Multi-physics Unit Model of Fuel cell for Railway Vehicle Propulsion Systems

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ABSTRACT

Fuel cell powered Railway Vehicle Propulsion Systems (RVPSs)_are highly desirable due to environment friendly characteristics, and high efficiency of fuel cell (FC). Among various types, the faster start up and optimality to frequent starts and stops of Polymer electrolyte membrane fuel cell (PEMFC) makes it well suited for propulsion systems. A comprehensive model of PEMFC with reflection of multi physics behavior required to identify and validate its performance in real RVPSs. Thus this paper will model and simulate the PEMFC unit cell model: a detailed reflection of governing laws and account of dynamic conditions.

Introduction

FC as primary power source for RVPSs substantiates itself for best choice due to zero emission, improved efficiency as compared to diesel engines and fast refueling as compared to battery. Usually the FC is hybridized with battery for recovering of braking energy (Figure1) [1]. FC for being multi physics system, depends on changing operating conditions for energetic performance and this dynamic dependence necessitates a detailed model capable to predict the performance in real hybrid propulsion systems [2]. To operate the FC at high efficacy and high power density, optimal values should be met for pressure, temperature, flow rate, and humidity of reacting species and substrate with the help of controlled sub systems. [3]. With the above driving reasons this paper presents a FC model along with sub systems.

2. Fuel cell Voltage and Polarizations

The thermodynamic potential of the fuel cell is governed by thermodynamic laws and given by Nernst equation (1).

$$E_{thermo} = E^0 - \frac{RT}{2F} ln \frac{a_{H20}}{a_{H_2} a_{o_2}^{1/2}} \qquad (1)$$

E^0 : $Standard Thermodynamic potential$
a : $activity of species$
R: $gas constant$
F: $Faraday constant$
T: $Temperature$

The terminal voltage (2) is less than the thermodynamic potential by amount equal to the sum of polarizations: Activation polarization η_{act}, Concentration polarization η_{conc}, and Ohmic $\eta_{\Omega ic}$ as shown in Figure 2.

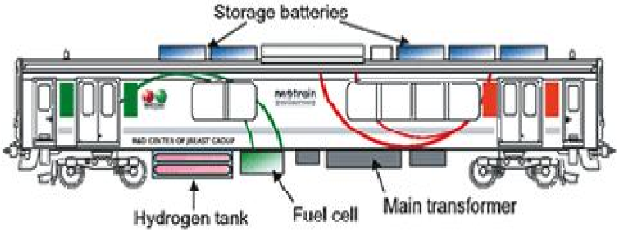

Figure 1 Fuel cell Battery Hybrid Train

$$V = E_{thermo} - \eta_{act} - \eta_{\Omega ic} - \eta_{conc} \qquad (2)$$

$$\eta_{conc} = \frac{RT}{nF} ln(\frac{i_l - i}{i_l}) \qquad i_l : \text{ max}imum\, current$$

$$\eta_{conc} = \frac{RT}{nF} lni_0 - \frac{RT}{nF} lni \qquad i_0 : Equilibrium\, current$$

$$\eta_{\Omega ic} = \frac{\rho_m {}^* l}{A} \qquad \rho_m : PEM\, resistivity$$

3. Fuel cell Subsystems

The fuel cell system is augmented by four subsystems: (i) Hydrogen supply system, (ii) Air supply system, (iii) Air cooling system, (iv) Humidification system.

3.1 Hydrogen Supply system

A hydrogen tank with a valve for flow regulation was assumed. The important consideration for regulation is to minimize pressure difference between anode and cathode. The flow rate into anode $W_{an,\in}$ takes the form (3).

$$W_{an,\in} = K1(K2P_{sm} - P_{an}) \qquad (3)$$

$K_1 = proportional\ gain$
$K_2 = pressure\ drop\ compensation$
$P_{sm} = {}^{ply} manifold\ pressure$
$P_{an} = anode$ Pressure

3.2 Air Supply System

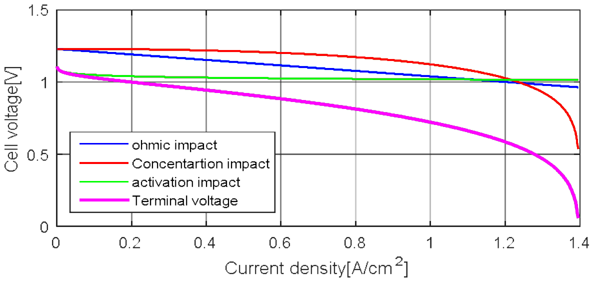

Figure 2 Terminal voltage along with polarizations

Compressor, supply manifold and return manifold constitute the air supply system. Supply manifold and return manifold are the pipes transporting reactants into cell and taking products out of cell.

3.2.1 Compressor Modelling

Increasing pressure of air higher than atmospheric pressure using compressor significantly improves the efficiency of FC [4]. Every compressor comes with the compressor map (Figure 2) which relates pressure ratio to mass flow rate for different speeds of compressor to operate in efficient region. The increase in pressure ratio also increase the temperature of air (Figure 4). The pressure ratio PR determined as by (3)

$$PR = \frac{P_{cp,\, out}}{P_{cp,\, \in}} \qquad (4)$$

$P_{cp,out}$: $compressor\ \ outlet\ \ pressure$
$P_{cp,\in}$: $compressor\ \ \in \leq t\ \ \ pressure$

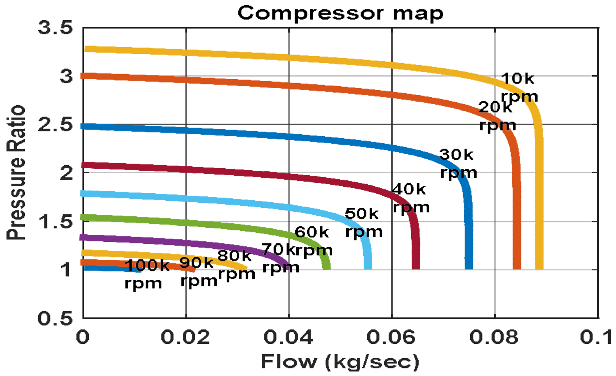

Figure 3 Compressor Map

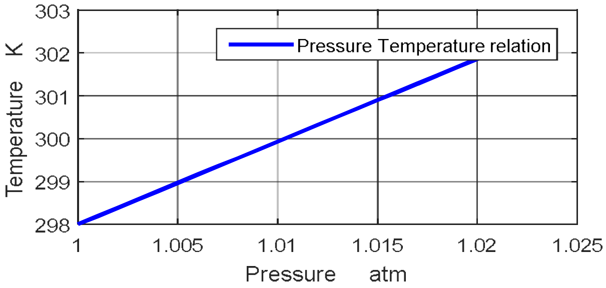

Figure 4 Compressor outlet Temperature/Pressure relation

3.3 Air cooling system

Usually the PEMFC is operated at 80℃. The air cooler brings the temperature of air to 80℃. The temperature of air entering and exiting the cooler are shown in Figure 4.

3.4 Humidifier

The humidifier injects the water and thus increases the humidity of air. The voltage drop by 20 40% could occur with out proper humidification control [5]. The relative humidity of inlet and outlet compared in Figure 5.

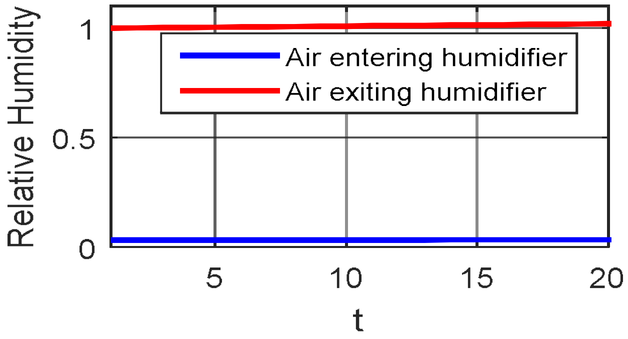

Figure 5 Humidity at Inlet and outlet of humidifier

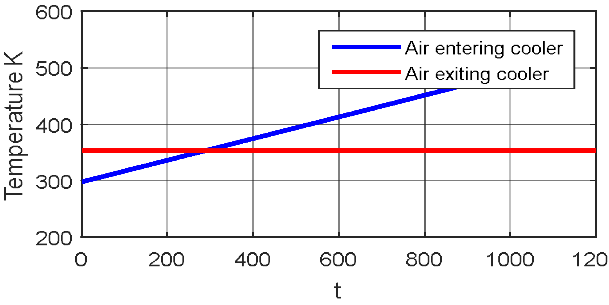

Figure 6 Temperature at Inlet and outlet of cooler

3. Conclusion

A unit cell FC model was developed along with sub systems for RVPSs, based on thermodynamics, fluid equations and electrochemistry.

본 연구는 국토교통부에서 시행한 철도기술연구사업 "수소연료전지 하이브리드 동력시스템(1.2MW 이상)을 적용한 철도차량 추진시스템 최적화 및 운용 기술개발 "1세부 수소연료전지 기반 하이브리드 추진시스템 최적화 기술개발 (18RTRP B146008 01) 과제의 연구비로 수행한 결과입니다.

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