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Original Research Article

A novel approach for fuel cell parameter estimation using simple Genetic Algorithm

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A B S T R A C T

A new problem formulation for effective identification of fuel cell parameters is proposed. The proposed formulation is solved by applying Genetic Algorithm optimization technique. The algorithm steps are coded in MATLAB and the objective function is solved for PEM fuel cell. In order to estimate the performance of the proposed formulation; extensive simulations are performed with both the proposed and conventional objective functions and the results obtained are compared. Further, a comprehensive evaluation based on objective function value, convergence speed and absolute voltage error value is also made to prove the superiority of the proposed formulation over the conventional curve fitting approach.

Introduction

Renewable energy resources can effectively replace conventional fossil fuels in various applications like distributed power generation, hot water/space heating and rural (off-grid) energy services. Fuel cells are considered to have the best prospects in applications like backup power sources in remote locations such as spacecraft, weather stations and communication centres. In addition, it exhibits several attractive characteristics like high conversion efficiency, low environmental pollution with superior reliability and durability [1].

Fuel cell is an electrochemical device which converts the stored chemical energy into electrical energy [2]. Basically, fuel cell consists of two electrodes namely anode and cathode with an electrolyte between them. Hydrogen fuel is supplied to the anode, where it splits into ions and electrons. The ions move towards the cathode through the electrolyte whereas the electrons move through the external electric circuit to reach the cathode as the membrane is electrically insulated. Fuel cells are classified based on the type of electrolyte used and the start-up time required. For instance, the start-up time of the Proton Exchange Membrane Fuel Cell (PEMFC) is 1 s whereas it is 10 min for Solid Oxide (SO) fuel cell. Under normal operating conditions, the output voltage of a fuel cell is in the range of 0.5–0.9 V [2]. However, in order to meet practical applications stack of fuel cells are arranged in series so that the required voltage can be achieved [3]. PEMFC is the most commonly used fuel cell due to its distinct features like high efficiency, low operating pressure and temperature for safer operation and superior durability [4]. Hence, PEM fuel cell are treated as one of the prominent power source and it has been widely used in many applications like vehicle propulsion, small distributed generation and portable applications [5].

The key issue in fuel cell technology is its mathematical modelling [6]. Further, to improve the performance of PEMFC system and to design its power conditioning circuits it is necessary to build a mathematical model that can reveal the actual performance of PEMFC [7]. Besides, an efficient and effective fuel cell model is essential before proceeding into the installation part of it. Moreover, modelling makes the designing and testing of the fuel cell much easier and helps to better understand the phenomena occurring within it [2,8]. While modelling, the major problem faced by the researchers is the difficulty in accurate prediction of fuel cell characteristics; since the model parameters relate closely to its operating conditions [9]. Furthermore, parameter estimation of PEMFC is seen as one of the most challenging problem since PEMFC's are complex, non-linear, multi variable and strongly coupled systems [10].

Two main modelling approaches that exist in the literature are: (1) the mechanistic model which focuses on simulating the heat, mass transfer and electrochemical phenomena. (2) Electro

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Nomenclature

$\varepsilon_1, \varepsilon_2, \varepsilon_3, \varepsilon_4$	semi-empirical coefficients	R_m	equivalent membrane resistance
λ	adjustable parameter	R_c	equivalent contact resistance
b	parametric coefficient (V)	ρ_m	membrane specific resistivity
V_{FC}	output voltage of fuel cell	l	thickness of the PEM (cm)
E_{Nernst}	thermodynamic potential of the cell	A	cell active area (cm^2)
V_{act}	voltage drop due to activation of anode and cathode	N_S	number of cells
V_{Ohmic}	Ohmic voltage drop	V_{mpp}	voltage at maximum power point
V_{con}	diffusion over potential	I_{mpp}	current at maximum power point
T	cell absolute temperature in (K)	P_{max}	maximum value of power
P_{H_2}	partial pressure (atm) of hydrogen	V	cell voltage (V)
P_{O_2}	partial pressure (atm) of oxygen	I	actual current density of the cell (A/cm^2)
C_{O_2}	concentration of oxygen in the catalytic interface	i_{cell}	cell current
I_{max}	maximum value of I		

chemical model which is based on empirical or semi-empirical equations [11,12]. In the second method, a set of unknown model parameters namely $\varepsilon_1, \varepsilon_2, \varepsilon_3, \varepsilon_4$, b, R_c and λ are required to be determined for accurate modelling and are derived via optimization procedure. Since, these methods can be tailored to suit the problem's structural properties allowing good solutions [13–16].

In literature many intelligent optimization techniques have been proposed for fuel cell parameter estimation. In [17] the authors proposed a hybrid genetic algorithm (HGA) in which the genetic algorithm was combined with a niche technique to improve the accuracy of parameter estimation. Inspired by mechanism of biological RNA, an Adaptive RNA genetic algorithm is used to estimate the fuel cell parameters in [18]. In this method cross over or mutation operation was performed according to dissimilarity degree of individuals instead of probability. Particle swarm optimization (PSO) proposed in [19] simulate fuel cell parameter with three groups of experimental data and more accurate results were reached when compared with traditional optimization methods. In [20] authors used circular genetic operator based RNA Genetic Algorithm (cRNA-GA) to find optimal parameter set for PEM fuel cell. In this method they used stem loop mutation operator, to increase the population diversity and reduce premature convergence. In [21] BMO method based on multi parametric sensitivity analysis was used to determine five distinct parameters to move through the search space. The authors in [22] used 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. In this method the adaptive Boltzmann selection scheme is adopted, which adjusts selective probabilities in different stages. Authors in [23] proposed adaptive differential evolution to avoid the premature convergence and increase search efficiency of Genetic Algorithm. The seeker optimization algorithm (SOA) is proposed in [24], this method is based on the concept of simulating human searching behaviours, where the choice of search direction is based on the empirical gradient by evaluating the response to the position changes and the decision of step length is based on uncertainty reasoning by using a simple Fuzzy rule. A grouping based global harmony search algorithm is proposed in [25] for fuel cell parameter estimation and results were presented for Ballard PEM fuel cell. All the above mentioned methods used the conventional curve fitting procedure and focussed on improving the matching between the predicted and actual curve by applying an efficient algorithm. Since, curve fitting procedure is strenuous, time consuming, prone to errors, and requires extensive computations, hence, an efficient algorithm is needed [2]. Instead, a simple and effective formulation might reduce the burden on the optimization technique. Hence, in this paper an attempt is made to propose a new formulation based on the fact that derivative of power with respect to current at maximum power point is zero to find optimal fuel cell parameter set.

The proposed formulation is solved using population based Genetic Algorithm (GA) method; since GA method has already been applied for curve fitting procedure to solve the fuel cell parameter identification problem [12]. Further, GA method is a useful tool in assessing the effectiveness of any new problem formulation. The main advantages associated with GA are neither it requires a mathematical expression of response surface nor any derivative or gradient information. In addition, it solves problems with multiple solutions and easy to understand [10]. In this work MATLAB codes are written for GA and other methods for parameter extraction problem. To test the accuracy of calculated parameters, simulated characteristics with proposed and existing formulations are taken. Moreover to demonstrate the effectiveness of the proposed formulation the results derived via GA procedure are compared with methods applying curve fitting procedure.

The remaining part of the paper is divided into 5 sections. Section "PEM fuel cell model" expounds the PEM fuel cell model. Section "Problem formulation" explains the proposed problem formulation. Section "Optimization technique" describes the application of Genetic Algorithm (GA) for solving the proposed formulation. Section "Results and discussions" discusses the results obtained in detail.

PEM fuel cell model

The electro chemical model of fuel cell is widely accepted by the electrical engineer to evaluate fuel cell performance. In this work popular electro chemical model proposed by Amphlett [26] is used. In this model, equations governing fuel cell operation are expressed by a set of model parameters. The output voltage of a fuel cell is expressed as sum of equilibrium potential denoted by E_{Nernst} and voltage drops that occur in fuel cell. Four different losses that occur in fuel cell are: (1) activation voltage drop (V_{act}). (2) Ohmic voltage drop (V_{Ohmic}). (3) Drop due to fuel cross over and 4. Mass transport or concentration losses (V_{con}). Therefore, fuel cell output voltage can be written as [1] $V_{fc} = E_{Nernst} - V_{act} - V_{Ohmic} - V_{con}$. The fuel cell cross over losses is usually neglected since its value is of little importance. The equilibrium potential E_{Nernst} of a fuel cell can be obtained from Eq. (1) [19]

$$E_{Nernst} = 1.229 - 0.85 \times 10^{-3}(T - 298.15) + 4.3085 \times 10^{-5} \times T\,[\ln(P_{H_2}) + 0.5\ln(P_{O_2})] \quad (1)$$