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# Fuel cell power conditioning unit for standalone application with real time validation

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ABSTRACT

In recent era, fuel cells are emerging as better alternative to wind and solar based energy sources due to its reliability and high efficiency. Polymer Electrolyte Membrane Fuel Cell (PEMFC) is widely used in various applications due to low operating temperature and high energy density. On the other side low and unregulated stack voltage demands PEMFC integration with suitable power conditioning unit. However, the use of actual fuel cell power conditioning unit in design and testing for research is expensive. Any failure may lead to damage of source or power circuit. In this regard, the present work aims at developing a soft-computing model of PEMFC. Also, a DC-DC converter is designed to step-up the stack voltage. A classical PI controller is implemented to regulate the PEMFC fed power conditioning units for resistive loads. The proposed system is implemented is Hardware-In-the-Loop (HIL) using OPAL-RT's OP5600 Real Time Digital Simulator (RTDS).



## Introduction

The PEMFC power source attracted enormous R&D interest of the researchers due to its compact design, low maintenance cost, low operating temperature, high durability, no carbon emission as well as quick startup capability [1]. Presently, the research study mainly concentrates on mathematical modeling, optimization and its simulation. In order to investigate the performance of PEMFC power system, accurate modeling as well as power converters along with efficient control strategies is needed. To simulate the PEMFC based on electrochemical, fluid dynamics and thermal phenomenon many models have been reported in literature [2–8]. Nowadays, the parameters of PEMFC are identified by optimization techniques such as, Simulated Annealing [9], Differential Evolution [10,11], Particle Swarm Optimization (PSO) [12], Support Vector Regression (SVR) approaches [13] etc. The Li et al. [12] has compared different versions of the PSO algorithms for a parameter identification. A complex phenomenon and their interaction inside the fuel cell significantly limit the optimization approach of the parameter identification of a mechanistic model. This limitation can be overcome by black-box modeling approach such as ANN [14,15].

The severe impediment exist with FC, such as poor performance at high current ripple, lower operating voltage, unidirectional operational constraint, sluggish response and restricted overload capability, forced the power conditioning unit mandatory for FC power system application. In Ref. [16] author has reported more than 99% FCs are integrated to load or power system through DC bus. Therefore, various topologies of DC converters are reviewed for interfacing FC with the load [17–19].

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**Nomenclature**

| | |
|---|---|
| $\Delta G$ | Change in free Gibbs energy (J/mol) |
| $F$ | Faradays constant (96487C/mol) |
| $T$ | Stack temperature (K) |
| $E_{Nerst}$ | Thermodynamic potential |
| $R$ | Universal gas constant (8.314J/K.mol) |
| $k_E$ | Empirical constant (8.5E-4 V/K) |
| $Ed$ | Voltage drop during load transient caused by delay in hydrogen and oxygen flow |
| $P_{H2}$ | Partial pressure of hydrogen (mbar) |
| $P_{O2}$ | Partial pressure of oxygen (mbar) |
| $I_{st}$ | Stack current |
| $\zeta_i; i\forall(1..4)$ | Parametric coefficients for each cell |
| $C_{O_2}$ | Oxygen concentration at membrane |
| $C_{H_2}$ | Hydrogen concentration at membrane |
| $V_{act}$ | Activation potential drop |
| $V_{ohm}$ | Ohmic potential drop |
| $V_{con}$ | Concentration potential drop |
| $V_{fc}$ | Stack voltage |
| $N_{cell}$ | Number of cell in stack |
| $l$ | Thickness of FC membrane (cm) |
| $A$ | Activation area of FC ($cm^2$) |
| $R_t$ | Transfer equivalent resistance of FC |
| $J$ | Current density ($A/cm^2$) |
| $J_{max}$ | Maximum current density ($A/cm^2$) |
| $d$ | Duty cycle of converter |
| $\Delta I_{L(p-p)}$ | Current ripple in the inductor |

The use of commercial fuel cell unit in design and testing is expensive that may lead to failure. Aforementioned, limitation can be overcome by developing a real time emulators and simulators as reported in literature in Ref. [20–25].

In this paper, modeling and control of PEMFC power system is presented. In order to model the PEMFC neural network is adopted due to its better dynamic response. For power conditioning, a BC (Boost Converter) and SEPIC (Single-Ended-Primary-Inductor-Converter) are used that act as interfacing to synthesis the required load voltage. The output voltage of DC converters is regulated through digital PI controller under wide load variations. To validate the performance, proposed scheme is implemented in real time simulators such as OPAL-RT (RT Lab) and dSPACE DS1103.

This paper is organized as follows, Section-PEMFC modeling discuss the ANN based PEMFC modeling. Section-PEMFC integrated power conditioning unit details the design and integration of SEPIC/Boost converter based power conditioning units for PEMFC application. Section-Experimental setup for real time validation is depicted with the Real time implementation of proposed scheme and Section-Results and discussion discusses the simulation and real time results. Finally, Section-Conclusion concludes the paper.

## PEMFC modeling

A PEMFC consists of a solid polymeric membrane electrolyte pressed between anode and cathode electrodes. PEMFC takes Hydrogen as fuel to produce electricity through chemical reaction and water as by product.

The empirical output voltage equation of PEMFC consists of thermodynamic potential, activation potential drops, Ohmic and Concentration potential drops that are depicted as follows [5,9,12,26]:

$$V_{fc} = N_{cell} \times (E_{Nernst} - V_{act} - V_{ohm} - V_{con}) \tag{1}$$

where;

$$\left.\begin{aligned} E_{Nernst} &= 1.229 - (8.5e-4)(T - 298.15) \\ &\quad + (4.308e-5)T\left(\ln\left(P_{H_2}P_{O_2}^{0.5}\right)\right) - E_d \end{aligned}\right\} \tag{2-a}$$

$$\left.\begin{aligned} V_{act} &= \zeta_1 + \varphi T + \zeta_3 T \ln(C_{O_2}) + \zeta_4 T \ln I_{st} \\ \varphi &= \zeta_2 + 2\times 10^{-4} \ln A + 4 \times 10^{-5} \ln(C_{H_2}) \\ C_{O_2} &= 1.97 \times 10^{-7} \exp\left({}^{498}/_{T}\right) P_{O_2} \\ C_{H_2} &= 9.17 \times 10^{-7} \exp\left({}^{-77}/_{T}\right) P_{H_2} \\ V_{ohm} &= \left(\left(\frac{l}{A}\left\{\frac{181.6\left[1 + 0.03\frac{I_{st}}{A} + 0.062\left(\frac{T}{303}\right)^2\left(\frac{I_{st}}{A}\right)^{2.5}\right]}{\left[\sigma - 0.634 - \frac{3I_{st}}{A}\right]\left[\exp\left(4.18\left(\frac{T-303}{T}\right)\right)\right]}\right\} + R_t\right) I_{st}\right) \\ V_{con} &= \frac{RT}{2F}\ln\left(1 - \frac{J}{J_{max}}\right) \end{aligned}\right\} \tag{2-b}$$

The PEMFC modeling (1) and (2) involves parameter estimation that is very uncertain. Proposed optimization based approaches in literature suffer with the limitation of global convergence and computational burden. Also these approaches fail to predict the output voltage under wide operating conditions. In this context, ANN approach has been adopted that do not require rigorous iterative calculations or tuning after they are trained. Further, proposed ANN approach is quick and easy for emulator design/RTDS implementation.

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