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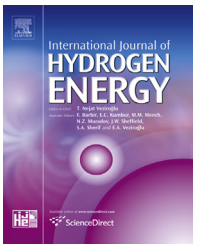

Maximum power cold start mode of proton exchange membrane fuel cell

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ABSTRACT

Successful and fast cold start is important for proton exchange membrane (PEM) fuel cell in vehicular applications in addition to the desired maximum power in any case. In this study, the maximum power cold start mode is investigated in details and compared with other cold start modes based on a multiphase stack model. It is found that for the maximum power cold start mode, the current density is generally kept at high levels, and the performance improvement caused by the membrane hydration and temperature increment may not be observable. Therefore, before the melting point, the performance drops continuously. The maximum power cold start mode could better balance the heat generation and ice formation, leading to improved cold start survivability than that in the constant voltage and constant current modes, with a fast start-up generally guaranteed. Once the survivability can be ensured, the initial water content needs to be higher for fast cold start, suggesting that over purging should be avoided. The maximum power mode is suggested to be optimal for PEM fuel cell cold start based on the modeling results.

Introduction

Proton exchange membrane (PEM) fuel cell has been regarded as an ideal power source for vehicular applications due to its significant advantages, i.e., high efficiency, low emission, silence and simplicity [1]. The low operating temperature of PEM fuel cell facilitates the fast start-up/shutdown necessary for powering a vehicle but meanwhile introduces challenges for water management. Although certain amount of water is critical to maintain the membrane hydrated and thus a high ionic conductivity, too much water can hinder the reactant transport from the channel toward the catalyst site and result in increased mass transport losses. Therefore an optimum water amount/distribution is generally pursued by control strategy [2] and material innovation [3] to achieve improved fuel cell performance, with phase-change being carefully considered. Such a problem becomes even more complicated when the realistic application of a PEM fuel cell comes into people's attention. Due to the environmental temperature, it is necessary to operate a PEM fuel cell in subzero conditions. The formation of ice during phase-change can block the reaction sites, reduce the performance, accelerate the degradation and lead to the failure of cold start. Thorough

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Nomenclature

a	water activity
A	cell geometric area, m^2
ASR	area specific resistance, $\Omega\ cm^2$
c	mole concentration, mol m^{-3}
C_p	specific heat, J kg^{-1} K^{-1}
D	mass diffusivity, m^2 s^{-1}
EW	equivalent weight of membrane, 1.1 kg mol^{-1}
F	Faraday's constant, 96,487 C mol^{-1}
h	surrounding heat transfer coefficient, W m^{-2} K^{-1}
I	current density, A cm^{-2}
j_*	exchange current density, A cm^{-2}
k	thermal conductivity, W m^{-1} K^{-1}
M	molecular weight, kg mol^{-1}
p	pressure, Pa
$\dot{Q}$	heat transfer rate, W
R	universal gas constant, J mol^{-1} K^{-1}
s	volume fraction
S	source terms
t	time, s
Δt	time step size, s
T	temperature, K
T^0	standard temperature, 298 K
V	voltage

Greek letters

α	transfer coefficient
ε	porosity
ζ	water transfer rate, s^{-1}
κ	electric conductivity, S m^{-1}
λ	water content in ionomer
ξ	stoichiometry ratio
ρ	density, kg m^{-3}
ω	volume fraction of ionomer in catalyst layer
δ	thickness, m

Subscripts and superscripts

a	anode
act	activation
BP	bipolar plate
c	cathode, capillary
channel	flow channel
CL	catalyst layer
conc	concentration
eff	effective
env	environment
eq	equilibrium
f	frozen
fl	fluid phase
fmw	frozen membrane water
GDL	gas diffusion layer
H_2	hydrogen
H_2O	water
i	the ith components
in	inlet
init	initial condition
lq	liquid water
mem	membrane
N	cell number
nf	non-frozen
nmw	non-frozen membrane water
O_2	oxygen
out	outlet, output
ref	reference
sat	saturation
sl	solid phase
T	energy (for source term)
vp	water vapour
wall	surrounding wall of the stack

understanding of cold start characteristics and developing associated operating strategies are thus of top importance for state-of-art research.

In order to understand the cold start behaviors of PEM fuel cell, two categories of previous studies have been conducted. One approach is to optimize the structure and material design of PEM fuel cell so that the system can endure subzero conditions with more tolerance [4–9]. Hirakata et al. [10] studied the effect of pore diameter of gas diffusion layer (GDL) on cold start behavior and cell performance. They found that a GDL with smaller pore diameter exhibited favorable anti-flooding performance. Santamaria et al. [11] compared the cold start performance between parallel and interdigitated flow field PEM fuel cells at various current densities, concluding that an interdigitated flow field may provide better performance under less extreme cold start conditions than parallel flow fields. Ko et al. [12] presents a theoretical study on the effects of ionomer fraction and weight ratio of Pt to carbon support in the cathode catalyst layer (CL). Their calculations confirm that these two design parameters provide control of the ice storage capacity and water absorption potential of the cathode CL, and consequently demonstrate a substantial influence on the PEM fuel cell cold start behavior. On the other hand, a few studies focused on modification of the operating conditions to achieve a successful cold start [13–20]. Jiao et al. [21] developed a three-dimensional multiphase model to simulate various operating and initial conditions as to their influences on cold start, which include cell voltage, initial water content and distribution, anode inlet relative humidity (RH), surrounding heat transfer coefficient, and start-up temperature. Experimental investigation has been also attempted through the simultaneous measurements of current and temperature distributions during the cold start [22].

A consensus from these prior studies is that start-up mode [13–18], initial temperature [23,24] and initial water content [25–30] in membrane and CL are three essential conditions which determine the failure/success of cold start. Particularly for the start-up mode, the constant current start-up mode has been widely used in experimental [31–33] and modeling studies [34–38] of PEM fuel cell cold start. For example, Jiang et al. [39] modeled the current ramping method and found that this method is beneficial for cold start due to the

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