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SIMULATION OF HYDROGEN FUEL CELL TO PRODUCE POWER USING MATLAB

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Abstract: This paper looks into modeling a system of hydrogen fuel cells to generate power, using MATLAB Simulink. The study focuses on modeling the electrochemical processes within the fuel cell, optimizing control strategies, and evaluating the overall system performance. Through detailed simulations, the paper aims To provide a comprehensive comprehension of efficiency, stability, and dynamic response to clearly illustrate the effectiveness of the device converting into a system for producing electricity. The findings from this study contribute to advancing our understanding of hydrogen fuel cell technology and its potential applications in sustainable energy systems.

***Index Terms* - Fuel, hydrogen, simulation, energy.**

I. INTRODUCTION

In simulating a fuel cell that runs on hydrogen production usingMATLAB, your research paper introduction should outline the significance of hydrogen in the form of clean energy source, the relevance in terms of fuel cell technology, and the importance of simulation in optimizing performance. Highlight the environmental benefits and the potential impact on sustainableenergy solutions. Emphasize how MATLAB serves as a powerful tool for modeling and analyzing complex systems like hydrogen fuel cells, paving the way for efficient and environmentally friendly power generation.

The hydrogen fuel cells have become a key focus in the search for sustainable energy due to their rising popularity as an alternative power source. Hydrogen, as a clean and abundant fuel, offers a potential solution to address environmental concerns and reduce dependence on fossil fuels. Fuel cells, being efficient and emitting only water as a byproduct, it playsimportant role in the transition to greener energy.

The hydrogen fuel cell simulation using MATLAB provides a powerful means to understand, model, and optimize their performance. MATLAB's versatility allows researchers to simulate intricate electrochemical processes, fluid dynamics, and thermal behaviors within a battery system. This capability is crucial for predicting and enhancing How well of power generation, ultimately contributing to the The technology of hydrogen fuel cell is both viable and broad. As the focus on sustainable energy intensifies, research endeavors must not only explore innovative technologies but also employ robust tools for accurate analysis and design. MATLAB's role in this context becomes pivotal, enabling researchers to delve into the complexities within a fuel cell systems, identify optimization opportunities, and refine designs forreal-world applications.

This research paper aims to delve into the use of modeling to simulate hydrogen fuel cell operation MATLAB, offering a thorough investigation and thorough understanding of theunderlying principles, modeling techniques, and the potentialimpact on power generation. By bridging the gap between theory and practical implementation, this study aspires to contribute valuable insights to the evolving landscape of cleanenergy solutions.

II. LITERATURE SURVEY

Ibrahim Dincer et. al explains that **[1]** The study also addresses prospective future energy-utilization patterns for better environment and sustainable development, and shows how the principles of thermodynamics via energy can be beneficially used to evaluate Hydrogen and the Structure that uses it to make power cell systems and their role in sustainability. throughout the paper, current and future perspectives regarding thermodynamics and sustainable development are considered.

Mohamed Rahim atan Wan Ahmad Najmi Wan et. al explains that **[2]** Physical investigation on the thermal effects of air cooling for stacks in the range of 1 kW to 3 kW power rating is rare compared to publications on water-cooled systems. The majority of predictive modeling concerning stack power outputs, temperature profiles and cooling effects are obtained largely from analytical approach, built from the foundations of theoretical electrochemistry, species transport and heat transfer. However, it is acknowledged that actual fuel cell behavior is also specifically influenced by component, manufacturing and assembly methods such as clamping pressure distribution and sealing characteristics, additionally flow disturbances due to MEA deflection and imperfections in gas channel construction. In other words, each developed polymer electrolyte membrane fuel cell would actually exhibit its own unique operational signature.

Husseini.M et. al explains that **[3]** The compressor dynamic, supply and return manifold filling dynamics (anode and cathode), membrane hydration and time-evolving partial pressure of the reactant are the most significant parameters in transient and steady state of system. The impact of compressor performance conditions, changing inlet air pressure, and membrane humidity on the generated power is studied in this paper.

Viral Mehta et. al explains that **[4]** Six fundamental material and configuration specifications are included for PEM fuel cells, together with advantages and disadvantages of each design. It also takes into account the stack's performance in respect to operating conditions, fuel and oxidant composition, and thermodynamics water control. connections pertaining to water management, fuel and oxidant composition, operating pressures and temperatures, thermodynamics, and possible application problems.

C E Thomas et. al explains that **[5]** The energy density of the hydrogen system is fundamentally superior, and this advantage is amplified in cars because of weight compounding. To put it another way, fuel cell electric vehicles (FCEVs) require less stored energy per mile than battery electric vehicles (BEVs), because the latter require more energy to travel the same distance due to their heavier batteries and other components.

Leena O, Dr. Jyoti P Koujalagi et. al explains that **[6]** Hydrogen fuel cells provide many benefits, including silent operation and consistent electricity. They are efficient no matter the size and are ideal for settings like IT centers, hospitals, or mobile applications. It will take decades to transition to a cleaner energy infrastructure, including hydrogen, because of technological and financial obstacles. Simply expressed, losses connected to mass transit are covered in the third section, whereas losses resulting from internal resistance are covered in the second.

III. METHODOLOGY

A fuel cell stack operating under standard temperature and pressure conditions is represented by a simplified model in figure (1). Based on the polarization curve, as illustrated in figure. (2), the equivalent circuit's characteristics can be changed. The nominal and maximum operating points for the parameters to be determined, along with the voltage value at no load, are the inputs. One way to stop negative current from entering the stack is by using a diode.

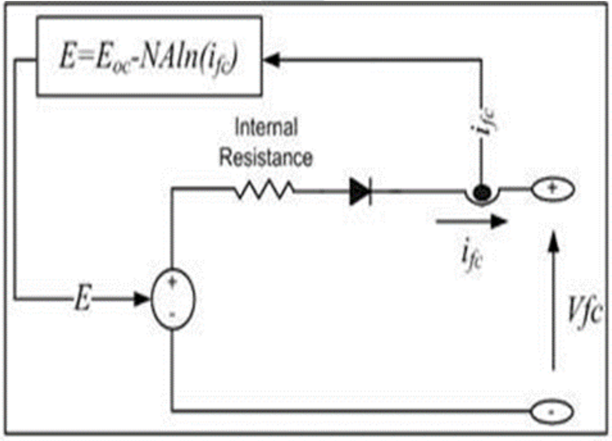


figure 1: the fuel cell stack's equivalent circuit

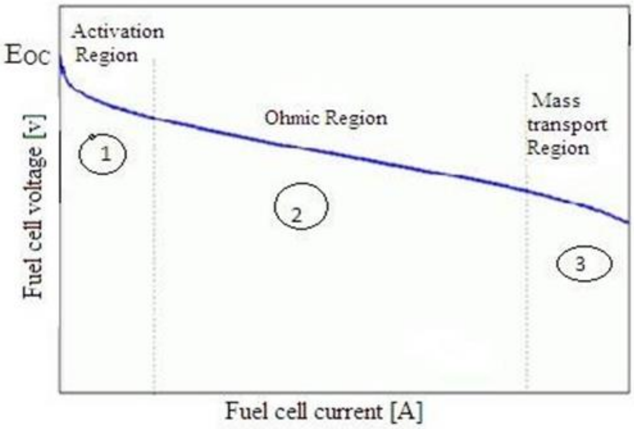


figure 2

Three sections make up the polarization curve in figure 2

3.1 Area 1

The activation voltage drop caused by the sluggish chemical reactions occurring at electrode surfaces is represented by the first area. This zone is more or less wide, depending on the type of electrode, catalyst, operating pressure, and temperature.

3.2 Area 2

The resistive losses resulting from the fuel cell stack's internal resistance are depicted in the second section.

3.3 Area 3

As a result of the reactant concentrations changing throughout fuel usage, the mass transport losses are finally represented by the third region.

3.4 Extensive Model

The intricate model depicts a stack of hydrogen fuel cells under varying conditions of pressure, temperature, fuel and air composition, and flow rates. Both the Tafel slope and the open circuit voltage are impacted by these fluctuations. Fig. 3 displays the simplified model and the comparable circuit. The following changes are made to the Tafel slope and open circuit voltage:

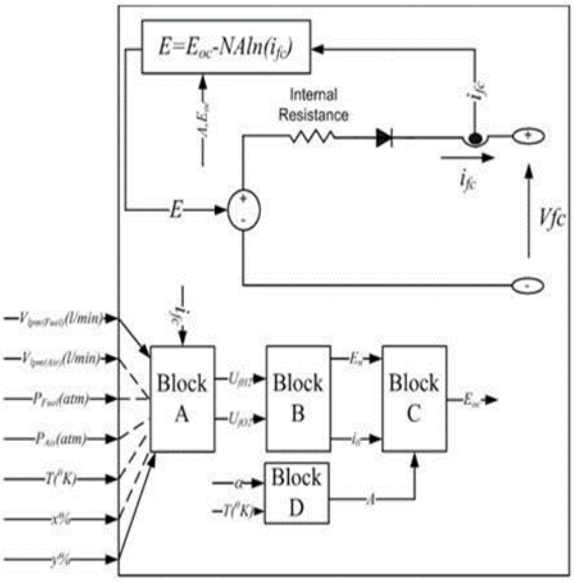


figure 3: a simplified fuel cell stack model

$$E_{OC} = N(\,En - A\ln(i_0)) \quad (1)$$

$$A = \frac{RT}{z\propto F} \quad (2)$$

where Tafel slope A = 8.3145
J/(mol K) and EOC = Open circuit voltage (v)
F = 96485 A s/mol
z = Electron number in motion
The thermodynamic voltage of the cells,
En = Nernst voltage dependent upon the temperatures and partial pressures of the reactants and products within the stack.
Exchange current (i0) is the current that results from the constant passage of electrons back and forth between with no stress on the electrolyte. It also depends on the reactant temperatures and partial pressures inside the stack.
a= Charge transfer coefficient, which varies according to the catalysts and electrodes utilized.
T is the operating temperature (K).

For a given air and fuel flow rate, the nominal rate of hydrogen and oxygen conversion is given by:

$$U_{f_{H_2}} = \frac{6000\,RTN\,i_{fc}}{zFP_{Fuel}\,V_{lpm\,(fuel)}Xx\%}\;0 \le U_{f_{H_2}} < 1 \quad (3)$$

$$U_{f_{O_2}} = \frac{6000\,RTN\,i_{fc}}{2zFP_{air}\,V_{lpm\,(air)}Xy\%}\;0 \le U_{f_{O_2}}\;1 \quad (4)$$

Where,
$U_{f_{H_2}}$ = Nominal hydrogen conversion rate
$U_{f_{o_2}}$ = Nominal oxygen conversion rate,
P_{Fuel} = Absolute air supply pressure(atm)
P_{air} = Air supply pressure at its maximum
$V_{lpm\,(fuel)}$= Rate of fuel flow (l/min)
$V_{lpm\,(air)}$ = Rate of air flow (l/min)
x = The fraction of hydrogen in the fuel
y = The proportion of oxygen in the oxidant

The Nernst voltage is determined when an exchange current density is given. (io) for the partial pressure of hydrogen and oxygen in the stack is supplied by:

$$E_n = \begin{cases} 1.229 + (T-298)\frac{-44.43}{zF} + \frac{RT}{zF}\ln(P_{H_2}P_{O_2}^{1/2})\;T \le 100°C \\ 1.229 + (T-298)\frac{-44.43}{zF} + \frac{RT}{zF}\ln(P_{H_2}\,P_{O_2}^{1/2})\;T > 100°C \end{cases} \quad (5)$$

$$i_0 = \frac{zFk\,(PH_2+PO_2)}{Rh}\,e^{\frac{\Delta G}{RT}} \qquad (6)$$

En is the Nernst voltage. & i_0 = switch current

P_{H_2} = Hydrogen partial pressure inside the stack
P_{O_2} = Oxygen partial pressure inside the stack
P_{H2O} = Water vapor's partial pressure inside the stack
k = Constant Boltzmann: 1.38 x 10^–23 J/°K
h = Constant Planck = 6.626 x J s
G = The size of the activation barrier is determined by the kind of catalyst and electrode that are utilized

The partial pressures and and are determined in steady state as follows :

$$P_{H_2} = P_{Fuel}\,x\%(1 - U_{f\,H_2}) \qquad (7)$$

$$P_{O_2} = P_{Air}\,y\%(1 - U_{f\,o_2}) \qquad (8)$$

$$P_{H_2O} = P_{Air}\,(w\% + 2y\%U_{f\,o_2}) \qquad (9)$$

Where,

W = The oxidant's percentage of water vapor (%)

The new open circuit voltage (EOC) and Tafel slope values are computed in Blocks C and D, respectively. The polarization curve at nominal operating circumstances is used to compute the material parameters, G, together with a few other factors including the stack's low heating value (LHV) efficiency, the fuel and air composition, supply pressures and temperatures, etc. The manufacturer's data sheet makes them easily accessible.

The following formula is used to determine the nominal rates of gas conversion:

$$U_{f\,H_2} = \frac{\eta_{nom}\,\Delta h^0(H_2o(gas))N}{zFV_{nom}} \qquad (10)$$

$$U_{f\,o_2} = \frac{6000\,RT_{nom}\,NI_{nom}}{2zFP_{air\,nom}\,V_{lpm\,(air)_{nom}}} \times 0.21 \qquad (11)$$

Where,

η_{nom}= Nominal LHV efficiency (%) of the stack
$\Delta h^0(H_2O(gas)) = 241.83\,X\,10^3$ J/mol
V_{nom}= Nominal voltage value (V)
I_{nom} = The nominal current in A
$V_{lpm(air)nom}$ = Rate of air flow at rest (l/min)
P_{airnom} = Absolute nominal pressure of the air supply (Pa)
T_{nom} = Operating temperature nominal in degrees

3.5 Extraction of Datasheet Parameters

The Ned Stack PS6 data sheet from Ned Stack is used in this example, as seen in Appendix-A

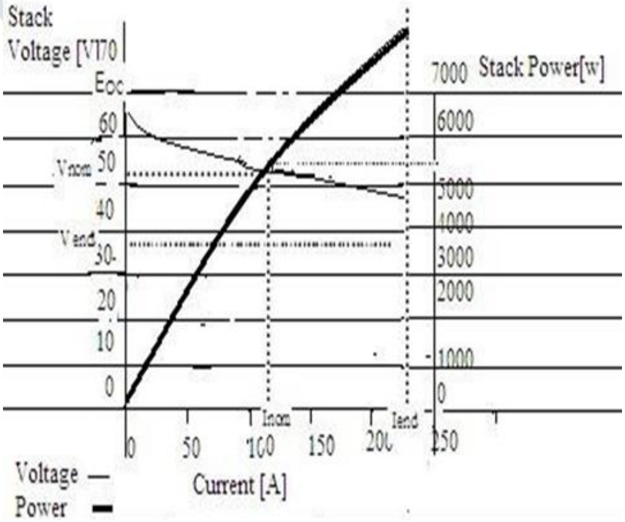


fig-4: ned stack ps6 curves from data sheet

The stack has a nominal voltage of 48 V and a rated power of 5.5 kW. Based on the information sheet, the following precise parameters are inferred. 65 V is the voltage of the open circuit (Eoc). [133.3, 45] is the operating point nominal (I nom, Vnom). [225, 37] is the maximum operational point for [I end, Vend]. %55 is the nominal efficiency of the stack (nom). 65 degrees is the operating temperature. [1.5 1] is the minimal pressure on supply [$H2$Air]. To obtain the absolute pressure, increase by one bar if the supplied pressure relates in relation to the air pressure. The nominal composition (%) is [21, 1; 99.999] [$H2$,$O2$,$H2O$(Air)]. In the event that Their proportions don't stated, Approximately 21 percent of H2O2 and 1% of H2O2H2O If the air is employed as an oxidant.

3.6 Quantity of cells:

Quality of cells is computed using the following formulas:

$$N = \frac{2\ X\ 96485.V_{nom}}{241.83\ X\ 10^{3}.\eta_{nom}} \tag{12}$$

$$N = \frac{2\ X\ 96485.45}{241.83\ X 10^{3}.0.55} = 65.28 = 65\ cells$$

3.7 Rate of air flow at nominal:

If the maximum air flow rate is given, the nominal flow rate can be calculated assuming constant oxygen consumption at all loads. What establishes the nominal flow rate is: The air flow rate has a linear relationship with the current that the cell draws.

$$V_{lpm\ (air\ )_{nom}} = \frac{I_{nom}\ x V_{lpm\ (air\ )_{nom}}}{I_{nom}} \tag{13}$$

Here,

$$V_{lpm\ (air\ )_{nom}} = \frac{133.3\ x\ 500}{225} = 297 litres/min$$

Assume that the majority of fuel cell stacks have an oxygen conversion rate of 50% and nominal air flow rates.

$$V_{lpm\ (air\ )_{nom}} = \frac{6000\, RT_{nom}\ N I_{nom}}{2zF P_{air\ nom}\ 0.5\ x\ 0.21} \tag{14}$$

3.8 10s is The reaction of the fuel cell time.

The polarization curve of the stack running at a fixed nominal rate of ga similar to the curves from the data sheet, as indicated below. The dotted power of the stack, respectively.

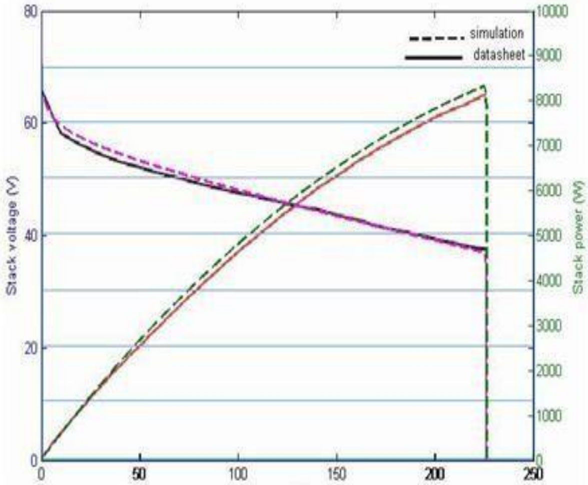


figure 5: the stack's polarization curve in the vicinity of the curves on the data sheet

The velocity at which gasses enter the stack reaches its maximum beyond the maximum current, and as additional current is pulled, the voltage of the stack drops sharply.

IV. SIMULATION RESULTS

The procedure for producing power is demonstrated in the hydrogen fuel cell study paper's MATLAB Simulink simulation. It involves a careful examination of all system parts as well as how they interact to provide enlightening details regarding how well the fuel cell system functions. The Findings offer significant new perspectives on the hydrogen fuel cell industry. research by highlighting important factors including efficiency, power quality, and potential obstacles.

Certainly. The simulation in MATLAB Simulink for the research paper involves a comprehensive exploration of the fuel made of hydrogen cell’s behaviour It delves into material properties, system configuration, and their impact on power generation. The simulation addresses variables like operation temperatures, pressure, and fuel's composition and oxidant, shedding light on the system’s efficiency and potential applications.

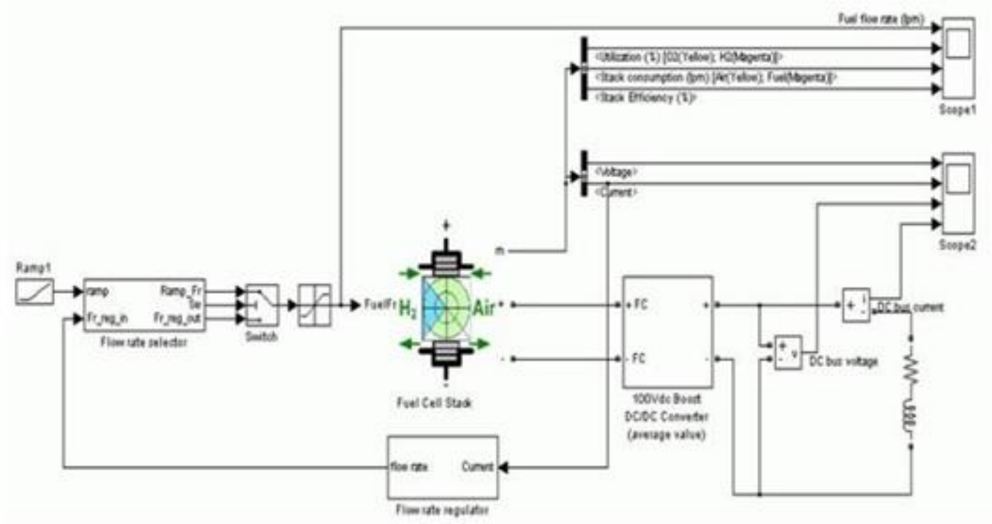
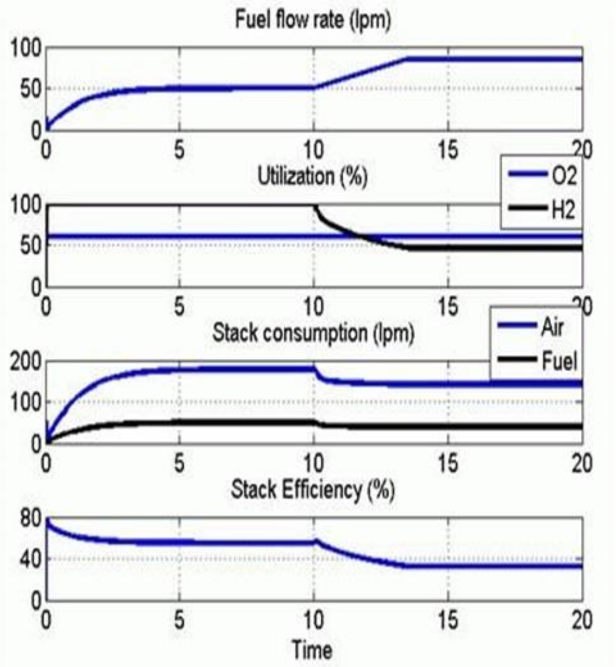


figure 6: a 6 kw, 45 v proton exchange membrane is part of the hydrogen fuel cell stack simulation model.



the simulation results figure 7 show the fuel use and flow rate, efficiency, and stack consumption.

The DC bus voltage is expertly managed by the converter. The first peak voltage of 122 Vdc in the simulation is caused by the voltage regulator's transient state.

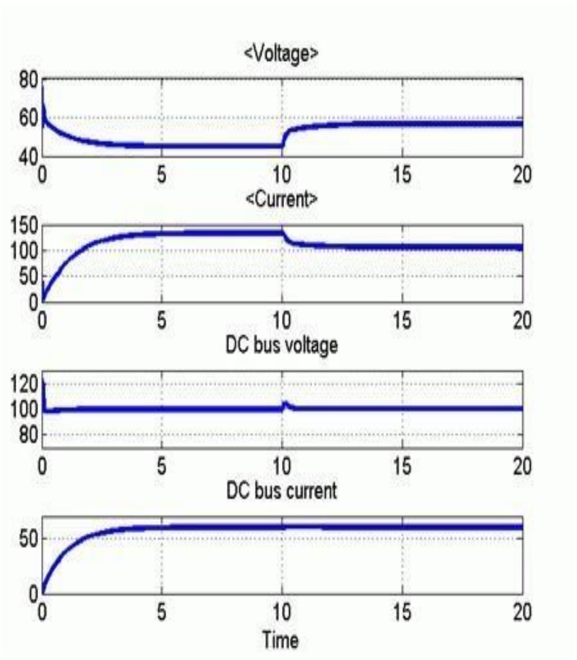


figure 8: simulation results showing the voltage and current of the dc bus.

V. FUTURE SCOPE

The prospective range for fuel cells in power generation using hydrogen is promising. Advances in technology are expected to enhance efficiency, reduce costs, and increase the practicality of energy cell applications. This includes potential use in transportation, stationary power generation, and even portable devices. As the focus on clean energy intensifies, fuel cells powered by hydrogen could be essential in achieving sustainable and environmentally friendly power solutions. Ongoing research and development aim to address challenges and further expand the applications of device turning fuel into electricity technology.

VI. CONCLUSION

The study looked on modeling hydrogen fuel cells. for power generation through MATLAB Simulink. The comprehensive analysis presented in this study underscores the potential inside fuel cells powered by using hydrogen as a sustainable and energy efficiency source. Through Simulink, we demonstrated the intricate characteristics and operation of the fuel cell system, providing valuable insights for optimizing its performance. As we navigate towards a cleaner energy future, the findings of this research to assist in the ongoing efforts in advancing hydrogen tech making power efficiently for a more sustainable and resilient power generation landscape.

The outcomes of the simulation revealed that The system of fuel cells powered by hydrogen is quite sensitive, stressing how crucial precise control and optimization. Are, the finding from this study set the foundation for upcoming research work in enhancing the total effectiveness, reliability, and cost-effectiveness of fuel hydrogen cells. Additionally, the integration of MATLAB Simulink In this investigation, not only did us comprehend the kinetics of fuel cells, but also serves as a valuable tool for engineers and researchers in designing and testing real-world applications.

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