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Optimal proton exchange membrane fuel cell modelling based on hybrid Teaching Learning Based Optimization – Differential Evolution algorithm

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Abstract Simulation proton exchange membrane fuel cell (PEMFC) performance accurately is a challenging process. Many mathematical models have been existed, yet due to lack of accurate parameter estimations, considerable errors might occur. Nowadays, meta-heuristic optimization algorithms have been successfully applied for parameter identification of PEMFC models. In this study, Teaching Learning Based Optimization method (TLBO) is hybridized with Differential Evolution (DE) algorithm for successful estimation of unknown PEMFC model parameters. Efficiency of the proposed algorithm is tested with several benchmark problems. A case study taken from the literature has been performed by hybrid TLBO–DE algorithm and other optimization methods such as Melody Search (MS), Backtracking Search (BS), Artificial Cooperative Search (ACS), Quantum behaved Particle Swarm Optimization (QPSO), Bat algorithm (BAT), Intelligent Tuned Harmony Search (ITHS) and Cuckoo Search (CS). TLBO–DE algorithm surpasses all these optimizers in terms of solution quality and accuracy.

1. Introduction

Increasing air pollution and depletion of fossil fuel resources have encouraged researchers to investigate the applications of fuel cell technologies for energy conversion facilities. Fuel cells have been drawn considerable interest as they are environmental friendly and energy efficient structures with a high power density. However, they still are not competitive with traditional power conversion technologies due to high costs resulted from the lack of cheaper catalysts [1–3]. Fuel cells can be operated between 40% and 60% electrical efficiencies

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[4]. A standard fuel cell provides 0.5–0.9 volt potential which is not sufficient for large scale applications. Therefore, they are connected in series and become "cell stack" when they are utilized in high powered energy conversion systems [5]. Fuel cells can be categorized with respect to electrolyte, anode and cathode types they used. Most common fuel cell types are [6]

- Alkaline Fuel Cell (AFC) with alkaline solution electrolyte
- Phosphoric Acid Fuel Cells (PAFC) with acidic solution electrolyte
- Proton Exchange Membrane Fuel Cell (PEMFC) with polymer electrolyte membrane
- Molten Carbonate Fuel Cell (MCFC) with molten carbonate salt electrolyte
- Solid Oxide Fuel Cell (SOFC) with zirconia ceramic ion conducting electrolyte

PEMFC might have an important role in future transportation industry since they can operate at lower temperatures (between 50 and 80 °C) and lower pressures, they have a rapid start-up capability, and they are relatively less pollutant when compared to other power technologies [5,7]. With these advantages mentioned above, PEMFC could become an encouraging technology in areas of transportation and light-weight portable applications [1,8]. Schematic of a basic PEMFC is given in Fig. 1.

Design of a traditional PEM fuel cell is a tedious and challenging task as it is multivariable and multi-coupled system [9]. Polarization curve indicates voltage versus current (*V–I*) characteristics of PEM fuel cells. Curve itself is highly nonlinear and simulation of the power condition units and system controllers utilize this characteristic curve for modelling purposes [10]. Literature approaches reveal that there are many published studies on mathematical modelling of PEM fuel cells [11–17]. Proposed models can be divided into two distinct categories: mechanistic models and semi-empirical models. Mechanistic models are concerned with the heat, mass transfer and electrochemical phenomena occur in a fuel cell. Second one is based on semi-empirical equations which aim to estimate the effects of different input parameters of on *I–V* characteristics without the investigation of physical and chemical phenomena taking place in cell operations. The model proposed by Amphlett et al. [18] employs semi-empirical equations to identify the characteristics of the polarization curve of the fuel cell considering many operating parameters such as cell temperature, air flow rate, hydrogen and oxygen pressure. This model is relatively easy to implement, recognized by many researchers and supported with mechanistic background [19,20]. No matter which model is utilized, there will be a mismatch between calculated values and actual PEMFC data since some approximations and assumptions are made in model design. In order to make more robust models to construct *V–I* curve properly, the use of optimization techniques for the estimation of unknown model parameters has become a promising alternative.

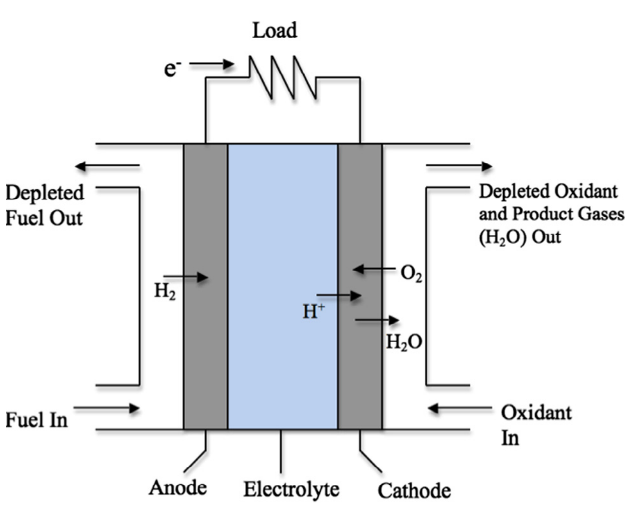

Figure 1 Schematic of a PEMFC model [4].

Due to the highly nonlinear characteristics of polarization curve, conventional optimization methods had failed to predict exact parameters of the fuel cell model. To conquer this drawback, metaheuristic algorithms such as Genetic Algorithms (GA) [20–25], Simulated Annealing (SA) [26,27], Differential Evolution (DE) [28,29], Particle Swarm Optimization (PSO) [30,31], Artificial Immune System (AIS) [5], Seeker Optimization Algorithm (SOA) [32], Harmony Search (HS) [33,34], Hybrid Artificial Bee Colony (HABC) [19], Artificial Bee Swarm Algorithm (ABSA) [35], P System Based Optimization (PSBO) [36], Teaching–learning-based optimization (TLBO) [37], Biogeography-based optimization [38] and Bird Mating Optimization (BMO) [39] have been applied in this problem. Metaheuristics generally do not need domain information and they are derivative free methods which perform stochastic movements to obtain global optimum point. These advantages make them suitable for parameter estimation problems; however, there are still needs for efficient algorithms to acquire better results due to the complexity of the mentioned design problem.

In this study, TLBO and DE optimizers have been hybridized in order to enhance the global search mechanism and increase the convergence speed of the whole algorithm. A case study taken from the literature has been investigated with the hybrid algorithm and the results have been compared with the findings of Quantum behaved Particle Swarm (QPSO) [40,41], Melody Search (MS) [42], Artificial Cooperative Search (ACS) [43], Backtracking Search (BS) [44], Bat algorithm (BAT) [45], Cuckoo Search (CS) [46], Intelligent Tuned Harmony Search (ITHS) [47] and literature studies. Comparisons reveal that TLBO–DE is superior to all compared algorithms in terms of solution accuracy and efficiency.

2. Problem description

2.1. PEMFC concept

Fuel cell, which was firstly invented by Sir William Robert Grove in 1839, is a simple energy conversion unit that converts chemical energy into electrical energy. A typical PEM fuel cell comprises two electrodes (anode and cathode) with thin catalyst layers and a membrane layer (acting as a electrolyte) which is sandwiched between these electrodes. There also exists gas channels of the anode and cathode sides where hydrogen and air are fed in, respectively. Hydrogen is supplied from the anode through gas channels and diffuses through the electrode into the three phase interface. At the same time, air departed