Abstract

Proton exchange membrane fuel cells (PEMFCs) are a challenging energy conversion technology used in transportation and distributed power generation due to their advantageous characteristics, including high power density, low operating temperature, minimal emissions, negligible noise, and high efficiency. Designing a (PEMFC) fuel cell model is exceedingly challenging because of its multivariate in nature. All the input variables in PEMFC are changing under dynamic operating condition. Therefore, it is very difficult to get steady power output from PEMFC under simulated environment due the complex thermodynamics which governed by the Nernst equation. The optimization of various input parameters including in the governing equations of PEMFC is much essential to achieve best performance for multi-input multi-output system. Mostly the data driven techniques are used to predict the real time voltage and power losses with respect to the input parameters in PEMFC.

It has been observed that the various mathematical techniques are used for the optimization of PEMFC including fuzzy logic, Artificial Neural network (ANN), or adaption of metaheuristic algorithm etc. In case of optimization using ANN, the most important input parameters like stack temperature, pressure, relative humidity, partial pressure of hydrogen, partition pressure of oxygen, anode stoichiometry, and cathode stoichiometry have been considered to analyze the fuel cell performance. These parameters are given as input layer of ANN, which passes through hidden layer. The ANN model utilized the Levenberg-Marquardt (LM) learning technique to develop a multilayer perceptron network, demonstrating that the LM back-propagation algorithm is the most effective method for determining fuel cell performance parameters where the predicted voltage of a single cell was 0.8 volt.

The developed ANN model reveals both the maximum and minimum power outputs and the optimal operating conditions for any load changes, which helps to predict the best PEMFC

operating conditions for achieving maximum power output. An R^2 (coefficient of determination) value of 0.98 indicates that the ANN model has an excellent fit and can accurately predict the actual output voltage with 98% precision. It is observed that the best ANN outputs results are due to the approximation of the various parameters in the hidden layer.

The predicted output voltage from the ANN model is equal to the open-circuit voltage of the fuel cell minus the voltage corresponding to the loss components of the fuel cell. These losses are categorized as activation losses, Ohmic losses and concentration losses. By minimizing these losses, the predicted output voltage can be increased, resulting in higher stack power generation. Each loss is governed by some parametric co-efficient (for example membrane resistance, contact resistance etc.). These co-efficient values are not specific. To minimize the loss voltages, these co-efficient plays an important role. Based on this concept, a metaheuristic algorithm has been introduced to optimize these coefficients, effectively reducing loss voltages, achieving the actual output voltage, and ultimately increasing power generation. During this phenomenon of reducing losses, it was tried to evaluate the parametric co-efficient in such a manner that the loss voltage can be controlled to minimum value using metaheuristic Algorithm.

By coupling an ANN model with a metaheuristic optimization algorithm, the methodology allows predicting the overall voltage, systematically minimizing the contributions from concentration, activation, and ohmic losses, and enhancing the net voltage output and overall power efficiency of the PEM fuel cell. This hybrid approach leverages the ANN's ability to model complex nonlinear relationships and the metaheuristic's strength in handling multivariate optimization problems, ultimately leading to improved fuel cell performance through reduced internal losses.

In this research, it has been analyzed that several metaheuristic algorithms, each operating based on a unique mechanism. For example, the Artificial Bee Colony (ABC) algorithm is inspired by the foraging behaviours of bees, while the Genetic Algorithm (GA) mimics biological evolution. This research focuses on determining the parametric coefficients under different optimization algorithms and tabulating these values, which ultimately lead to the "calculated voltage" of a Proton Exchange Membrane Fuel Cell (PEMFC). The Sum of Squared Errors (SSE), introduced earlier, quantifies this difference. The primary objective to introduce metaheuristic algorithm along with ANN is to minimize the SSE. It can be observed that the around 20% improvement in the open circuit voltage due to the incorporation of Dynamic Ant Colony Optimization (DACO) in the metaheuristic algorithm. This improvement can be attributed due to the minimization of various losses when used DACO over Ant Colony Optimization (ACO).

The Ant Colony Optimization (ACO) is a widely used optimization technique inspired by the natural path-selection behaviour of ants searching for food, where the most efficient route is reinforced and selected. However, in conventional ACO, the food particles remain stationary over time. To address this limitation, a novel optimization technique called Dynamic Ant Colony Optimization (DACO) was proposed. Unlike ACO, DACO considers food particles as dynamic entities, increasing accessibility and improving accuracy. DACO has been tested using ten different benchmark functions and compared against other optimization algorithms, including GA, ABC, ACO, and GWCO. The results demonstrate that DACO is a more reliable algorithm for minimizing SSE. Its dynamic nature allows for a lower SSE with the same or lesser computation time while maintaining efficiency across multiple domains. Additionally, DACO exhibits superior convergence and provides more accurate results than other algorithms such as DE, ABC, ACO, and GWCO. Although DACO proves to be an effective metaheuristic algorithm for the minimization of various characteristic losses of the OCV, further an enhanced technique known as Wild Chimpanzee Hunting Optimization Algorithm (WCHO) was developed to get higher OCV. This algorithm follows a similar working principle to DACO but incorporates additional features such as time of flight and range of oscillation to refine results. The convergence curve indicates that WCHO achieves a lower SSE than DACO, albeit at the cost of increased computational time.

Applying WCHO to the fuel cell output equation produces parametric coefficients closely aligned with those obtained from DACO. However, WCHO requires a longer computation time. Ultimately, while WCHO offers sharper results, DACO remains the preferred metaheuristic algorithm for the objective function due to its faster convergence time approx. 30% less.

Henceforth this optimization algorithm also used in Optimization of PID controller. This article discusses improving the performance of PEMFCs by controlling a DC/DC converter using various methods, including conventional PID, DACO (Dynamic Ant Colony Optimization)-based PID, DACO-based FOPID, PSO-based PID, PSO-based FOPID, BEE Colony-based PID, and BEE Colony-based FOPID controllers. A Simulink model of a PEMFC was created with controllers and dual inputs for oxygen airflow and hydrogen flow. The suggested methods were compared with the system-generated results and a conventional PID controller. The optimization algorithms DACO, BEE Colony, and PSO were used with fitness functions IAE, ISTE, and ITAE. Performance was evaluated based on rising time (T_S), maximum overshoot (M_P%), and fitness function value. The suggested techniques optimized the PID and FOPID parameters, and outcomes were analysed against conventional PID methods, identifying the optimal values empirically. The research found that the proposed methods were more effective than the normal PID method, with the DACO-FOPID approach being the most superior. Simulation results indicated that control performance was acceptable for a PEMFC model using traditional PID and FOPID controllers adjusted by DACO, BEE colony.