Energy Conversion and Management 133 (2017) 20–30

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Long term performance degradation analysis and optimization of anode supported solid oxide fuel cell stacks

Tarannom Parhizkar, Ramin Roshandel *

Department of Energy Engineering, Sharif University of Technology, Tehran, Iran

ARTICLE INFO

Article history:
Received 9 August 2016
Received in revised form 14 November 2016
Accepted 18 November 2016

Keywords:
Degradation based optimization
Cost of electricity
Optimum operating conditions
Solid oxide fuel cell

ABSTRACT

The main objective of this work is minimizing the cost of electricity of solid oxide fuel cell stacks by decelerating degradation mechanisms rate in long term operation for stationary power generation applications. The degradation mechanisms in solid oxide fuel cells are caused by microstructural changes, reactions between lanthanum strontium manganite and electrolyte, poisoning by chromium, carburization on nickel particles, formation of nickel sulfide, nickel coarsening, nickel oxidation, loss of conductivity and crack formation in the electrolyte. The rate of degradation mechanisms depends on the cell operating conditions (cell voltage and fuel utilization). In this study, the degradation based optimization framework is developed which determines optimum operating conditions to achieve a minimum cost of electricity. To show the effectiveness of the developed framework, optimization results are compared with the case that system operates at its design point. Results illustrate optimum operating conditions decrease the cost of electricity by 7.12%. The performed study indicates that degradation based optimization is a beneficial concept for long term performance degradation analysis of energy conversion systems.

1. Introduction

In recent years, the interest in electrochemical power generation devices based on solid electrolytes has dramatically grown. This concern is due to the advantages of solid electrolytes over liquid electrolytes. For instance, solids can operate in a wider range and therefore, have a lower activation loss [1]. However, the long term operation with respect to contaminants and degradation mechanisms is still mitigates a broad implementation of SOFCs. Thus, a fundamental understanding of degradation mechanisms to analysis the long term operation of SOFCs is of great interest [2].

1.1. Concept

In long term operation, solid oxide fuel cell characteristics and performance deteriorates dramatically. Operating conditions affect the rate of degradation mechanisms. To study SOFC in long term operation, considering degradation mechanisms is unavoidable [3].

The degradation based optimization (DBO) is an optimization framework that considers system degradation mechanisms in the optimization procedure [4]. The flow diagram of the developed DBO framework for SOFC stacks is presented in Fig. 1. At the initial time, system characteristics are known. In the degradation model, the rate of degradation can be calculated based on the system operating conditions. Degradation mechanisms caused by physical, chemical or electrochemical reactions. These mechanisms affect the components characteristics such as the length of triple phase boundaries (TPB) and the electrolyte conductivity. Based on the values of degraded parameters, the system input/output (I/O) performance model calculates system performance indexes (such as system efficiency or output power). At the next time step, updated values are applied to the degradation model and this cycle is repeated until the end of the system operation lifetime. Up to this stage, the system performance deterioration as a function of operating conditions can be presented. At the next step, using this function, the optimum decision variables including operating conditions will be derived.

Generally, optimization models tries to find the operating conditions or/and design parameters which minimize the cost of electricity (COE), maximize the efficiency or profit through system operating lifetime [7]. In this study, our developed DBO framework optimizes operating conditions to achieve a minimum cost of electricity. The DBO framework addresses the influences of a given operating condition on the degradation rate of the system and includes degradation effects in the techno-economic optimization [5].

* Corresponding author.
E-mail addresses: Parhizkar@energy.sharif.edu (T. Parhizkar), Roshandel@sharif.edu (R. Roshandel).

http://dx.doi.org/10.1016/j.enconman.2016.11.045
0196-8904/

Nomenclature

A	area, m^2
c	gas phase concentration, mol m^{-3}
C_{NG}	natural gas cost, \$ m^{-3}
D	mass diffusivity, m^2 s^{-1}
E	activation energy, kJ mol^{-1}
F	Faraday's constant, C $equiv^{-1}$
H	enthalpy, J mol^{-1}
i	current density, A m^{-2}
I	working current, A
k'	constant coefficient
k_{ox}	rate constant for oxidation reaction, m^3 kg^{-1} s^{-1}
$k_{s,cap}$	Nickel particles growth rate
L	length, m
m_{NG}	natural gas mass flow rate, m^3 s^{-1}
M	molecular weight, kg mol^{-1}
n	equivalent electron per mole of reactant, equiv mol^{-1}
ni	number of nickel particles, mol
p	pressure, Pa
P	dimensionless pressure
pr	site occupation probability
R	universal gas constant, J mol^{-1} K^{-1}
r	Nickel particles radius
r_{ox}	rate of oxidation, mol kg^{-1} s^{-1}
S^0	standard entropy, J mol^{-1} K^{-1}
t	time
T	temperature, K
TPB	triple phase boundary, m m^{-3}
u	decision variable
V	voltage, V
x	state variable
X	molar fraction of component in the mixture
β	Ohmic resistance, Ω
η	over potential, V
σ	electrical conductivity, $\Omega^{-1}.m^{-1}$
φ	porosity
ψ	tortuosity
v	diffusion volume of simple molecules, cm^3
α	fraction of the reaction heat that is generated at the anode
δ	pre-exponential factor, Ω^{-1} m^{-2}
θ	overlap angle, 15^0
θ_0	bulk oxygen coverage, dimensionless
γ	exponential activity parameter, kJ mol^{-1}
τ	perimeter

Subscript and super script

0	initial condition
1	bipolar plate (interconnect)
2	fuel channel
3	anode
4	electrolyte
5	cathode
6	air channel
act	activation
c	critical
ch	channel
conc	concentration
eff	effective
f	fuel
max	maximum value
min	minimum value
ocv	open circuit voltage
ohm	Ohmic
opt	optimal
ox	oxydation
ref	reference
x	x direction
y	y direction
z	z direction

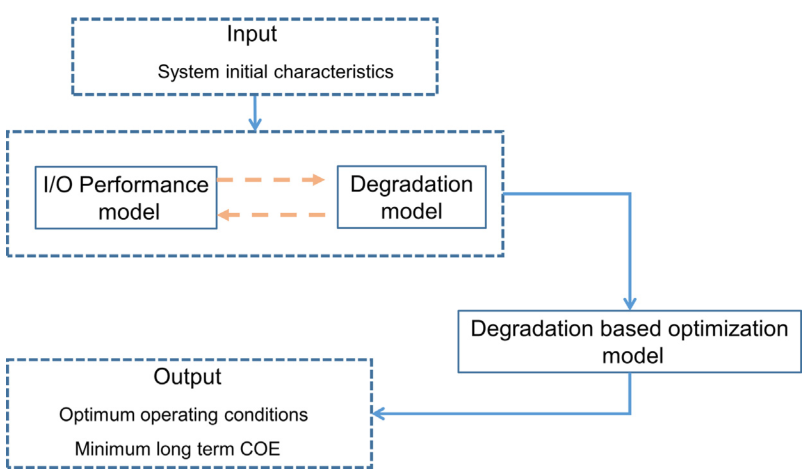

Fig. 1. Proposed framework for considering degradation mechanisms in optimization model.

1.2. Background

The relatively high investment cost of SOFC stacks leads most studies to provide an analysis of possible scenarios that make SOFC applications feasible from an economic point of view [8]. In this respect, recent studies aim at improving the understanding of degradation in SOFC stacks to manage system degradation rate in order to develop cost-competitive SOFC stacks applications in long term operation. The degradation is the process of systems performance deterioration; results from irreversible and gradual growth