Article

Fuel Cells with Proton Exchange Membrane Modeling and Control Techniques

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Abstract: Comprehensive mathematical models with three distinct controllers (PID, FOPID, and fuzzy + PID) for polymer electrolyte fuel cells (PEFCs) are constructed in this work. The models are made to indirectly control the input hydrogen mass flow rate in order to set the output voltage of the PEMFCs at a predetermined value. The simulation results demonstrate how effectively the established model fits the task of characterizing a PEFC's performance. While the developed controllers are capable of stabilizing voltage, the fuzzy + PID controller performs better, exhibiting a reduced overshoot and a faster response time.

Keywords: fuzzy + PID controller; fuzzy + PID controller; FOPID controller; modeling

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1. Introduction

Polymer electrolyte fuel cells, or PEFCs, have shown to be the best option for automotive, stationary, and portable applications because of its great durability, low operating temperature, and high-power density [1, 2].

In order to assess and forecast the behavior of the system and to maximize its output performance, modeling studies and control strategies for PEFCs are crucial [3]. In ref. [4], temperature regulation in a system model is achieved by employing traditional PID controllers to enhance the PEFC dynamic stack behavior. A FOPID controller is employed in ref. [5] to improve the PEFC's dynamic performance and efficiency. Fuzzy logical control theory is applied in ref. [6] to optimize the PEFC system under high temperature conditions.

An adaptive fuzzy logic controller (AFLC) is used in ref. [7] to obtain good control effects for PEFC voltage control in the presence of fluctuations. Though very little research has been done to compare the various controllers described above, each has been researched in the past. A thorough mathematical model for perovskite energy converters (PEFCs) is developed in this paper. More importantly, three distinct controllers—PID, fuzzy + PID, and FOPID—are designed concurrently to control the PEFC system and maintain a constant output voltage. Their various features and benefits are thoroughly compared.

2. Materials and Methods

2.1. Static Model Electrochemical Equations

In this work, several necessary presumptions are taken into consideration for a more practical examination of the PEFC models. These include perfect reactant gases, pure hydrogen as fuels, consistent temperature throughout the fuel cell, and the disregard of steam [8]. The electrochemical formulas utilized to describe the static characteristics of PEFCs, such as voltage, power, efficiency, and temperature change, are all taken from [9].

2.2 The Dynamic Model

Fuel cells exhibit a phenomenon known as the "charge double layer," which is crucial to comprehending the dynamic behaviors. Specifically, this phenomenon refers to the build-up of charge or transfer of load on the surfaces of two separate charged materials that come into contact with one another. The custody cover on the border electrode / electrolyte functions as an electrical capacitor by storing electrical charges and energy [10]. Figure 1 shows the corresponding circuit diagram. The operating state settings, the experimental data utilized for validation, and the thorough information about the PEFC's across the static and dynamic method characteristics are all taken from [11].

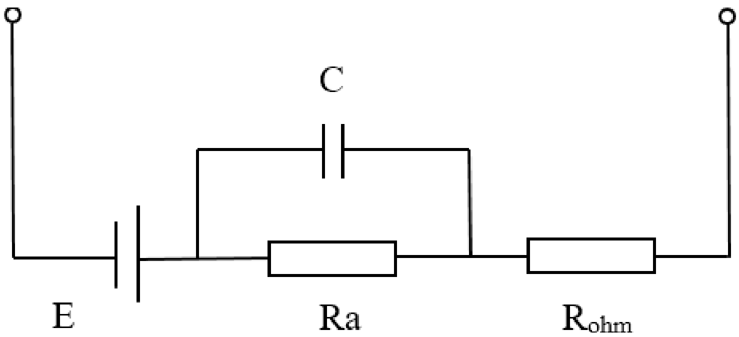

Figure 1: Analogous circuit schematic

2.3 Voltage Control System

Because of its precise and quick correction to a control function, PID control is the most exploited type of feedback regulator in modern functions. Three units make up this composition: differential, integration, and proportion. An automobile tuning technique is used to get the parameters [12]. Five parameters define the FOPID controller, a useful fractional order structure used for control: (i) the proportional gain; (ii) the integrating gain; (iii) the derivative gain; (iv) the integrating order; and (v) the derivative order. The FOPID approach is based on ref. [13], with the two additional units (iv) and (v) indicating that it is more accurate than the conventional PID controller. The fuzzy logical control method and the PID control algorithm are combined to create the fuzzy + PID controller. It has the ability to change PID parameters online, which could significantly enhance con troller performance [14].

A PEFC system has numerous characteristics that can readily alter its output voltage. It is a nonlinear, intricate, and strongly coupled system. In this study, the controllers regulate the mass flow rate of hydrogen to balance its voltage. Figure 2 displays the architecture of the entire control system as well as the structures of three distinct controllers.

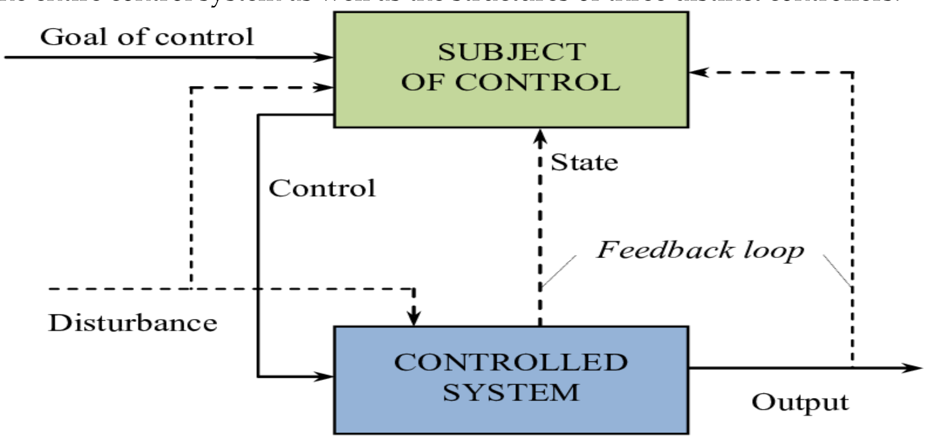

Figure 2: The controllers' and the control system's overall structures

3. Results

3.1 The Static Model

Figure 3 displays the static behavior of the PEFC. From 0.1 A to 34.9 A, the supplied load current is progressively increased. The calculated polarization curve shows an excel lent agreement with the experimental results, as shown in Figure 3(a). The activation polarization causes the stack voltage to fall quickly at first. Ohmic polarization causes it to decrease linearly with increasing current, and when the current increases more, the voltage lowers dramatically. As the power behavior is displayed in Figure 3(b), a peak with a value of 833.9 W at the current of 30.9 A is visible. The behavior of the stack efficiency, which is displayed in Figure 3(c), is comparable to that of voltage. For low current and low power, the efficiency is excellent, which is crucial for assessing the PEFC system.

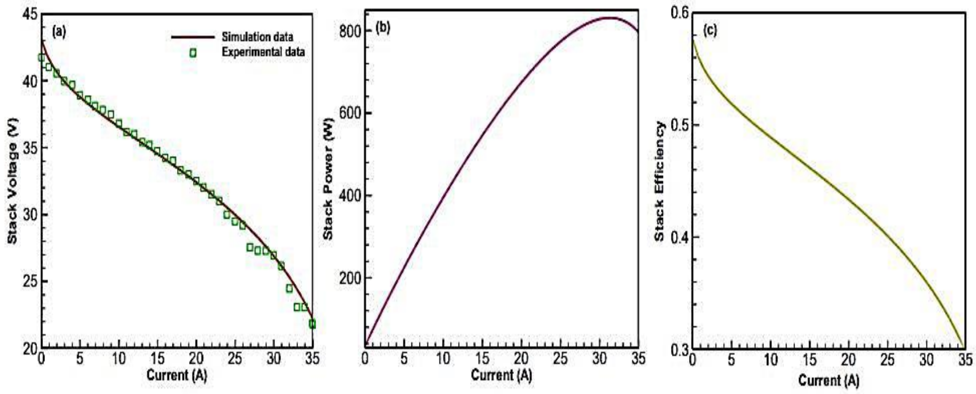

Figure 3: PEFC static model simulation results

3.2 The Dynamic Model

The dynamic behavior of PEFC is seen in Figure 4. In Figure 4(a), the load receives 4.9 A from the stack after 2.99 s, and concurrently, the current is increased to 14.99 A, staying at that level for 5.99 s. At last, the load current is reduced to 5 A, lasting until the simulation's 10-second end. Figure 4(b) shows the voltage curve, and it is evident that there is a reaction delay when the load current suddenly changes. Before the current is increased, the voltage is 39.459 V; it is 34.95 V when the current is maintained at 14.99 A; and it is 39.45 V once more after the load is reduced. The stack power response is depicted in Figure 4(c), peaking at the first instant of rise in load current and reaching a maximum value of 579.98 W. When the current starts to drop, the power shows a minimum of 179.97 97 W. In a steady-state scenario, the power would be 195.48 W at 4.99 A of current and 529.8 98 W at 14.99 A of current. The stack efficiency is displayed in Figure 4(d). Given their direct relationship, the curve and the voltage curve are only slightly different. It is clear that when load current is raised, efficiency significantly decreases. The steady-state values for stack efficiency are 52.99% (HHV) for a current of 4.99 A and 45.98% (HHV) for a current of 14.99 A. It is evident that when load current increases, efficiency significantly decreases. This is something that needs to be considered while assessing a certain system.

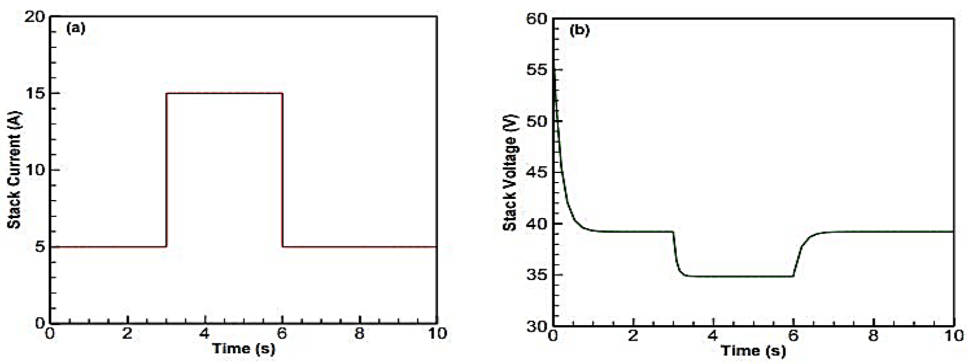

Figure 4: a and b show the PEFC dynamic model simulation results.

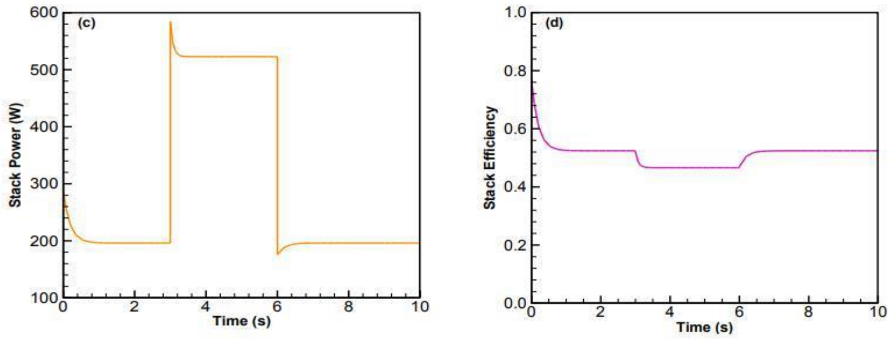

Figure 4: c and d show the PEFC dynamic model simulation results.

3.3 Voltage Control System

The three distinct controllers are built and implemented in accordance with Figure 4(d) using the parameters, with the outcomes displayed in Figure 5. The input current in Figure 5(a) starts at 3 A and increases to 5 A after 30 seconds, staying at that value until the simulation is finished. It is evident from Figure 5(b) that each of these three controllers is able to describe the systematic disturbance and keep the voltage at the specified level. With a lesser overshoot, it is evident that the FOPID controller outperforms the PID con troller by a little margin. The Fuzzy + PID controller performs the best, responding the fastest and with the least amount of overshoot.

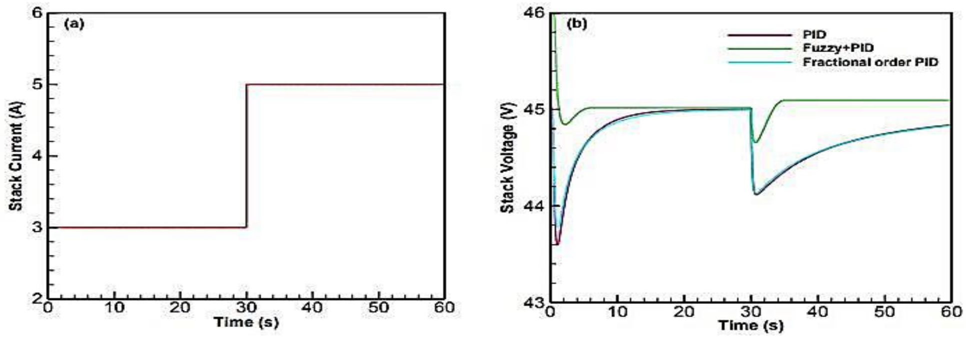

Figure 5: Voltage control results

5. Conclusions

This work develops extensive scientific patterns of PEFCs, including PID, FOPID, and Fuzzy + PID controllers. These controllers are intended to manage the output voltage of PEFCs by adjusting the mass flow rate of hydrogen. Fuzzy + PID controllers are chosen because they can adjust PID parameters online, which will improve control performance when compared to traditional PID controllers. The use of FOPID controllers is prompted via the statement that the existence of additional tuning parameters (fractional parameters) allows excellent plasticity in realizing the model designs. The results of the simulation demonstrate that the created model is a good fit for explaining both the dynamic behavior and steady-state performance of the PEFC. Furthermore, a very good agreement between the model predictions and experimental studies is demonstrated. The Fuzzy + PID controller displays the highest deed with a reduced overshoot and a faster response time, but all three controllers are equally good in tracking the reference voltage and limiting system disruption. The findings in this research can be applied to better optimize the fuel cells' total cost and efficiency.

Conflicts of Interest: Declare conflicts of interest or state "The authors declare no conflict of interest."

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