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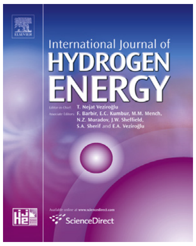

Parameter estimation of fuel cell polarization curve using BMO algorithm

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ABSTRACT

Polarization curves of proton exchange membrane fuel cells (PEMFCs) are affected by various parameters. The relative importance and effect of each parameter on the polarization curve is different. This paper studies estimation of parameters with the most influence on the electrochemical model. In order to evaluate the obtained results, the model accuracy is compared with that model in which all the parameters are estimated. Because PEMFCs parameter estimation is a complex optimization problem, a recently invented nature-inspired algorithm, bird mating optimizer (BMO), is proposed. For this aim, two real systems, the SR-12 Modular PEM Generator and the Ballard Mark V FC, are considered. The obtained results show that when the whole parameters are estimated, the accuracy of the model increases. Also, BMO algorithm yields better results than the other studied methods in terms of precision and robustness.

1. Introduction

As promising sources for producing electrical energy, proton exchange membrane fuel cells (PEMFCs) need fundamental studies [1]. Polarization curves which show voltage vs. current are important characteristics and need accurate modeling. During past years, various mechanistic and empirical or semi-empirical models have been developed to model the PEMFCs performance [2,3]. Since some assumptions are regarded in modeling, there are some errors between the model result and the real performance. A suitable model can be used for testing the controllers, evaluating the available power and optimizing the system [5]. As a result, the most acceptable model for electrical engineers is the electrochemical model used in many researches [4–18]. This model has been validated by many researchers and has shown good performance [4–7]. In this model, the equations are expressed by a group of parameters whose values are unknown for each operating condition. The importance and effect of the parameters on the model performance is different. Knowing the relative importance of the parameters leads to better understanding the effect of each phenomenon on the system and provides the ability of focusing on the estimation of the most important parameters.

Parameter estimation is one of the most challenging problems of PEMFCs, because fuel cells are complex, nonlinear, multi-variable, and strongly coupled systems. Hence, many researchers have focused on using metaheuristic algorithms rather than traditional ones. Metaheuristic algorithms could be suitable tools because they are stochastic and derivative-free techniques which have global search ability. Study of the literature reveals that various metaheuristic algorithms such as genetic algorithm (GA) [8,10,11], particle swarm optimization (PSO) [12,13], simulated annealing (SA) [14,19], hybrid artificial bee colony algorithm

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Nomenclature

Model	
P_{H_2}	hydrogen partial pressure, atm
P_{O_2}	oxygen partial pressure, atm
E_{Nernst}	irreversible voltage, V
A	active area, cm^2
i	current, A
T	temperature, K
N_s	number of cells connected in series
ξ_j ($j = 1, \ldots, 4$)	parametric coefficients of activation voltage drop
b	constant of concentration voltage drop, V
V_s	stack voltage, V
ρ_M	membrane specific resistivity, Ω cm
l	thickness of the membrane, cm
λ	water content of the membrane
R_C	resistance against electron flow, Ω
i_n	no-load current, A
i_{max}	maximum current, A
J ($J = i/A$)	current density, A cm^{-2}
BMO	
gen_{max}	maximum number of generations
mcf	mutation control factor
mcf_p	parthenogenetic's mutation control factor
d	problem dimension
N	number of interesting birds
$\vec{r}$	a vector including random numbers uniformly distributed between 0 and 1
rand	a random number uniformly distributed between 0 and 1
$\vec{x}$	bird vector
$\vec{x}_b$	brood vector
$\vec{x}^{in}$	interesting bird vector
w	time-varying weight
μ	step size

[16], artificial immune system (AIS) [15], seeker optimization algorithm (SOA) [17], and harmony search (HS) [9] have been proposed for parameter estimation. Among metaheuristic algorithms, population-based ones have more chance to find global solution because they can simultaneously sample different regions of search space.

Inspired by the evolution process of the bird species, bird mating optimizer (BMO) is a newly invented nature-inspired optimization algorithm [18] which borrows some operators of the other metaheuristic algorithms such as genetic algorithm (GA), particle swarm optimization (PSO), differential evolution (DE), etc. In BMO, a society of birds is employed to seek the search space and find the optimal or near optimal solution by using some basic rules and simple mathematical calculations. The main difference between BMO and other well-known metaheuristic methods is using five distinct patterns to move through the search space. This feature helps to maintain the diversity, escape local optima, and so avoid premature convergence.

This paper provides a comprehensive framework for parameter estimation of PEMFCs. For this aim, multi parametric sensitivity analysis (MPSA) is used to determine the relative importance of the model parameters and BMO is used to estimate the optimal values in two states: (1) estimating the most important parameters and (2) estimating all the parameters. In order to assess the usefulness of BMO, the obtained results are compared with the results found by the other well-known metaheuristic techniques.

2. Problem formulation

The electrochemical model is a helpful tool for electrical engineers to evaluate the PEMFCs performance and optimize them for desired operation. Since there are several factors causing voltage drop, the real voltage decreases from its equilibrium potential, E_{Nernst}, whose value is obtained by the Nernst equation. There are four types of voltage drops, namely, activation voltage drop, V_{act}, ohmic loss, V_{ohmic}, concentration voltage drop, V_{con}, and voltage drop resulted from fuel crossover and internal currents which is considered by adding a no-load current density to the real current density. At low current densities, the activation loss is responsible for the potential drop and at high current densities, the concentration loss becomes more significant.

$$V = E_{Nernst} - V_{act} - V_{ohmic} - V_{con} \tag{1}$$

$$V_s = N_s \times \left(\begin{array}{c} \left[1.229 - 0.846 \times 10^{-3}(T - 298.15) + 4.308 \times 10^{-5} T\left[\mathrm{Ln}\left(P_{H_2}\right) + \frac{1}{2}\mathrm{Ln}\left(P_{O_2}\right)\right]\right] - \\ \left[(i + i_n) \times \left(R_C + \frac{l}{A} \times \frac{181.6\left[1 + 0.03\left(\frac{i+i_n}{A}\right) + 0.062\left(\frac{T}{303}\right)^2\left(\frac{i+i_n}{A}\right)^{2.5}\right]}{\left[\lambda - 0.634 - 3\left(\frac{i+i_n}{A}\right)\right]\exp\left(4.18\left[\frac{T-303}{T}\right]\right)}\right)\right] + \\ \left[\xi_1 + \xi_2 T + \xi_3 T\mathrm{Ln}\left(\frac{P_{O_2}}{5.08 \times 10^6 \exp\left(-\frac{498}{T}\right)}\right) + \xi_4 T\mathrm{Ln}(i + i_n)\right] + \left[b\mathrm{Ln}\left(1 - \frac{i+i_n}{i_{max}}\right)\right] \end{array} \right) \tag{2}$$