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Hybrid artificial bee colony algorithm for parameter estimation of proton exchange membrane fuel cell

Wei Zhang, Ning Wang, Shipin Yang*

National Laboratory of Industrial Control Technology, Institute of Cyber-Systems and Control, Zhejiang University, Hangzhou 310027, PR China

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ABSTRACT

The accurate electrochemical model plays an important role in design and analysis of hydrogen fuel cell systems. For the purpose of estimating parameters of the proton exchange membrane fuel cell (PEMFC) model, and inspired by the foraging behavior of bacteria and bees, a hybrid artificial bee colony (HABC) algorithm is proposed. The HABC uses an improved solution search equation that mimics the chemotactic effect of bacteria to enhance the local search ability. To avoid premature convergence and improve search accuracy, the adaptive Boltzmann selection scheme is adopted, which adjusts selective probabilities in different stages. Performance testing has been conducted on some typical benchmark functions. The results demonstrate that the HABC outperforms other methods (BIPOA, PSOPS and two improved GAs) in both convergence speed and accuracy. The proposed approach is applied to estimate the PEMFC model parameters and the satisfactory model predictive curves are obtained. More experimental results in different search ranges and validate strategies indicate that HABC is an efficient technique for the parameter estimation problem of PEMFC.

1. Introduction

Worldwide concern about environmental pollution has stimulated expanding interest in new energy conversion technologies [1]. Hydrogen fuel cell, as an electrochemical device that converts hydrogen fuel to electrical energy directly and continuously, has attracted considerable attentions in recent years. Among a variety of fuel cells, the proton exchange membrane fuel cell (PEMFC), also called polymer electrolyte membrane fuel cell [2], is considered as a promising powersource for many applications, such as transportation (propulsion and/or auxiliary power unit) and mobile device (cell phone, camera and laptop computer) [3–6]. Owing to its many advantages, low operating temperature, high power density, fast startup, quick response and zero emission [7], nowadays the PEM fuel cells are the subject of priority research in many countries [6].

Generally, the reactants of PEMFC are hydrogen-rich gas and oxygen-rich gas (or air). They are separately fed to the anode and cathode channels. After diffusing through the electrodes, the reactants reach the catalytic layer respectively and electrochemical reactions take place. Along with the exchange of protons that permeate through the membrane, hydrogen energy is consumed and electric current is produced in an external circuit or load. The overall reaction process is complicated, and the electric outputs of PEMFC are extremely related to a variety of operating conditions. For further understanding the phenomena occurring within

* *Corresponding author.*
E-mail addresses: nwang@iipc.zju.edu.cn, nwang126@126.com (N. Wang).
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the cell, a reliable mathematical model is necessary. Over the past decades, many researchers have focused their interest on the modeling study of PEMFC. In previous literatures [1,8–15], different modeling approaches are available. Among these studies, the semi-empirical model developed by Amphlett et al. [14] is suitable for engineering purpose because it can be easily solved, and is widely accepted by the public. It allows designers and engineers to conveniently predict the effect of different operating variables (such as fuel flow rate, hydrogen pressure, air pressure, oxygen excess ratio, cell temperature) on the *V–I* characteristics of the fuel cell. However, there are non-mechanistic terms in the model, especially the ohmic overvoltage, which is primarily empirically based [14]. These low-accurate empirical values will seriously impair the model's effectiveness in engineering simulation, analysis and optimization. In order to make models reflect the actual PEMFC performances better, the problem of parameter estimation and optimization has become the key and essential issue.

Because the PEMFC is a complex nonlinear, multivariable and strongly coupled system, traditional optimization methods cannot solve this parameter estimation problem efficiently. In recent years, many intelligence optimization techniques have been applied in the research of fuel cell systems. Mo et al. proposed a hybrid genetic algorithm (HGA) which combined genetic algorithm (GA) with a niche technique to improve the parameter accuracy of PEMFC model [16]. Ohenoja and Leiviskä using real-coded GA validated the fuel cell model, and showed the effects of parameter ranges, validation strategies on parameter identification results [17]. Ye et al. applied particle swarm optimization (PSO) to simulate a PEMFC model with three groups of experimental data respectively, and more accurate parameters were reached when compared with some traditional optimization methods [18]. Li et al. proposed an EIA-PSO method for PEMFC model, and verified the algorithm validity with experimental dada even in the presence of measurement noise [19]. Askarzadeh and Rezazadeh developed a grouping-based global harmony search method called GGHS, then identified the model parameters with the Ballard PEMFC data [20]. Yang and Wang combined some new bio-inspired rules with the nested membrane structure, and presented well-matched polarization curves of PEMFC stacks with the BIPOA method [21]. Zhang and Wang put forward an adaptive RNA genetic algorithm (ARNA-GA) inspired by the mechanism of the biological RNA to estimate the PEMFC model parameters, and satisfactory results were reached [22]. Additionally, many other intelligence methods were developed for PEMFC modeling in literatures, such as differential evolution (DE) [23,24], simulated annealing (SA) [25], seeker optimization algorithm (SOA) [26] and support vector machine (SVM) [3]. In this paper, a novel bee-based method, hybrid artificial bee colony (HABC) algorithm, is proposed for the parameter estimation problem of the PEMFC model.

Artificial bee colony (ABC) algorithm is a recently introduced high-performance optimization technique by Karaboga [27], which mimics the foraging behavior of honeybee swarm [28]. Because of clear algorithm structure, ease of implementation [29], fewer control parameters and superior performance [27,30], the ABC has attracted much attention of researchers. It has been successfully applied to solve many real-parameter optimization problems [31–34]. However, it is considered being good at exploration but poor at exploitation [29]. In other words, the ABC does not adequately use the gradient information, and its local search capability is weak. This will cause slower convergence speed than other population-based methods, such as DE and PSO, especially for handling unimodal problems [29]. In addition, bacterial foraging algorithm (BFA) [35] is another competitive swarm optimization algorithm inspired by the foraging behavior of *Escherichia coli* bacteria. It models the way bacteria react to chemoattractants in concentration gradients, which is called the chemotactic effect in biology. To enhance the local search ability, in this paper we combine the chemotactic effect of bacteria with the ABC method, and propose a hybrid ABC algorithm (HABC). In order to avoid the premature convergence and improve solution accuracy, adaptive Boltzmann probability [36] is also employed in HABC to adjust the selective pressures in different stages.

The rest of the paper is organized as follows. Section 2 introduces the electrochemical model of PEMFC and the objective function. Section 3 detailedly describes the proposed HABC algorithm. In Section 4, numerical tests are conducted on some benchmark functions to investigate the algorithm performance. Then in Section 5, the HABC is applied to identify parameters of a PEMFC stack, and the results are compared with some other methods. Finally, conclusions are drawn in Section 6.

2. Problem formulation

A PEMFC is composed of an anode and a cathode electrode, and a thin solid proton-conducting membrane sandwiched between the electrodes [21], as shown in Fig. 1.

The reactions occurring at two electrodes are illustrated in Fig. 1, and the overall reaction can be represented as [1]

$$H_2 + 1/2O_2 \rightarrow H_2O + \text{heat} + \text{electricity} \quad (1)$$

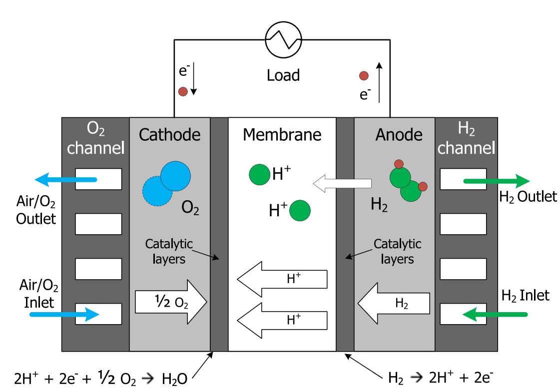

Fig. 1 – The reaction principle of the PEMFC [1,24].