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Original Article

Optimization and Integration of PEM Fuel Cell System with Intelligent Controller and DC/DC Boost Converter for Enhanced Efficiency and Reliability

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Abstract *- Polymer Electrolyte Membrane (PEM) fuel cells stand at the forefront of sustainable energy technologies in harnessing the chemical energy of hydrogen to generate electrical power with unparalleled efficiency and minimal environmental impact. By converting hydrogen fuel directly into electricity, PEM fuel cells offer a promising path to mitigate energy consumption, reduce pollutant emissions and restrict reliance on fossil fuels. PEM fuel cells are also known as Proton Exchange Membrane fuel cells, which boast advantages such as low weight and volume, distinguishing them from other fuel cell technologies. This progress has prompted a comprehensive optimization of PEMFCs aimed at validating calculated stack power against nominal power and assessing overall efficiency. Notably, the investigation also underscores the key role played by internal cell resistance in determining stack power and studying the strategies to minimize the impact of internal cell resistance. To enhance the integration of PEMFCs into applied energy systems, this study takes a step further by coupling the fuel cell with a DC/DC boost converter featuring an intelligent controller in the SIMULNIK platform. This strategic integration not only optimizes the performance of the fuel cell but also contributes to DC microgrid stability, enhancing the overall viability and reliability of the sustainable energy solution. This research investigates the better optimization and analysis of PEM fuel cells, which emphasize their potential to revolutionize energy generation by efficiently converting chemical energy into electricity. This study doesn't just stop at theoretical advancements by exploring intelligent control and converter technologies; it presents a comprehensive and holistic outline for routing PEMFCs into the forefront of a sustainable and reliable energy research community.*

Keywords *- PEMFC, Intelligent control, Efficiency, Temperature management, Sustainable, SIMULINK, Optimization.*

1. Introduction

The intermediary stage of energy storage and conversion plays a crucial role in bridging the gap between energy production and consumption. Depending on fossil fuels are natural but not a good way to store energy, which brings problems like limited reserves and pollution. Consequently, there is an urgent need for a more sustainable alternative that can efficiently store and harness the abundance of green and renewable energies for future use [1].

The temperature at which a fuel cell works really affects how much power it can produce. If it gets too hot, the efficiency drops, and it struggles to generate as much power. But running it at a higher temperature can make it better at using leftover heat. It's important to note that an ideal temperature range is one where a certain type of fuel cell works well and reliably. So, temperature management in fuel cell systems is all about keeping the fuel cell working in that perfect temperature range for the best performance.

In the search for sustainable and efficient energy solutions, PEM fuel cells have emerged as a pioneering technology in harnessing the chemical energy of hydrogen to generate electricity with exceptional efficiency and minimal environmental impact. Significant efforts have been dedicated to advancing PEM fuel cell technology and fundamental research, especially in the recent couple of decades [2].

PEM fuel cells stand out due to their remarkable characteristics, including a low operating temperature, high power density and straightforward scalability. These qualities position PEM fuel cells as a highly promising option for the next generation of power sources in areas such as transportation, stationary applications, and portable devices. The schematic diagram of the PEM fuel cell is shown in Figure 1. The polymer-electrolyte membrane serves as the core component in a PEM Fuel Cell which facilitates the ion conduction while delaying electron transfer between electrodes.

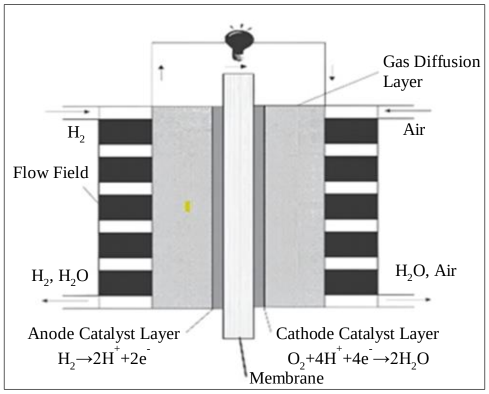

Fig. 1 Schematic diagram of PEM fuel cell [3]

Within the catalyst layers, intricate structures comprised of precious metal nanoparticles supported on porous carbon and ionomer create pathways for the transportation of reactants, products, electrons and protons to and from active sites where electrochemical reactions occur.

The anode is where fuel oxidation transpires to release protons and electrons when hydrogen is utilized as the fuel. Protons traverse the membrane, and electrons navigate the external circuit. At the cathode catalyst layer, protons and electrons recombine with oxygen, which yields water [3].

To facilitate the distribution of gaseous hydrogen and oxygen across electrodes and complete the electron flow circuit, the membrane and electrodes are enclosed between graphite blocks featuring gas flow channels and porous diffusion media. These carbon media consist of a macro-porous gas-diffusion layer and a microporous layer adjacent to the catalyst layer [3].

The electrical energy carried by electrons through the external circuit can power devices. The electrical power (P), which is generated by the fuel cell, is the product of the cell potential (V), representing energy per electron transported and the current (I), indicating the number of electrons transported per unit time: $P=V \times I$ [3].

This briefly captures the operating principle of a PEM Fuel cell, where the conversion of chemical energy from hydrogen and oxygen into electrical energy occurs through controlled electrochemical reactions and electron transport [4].

The need for comprehensive optimization of PEMFCs to harness hydrogen’s chemical energy efficiently for electricity generation has been identified as the problem statement. The research gap lies in addressing the challenges related to internal cell resistance, stack power validation and overall efficiency assessment. Additionally, a gap in integrating PEMFCs with intelligent controllers and DC/DC boost converters, emphasizing the importance of enhancing microgrid stability and overall viability. The main objective of this study is to develop an enhanced PEM fuel cell by considering the effect of internal cell resistance on stack power and overall efficiency. The enhanced model of the PEM fuel cell stack is to integrate with the DC/DC Boost Converter and Intelligent Controller for performance analysis.

The fuel cell-powered system is basically a low voltage and high current source. So, a DC/DC boost converter is required to boost the cell voltage. The significance of the study lies in its potential to address critical issues related to energy consumption, environmental impact and the transition towards sustainable energy solutions. By enhancing the efficiency of PEM fuel cells, the study contributes to more efficient energy conversion processes. Increased efficiency means that a larger proportion of the input energy from hydrogen is converted into electricity by reducing overall energy consumption.

PEM fuel cells produce electricity through electro-chemical reactions by emitting only water vapor as a byproduct. Compared to traditional fossil fuel combustion, this represents a cleaner and more environmentally friendly way of generating electricity by contributing to lower greenhouse gas emissions.

The study’s focus on improving the efficiency of PEM fuel cells aligns with the global push towards integrating more green and renewable energy sources into the energy mix. This can help reduce the environmental impact associated with electricity generation. This work has aimed to integrate with enhanced PV systems and supercapacitors for power management studies as the extension of this research.

This study also aimed to integrate the PEM fuel stack with a PV system and supercapacitor-based DC micro-gird system for energy management studies as a future extension.

2. Literature Review

The authors Keith Promislow and Brian Wetton have concluded that the study of PEM fuel cells is inherently multidimensional, spanning the nanoscale to the macroscale. The complexity of these energy conversion systems requires advanced mathematical models that are inherently multiscale and Multiphysics.

Computational realization of these models demands sophisticated numerical methods, and while reduction to lower-dimensional models is possible in certain regimes, highly structured and adaptive approaches are essential for resolving material science and device performance questions.

The synergy between mathematical analysis and scientific computation is key to advancing our understanding of PEM fuel cells and optimizing their performance for sustainable energy solutions [5].

The author's Lei Mao, Lisa Jackson and Tom Jackson have concluded that their study investigated the variation in the internal behavior of PEM fuel cells throughout their operational lifespan. The research analyzes both steady-state and dynamic conditions using a PEM fuel cell behavior model with parameters adjusted for different fuel cell losses.

The findings highlight that ohmic loss is the dominant contributor to PEM fuel cell degradation in this study, with larger variations in model parameters observed under dynamic conditions, which leads to a shorter overall lifetime [6].

The authors Escobar-Yonoff R, Maestre-Cambronel D, Charry S, Rincón-Montenegro A, & Portnoy I developed a comprehensive model for assessing PEM electrolyzer and PEM fuel cell behavior individually and when integrated by incorporating an economic evaluation. Matlab/Simulink® is employed to analyze parameters like temperature, pressure and current density.

Ohmic overpotential significantly impacts both devices with a temperature rise, improving performance by up to 10%. Pressure mainly affects PEM fuel cells (2–5%). The integrated system achieves an overall efficiency of 25–75% for the peak temperatures ranging from 55-60°C and pressures 2-7 atm [7].

The authors Tao Hai, Ammar K. Alazzawi, Jincheng Zhou and Hamid Farajian have concluded that the research emphasizes the development of an advanced MPPT controller using the MFSO algorithm coupled with a 25-rule base fuzzy logic controller to significantly enhance power extraction from a PEM Fuel Cell system.

The proposed controller proved its robust performance very effectively in addressing the varying temperatures and membrane water content for common challenges in fuel cell operation. The suggested MPPT method offers several advantages, including swift transient response, minimal losses, and reduced power oscillations.

This research concludes with an intelligent MPPT controller that influences the Modified Fluid Search Optimization (MFSO) algorithm and FLC to maximize power extraction from PEMFCs despite varying operating conditions [8].

The work of multidimensional modeling, understanding degradation factors, comprehensive assessment models, and advanced control strategies, which are observed from the literature review, is crucial for optimizing the efficiency and reliability of PEM fuel cells.

These findings collectively provide a foundation for further advancements in the integration and enhancement of PEM fuel cell systems for sustainable energy solutions.

3. Design and Optimization of PEM Fuel Cell

The optimization and analysis of PEM Fuel Cells play a pivotal role in advancing the field of clean and efficient energy conversion. As an environmentally friendly alternative to conventional power sources, PEM Fuel Cells have garnered significant attention for their potential application in various industries.

In this context, a comprehensive methodology is essential for developing a thorough understanding of its performance by addressing critical aspects such as stack power, internal cell resistance and overall efficiency.

3.1. Design and Calculation of P_{stack} & Efficiency

The mathematical modeling of PEM Fuel Cells involves considering various electrochemical and thermodynamic processes. One of the fundamental parameters to calculate in a PEMFC is the stack power. The reference parameters of the PEM Fuel Cell stack have been extracted from SIMULINK with 24V and 1.26KW PEMFC, as given in Table 1.

Table 1. PEM fuel cell specifications

S. No.	Parameter	Value
1	Standard Cell Potential (E^0_{cell})	1.115V
2	Ideal Gas Constant (R)	8.314J/(mol·K)
3	System Temperature (T)	328K
4	Faraday's Constant (F)	96,485 C/mol
5	Nominal Utilization of H_2 (pH_2)	99.92%
6	Nominal Utilization of O_2 (pO_2)	1.813%
7	I_{stack} Nominal	52A
8	I_{stack} Maximum	100A
9	V_{stack} Nominal	24.23V
10	V_{stack} Maximum	20V
11	P_{stack} Nominal	1259.96W
12	P_{stack} Maximum	2000W
13	$R_{internal}$	0.061871 Ω

The stack power (P_{stack}) can be calculated by considering the voltage (V_{cell}) across a single cell and the current (I_{stack}) passing through the stack. The relationship is given by Ohm's Law:

$$P_{stack} = I_{stack} \times V_{stack} \tag{1}$$

Now, the voltage across a single PEM Fuel Cell (V_{cell}) is a function of the cell potential (E_{cell}) and the current passing through the cell (I_{cell}). This relationship can be expressed as follows:

$$V_{\text{cell}} = E_{\text{cell}} - I_{\text{cell}} \times R_{\text{internal}} \quad (2)$$

Where R_{internal} is the internal resistance of the fuel cell, the internal resistance of the fuel cell can be calculated and modified from the modification of Equation 2.

The Nernst equation is applied to calculate the cell potential (E_{cell}) using the given data. E^0_{cell} is the potential of a cell under standard conditions, which serves as a reference point for thermodynamic considerations. Ecell is the actual potential of the cell under specific non-standard conditions, accounting for changes in concentration, temperature and pressure. The Nernst equation is given by [9]:

$$E_{\text{cell}} = E^0{}_{\text{cell}} - \frac{RT}{nF}\ln\left(\frac{\text{pO2.pH2O}}{\text{pH2.pO2}}\right) \quad (3)$$

Where n (≈2) is the number of electrons involved in an electrochemical reaction. The efficiency formula is crucial for evaluating the effectiveness of a power generation system in converting fuel into usable energy, as given in Equation 4,

$$\eta(\%) = \frac{\text{calculated stack power}}{\text{fuel energy input}} \times 100 \quad (4)$$

The fuel energy input (kJ) is calculated by multiplying the nominal consumption of fuel with the lower heating value of hydrogen. A higher efficiency indicates that a greater percentage of the energy from the fuel is being effectively converted into useful work.

This analysis is carried out in this work to assess the efficiency of fuel cells at various internal cell resistances. The electrical characteristics of the 24V, 1.26KW PEM Fuel cell Stack with nominal and maximum values of stack voltage, current and power are shown in Figure 2.

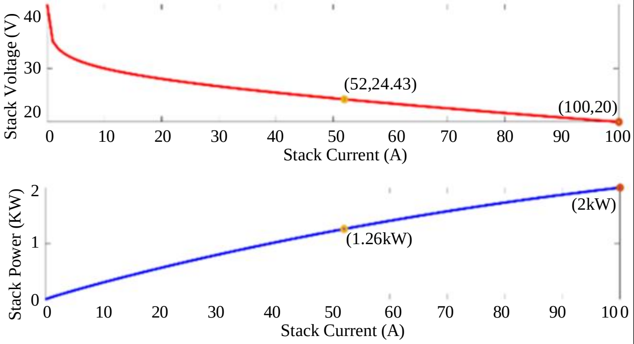

Fig. 2 Electrical characteristics of PEM fuel cell stack

3.2. Validation against Nominal P_{stack}

The validation of simulated stack power and efficiency has been done against nominal stack power in a detailed manner, as shown in Table 2. The expected stack power is calculated initially based on the nominal current, nominal voltage and initial fuel cell resistance. The tuning factor is a numerical value that can be adjusted to fine-tune the internal cell resistance of the fuel cell system.

It provides a way to systematically and dynamically modify the behavior of the system without directly changing the original parameters. The magnitude of the P_{stack} of the PEM fuel cell system depends on the value of internal cell resistance irrespective of system efficiency.

The variations in R_{internal} lead to a huge impact on the overall system efficiency, as estimated in Table 2. The maximum efficiency is achieved for the minimum value of internal cell resistance, and the PEM Fuel Cell has been optimized.

Table 2. Simulation analysis of PEM fuel cell

Tuning Factor	Simulated P_{stack} (W)	Nominal P_{stack} (W)	Simulated Efficiency (%)	R_{internal} (Ω)
1	1092.66	1259.96	59.77	0.061871
0.8	1126.12	1259.96	61.60	0.049497
0.6	1159.58	1259.96	63.43	0.037123
0.4	1193.04	1259.96	65.26	0.024748
0.2	1226.50	1259.96	67.09	0.012374

PEM fuel cell stack power and its efficiency variations for the variations in internal cell resistance (R_{internal} = 0.012374 & 0.061871) are simulated using m-file in MATLAB platform as shown in Figure 3. The optimization of the PEM fuel cell has been done to increase its reliability and stack efficiency, which will be integrated with a DC/DC boost converter and an intelligent controller to assess the performance at various load conditions.

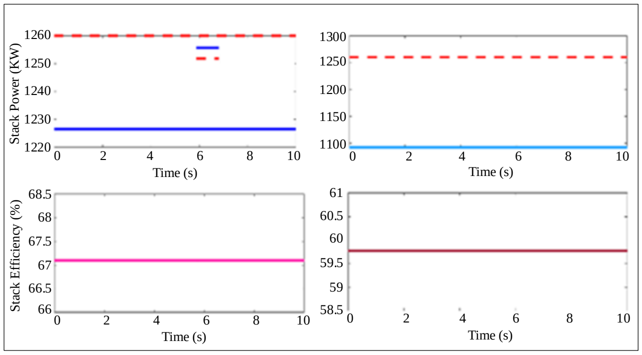

Fig. 3 Simulation of PEM fuel cell stack power and efficiency

Recognizing the significance of internal cell resistance implies a dedicated commitment to thoroughly explore the factors that influence the performance of PEM Fuel Cells and to investigate the intricate mechanisms governing their operation. The research seeks not only to advance theoretical understanding but also to provide practical insights for enhancing PEM Fuel Cell efficiency by highlighting strategies to mitigate the impact of internal cell resistance.

The coupling of the fuel cell with a DC/DC boost converter using an intelligent controller within the SIMULNIK platform provides a layer of complexity to the research. It also represents a logical approach to optimizing fuel cell performance while contributing to the stability of DC microgrids.

4. Integration with DC/DC Boost Converter and Intelligent Controller

4.1. Overview of DC/DC Converter and FLC

A Boost Converter is a type of DC/DC power converter that steps up the input voltage to a higher output voltage. It is a crucial component in power electronics and is widely used in various applications where a stable and higher voltage is required. The basic principle of a Boost converter involves the use of an inductor, a switch, a diode and a capacitor [10].

The Boost converter is known for its ability to efficiently step up voltage levels, which makes it a valuable tool in applications such as power supplies for electronic devices, renewable energy systems and electric vehicles [11, 12]. DC/DC converters are presented as the best choice for regulating the output voltage of PEMFC systems. This emphasizes their effectiveness in maintaining a stable and controlled voltage level [13].

The passage suggests that DC/DC converters are well-suited to meet the dual-power bus requirement. DC/DC converters are versatile and can adapt to different operating conditions. They can step up (boost) or step down (buck) the input voltage as needed [14]. Fuzzy Logic Control (FLC) is designed to handle problems where input information is vague, ambiguous, imprecise, noisy or even missing. This is particularly useful in situations where traditional control systems may struggle due to the presence of uncertainty [15].

FLC provides a systematic and efficient framework for incorporating linguistic fuzzy information from human experts. This is valuable in fields where human expertise plays a crucial role [16]. Fuzzy logic simplifies the design complexity of control systems. It is easy to understand and implement quickly and is cost-effective compared to some other control methodologies [17].

FLC is a versatile and effective methodology for dealing with complex systems where uncertainty and imprecision are prevalent. Its rule-based linguistic approach makes it accessible and practical for a variety of applications.

4.2. Benefits of Integration with PEM Fuel Cell System

Integration with FLC and DC/DC Boost converter can enhance the overall energy efficiency of a PEM fuel cell system. Fuzzy Logic Controllers are known for their ability to optimize and fine-tune control parameters in real-time by ensuring the fuel cell operates at peak efficiency under varying conditions [18].

FLC can adapt to changes in operating conditions and load demands by providing a dynamic response to fluctuations in power requirements. This adaptability is crucial for systems powered by renewable sources like fuel cells, where energy production can be variable [19].

The combined use of FLC and DC/DC Boost converter can contribute to improved system reliability by adapting to changing conditions and efficiently managing power flow. This adaptability can enhance the overall robustness of the fuel cell system. The precise control provided by FLC can help in minimizing stress on the fuel cell components by potentially reducing degradation over time. This may contribute to extending the lifespan of the fuel cell system [8].

5. Simulation on SIMULNIK Platform

The optimized PEM fuel cell is used for performance investigation using a DC/DC boost converter. FLC is employed to regulate and stabilize the converter output parameters under specified operating conditions. The DC/DC boost converter is specifically designed for this application using the most commonly used method, as shown in Equations 5, 6, 7, 8, 9 and 10, respectively.

$$\mathrm{I_{outmax}} = \frac{\mathrm{P}}{\mathrm{V_{out}}} \tag{5}$$

$$\Delta\mathrm{I_L} = 0.01 \times \mathrm{I_{outmax}} \times (\mathrm{V_{out}}/\mathrm{V_{in}}) \tag{6}$$

$$\Delta\mathrm{V_{out}} = 0.01 \times \mathrm{V_{out}} \tag{7}$$

$$\mathrm{L} = \frac{(\mathrm{V_{in}} \times (\mathrm{V_{out}} - \mathrm{V_{in}}))}{(\Delta\mathrm{I_L} \times \mathrm{f_s} \times \mathrm{V_{out}})} = 0.0019\mathrm{H} \tag{8}$$

$$\mathrm{C} = \mathrm{C_{IN}} = \mathrm{C_O} = \frac{(\mathrm{I_{outmax}} \times (1 - (\mathrm{V_{in}}/\mathrm{V_{out}})))}{(\mathrm{f_s} \times \Delta\mathrm{V_{out}})} = 1000\mu\mathrm{F} \tag{9}$$

$$\mathrm{D} = \frac{(\mathrm{V_{out}} - \mathrm{V_{in}})}{\mathrm{V_{out}}} = 0.9545 \tag{10}$$

Where,
I_{outmax} is converter output current,
ΔI_L is changing in inductor current,
P is maximum power delivered by PEM Fuel Cell (2000W),
V_{out} is converter output voltage or DC link voltage (440V),
V_{in} is maximum voltage delivered by fuel cell system (20V) as shown in Figure 2,
f_s is the sampling frequency (10KHZ),
ΔV_{out} is change in converter output voltage,
L is inductor and
C is filtering capacitance.

The SIMULINK diagram of the implemented DC/DC boost converter is shown in Figure 4.

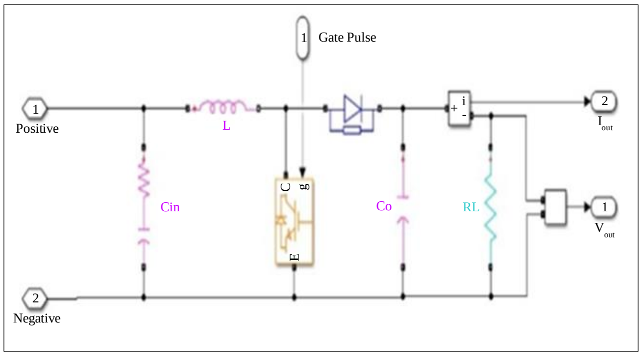

Fig. 4 SIMULINK diagram of DC/DC boost converter

The FLC is the major tool in renewable energy resources due to its ability to handle uncertainties and non-linearities. The SIMULINK diagram of the FLC model, which is implemented in this work, is shown in Figure 5.

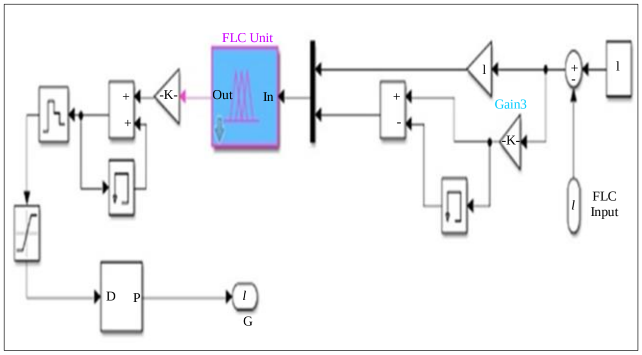

Fig. 5 SIMULINK diagram of the FLC model

The Mamdani model of FLC (7✕7) based closed-loop control is introduced for the PEM fuel cell Stack application with 49 rule bases. These rules define the behavior of the system based on input conditions.

The universal procedure for implementing an FLC in Simulink for a PEM fuel cell system is classified as Model initialization, Fuzzification, Rule base and rule evaluation, Aggregation, Defuzzification and Controller output to observe the behavior of the PEM fuel cell system under the control of the FLC. A fuzzy logic controller has two inputs, namely, error e(k) and changes in error Δe(k), and it is given by,

$$\mathrm{e(k)} = (\mathrm{V_{ref}} - \mathrm{V_k})$$

$$\Delta\mathrm{e(k)} = \mathrm{e(k)} - \mathrm{e(k-1)}$$

Based on initial simulation results, the performance optimization has been done by fine-tuning the parameters of the FLC. The fuzzy rule base (NB is Negative Big, NM is Negative Medium, NS is Negative Small, Z is Zero, PB is Positive Big, PM is Positive Medium, and PS is Positive Small) is constructed using the truth table given in Table 3.

Table 3. Truth table

Variable	**NB**	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
PB	Z	PS	PM	PB	PB	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PS	NM	NS	Z	PS	PM	PB	PB
Z	NB	NM	NS	Z	PS	PM	PM
NS	NB	NB	NM	NS	Z	PS	PM
NM	NB	NB	NB	NM	NS	Z	PS
NB	NB	NB	NB	NB	NM	NS	Z

The optimized PEM fuel cell stack, DC/DC boost converter and FLC-based closed-loop control system are implemented in the SIMULINK platform to analyze the performance of the projected system under different working conditions. The overall SIMULINK model of the projected system is shown in Figure 6.

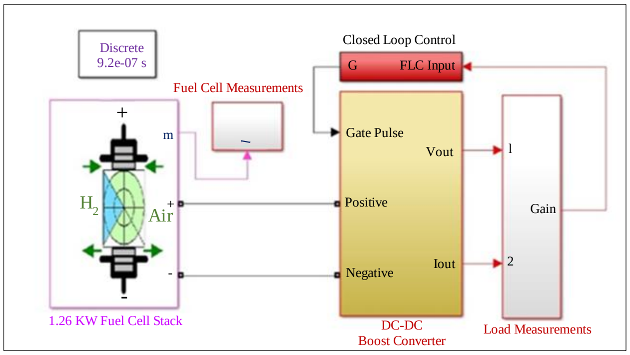

Fig. 6 SIMULINK diagram closed-loop control for PEM fuel cell system

6. Simulation Results and Discussion

The closed-loop control of the PEM fuel cell system has been implemented using FLC and DC/DC boost converter. The simulation is done for low voltage high current (20V, 100A) to low current high voltage (4.4A, 440V) conversion. The Stack current, voltage and power for a standard load of 96Ω have been observed, as shown in Figure 7.

In this view, FLC provides better stability in all parameters of the fuel cell side and is fast-acting when settling the oscillations. Also, it is proved that the PEM Fuel Cell is activated for higher efficiency by generating 20V of stack voltage and 100 A of stack current.

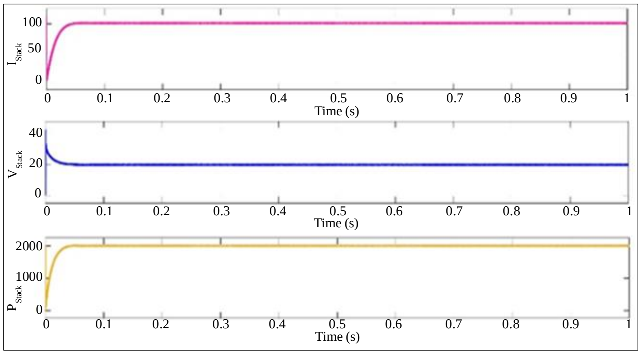

Fig. 7 Electrical characteristics of the PEM fuel cell system

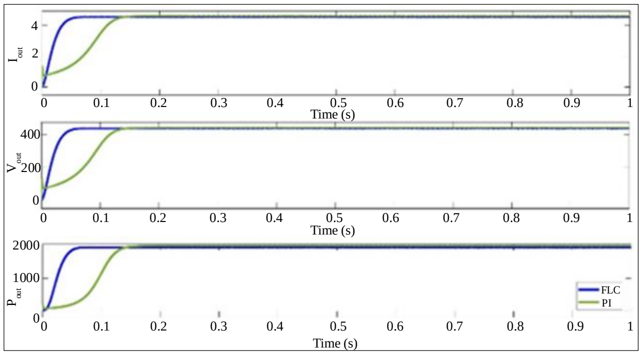

Fig. 8 Converter output comparison using FLC and PI controllers

Table 4. Comparison of FLC & PI controllers in PEM fuel cell closed-loop control

Control Type	V_{out} (V)	Rise Time (ms)	Settling Time (s)	Overshoot (%)
FLC	438	30	0.078	0
PI	435	76.26	0.26	1.9

The PWM generator is activated at 10KHZ frequency to enhance the accuracy of converter output parameters, and the duty cycle generated by FLC is exactly matched with the calculated value (D=0.9545). Simulation has been done to observe the DC/DC boost converter's output current, voltage and power using an FLC-based closed loop system, as shown in Figure 8.

The FLC-implemented converter output parameters were compared with the Proportional and Integral (PI) controller-based closed loop system to interpret the effectiveness of the FLC-based system, as shown in Figure 8. FLC demonstrates faster rise time (30 ms) compared to PI (76.26 ms). FLC has a quicker settling time (0.078 s) compared to PI (0.26 s), as given in Table 4.

FLC exhibits zero overshoot, while PI has a slight overshoot of 1.9%. The comparison suggests that FLC provides better dynamic performance with faster response and minimal overshoot. The comparison indicates that the FLC system may offer advantages in terms of faster response and lower overshoot.

7. Conclusion

In conclusion, this research delves into the optimization and integration of PEM fuel cells with an intelligent controller (FLC) and a DC/DC boost converter to enhance efficiency and reliability. The study not only focuses on theoretical advancements in PEM fuel cell technology but also extends its scope by incorporating cutting-edge technologies such as intelligent control and converters.

The comprehensive investigation addresses critical aspects such as internal cell resistance, stack power validation and overall system efficiency. The thorough analysis of internal cell resistance highlights its significant impact on stack power and system efficiency, which provides a basis for optimization strategies.

The validation against nominal stack power further confirms the effectiveness of the proposed model, which has a keen focus on minimizing internal cell resistance to achieve maximum efficiency. Also, the integration with a DC/DC boost converter and FLC brings additional benefits to the PEM fuel cell system.

The boost converter efficiently steps up voltage levels by using the low voltage and high current nature of the fuel cell. The simulation results on the SIMULINK platform showcase the successful implementation of closed-loop control by emphasizing the stability and efficiency achieved through FLC and the boost converter.

The comparison with a PI controller-based system underscores the superior dynamic performance of the FLC system, which exhibits faster response times, minimal overshooting, and improved settling times. This suggests that the integration of FLC and the boost converter not only enhances energy efficiency but also contributes to system reliability by adapting to dynamic operating conditions.

This research sets a new stage for future extensions by integrating the PEM Fuel Cell system with Energy Storage Systems (ESS) for better power management on the load side during decreased fuel and air pressure rates.

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