

Technical review notice

Educational PEM Fuel Cell Performance

Abdul Barek | 8 October 2026

Please read this notice before the original academic material.

The following pages preserve the original dissertation extract or presentation. This notice supersedes their experimental efficiency interpretations and direct simulation-validation claims. It does not alter the original measurements or establish corrected experimental results.

Experimental efficiency

The percentages labelled as efficiency in dissertation Table 4.7 and the related presentation do not substantiate hydrogen-to-electricity conversion efficiency. Power-percentage pairs imply a reference near 1.24-1.25 W, but its physical meaning is undocumented. Values above 100% cannot be explained as demonstrated fuel-energy conversion exceeding the energy input. These percentages and their causal explanations must not be treated as verified efficiency results.

Power, timing and measurement boundaries

Several reported powers differ from the products of the tabulated voltage and current. Original logs are needed to confirm simultaneous readings, units and the electrical measurement boundary. Entries such as 3.40 in the runtime table cannot yet be resolved as decimal minutes or minutes-and-seconds. Missing readings must remain missing rather than being assumed to be measured zeros.

Scope of the supported conclusions

The educational bench experiments and automotive-scale Simscape analysis are separate studies. The model was not directly validated against the educational stack. The records support a descriptive discussion of operating behaviour; they do not establish experimental efficiency, durability or the causes of performance variation.

Before journal submission

Recover the original logs, reconcile voltage-current-power calculations, confirm timing notation and cell/stack boundaries, and measure hydrogen consumption matched to electrical energy output. Specify HHV or LHV consistently. No replacement efficiency is claimed until these inputs are verified. The manuscript remains in preparation.

Project Title:

**PERFORMANCE ANALYSIS OF AN EDUCATIONAL
PROTON EXCHANGE MEMBRANE FUEL CELL STACK**

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1. Introduction

- Hydrogen fuel cells are essential for sustainable energy and decarbonisation, contributing to the global energy transition.
- Proton Exchange Membrane (PEM) fuel cells have low operating temperature, quick response and high-power density.
- The research proposes a four-stack reversible PEM fuel cell system based on the FCJJ-11 education platform.
- It can be used for both hydrogen production (electrolysis) and electricity generation (fuel cell).
- The study seeks to enhance energy efficiency, scaling, and stability, and transfer knowledge from educational platforms to practical industrial systems.
- This Study examines the performance of a Proton Exchange Membrane (PEM) fuel cell stack of automotive scale with the help of the PEM Fuel Cell System model in the MATLAB. Its purpose is to evaluate efficiency, Current and Voltage analysis, power output, for the application of automotive power range of 80-100kW.

1.1 Problem Statement

- Current educational systems (e.g., FCJJ-11) are single-stack only, limiting the study of real multi-stack systems.
- Multi-stack PEM systems face issues with current distribution, water balance and thermal stability.
- Limited experimental data and scalable models exist for reversible multi-stack PEM fuel cells, particularly in research and education.



1.3 Aim and Objectives

The goal of the dissertation is to design, develop and to analyse a Reversible Educational kit of Proton Exchange Membrane (PEM) Fuel Cell system and to test the performance of this system both by experimental testing and MATLAB to test performance in educational and laboratory scale applications. The research concentrates on the operational behaviour, efficiency as well as performance features of the fuel cell under both the electrolyser and fuel cell operation.

1. Design and create a 3D CAD model of the PEM fuel cell, fabricate and assemble a working reversible educational prototype.
2. Experimentally assess the performance of the fuel cell by measuring the important parameters like voltage, current, power output, hydrogen production, and efficiency under varying operating conditions.
3. Determine the steady-state behaviour of the system, such as power output, efficiency trends, and hydrogen utilisation.
4. Create a MATLAB/Simulink model which will simulate the behaviour of the fuel cell and model the experimental conditions.
5. Compare and confirm the simulation results with experimental data to evaluate the accuracy and determine variations in performance.



2. Literature Review

Author & Year	Function	Key Findings	Limitation / Drawbacks	Research Gap
Amphlett et al., 1995	Semi-empirical PEMFC model	Modeled activation, ohmic, and concentration losses; predicted polarization curves	Limited to single-cell steady-state analysis	No stack-level or transient performance evaluation
Springer et al., 1991	Membrane conductivity & water transport	Established relation between hydration and ionic conductivity	Focused on lab-scale single cells	No automotive-scale or dynamic analysis
Pukrushpan et al., 2004	Dynamic control-oriented PEMFC model	Included gas flow and transient load response for vehicles	Simplified thermal and flow effects	Lacked full multi-physics integration for automotive stacks



Author & Year	Function	Key Findings	Limitation / Drawbacks	Research Gap
Zhang & Kandlikar, 2012	Water management & transport phenomena	Studied flooding and dehydration in PEM stacks	No full system-level MATLAB Simscape simulation	No parametric study on automotive-scale stacks
Ouyang et al., 2016	Adaptive control & MPPT	Improved efficiency under variable load conditions	Focused mainly on control strategy, limited modeling	Lacked validated high-power automotive-scale stack simulation
Barbir, 2013	Automotive PEMFC performance analysis	Highlighted durability, power density, and transient response requirements	Mostly theoretical discussion, minimal simulation validation	Need for validated dynamic MATLAB Simscape models for 80–100 kW stacks



3. Research Methodology

- The experimental design involves multiple reversible PEM fuel cell stacks connected in series as shown in Figure 1, to produce higher voltage output and system scalability.
- A voltage-ampere controller (WEIR 4000) is used to provide stable current and voltage during electrolysis, ensuring consistent hydrogen generation as in Figure 2.
- Hydrogen and oxygen gases are collected using the water displacement method, allowing accurate measurement of gas volume produced during electrolysis as shown in Figure 3.
- Distilled water reservoir and measuring beakers are used to maintain purity and ensure reliable electrochemical reactions as shown in Figure 4.
- Real-time measurements of voltage, current, and time are monitored via digital multimeter and stopwatch, allowing calculation of energy input and efficiency to be performed accurately.
- The resistors are used to simulate the load and maintain consistent voltage-current behaviour and measure power output accurately when the fuel cell is operating.

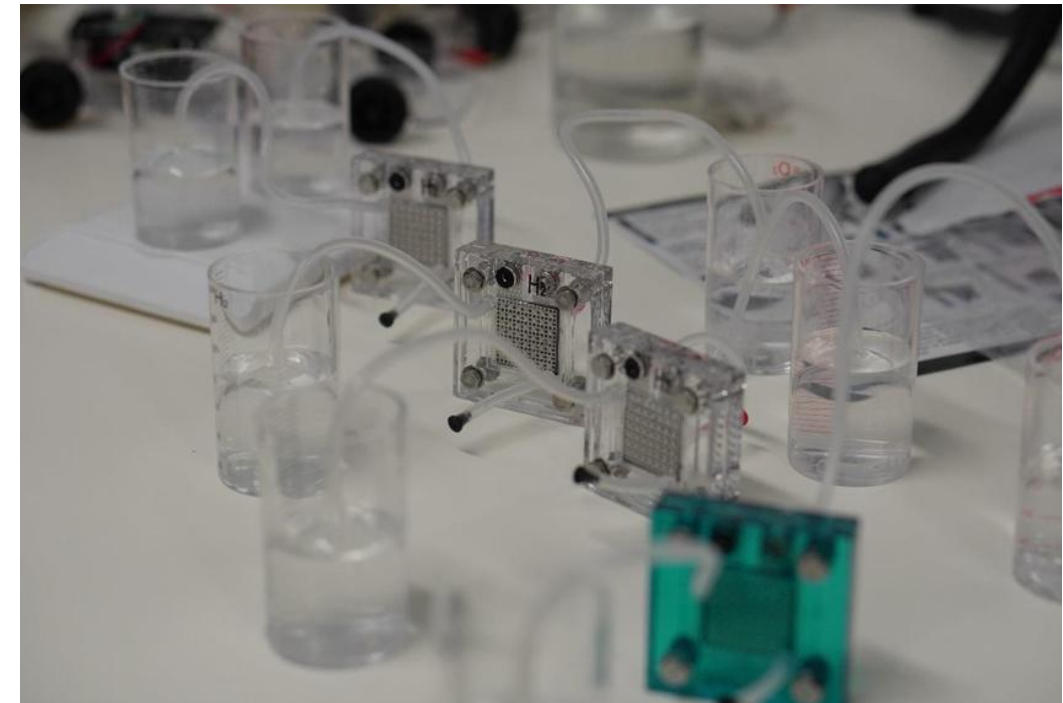
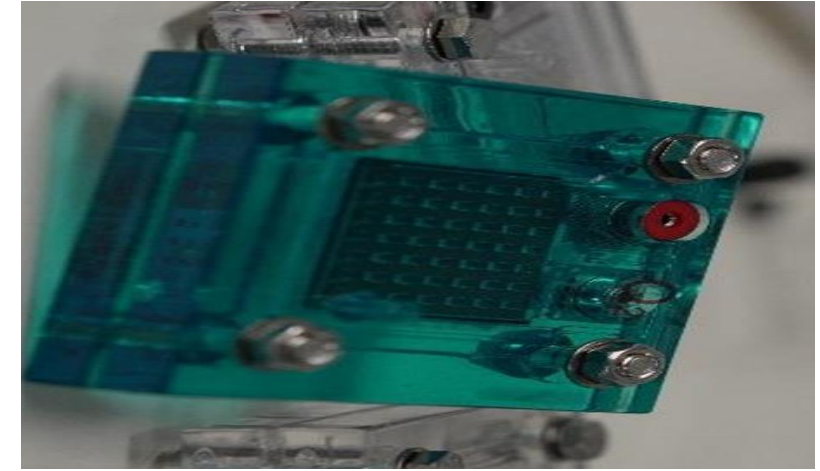


Figure 1: Multiple reversible PEM fuel cell





Figure 2: Electrolysis Module

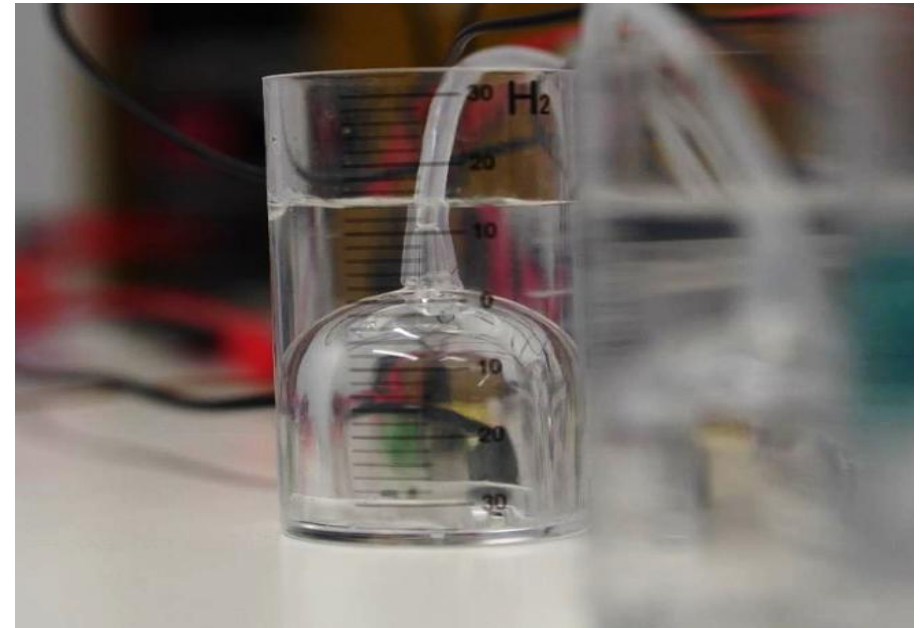


Figure 3: Water Displacement Beaker

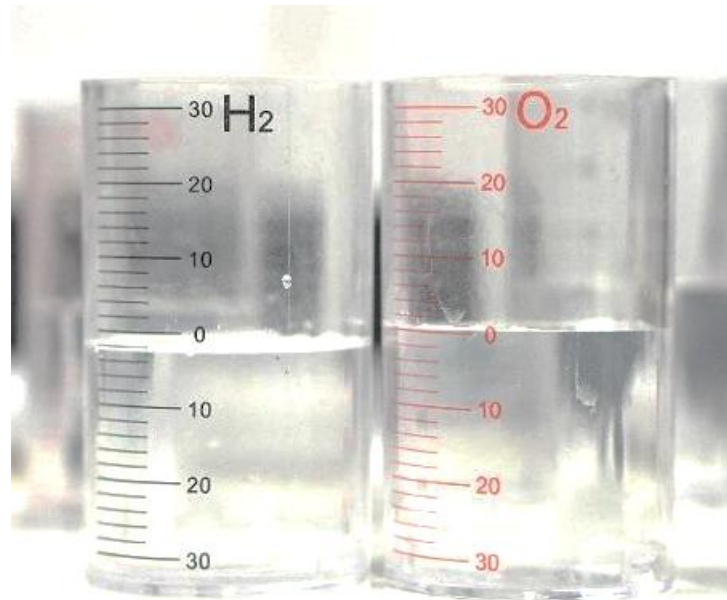


Figure 4: Measuring Beaker



- MATLAB Simulink and Simscape are used to develop a physics-based model of a PEM fuel cell to simulate the behaviour of electrochemical, thermal and fluid dynamics.
- There are electrochemical, thermal and reactant flow sub-models within the system architecture, which are compiled into a full fuel cell stack model as in Figure 5.
- Electrochemical modelling is a model that relies on the Nernst voltage and losses (activation, ohmic, concentration) to predict the fuel cell performance.
- Thermal modelling uses energy balance equations to analyse heat generation and cooling system behaviour (Figure 3.2).
- The MATLAB model allows the simulation of steady-state and transient cases as well as load variations and performance analysis.
- Experimental setup for results (voltage, current, hydrogen production) are used to validate and compare simulation results, ensuring model accuracy and real-world relevance as shown in Figure 6.

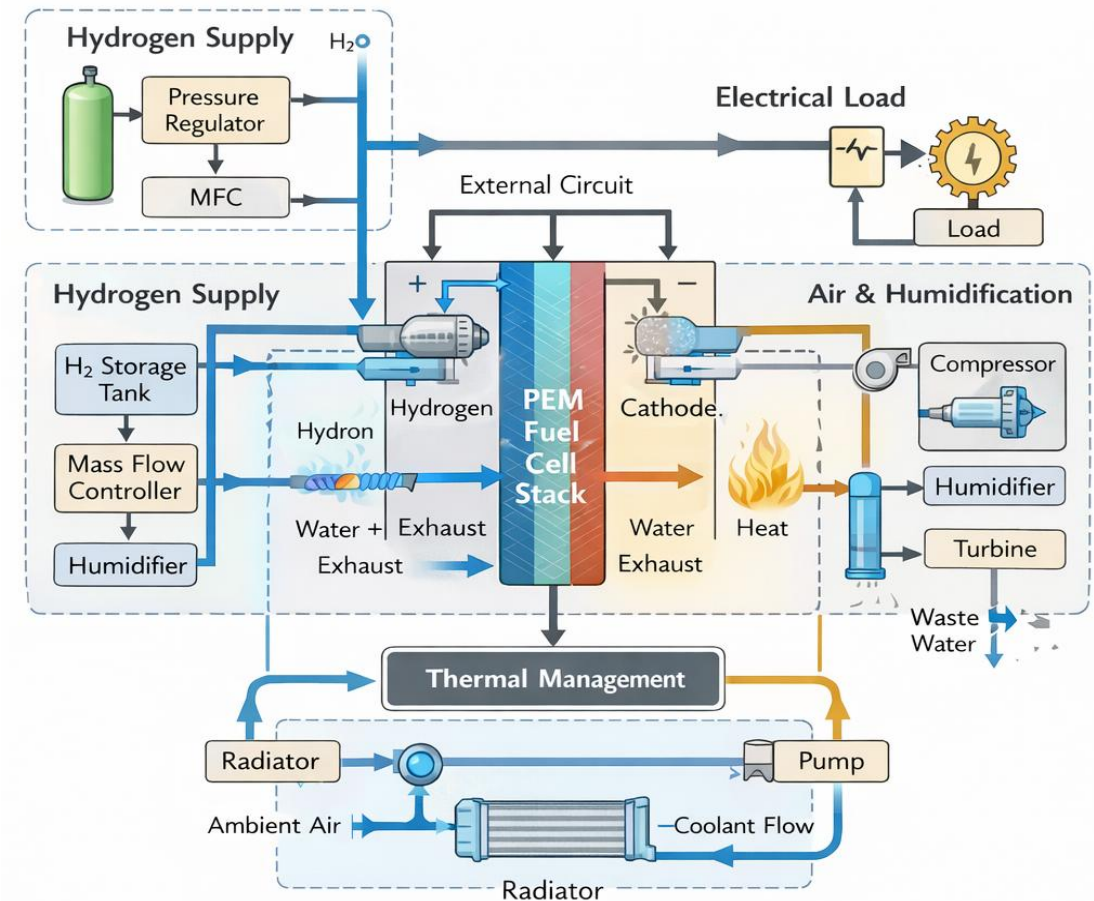


Figure 5: PEMFC system architecture



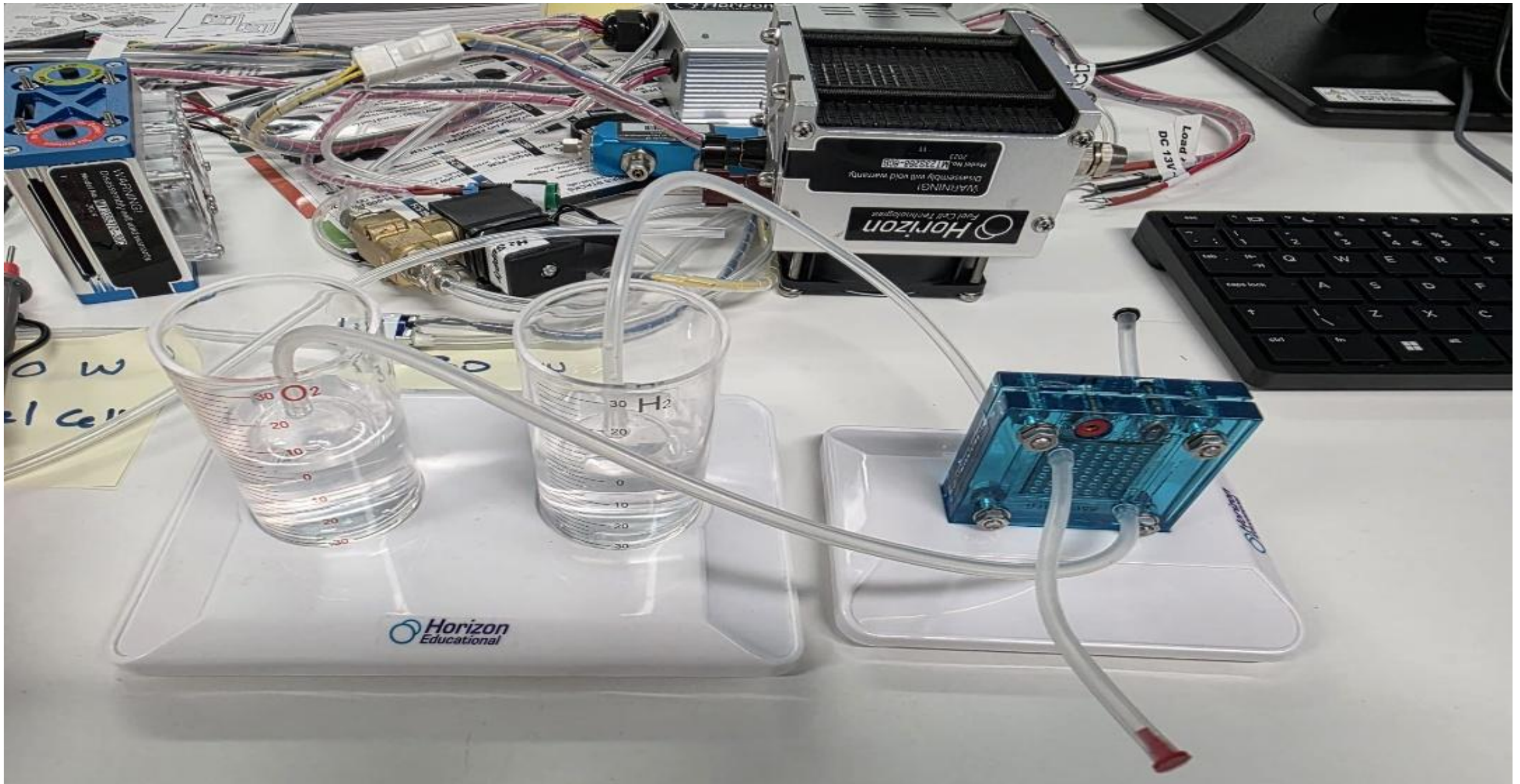


Figure 6: PEMFC Experimental setup



4. Results analysis

4.1 Hydrogen & Discharge Performance

- The time of hydrogen generation does not change significantly in all tests with an average of 2.30 min, which is stable performance in electrolysis as illustrated in Figure 7.
- Voltage fluctuations, temperature and electrolyte conditions cause slight changes in filling time, although overall consistency confirms system reliability (Figure 7).
- The range of fuel cell discharge is between 2.3 to 4.25 minutes with an average of 3.28 minutes as shown in Figure 8.
- A longer discharge time is a sign of greater hydrogen utilisation and electrochemical performance (Figure 8).
- Membrane hydration, consistency of hydrogen storage and load conditions influence variations in run time.
- In general, the findings indicate that hydrogen production and fuel cell functioning are stable when the test conditions vary.

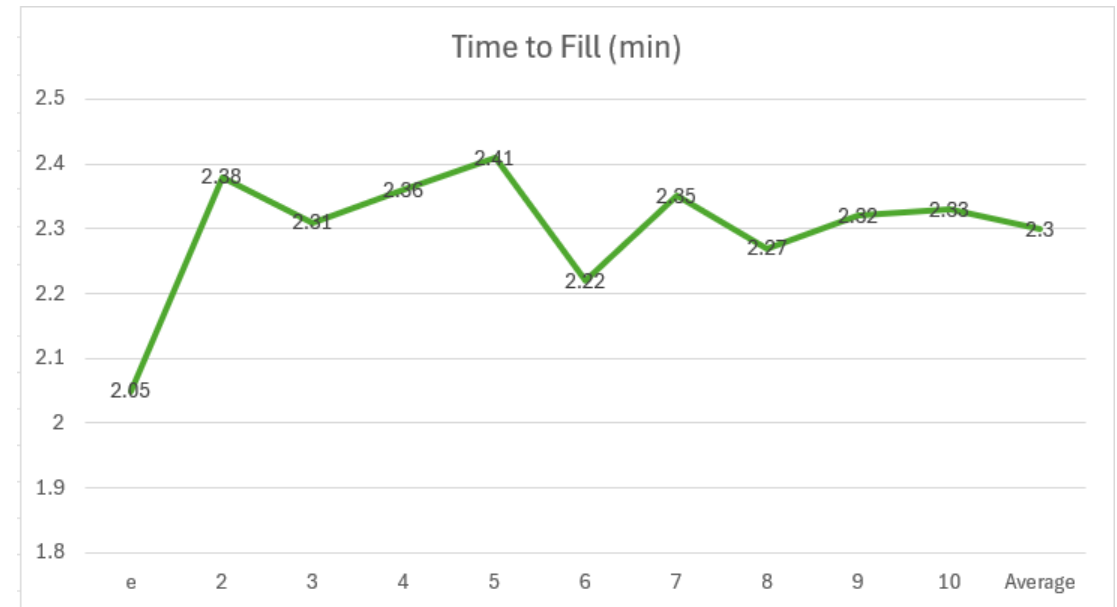


Figure 7: Time of Filling Hydrogen vs Number of Test



Figure 8: Run Time vs Test Number

4.2 Electrical Performance Behaviour of PEMFC

- Primary discharge has high current (approximately 2 A) and voltage of about 0.7-0.8 V, which verifies the presence of active electrochemical activity as in Figure 9.
- The maximum power output is about 1.5 W, which means that the chemical energy is effectively converted to electrical energy (Figure 9).
- Figure 10 shows that the voltage drops with time, between 0.749 V and 0.640 V, because of ohmic losses and fuel depletion.
- The current decreases to 0.71 A with drops in reaction rates and availability of hydrogen as illustrated in Figure 11.
- The power output decreases 1.00 W to 0.52 W, and this indicates that there is a degradation of performance during discharge as in Figure 12.
- Overall, tendencies prove that voltage, current, and power strongly depend on the availability of hydrogen and system losses.

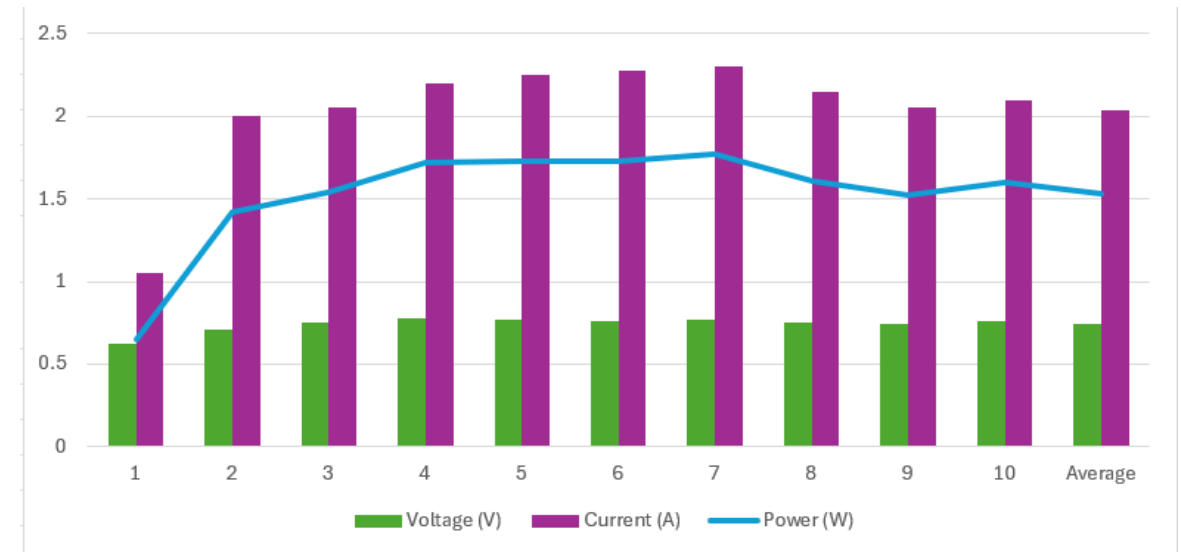


Figure 9 Voltage, Current and Power vs Number of Tests

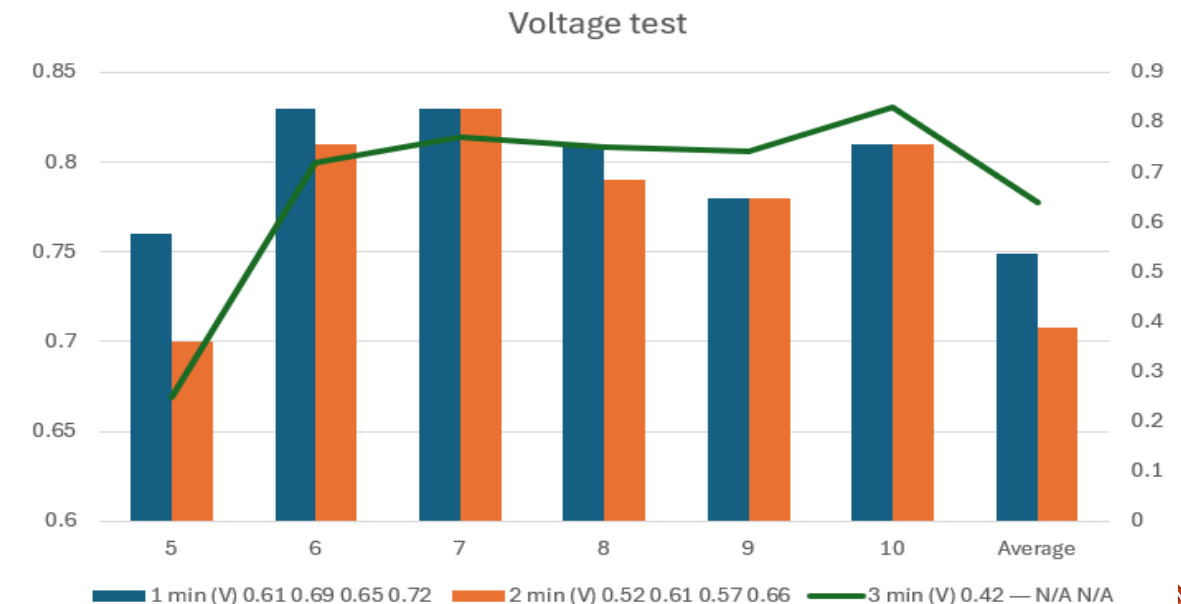


Figure 10 Voltage vs Time Excel Plot



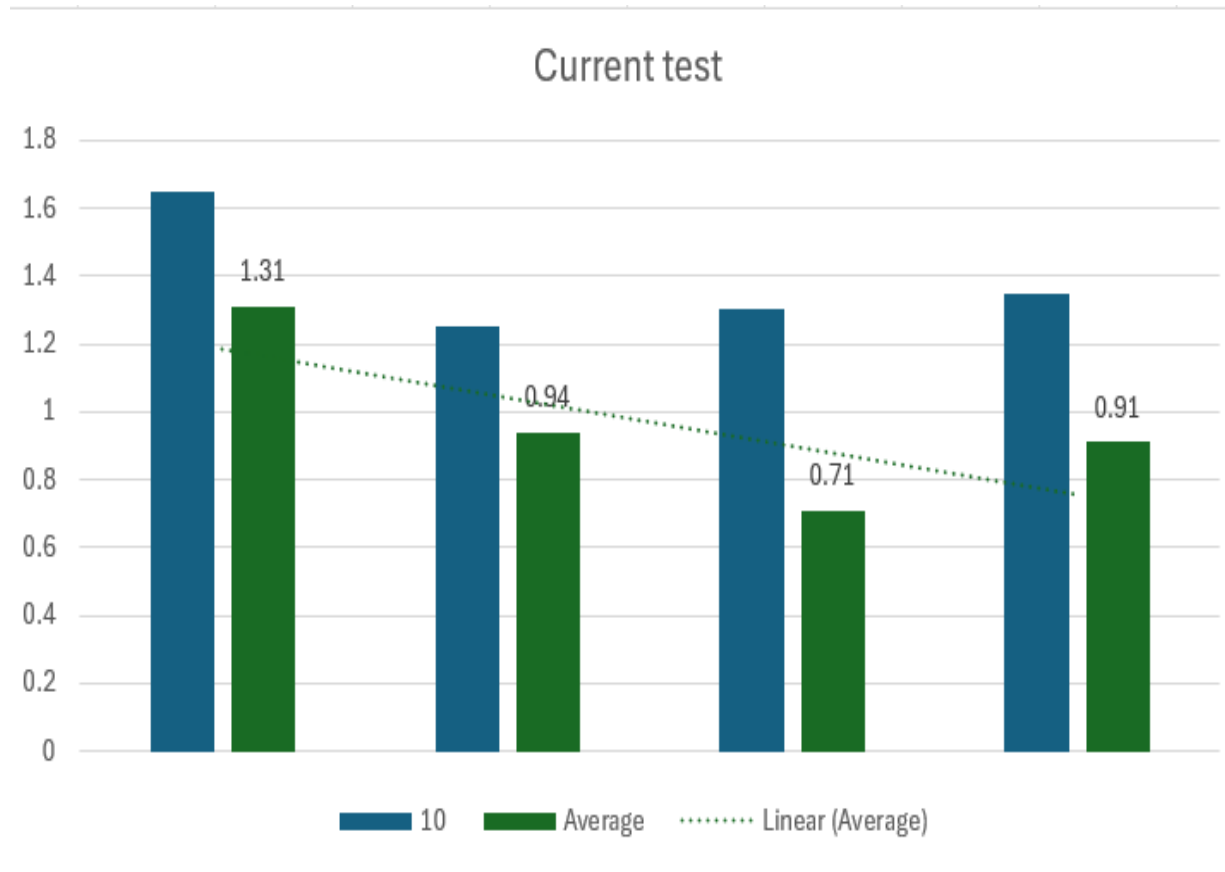


Figure 11 Current vs Time Excel Plot

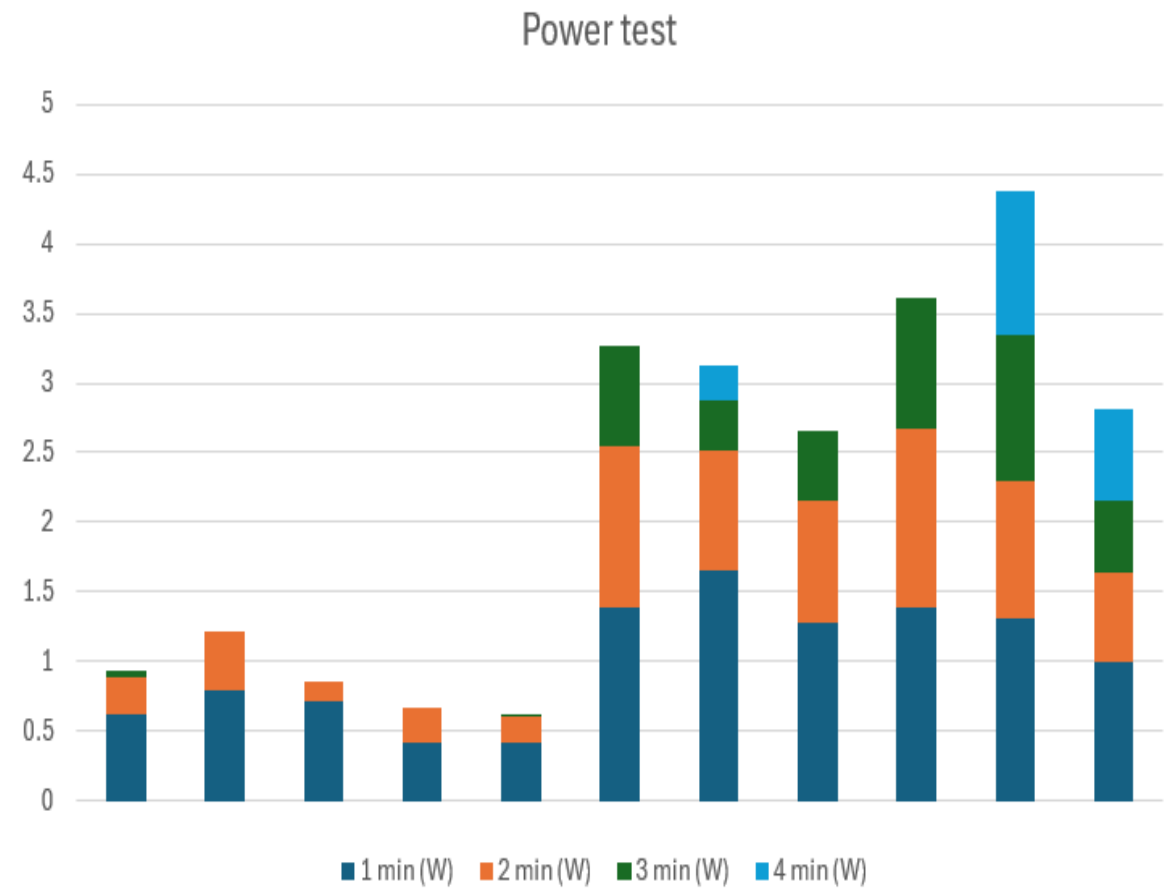


Figure 12 Power vs Time analysis



4.3 Efficiency & MATLAB Simulation

- Experimental efficiency begins at a high level (~80 percent) and declines to a very low level (~11 percent) with time, because of fuel depletion and system losses as shown in Figure 13.
- Efficiency above 100% in some tests is due to initial transient energy release and measurement variations (Figure 13).
- The current variation is dynamic (up to 250 270 A) under realistic load conditions as seen in MATLAB simulation as shown in Figure 14.
- Stack voltage is inversely proportional to current (around 350-500 V), and this is the anticipated behaviour of PEM fuel cells (Figure 14).
- The power output goes up to approximately 90 kW, and the heat production varies with the load, which is a sign of thermal losses as shown in Figure 15 and Figure 16.
- The model is confirmed by temperature stabilising at 70-80 C with cooling system and consumption of hydrogen matching energy production Figure 17.

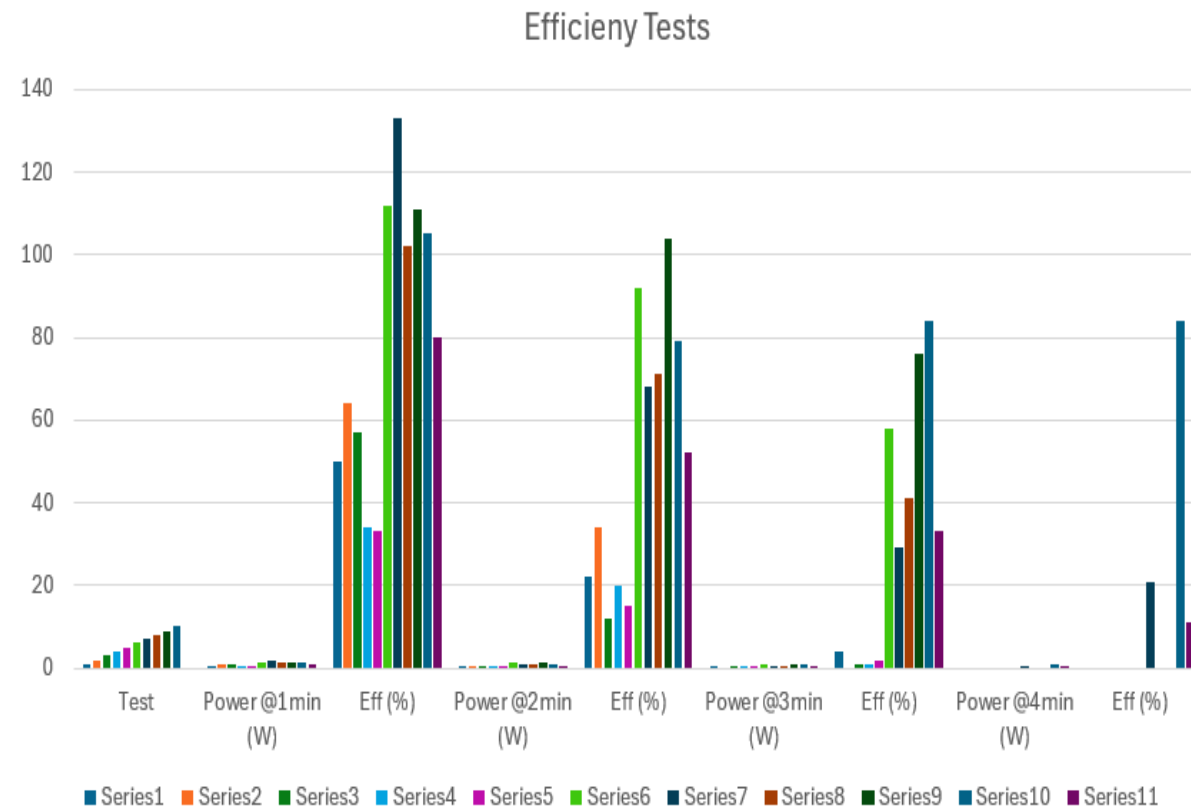
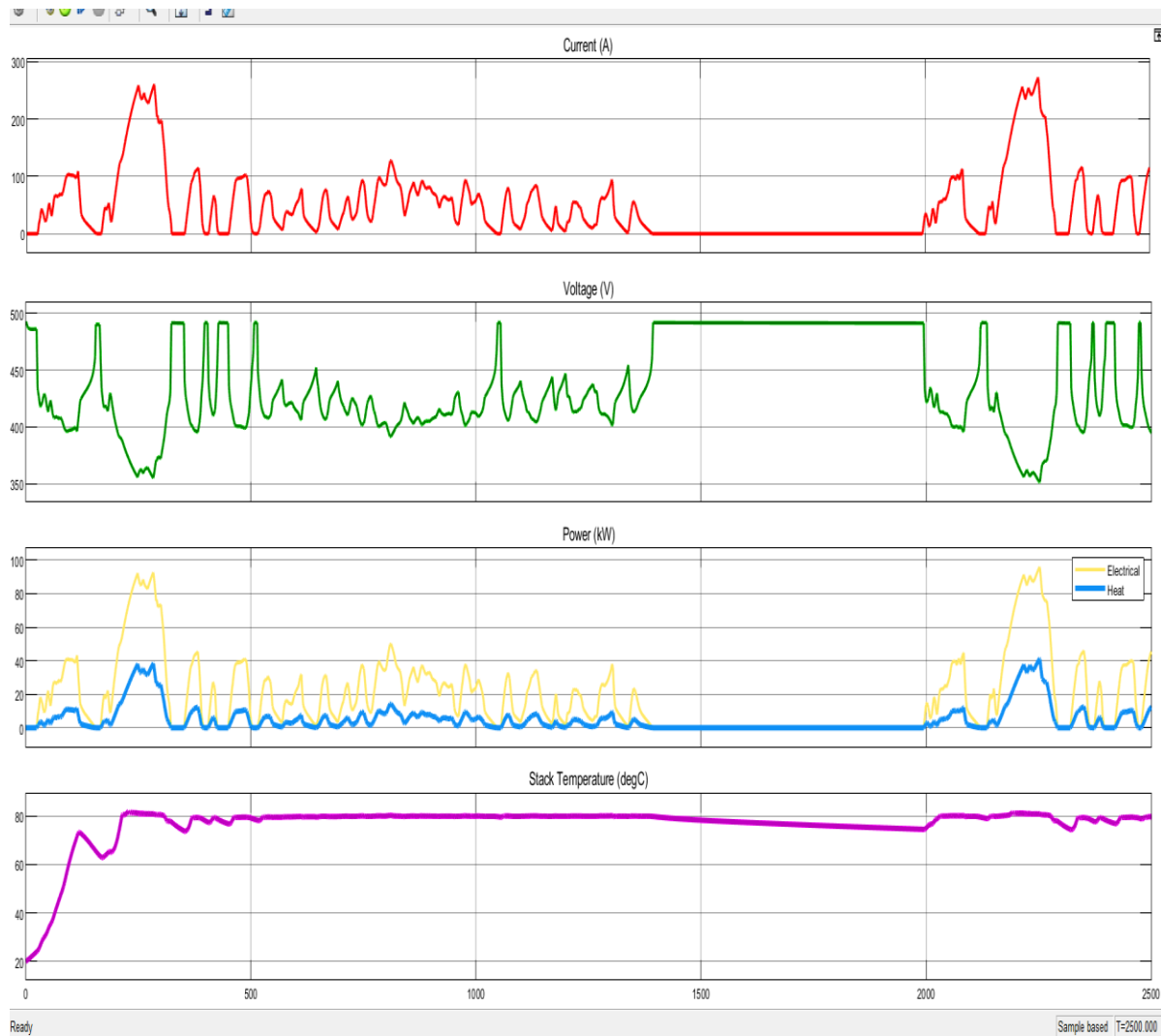
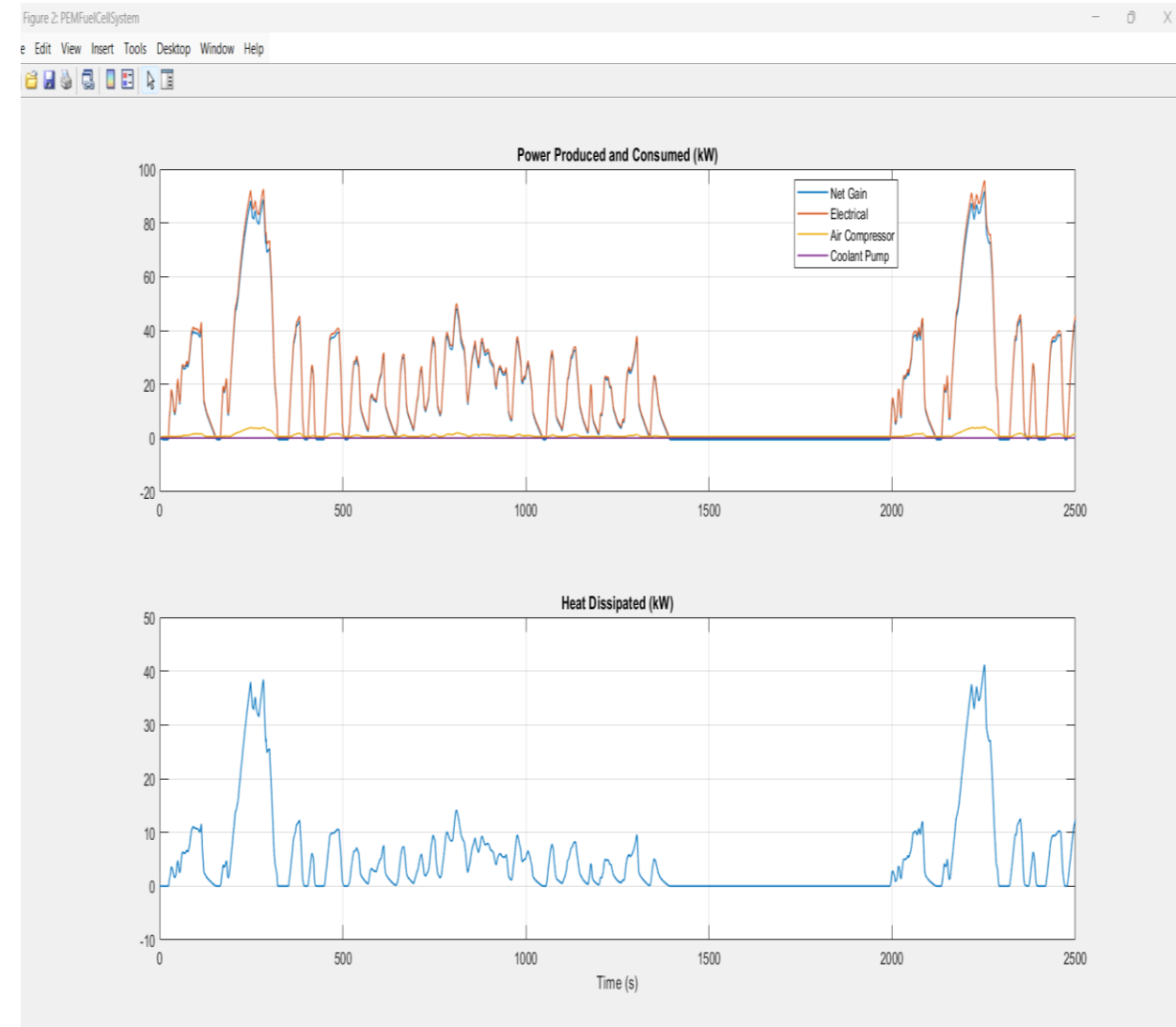


Figure 13 Efficiency tests vs Time Excel Plot





**Figure 14 Current, Voltage and Power variation
MATLAB Simulation Plot**



**Figure 15 Power Consumption and Electrical Power
Production Plot**

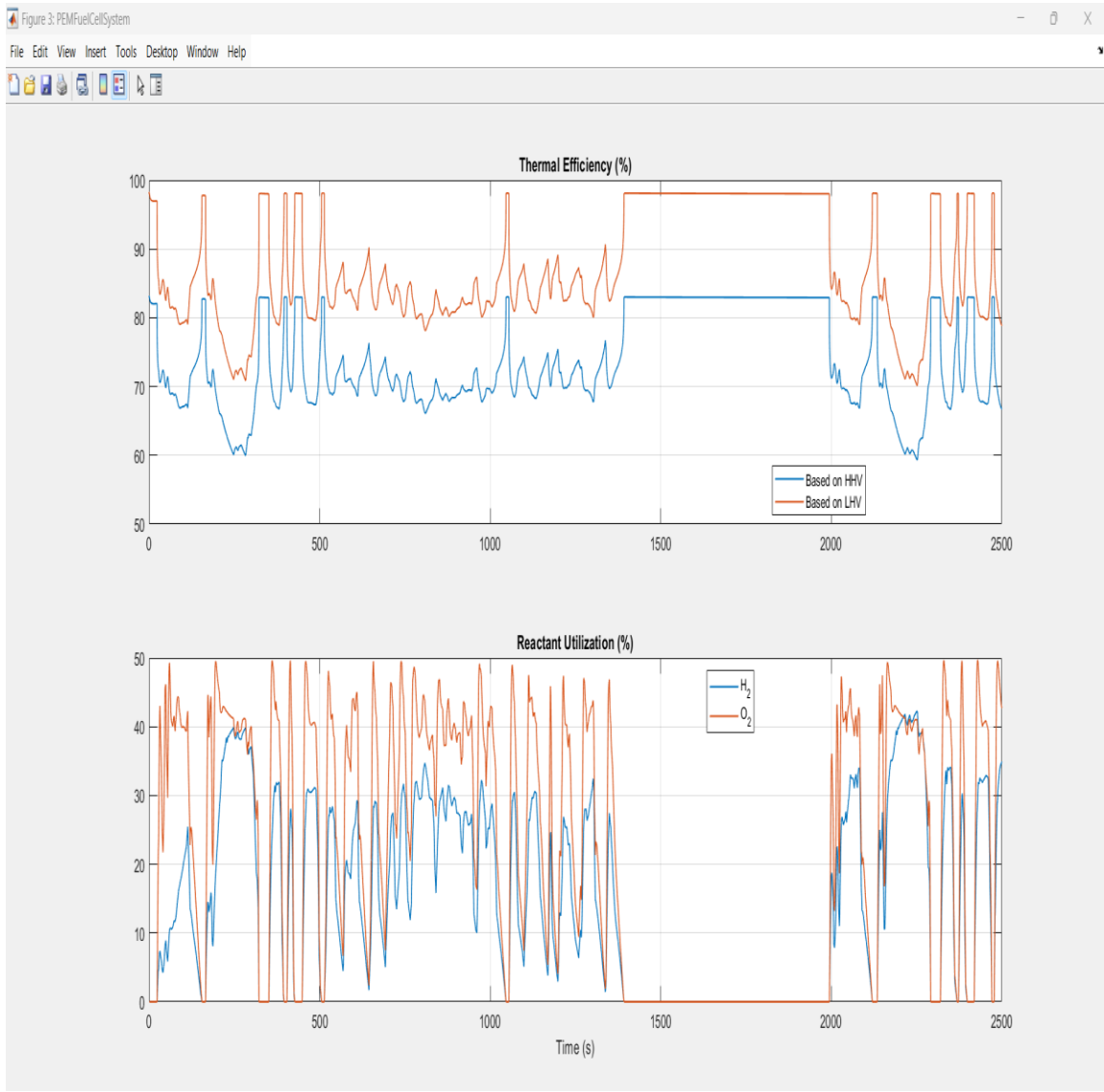


Figure 16 Fuel cell stack Plot

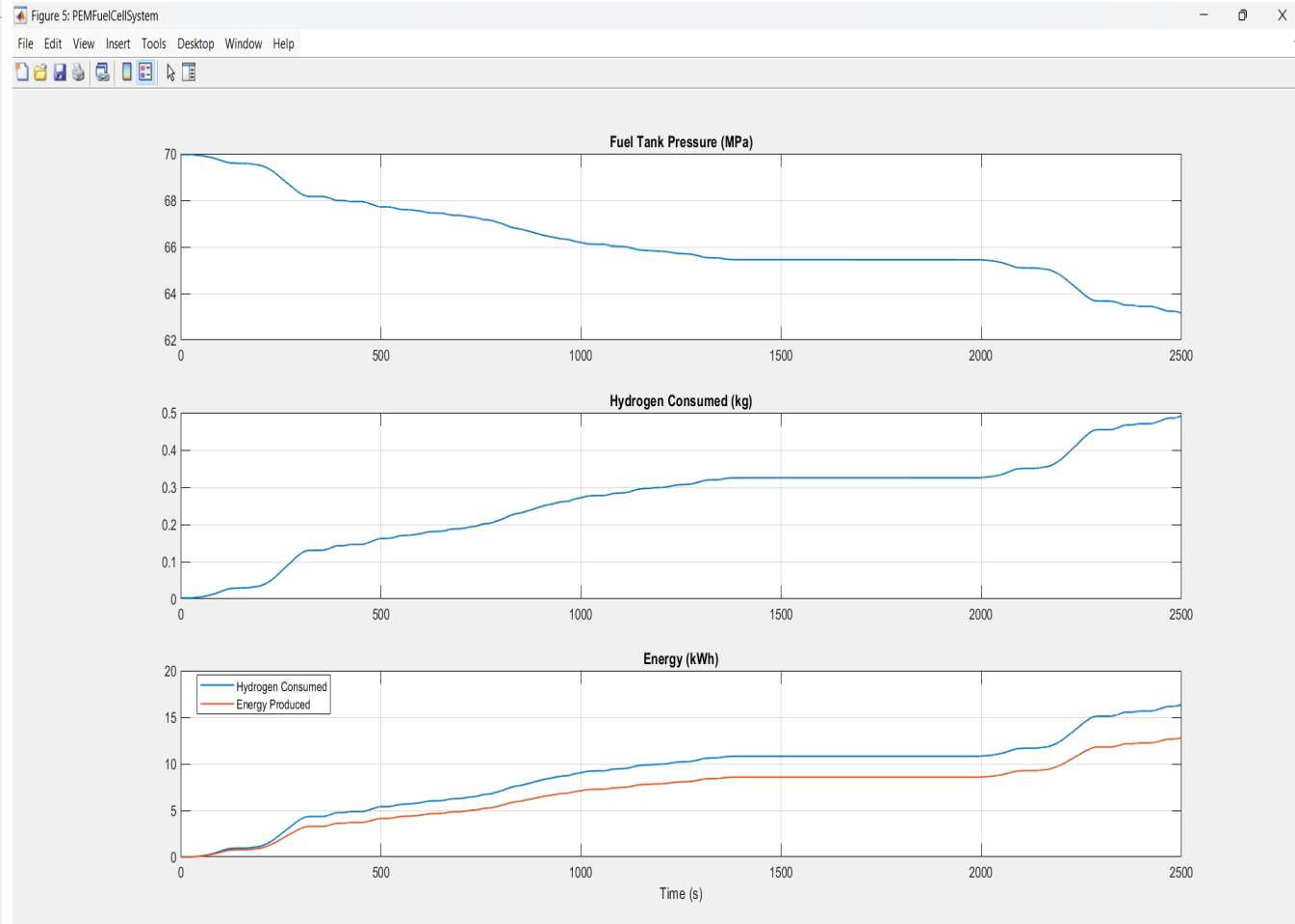


Figure 17 Hydrogen utilization & energy production of PEMFC



5. Conclusion

- The PEM fuel cell demonstrates satisfactory behaviour in the initial mode of operation with an average run time of approximately 3.28 minutes, but voltage, efficiency, and power decline with time because of fuel depletion and system loss.
- Efficiency decreases dramatically, at 1 minute to about 80 percent, then 4 minutes to approximately 11 percent, meaning that it heavily relies on a continuous supply of hydrogen and the increasing internal losses.
- The performance and stability of the experimental results are lower and less stable than the results of the simulation in MATLAB due to the assumption of ideal conditions in simulations and lack of real-world inefficiencies.
- Hydrogen leakage is a significant problem in the system because of poor joint and pipe connection sealing, decreasing fuel availability and the overall efficiency.
- The natural pressure hydrogen supply mechanisms result in an uneven flow rate resulting in unstable voltage, current, and power delivery.
- Performance can be enhanced by several design enhancements including enhanced sealing (gaskets, sealants), enhanced pipe connections, dotted hydrogen delivery (pump and regulator) and expanded storage capacity.
- The system is effective for educational purposes but lacks engineering optimization; improving design factors like sealing, thermal management, and fuel control can make it more practical and efficient.



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