Abstract

The development of proton exchange membrane fuel cells, or PEMFCs, has advanced the search for sustainable and clean energy sources significantly. These fuel cells are an appealing substitute for conventional internal combustion engines because of their high theoretical efficiency, quiet operation, and almost negligible emissions, which come from the electrochemical reaction of hydrogen and oxygen. Nevertheless, there are a number of obstacles that prevent PEMFCs from achieving their optimum theoretical efficiency in real applications. These difficulties are mostly caused by the intricate flow and pressure control within the PEMFC stack, which can result in problems including flooding, catalyst deterioration, and decreased efficiency.

This thesis suggests creating and implementing sophisticated control strategies—with a particular emphasis on fractional-order controllers—to address these issues. The potential of fractional-order dynamic models to more correctly depict real-world circumstances in comparison to conventional integer-order models is becoming more widely acknowledged. This study makes use of the special qualities of fractional calculus to improve PEMFC control and optimization, which raises the devices' overall performance, stability, and efficiency.

A seventh-order nonlinear PEMFC model is introduced at the outset of the thesis and linearized to make control technique implementation easier. Accurate initial conditions and equilibrium points are taken into consideration during the linearization process, guaranteeing that the model closely resembles the dynamic behaviour of the real system. One common disruption in real-world applications, fluctuating load current, is considered a significant characteristic that impacts the system's performance. The main aim of this project is to use a

fractional PID (Proportional-Integral-Derivative) controller optimized by a genetic algorithm (GA) to create a control rule for a multi-input, multi-output (MIMO) system.

The $PI^{\lambda}D^{\mu}$ (FOPID) form of the fractional PID controller is specifically engineered to maximize the PEMFC reactor's inherent reaction. The objective is to continue producing the intended amount of power notwithstanding ambiguities and disruptions. since of its non-integer order components (λ and μ), the FOPID controller is especially well-suited for this application since it may offer a finer level of control over the dynamic behaviour of the system. By providing more tuning options, these parts help the controller strike a more accurate balance between overshoot, reaction time, and stability.

A lot of simulations were run to confirm that the FOPID controller works as intended. The outcomes show that, especially in terms of stability and overshoot, the FOPID control approach performs noticeably better than conventional PID control. With a response time of less than 0.1 seconds, the PEMFC system's operational efficiency increased by 2%, demonstrating the controller's capability to react to system changes quickly and precisely.

The thesis tackles the crucial problem of pressure regulation at the fuel cell's cathode side in addition to maximizing the dynamic response of the PEMFC. Flooding, which can happen when too much water builds up inside the cell, can be avoided by carefully controlling the hydrogen and oxygen inflow flow rates and pressures. Flooding causes a drop in total efficiency as well as a reduction in the catalyst's performance. Thus, in order to guarantee ideal PEMFC performance, the thesis highlights how crucial it is to maintain constant exponential pressure at the cathode side.

The study investigates the development and application of a fractional PI/D controller intended primarily for pressure control. The controller is intended to accomplish three main

goals: first, it will monitor the PEMFC's operating pressure and determine which fractional PID controller is best based on which has the lowest Integration Absolute Error (IAE) to disturbances; second, it will assess the fractional PID controller's effectiveness in achieving optimal plant performance by comparing its IAE performance with that of conventional SIMC (Simplified Internal Model Control) rule based PID controller; and third, it will use MATLAB software to design a non-integer order PEMFC plant with the fractional controller and compare the results with existing models.

The thesis compares the performance of the fractional controllers with traditional optimization techniques, such as Genetic Algorithm (GA)-based PI, Particle Swarm Optimization (PSO)-based PI, and Grey Wolf Optimization (GWO)-based FOPI controllers, in order to further validate the suggested control strategies. Mathematical Simulink models of a PEMFC system with two inputs—oxygen air flow and hydrogen consumption—were used to perform these comparisons. A number of important parameters, such as rising time, maximum overshoot, and fitness function values (IAE, ISTE, and ITAE), were used to assess the controllers' performance.

These comparisons show that the fractional controllers, and especially the GWO-FOPI controller, perform better than the conventional PI controllers on every metric. Better overall stability, less overshoot, and quicker reaction times were all displayed by the GWO-FOPI controller. These results demonstrate how fractional-order control methods can be used to improve PEMFC system performance and provide a more reliable and effective solution than traditional integer-order controllers.

To sum up, this thesis offers a thorough investigation of sophisticated PEMFC control schemes, with an emphasis on fractional-order controllers. The study highlights the many

benefits of employing fractional calculus in control system design and optimization for intricate dynamic processes. PEMFC systems can benefit greatly from the higher stability, decreased overshoot, and increased efficiency of the proposed fractional $PI^{\lambda}D^{\mu}$ (FOPID) and PI/D controllers. Fractional-order control techniques have the potential to revolutionize the regulation of PEMFCs and other comparable systems, opening the door to more dependable, efficient, and sustainable energy solutions, as demonstrated by the successful deployment of these controllers in simulations.