PEM Fuel Cell Stack Modeling based on Diffusion Effects in the Gas Flow Channel

Suk Heung Song
Korea Institute of Energy Research
Daejeon, 305-343, Rep. of Korea
Jong Hoon Jang
School of Mechanical and Automotive Engineering,
University of Ulsan
Ulsan, 680-749, Rep. of Korea
Yuyao Shan and Song-Yul (Ben) Choe
Department of Mechanical Engineering
Auburn University
Auburn, AL 36849

PEM fuel cell is a potential candidate that can replace current ICE (Internal combustion Engine). Modeling and simulation of fuel cell provide scientific means and methodologies to fundamentally understand the physical mechanisms and to optimally design a fuel cell powered system. Current available models can be classified in two categories, for designing the layers of a single cell with a high resolution analysis capability and for optimizing system components and controls in conjunction with BOP (Balance-of-Plant) and power system. The former generally based upon CFD (Computational Fluid Dynamics) requires intensive computation time and more than 30 parameters to be identify. In addition, a deep understanding and wide knowledge in the electrochemical mechanisms are necessary, which impedes practical utilization of the models for a system analysis. The latter, however, is based upon the static behavior of a fuel cell that represents typical I-V curve of the polarization curve. The parameters are determined by fitting the curve to empirical values. One of the drawbacks is the lack of dynamics that should be considered in designing controls and optimizing the system components. The focus of this paper is placed on research and development of a dynamic model that considers the diffusion behavior of gas in flow channel and gas diffusion layer.

Several dynamic models for PEM fuel cell have been developed and announced for designing advanced controls and optimizing system efficiency. The frame work of such a system is based upon the models (Pukrushpan, 2002), where the dynamics of the inlet and outlet manifolds, the static characteristics of the stack and the auxiliaries are mainly considered. Hence, we have enhanced the stack model with a simplified fluid mechanism in the cell. The proposed model composed of typical four layers are governed by the following equations shown in the Table 1., where a homogeneity in the plane is assumed.

Table 1. Governing Equations for layers in a single cell

Component	Governing equation	Analyze object
Gas channel	Navier-Stokes Species conservation	Multiphase multi-component convection-diffusion flow with porous boundary condition
Gas diffusion Layer	Continuity Energy Species conservation	Multiphase multi-component convection-diffusion flow in porous media
Catalyst layer	Reaction-diffusion	Diffusion-reaction flow
Membrane	Nernst-Plack	Proton and water transfer

Those are cathode/anode gas diffusion layer, catalyst layer and membrane. The behaviors of gases in the fuel delivery system are described with mass and energy balance, and stoichiometric relationship between reactants. Specially, the fluid flow in the manifold is governed by the filling dynamics. The operation conditions include cell temperature, air pressure in inlet of cathode, oxygen partial pressure, oxygen concentration and membrane humidity. The current presents a load. The necessary data for models are obtained from different references (Lee, 1998; Guzzella, 1999; Pukrushpan,2002)

In the simulation, following assumptions have been made ; 1) hydrogen supply is relatively fast: 2) hydrogen flow rate can be instantaneously adjusted to provide minimum pressure difference across the membrane: 3) Stack pressure is equal to the anode and the cathode pressure: 4) The relative humidity of the stack inlet hydrogen and air flow can be reached to 100% at maximum: 5) Heat transfer effects are ignored, so that the temperature of the reactant flows and fuel cell stack are constant at 80◦*C*. The operating conditions are as follows; 1) the excess oxygen ratio is equal to 2. 2) The step changes of load current are from 100A to 280A with several steps.

As a result, the stack voltage can be presented with ideal I-V polarization curve, activation, ohmic and concentration losses. The results with the empirical model show that the stack voltage drops rapidly when a stack current implies. After having increase the current, oxygen excess ratio drops due to depletion of oxygen. Consequently, it causes an abrupt drop in the cell voltage. The voltage also depends on oxygen partial pressure. The waveforms are shown in Fig-1, Fig-2, respectively. The simulation demonstrates that a transient response of stack voltage can be achieved with the models. In addition, the transient effects of anode and cathode pressure and oxygen excess ratio in an operating environment are obtained.

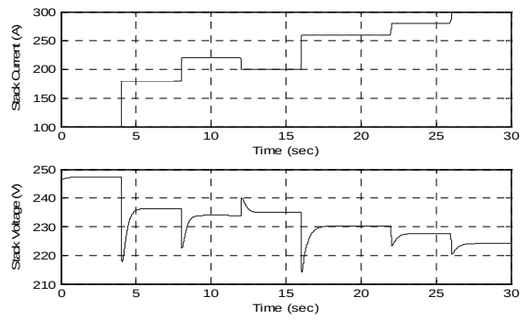

Figure 1: Simulation results of current and stack voltage

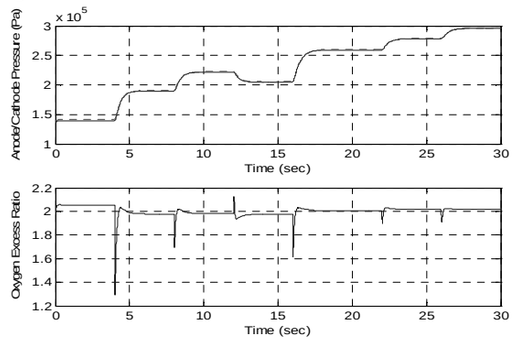

Figure 2: Simulation results of anode/cathode pressure and oxygen excess ratio

Future work of the paper is an integration of CFD model into the developed system model. Thereafter, comparisons between an empirical model and this new model will be undertaken to discuss the effectiveness in an operating environment.