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A cell interaction phenomenon in a multi-cell stack under one cell suffering fuel starvation

Zunyan Hu[a,b], Liangfei Xu[a,b,1], Jianqiu Li[a,b,*], Junming Hu[a,b], Xin Xu[c], Xiaoli Du[c], Weihua Sun[a,b], Minggao Ouyang[a]

[a] State Key Lab of Automotive Safety and Energy, Tsinghua University, Beijing 100084, PR China
[b] Collaborative Innovation Center of Electric Vehicles in Beijing, PR China
[c] Shanghai Shen-li High Tech Co.,Ltd, Yuandong Rd., Industry Comprehensive Development Zone, Shanghai, PR China

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ABSTRACT

Cell interaction is the main factor resulting in a shorter lifespan for multi-cell stacks than for a single fuel cell stack. To explain this mechanism, we propose a cell interaction phenomenon in which one cell experiences fuel starvation. A specific voltage distribution along the straight channel direction has been observed with an innovative multipoint monitoring method. This phenomenon also can be used for fuel starvation diagnosis. This study proposes an ingenious simplified two-chamber model to analyze the current and voltage redistribution mechanism under fuel starvation. The reliability of this model has been validated in this paper. The model shows that current convergence resulted by fuel starvation in one cell can lead to a concomitant local current convergence in nearby normal cells. Based on our calculation, > 85% of reaction current concentrates in the anode inlet region of the fuel-starved cell, resulting in a 70% current convergence in the two adjacent normal cells. A serious corrosion of the fuel-starved cell is observed in the post-mortem study. The faulty cell presents a 5° contact angle decrease and a 28% ECSA loss. Scanning electron microscopy and Transmission electron microscopy results show that the decline of anode outlet regions' cathode catalyst layers are more serious. Some optimal strategies have been proposed to solve this problem.

1. Introduction

Fuel cells are well known for having high efficiency [1], a low environmental impact [2], and a relatively long service life [3]. In addition, many governments and research institutions have recognized fuel cells as a potential power source [4]. Currently, fuel cell stack performance has met commercial demand, but service life remains a major bottleneck [5]. In order to prolong the service life, a lot of works, like configuration design [6] and structure design [7], have been adopted to improve the durability. However, a commercial fuel cell stack consists of many serial-linked cells. Such a structure enhances output voltage, but at the expense of robustness, as a small problem in one of the cells could result in failure of the fuel cell stack.

The most common reasons for fuel cell stack failure are anode flooding and cathode flooding [8], both of which may lead to gas starvation and voltage drop. In fact, the failure of a multi cell stack is related to the specific worst cell. When that cell is flooding, intake resistance increases [9], resulting in nonuniform gas distribution and leading to a feedback loop of failures. Interaction between cells is the most significant difference between a single fuel cell stack and a multi-cell stack, which becomes more pronounced during fuel starvation. According to experiments and simulations on single cell stacks, current and voltage redistribution happens in the cell experiencing fuel starvation [10]; however, because all cells in the stack are connected, the distribution of current and voltage is also limited by neighboring cells. Freunberger et al. [11] tested a specialized two-cell stack using advanced localized diagnostics to analyze the mechanism and effect of cell-to-cell coupling resulting from operationally relevant reactant feed flow variations. In-plane current and inhomogeneous polarization were observed balancing unequal cell operation, and increasing and decreasing polarization observed along the air-flow path were different from normal operation. Promislow et al. [12] analyzed the spread of heat from an anomalously hot cell to neighboring cells in a stack environment. In addition, some researchers focused on multi-dimensional

* Corresponding author at: State Key Lab of Automotive Safety and Energy, Tsinghua University, Beijing 100084, PR China.
E-mail addresses: huzy14@mails.tsinghua.edu.cn (Z. Hu), xuliangfei@tsinghua.edu.cn (L. Xu), lijianqiu@tsinghua.edu.cn (J. Li), xux@sl-power.com (X. Xu), duxl@sl-power.com (X. Du), swh16@mails.tsinghua.edu.cn (W. Sun), ouymg@tsinghua.edu.cn (M. Ouyang).
[1] Co-corresponding author.

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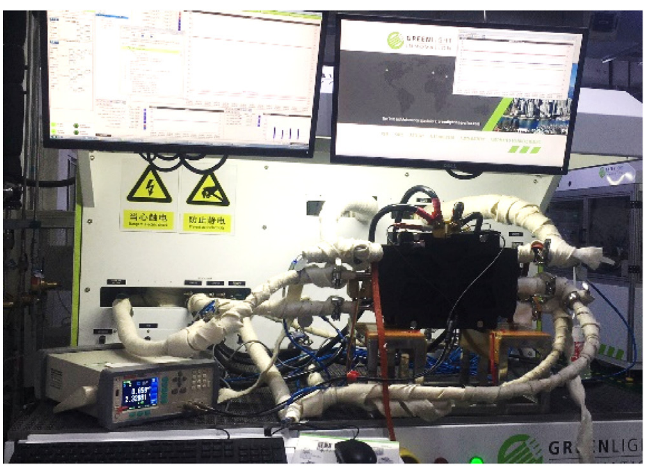
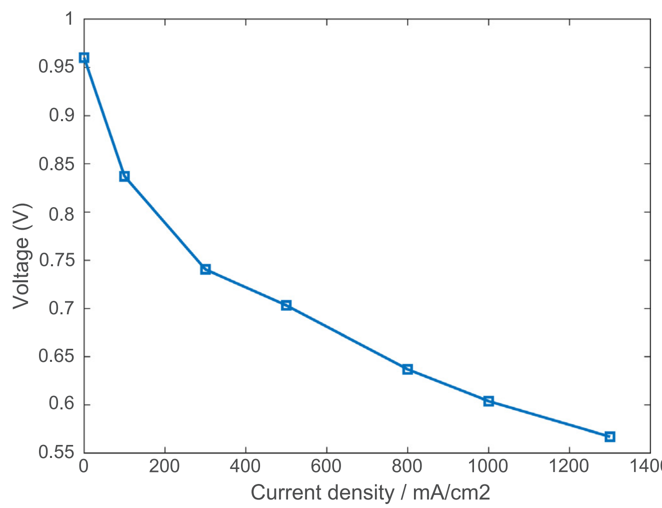
Nomenclature

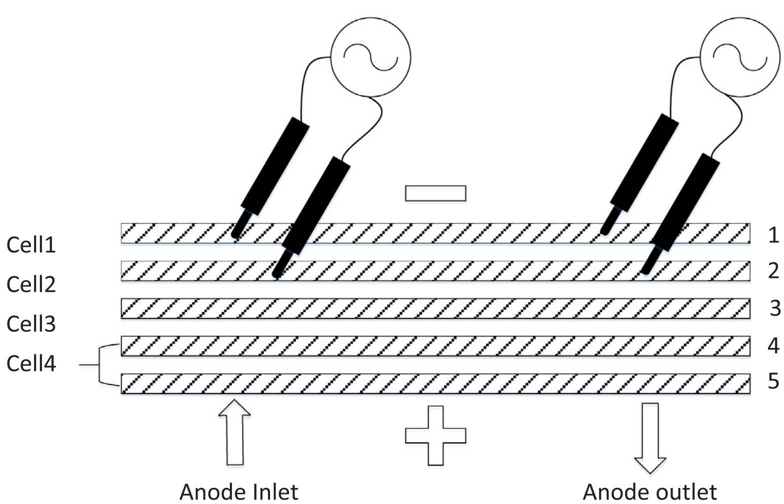
F	Faraday constant, 96487C mol^{-1}
R	gas constant, 8.314 J mol^{-1} K^{-1}
C_{ch1}^{O2}	oxygen concentration at cathode inlet, mol m^{-3}
C_{ch2}^{O2}	oxygen concentration at cathode outlet, mol m^{-3}
P_{ch1}	total pressure at cathode inlet, Pa
P_{ch1}^{N2}	nitrogen partial pressure at cathode inlet, Pa
P_{ch1}^{O2}	oxygen partial pressure at cathode inlet, Pa
P_{ch2}	total pressure at cathode outlet, Pa
P_{ch2}^{N2}	nitrogen partial pressure at cathode outlet, Pa
P_{ch2}^{O2}	oxygen partial pressure at cathode outlet, Pa
W_{12}	gas flow rate from inlet to outlet, mol s^{-1}
W_{out}	exhaust gas flow rate, mol s^{-1}
s/s_c	liquid saturation in cathode GDL
x_{ch1}^{O2}	volume fraction of oxygen at cathode inlet
x_{ch2}^{O2}	volume fraction of oxygen at cathode outlet
Δi	current density difference, A m^{-2}
η_c	cathode overpotential, V
A_{fc}	fuel cell active area, m^2
C_{ref}^{O2}	reference oxygen molar concentration, mol m^{-3}
D_{O2}^{eff}	effective oxygen diffusion coefficient, m^2 s^{-1}
E_{cell}^{0}	thermodynamic equilibrium potential, V
L_{GDL}	GDL thickness, m
Num	number of cells in stack
P_{sat}	saturation pressure, Pa
R_m	membrane resistance, U m^2
V_{ca}	cathode channel volume, m^3
h_m	convective mass-transfer coefficient, m s^{-1}
$ai_0{}^{ref}$	exchange current density, A m^{-2}
α_c	cathodic transfer coefficient for ORR
P_{mm}	cathode outlet pressure, Pa
T	time, s
T_{fc}	fuel cell operating temperature, K
V_{fc}	cell voltage, V
ΔV_{fc}	half-cell voltage difference, V
W_{in}	dry air flow rate, mol s^{-1}
i	current density, A m^{-2}
i_1	current density at cathode inlet, A m^{-2}
i_2	current density at cathode outlet, A m^{-2}



a) Test bench



b) Polarization curve under a 1.4 fuel stoichiometric ratio



c) Two voltage sampling method

Fig. 1. Experiment equipment and test method.