays a pivotal role in renewable generation of electrical power; it is economic and environmental friendly. This paper objective is modeling of Proton exchange membrane fuel cell (PEMFC) to feed linear and non-linear loads. The performance of the PEMFC model is analyzed for various loads connected nearer to the fuel cell generation and a permanent magnet synchronous machine (PMSM) load located at the distribution end through a 750KV back to back HVDC link. In this proposed system, PEMFC is connected to DC-DC Boost converter, and integrated electronic load controller (IELC) feeding Non-linear, linear and PMSM load. The IELC is a voltage source converter (VSC), which consists of a three leg insulated bipolar transistor based current controlled, and a chopper switch and auxiliary load on DC bus. The PEMFC power generating system is simulated using MATLAB/SIMULINK.
Keywords: Fuel cell (FC), proton exchange membrane fuel cell (PEMFC), Integrated electronic load controller (IELC), Voltage source converter (VSC).

I. Introduction

Energy is major requirement, its demand is briskly escalating , the non renewable energy resources are limited and not sufficient to sustain the growing energy demand. The PEMFC is one among the safe, clean, economical, technically efficient and environmental friendly method to meet the growing load demands in a sustainable manner[1].

The fuel cell is electro chemical device which converts chemical energy to DC electrical energy via electrochemical reaction. Among five different kinds of fuel cell, PEMFC is considered because of its high energy density, simple structure, they produce water as residue, they operate at low temperature, they have high efficiency when compare to thermal generations, they employ solid polymer as electrolyte which requires less safety measures[2]. The PEMFCs are being rapidly developed as the primary source for both stand-alone as well as grid connected applications. The PEMFCs use hydrogen and oxygen as input fuel and produce dc power at the output of the stack[3]. The cell voltage decreases almost linearly as the load current increases. Therefore, the output voltage should be regulated at a desired value. To keep the polarization characteristics at constant level, additional parameters such as cell temperature, air pressure, oxygen partial pressure and membrane humidity also needs to be controlled. Power electronic interfacing circuit is called power conditioning unit. It is necessary for FC based systems to condition its output dc voltage. It converts the dc voltage to ac voltage. The FC source is connected to the load or grid through inverter which must be synchronized with the grid in terms of voltage and frequency[5]. The DC bus voltage of the voltage source converter of integrated electronic load controller is less sensitive to load fluctuations. The control of the proposed system is applied to derive the reference load currents to get power quality improvement[6]. The three-leg voltage source converter operates as harmonic eliminator and load balancer. Thereby reducing device rating of voltage source controller[7]. PMSM is connected through a 750KV Back to Back HVDC link. This scheme is simulated under the MATLAB environment using simulink and power system block set toolboxes, and the results are verified by implementation of control scheme. The performance of the proposed scheme is demonstrated through simulation results.

The advantages of PMSM compared to other AC machines are its simple structure, high-energy efficiency, reliable operation, high power density and possibility of super high speed operation. Recent important applications of permanent magnet synchronous machine are in the area of distributed generation, mainly in wind and microturbine generation systems. An advantage of a high speed generator is that the size of the machine decreases almost in directly in proportion to the increase in speed, leading to a very small unit

II. Description of Fuel Cell

A. Reaction Process of PEMFC

Proton exchange membrane fuel cell is a device that converts hydrogen and oxygen to electricity [1]. The hydrogen in the anode release electrons and become hydrogen protons. The proton exchange membrane only allows proton to transit, so the electrons is collected by external circuit and generate electric current. In the cathode, Protons combine with oxygen and become water [2].

$$2H_2 + O_2 = 2H_2O \tag{1}$$

B. Overview and Assumption

The assumptions is made in this model

• Ideal and uniform distribution of gas
• The gas is adequate for the high flow rate
• Constant temperature in the fuel cell
• Parameter for individual cells can be lumped together to represent a fuel cell

The model can be broken up into four parts; the circuits for internal potential (E), the ohmic voltage drop (Vhom), activation loss (Vact), concentration voltage drop (Vcon). A fuel cell output voltage is the function of the for part as shown in (2)

Vcell = E − Vhom − Vact – Vcon (2)

C. Equivalent Circuit for Internal Potential

According to Nernst Equation, a fuel cell systems internal potential is a function of PH2 , PO2 and PH2O2 as expressed in (3).

$E = N[V_0 + (RT/2F)\ \ln(PH_2 \sqrt{}PO_2/PH_2O_2)]$ (3)

N is the numbers of the fuel cell. V0 represents the reference potential at a standard state. PH2 is the H2 pressure in Anode. PO2 and PH2O2 is the oxygen and water pressure in the cathode.

D. Equivalent Circuit for The Activation Loss

Activation polarization is due to the slow speed of the reaction occurring within the cell. It varies depending on the nature of the electrode, ionic interaction, ion-solvent interaction, and the electrode-electrolyte interface. The activation voltage is the sum of two parts Vact1 and Vact2. Vact1 is just dependent on temperature. Vact2 is dependent on both load current and the temperature. Vact1 could be expressed in (4), and Vact1 of a cell could be expressed in (5)

Vact1 = η0 + f(T) (4)

Vact2 = I · f2(I, T) (5)

E. Equivalent Circuit for Ohmic Voltage Drop

Ohmic polarization is caused by the resistance of the polymer membrane to the transfer of protons and the resistance of the electrode and collector plates to the transfer of electrons . It could be expressed as formula (6).

Vohm = N · I · Rohm (6)

F. Equivalent Circuit for Concentration Voltage Drop

Concentration polarization is caused by gas concentration changes at the surface of the electrodes. Concentration gradients can form during the reaction process; This is cause by mass diffusion from the gas flow channels to the reaction sites. Concentration voltage drop is expressed in the follow formula.

Vcon = N * m exp (n * I) (7)

Many attempts have been undertaken to develop and simplify mathematical model defining the behavior of a PEMFC. An accurate model can be obtained modifying equation and substituting the values of the different losses. This results in equation (8):

$$V_{FC} = E_{rev} – (2.3*RT/\ \alpha nF)\ln(I_{FC}/I_0) - R_{int}*I_{FC} – (RT/nF)\ln(1-I_{FC}/I_l) \quad (8)$$

Where the different parameters are:
R = Universal gas constant (8.31451 J/(mol. K)),
F = Faraday’s constant (96485 Coulomb/mol),
T = Stack temperature,
α = Transfer coefficient,
n = Number of electrons involved in the reaction,
R_{int} =Sum of electrical and photonic resistances,
FC I =Fuel cell current,
I_0 =Exchange current,
I =Limiting current of the fuel cell.

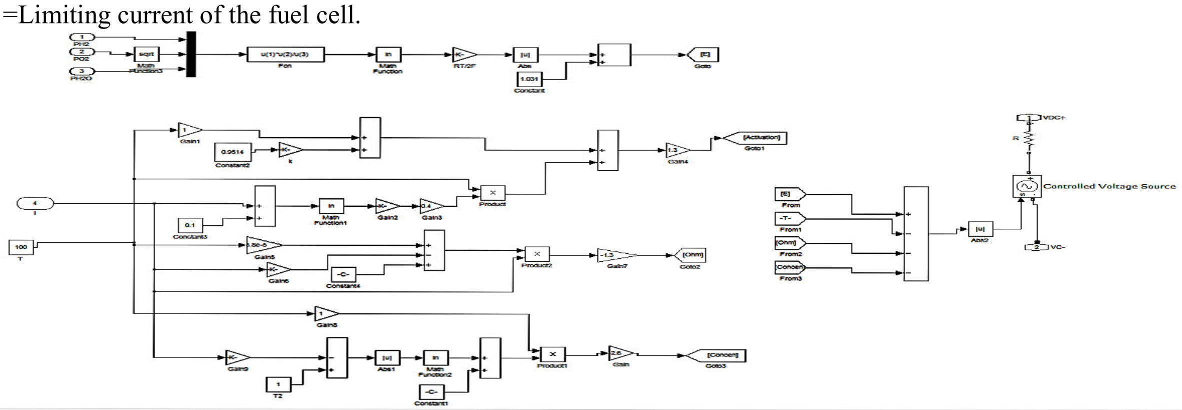

Fig.1Simulink model of PEM Fuel cell

Description of PMSM

Permanent magnet synchronous motors (PMSM) have attracted increasing interest in recent years for industrial drive applications. The high efficiency, high steady state torque density and simple controller of the PM motor drives compared to the induction motor drives make them a good alternative in certain applications. Other advantages of the PMSM are low inertia, high efficiency, reliability and low cost of the power electronic converters required for controlling the machine. All these facts make the PMSM an excellent candidate for being used in many applications. We can distinguish between two main kinds of PMSM: internal-mounted magnets (IM) or surface-mounted magnets (SM). The main difference is that the IM machine has a variable reluctance which varies with the rotor angle, while the SM machine has quite a fixed reluctance for any rotor angle. That leads in a uniform air gap, and thus, an equal magnetizing inductance for the direct and quadrature axis (Ld and Lq). Field oriented control of PMSM is one of the widely used methods in drive applications that is considered in this paper.

III. Control Stratergy

The current controlled PWM technique is used in this system. In current controlled PWM, source currents are measured and compared with reference currents. The errors generated are used as inputs to the PWM, which provides inverter switching signals. The main objective of current controller is to force the source current vector according to the reference current trajectory. it is a closed loop system where the switching pulses are dependent on the source currents. The source currents are fed back to the controller which constantly compares them to the reference currents. The error generated is processed by the controller whose output is used by the gate pulse generator to give the switching pattern of the inverter switches so as to minimize the error. This kind of a current control loop is present in most of the modern vector drives, Active power filters and grid connected inverters. It can be used in any application which requires a controlled current source.

Generally AC motor and non linear loads are if they are current controller feed they exhibit better performance, quick response, reduced dependency on stator parameter, has immediate effect on machine torque and increases stability of control loop.

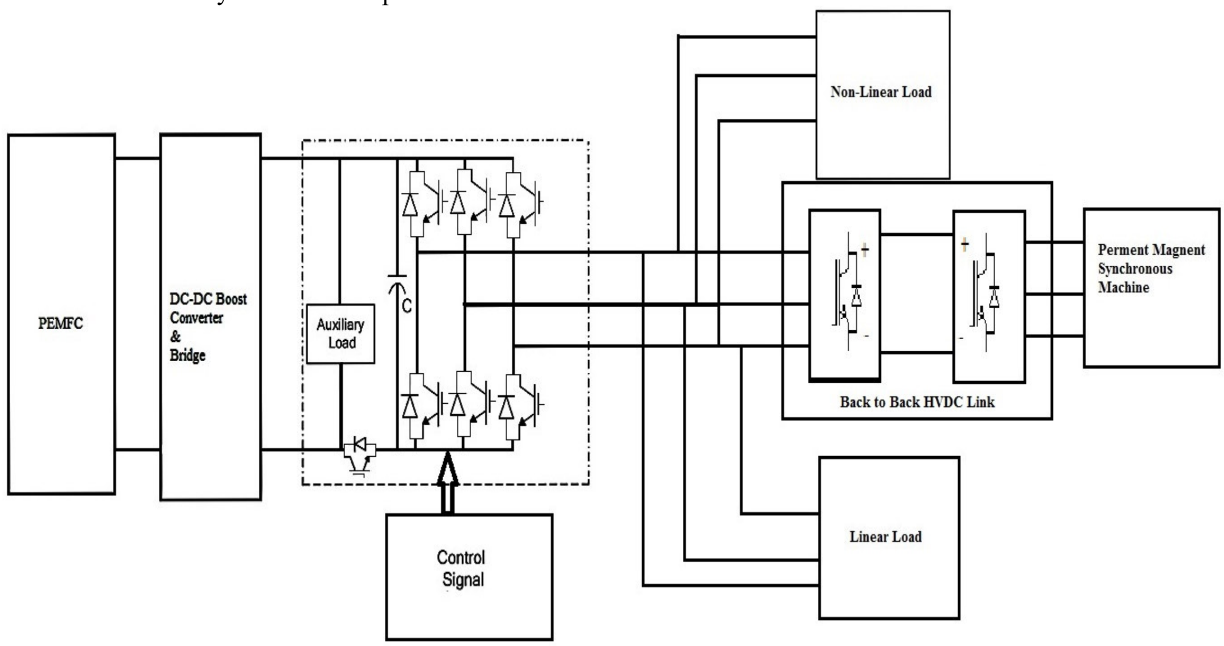

Fig 2. The proposed configuration of PEMFC with DC-DC Boost converter and IELC feeding Various loads

IV. matlab based modeling

The load interface PEMFC power generating system is modeled using MATLAB/Simulink. The three loads are connected to three- leg voltage source converter VSC through PEMFC is simulated in MATLAB as shown in fig.2. A three-phase four wire Non-linear load and a linear load is connected and a 1.5KW PMSM load is connected through a 750KV back to back HVDC link. The simulation of the proposed system is carried out on the MATLAB version 7.9.0 (R2009b) using the sim power system (SPS) toolbox and discrete step of 5e-6 with ode23tb ()stiff/TR-BDF-2) solver.

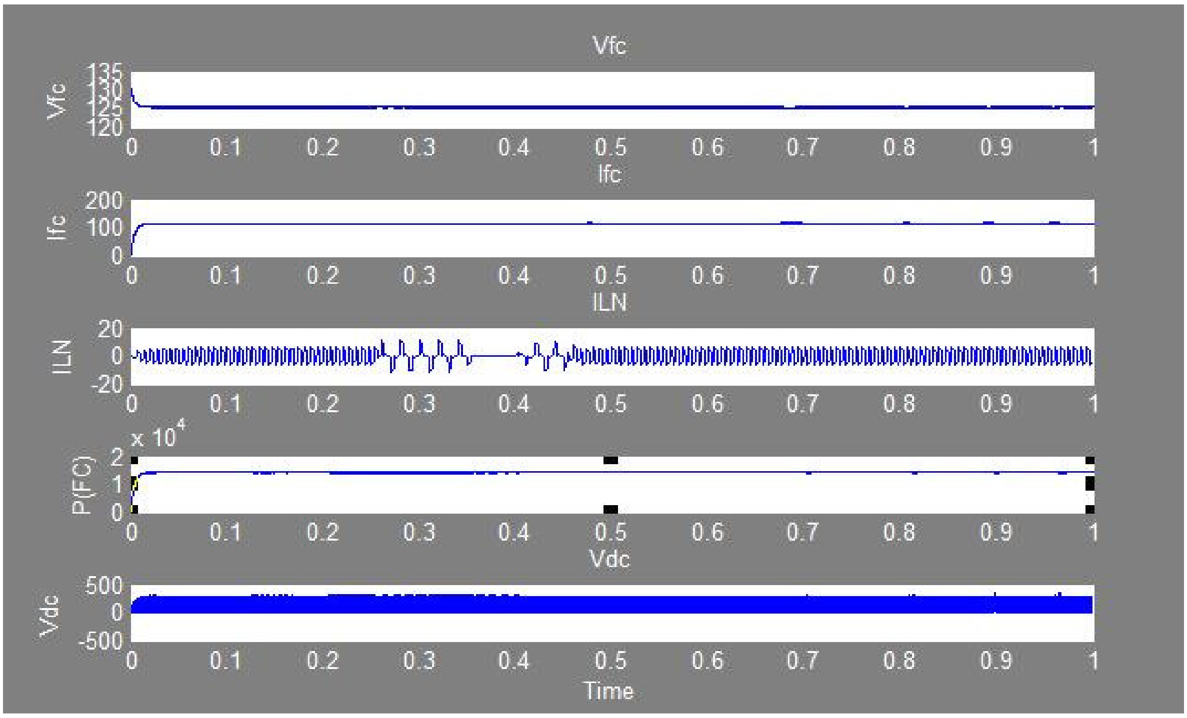

Fig.3 Performance of the PEMFC Generating system

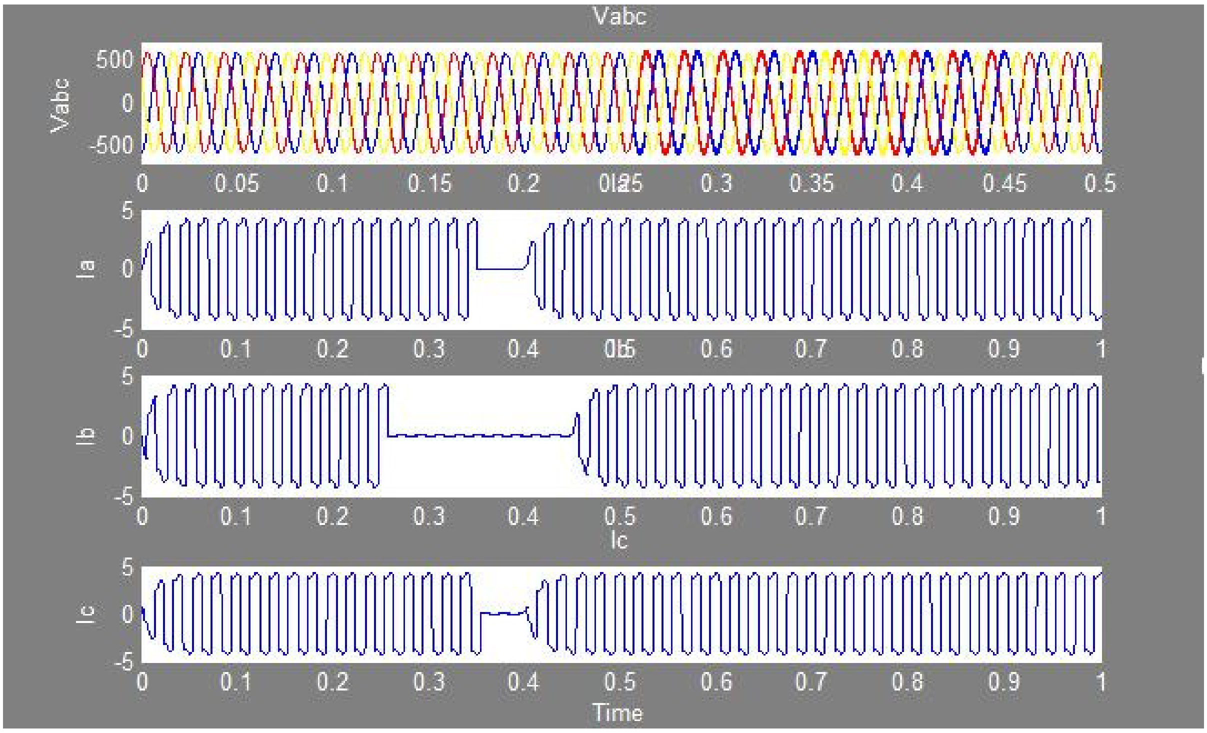

Fig.4 (a) Performance of the proposed system for non-linear load

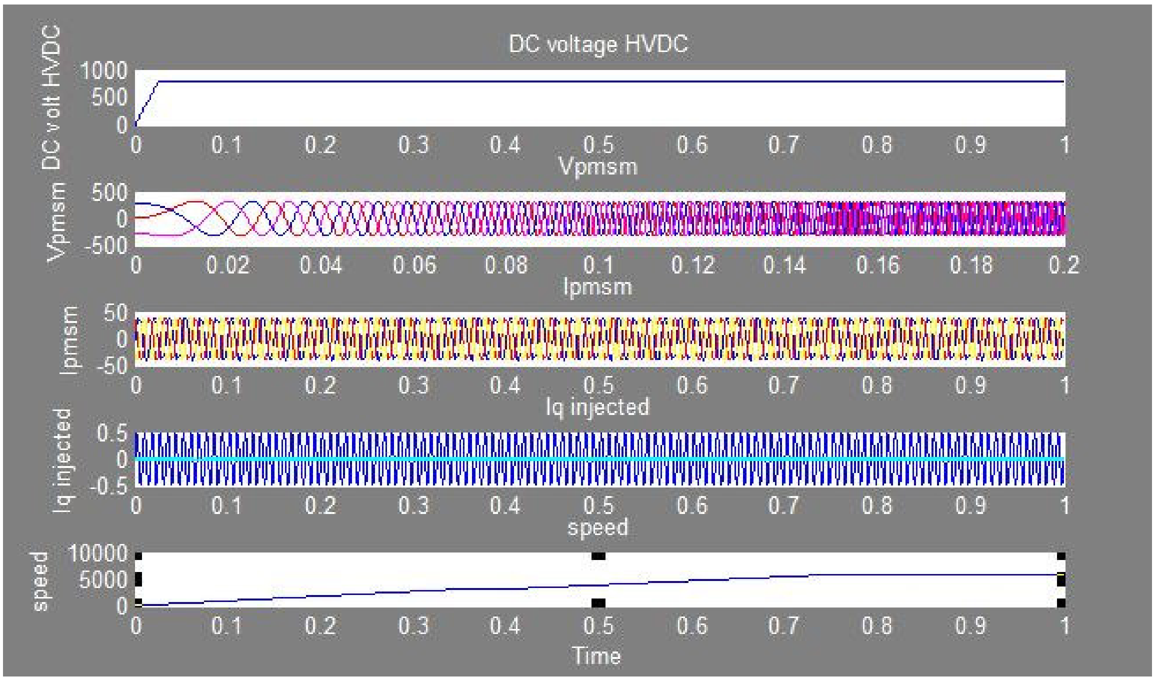

Fig 4(b) Performance of the proposed system for PMSM load.

V. results and discussion

Simulation results of the PEMFC power generating system connected to various load is shown in Fig.4 (a)-4(b). The PEM Fuel cell power generating system is controlled by a three-leg voltage source converter and performance of the fuel cell is shown in fig.3. Performance of the proposed system is represented in terms of fuel cell voltage (V_{FC}), DC bus voltage (V_{dc}) , DC bus current (I_{dc}),load currents at various laods , Fuel cell power (P_{FC}), Fuel cell current(I_{FC}), load voltage (V_{labc}), HVDC link Voltage (V_{HVDC}), PMSM load voltage (Vpsms), PMSM Load current (Ipmsm), and PMSM Load Power (Ppmsm). The THD of the Non-Linear load is noted as 0.97% and the THD of the PEM Fuel cell voltage and current are noted as 0.97% respectively and THD waveforms are shown in the figure 5(a)-5(b).

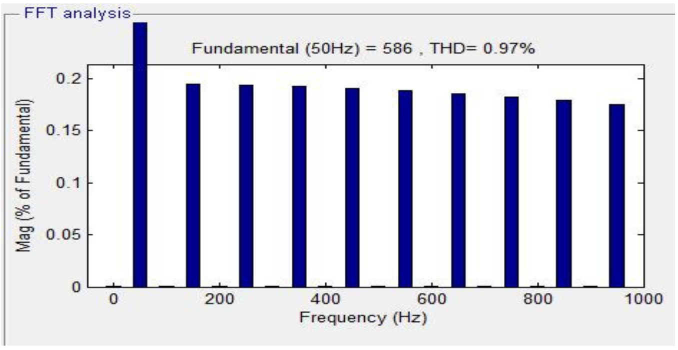

Fig.5 (a) THD of the Non-Linear laod

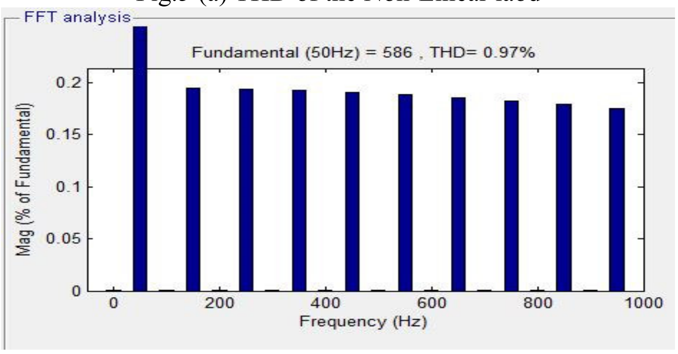

Fig.5(b) THD waveforms of the PEM Fuel cell

VI. Conclusion

The stand-alone PEMFC is modeled and its performance with current control PWM technique for an integrated electronic load controller is studied. The performance of the proposed system is studied under linear, non-linear and PMSM load condition. It was observed that the system performance is satisfactory with proposed integrated electronic load controller with current control based technique. This controller is simple to operate, easy to design and less sensitive to load perturbation

REFERENCES

[1] W. Kaewmanee, M. Phattanasak, P. Sethakul, M. Hinaje, and B. Davat, "A dynamic equivalent circuit model for gas diffusion layers of pemfc," in *Industrial Electronics Society*, Nov 2013, pp. 1450–1453.

[2] L. Spampanato, M.-C. Pera, D. Hissel, and G. Spagnuolo, " Performance parametric analysis of a pemfc model," in *Industrial Electronics (ISIE)*, July 2010, pp. 2041–2046.

[3] B. K. Bose, "Energy environment, and advances in power electronics," IEEE Transctions on Power Electronics, vol. 15, no. 4, 2000 pp.699-701.

[4] C. Wang and M.H. Nehrir, "Distributed generation applications of fuel cells," in Proceedings of the Power systems Conference, Advanced Metering, Protection, Control communications and Distributed Resources, 2006, pp.244-248.

[5] S. Parischa and S.R Shaw, " A dynamic PEM fuel cell model," Energy Conversion, IEEE Transaction on, vol.21,pp.484-490,2006.

[6] W. Choi, J.W. Howze and P. Enjeti, "Devlopment of an equivalent circuit model of a fuel cell to evaluate the effects of inverter ripple current," Journal of Power Sources, vol. 158,pp.1324-1332,8/25.2006.

[7] Remus Teodorescu, Marco Liserre and Pedro Rodrıguez, "*Grid* Converters for photovoltaic and wind power system," John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex, United Kingdom. 2011.