



## Modelling of Fuel Cell Based Electric Vehicle

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**ABSTRACT:** The global transportation sector is undergoing a critical transformation to address climate change and reduce carbon emissions, with electric vehicles (EVs) emerging as a promising sustainable alternative to conventional internal combustion engine vehicles. Fuel cell (FC) technology presents a compelling solution to overcome traditional battery electric vehicle limitations, offering longer driving ranges, rapid refueling capabilities, and zero tailpipe emissions. Despite the potential of FC-based EVs, comprehensive and accurate modeling remains crucial for understanding system performance, optimizing design parameters, and accelerating technological advancement. This research focuses on developing a detailed MATLAB-based simulation model for fuel cell electric vehicles, leveraging advanced computational tools to provide in-depth insights into system dynamics and performance characteristics. By utilizing MATLAB's sophisticated modeling capabilities, the study implements a comprehensive approach that integrates fuel cell power generation, electrical drivetrain components, and vehicle dynamics into a unified simulation framework. The primary contributions of this research include: (1) developing a high-fidelity MATLAB simulation model that captures the complex interactions of FC-EV subsystems, (2) validating the model against experimental data to ensure accuracy and reliability, and (3) providing insights into system efficiency, energy management strategies, and performance optimization. Preliminary results demonstrate the model's potential to predict vehicle performance under various driving conditions, offering valuable guidance for FC-EV design and development. The manuscript presents a systematic methodology for FC-EV modeling, showcasing MATLAB's capabilities in simulating advanced transportation technologies and contributing to the ongoing research in sustainable mobility solutions.

**Keywords:** Fuel cell, Battery, Electric vehicle, modelling MATLAB.

### 1. Introduction

The demand for efficient and sustainable transportation solutions around the world has accelerated research into alternative propulsion systems, especially hydrogen fuel cell electric vehicles (HFCEVs). Compared to traditional battery electric cars (BEVs), these vehicles, which use hydrogen as a clean energy source, have a number of benefits, such as longer range, quicker refuelling times, and the capacity to carry bigger loads. However, obstacles including exorbitant

prices, inadequate hydrogen infrastructure, and technical inefficiencies continue to restrict their wider implementations.

New approaches to solving these problems have been made possible by recent developments in artificial intelligence (AI) and computational modelling. Research has concentrated on contrasting HFCEVs with BEVs, modelling HEV designs using hydrogen fuel cells, and refining energy management systems using cutting-edge AI methods like deep learning and reinforcement

learning. In addition to demonstrating how HFCEVs have the ability to completely transform the transportation industry, this body of study emphasises the necessity of interdisciplinary approaches to get past present obstacles.

At the forefront of environmentally friendly transportation technology are hydrogen fuel cell hybrid electric vehicles (FCHEVs), which combine the advantages of hydrogen fuel cells with additional energy sources like batteries. These cars present a viable way to overcome the drawbacks of traditional battery electric vehicles (BEVs), such as their short range, lengthy charging periods, and inability to scale for heavy-duty uses. The technological and operational obstacles to FCHEV adoption have been the subject of recent studies, with a focus on system integration, real-time optimisation, and sophisticated energy management techniques.

## 2. Related Works

A comparison between HFCEVs and BEVs is presented by Fanti et al. (2024), with an emphasis on performance, environmental effect, and energy efficiency. The study assesses the postal car as a case study using MATLAB modelling, offering insights on the real-world use of HFCEVs in logistics (Fanti et al., 2024). While pointing out the difficulties with cost and hydrogen infrastructure, this study highlights the long-range potential of HFCEVs [1]. The use of hydrogen fuel cells in hybrid electric vehicle (HEV) systems is examined by Shchurov et al. (2024). Their simulation method assesses these vehicles' energy management and dynamic performance, aiding in the creation of effective hybrid systems (Shchurov et al., 2024). The advantages of integrating hydrogen fuel cells with conventional battery systems to improve energy efficiency are highlighted by this study [2]. For fuel cell electric vehicles (FCEVs), Kim et al. (2024) suggest a modelling and optimisation methodology based on deep neural networks. To maximise overall vehicle performance, this strategy combines the features of electric motors and power sources

(Kim et al., 2024). By using cutting-edge machine learning techniques, the methodology offers a possible path towards increasing HFCEV efficiency [3].

A deep reinforcement learning-based energy management approach designed specifically for hydrogen fuel cell-powered hybrid electric vehicles (HEVs) is presented by Huang et al. (2024). In order to increase the longevity of fuel cell systems, the study uses a model predictive control framework and emphasises energy use that is health-conscious (Huang et al., 2024). This study emphasises how artificial intelligence can be used to maximise system lifespan and real-time energy distribution [4]. Guo et al. (2024) investigate cost-effective predictive energy management techniques for FCHEVs. In order to increase energy distribution and overall system efficiency, their study makes use of real-time nonlinear optimisation techniques. The framework is appropriate for practical applications since it improves computing efficiency through the use of model continuity approximations. According to Guo et al. (2024), this study offers a crucial step in connecting theoretical optimisation models with real-world application [5]. Regional train systems are added to the list of FCHEV applications by Kapetanović et al. (2023). Their research addresses energy efficiency and consumption in passenger transport services by creating an energy model for regional trains that are fuel cell hybrid-electric. Additionally, the study looks at vehicle-to-grid applications, emphasising how hybrid systems might be integrated with larger energy networks. This study highlights how fuel cell technology can be used in a variety of transportation modes (Kapetanović et al., 2023)[6]. Eisner et al. (2024) concentrate on enhancing hydrogen dilution management and air supply to improve hydrogen fuel cell performance. The work improves fuel cell dynamics regulation through the use of explicit model predictive control, which lowers emissions and increases system efficiency. Maintaining optimal fuel cell operation under a variety of situations is one of the major issues in FCHEV

design that this study attempts to address (Eisner et al., 2024).[7]. Proton exchange membrane (PEM) fuel cell devices for energy-efficient electric vehicles are thoroughly reviewed by Jahan et al. (2024). The modelling, simulation, and system integration strategies used to maximise the performance of PEM-based FCHEVs are covered in their chapter. This study illustrates methods for attaining energy efficiency and provides insights into the difficulties of scaling PEM systems for various vehicle types (Jahan et al., 2024) [8]. A multi-objective energy management approach for FCHEVs based on stochastic model predictive control (SMPC) was presented by Ma et al. in 2022. Their research highlights the necessity of managing the inherent uncertainties in fuel cell performance, driving conditions, and energy demand. The suggested approach anticipates future driving habits and adjusts to shifting road conditions to maximise fuel usage, battery life, and the fuel cell's operational efficiency. The system can take into consideration random fluctuations, including erratic driving behaviour or environmental factors (like traffic conditions and road gradients), by using a stochastic model. As a result, the vehicle's energy management system makes more sound decisions [9]. Anbarasu et al. (2022) suggested employing advanced dynamic model predictive control (ADMPC) to improve energy management in FCHEVs in a novel way. By integrating dynamic adjustments based on the system's driving behaviour and real-time performance, this approach improves on the conventional model predictive control (MPC). Anbarasu et al.'s work emphasises the significance of managing the battery's state of charge (SOC), the fuel cell's hydrogen consumption, and the power distribution between the fuel cell and battery [10].

A handy tool for simulating fuel cell electric vehicle performance with straightforward input is presented by B. Yang et al. in this study. An internal hybrid/battery/fuel cell vehicle modelling tool (HBFCMT) can be used to study the fuel cell powertrain combination under the presumption of

a specific control strategy. The model results are within the expected range in terms of trend when compared to test data in this publication [11]. Shengyan Hou et al. describe the fuel cell electric car powertrain system's control technique and suggest an energy management approach based on reinforcement learning. The findings of the experiment and simulation demonstrate that the suggested algorithm may maintain battery SOC stability while reducing hydrogen usage [12].

Ryan A. et al. describe how a small "Neighbourhood" fuel cell hybrid electric vehicle (FCHEV) was validated using a chassis dynamometer and National Instruments Data Acquisition equipment after being modelled using MATLAB/Simulink. Predicting motor and battery performance when driving in transitory situations and estimating the vehicle's range when utilizing one or more fuel cell stacks are among the objectives of the model's development [13]. A. Ancuta et al. suggest modelling a fuel cell, which serves as the primary energy source for an electric propulsion system. MATLAB Simulink software is used to construct the model, which adjusts existing fuel cell and vehicle blocks to the actual vehicle scenario. The time development of a few key parameters for the vehicle and fuel cell is included in the simulation findings [14]. The simulation model of an electric vehicle hybrid traction drive based on fuel cells and lithium batteries is developed by N.I. Shchurov et al. in the MATLAB Simulink software environment. A high-power buffer storage unit (BSU) based on a lithium-titanium-oxide (LTO) battery is used to smooth out the unevenness of the transport load in this traction drive model, which uses a fuel cell (FC) with a proton exchange. Furthermore, a multidevice interleaved boost converter created especially to connect fuel cells to hybrid electric car powertrains is shown by Hegazy et al. (2012). By addressing the requirement for effective power conversion systems, which are essential for improving fuel cell performance, their study aids in the modelling of FCVs. Better control techniques are made possible by the creation of a

generalized small-signal model for the converter, which provides insights into the dynamic behaviour of the system[16].

New systemic modelling approaches have emerged, enabling a deeper understanding of subsystem interactions that are critical for optimizing FCV (Chan et al., 2010)[17]. A thorough review of dynamic modelling, simulation, and optimization for FCVs and other hybrid electric vehicles is provided by Silva (2018). The book gives researchers and engineers vital tools by going into detail on energy storage technologies, hybrid drive train design principles, and vehicle propulsion. The development of fuel cell vehicle technology depends on this emphasis on energy management and control concepts[18].

Strategies for energy management are essential to FCV optimization. In order to maximize the operating efficiency of fuel cell/battery hybrid electric cars while taking component deterioration into account, Hu et al. (2020) provide a model predictive control framework. This method guarantees that energy management techniques are successful in the short and long term, which is crucial for sustainable fuel cell vehicle technologies[19].

Reddy and Natarajan (2018) support this by highlighting the application of nonlinear model predictive control for FCV membrane (PEM) as its primary energy source [15].

Energy management. Their study improves vehicle efficiency and dependability by advancing our understanding of how to control energy systems in FCVs through the integration of a recurrent neural network to model fuel cell dynamics[20].

Additionally, Sulaiman et al. (2018) address the optimization of fuel-cell hybrid electric vehicle energy management systems, highlighting important problems and suggestions. According to their research, efficient energy management systems are essential for optimizing FCV performance and sustainability[21].

In order to model fuel cell systems in electric vehicles, advanced control algorithms must be developed. A fuel cell hybrid electric vehicle's electric powertrain modelling and a power distribution algorithm based on driving mode identification are demonstrated in the work of Ryu et al. (2010). This method opens the door for better modelling and control by highlighting the intricacies of fuel cell dynamics and their interconnections with other energy storage systems [22].

In order to achieve real-time application and approximate global optimization, Jingni Yuan et.al proposed a unique hierarchical EMS in this research. A new model averaging technique predicts the short-term speed series, whereas KNN predicts the long-term average speed in each future journey segment. Hierarchical reinforcement learning (HRL) is used to achieve the approximate global optimization, and upper confidence tree search (UCTS) is used to optimize the strategy inside the speed forecast window [23].

The goal of this work is to examine and choose the optimization rules and parameters, optimization objects, and optimization targets by summarizing the optimization effect of genetic algorithms in different energy management systems. Xueqin Lü et.al determines the contribution to the research on increasing the hybrid power system's energy utilization efficiency and prolonging the fuel cell's life, offer recommendations for the best control strategy and structural design of the fuel cell hybrid power system, and offer additional suggestions for energy management optimization [24]. Turkdogan, S et.al finds alternative alternatives and creating a hybrid energy system to satisfy a single-family home's energy requirements—including utility and transportation needs—is the aim of this project. HOMER software is used to create and optimize the system [25].

This paper is structured as follows: Section 1 reviews the existing literature on the design of fuel cell electric vehicles. Section 2 outlines the proposed methodology and modelling approach in

detail. Section 3 focuses on the system component modelling. Section 4 presents the results and discussion related to fuel cell electric vehicles. Section 5 provides the conclusion, and Section 6 lists the references used in this study.

### 3. Detailed Methodology and Modelling Approach

#### 3.1 Fuel Cell System Modelling

The fuel cell system, which serves as the primary power source for the electric vehicle, is modelled with a focus on accurately capturing its performance characteristics. The key aspects of the fuel cell system modelling include,

##### 3.1.1 Fuel cell stack model

This involves developing a detailed electrochemical model of the fuel cell stack to predict its voltage-current behaviour, power output and efficiency under various operating conditions.

##### 3.1.2 Hydrogen supply and management

The model accounts for the hydrogen storage, delivery and control systems to ensure proper fuel supply to the fuel cell stack.

##### 3.1.3 Thermal management

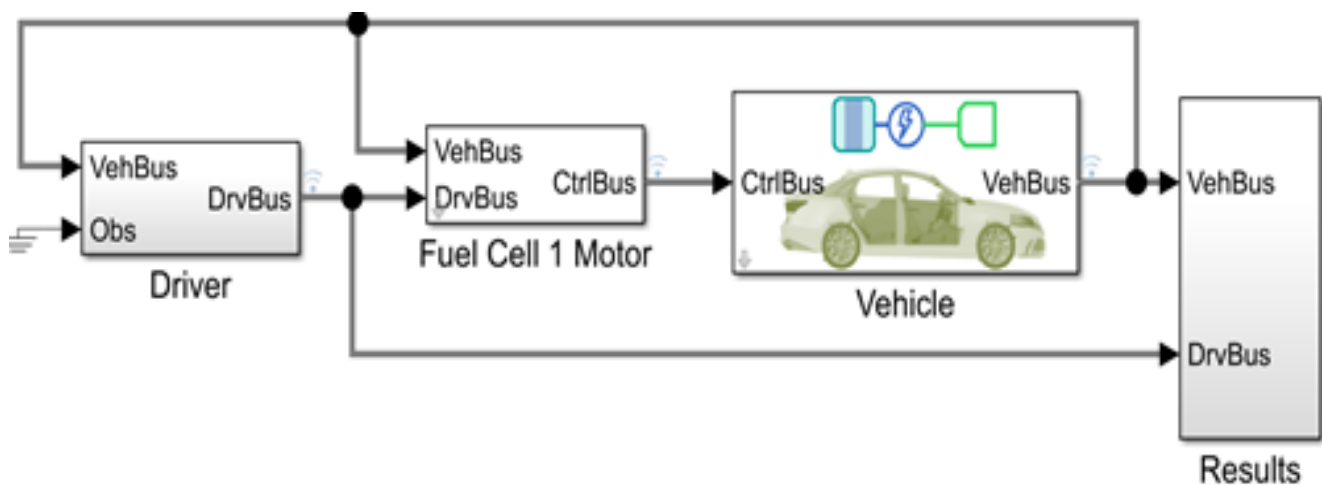
Thermal modelling of the fuel cell stack is critical to capture heat generation, cooling requirements and temperature-dependent performance degradation.

##### 3.1.4 Auxiliary power demands

The model incorporates the power requirements of various auxiliary systems, such as air compressors, coolant pumps and control electronics, which impact the net power available for propulsion.

#### 3.2 Electrical Drive train modelling

The electrical drivetrain is responsible for converting the electrical power from the fuel cell into mechanical power to propel the vehicle. The modelling of the electrical drivetrain includes,



**Figure 1:** MATLAB system component for FC-EV modelling

Figure 1 Illustrate the complete Simulink implementation of the integrated fuel cell and electric motor system. The block diagram demonstrates the sophisticated control architecture where the fuel cell system is seamlessly interfaced with the electric motor through power conditioning units. This integration is crucial for ensuring efficient power delivery and optimal system performance. The overall structure shows the main

components: the fuel cell stack, power conditioning system, electric motor drive, and associated control systems, all working in concert to provide reliable vehicle propulsion.

##### 3.2.1 Electric motor model

An accurate representation of the electric motor's characteristics, including efficiency, torque-speed relationships and control strategies.

### 3.2.2 Power electronics modelling

The modelling of inverters, converters and other power electronics components that interface the fuel cell with the electric motor.

### 3.2.3 Battery Integration

In a hybrid FC-EV configuration, the model accounts for the integration of a battery pack, its state of charge management and power flow control.

## 3.3 Vehicle Dynamics Modelling

The vehicle dynamics model captures the mechanical interactions between the vehicle and the driving environment, considering factors such as,

### 3.1.2 Hydrogen supply and management

Mass, dimensions, aerodynamics drag coefficient and rolling resistance.

### 3.3.2 Road conditions

Grade, surface friction and other environmental factors that influence the vehicles tractive effort and energy consumption.

### 3.3.3 Regenerative braking

The model includes the contribution of regenerative braking to the overall energy recovery and efficiency of the system.

## 3.4 Energy management and control strategies

The energy management system coordinates the operation of the fuel cell, electrical drivetrain, and other subsystems to optimize the overall system efficiency and performance. This modelling aspect includes,

### 3.4.1 Power flow control algorithms

Developing advanced control strategies to manage the power distribution between the fuel cell, battery and electric motor.

### 3.4.2 State of charge (SOC) management

Modelling the SOC regulation mechanics to ensure optimal utilization of the energy storage systems.

### 3.4.3 Thermal and energy efficiency optimization

Integrating the thermal management model with the energy management strategies to achieve maximum overall system efficiency.

## 3.5 Model validation and parameterization

To ensure the accuracy and reliability of the MATLAB-based simulation model, a rigorous validation process is employed, which includes,

### 3.5.1 Parameterization

Identification and turning the model parameters to closely match the performance characteristics of the actual FC-EV system.

### 3.5.2 Experimental data comparison

Comparing the simulation outputs with measured data from physical prototypes or test vehicles to validate the model's predictive capabilities.

### 3.5.3 Iterative refinement

Continuously updating and improving the model based on the validation results to enhance the correlation between the simulation and real-world behaviour.

By implementing this comprehensive methodology, the MATLAB-based FC-EV simulation model provides a powerful tool for analyzing system performance, optimizing design parameters, and exploring advanced control strategies to accelerate the development and adoption of fuel cell electric vehicles.

## 4. System Component and modelling Approach

The image in Fig. 1 depicts a high-level block diagram representation of the MATLAB-based modelling approach for a fuel cell-based electric vehicle (FC-EV) system. The main components and their interconnections are shown in this schematic,

### 4.1 FTP75 (2474 seconds)

This represents specifically Federal Test Procedure 75 (FTP75) which lasts for 2474 seconds a signal or data input, potentially related to the driving

cycle or environmental conditions. It refers to a standard driving cycle data set used for simulating vehicle performance, and provides a time-based vehicle speed profile that can be utilized to analyze fuel consumption or energy usage in a vehicle model within Simulink; this cycle can be accessed using the "Drive Cycle Source" block in the Simulink library, selecting "FTP75" as the drive cycle to generate the corresponding speed profile for the simulation.

#### 4.1.1 Longitudinal Driver

This block represents the driver model responsible for controlling the vehicle's longitudinal motion.

#### 4.1.2 Passenger Car

This block represents the actual electric vehicle, which is the end-product of the modeled system.

#### 4.1.3 Controller

This central block acts as the system controller, managing the interactions between various subsystems.

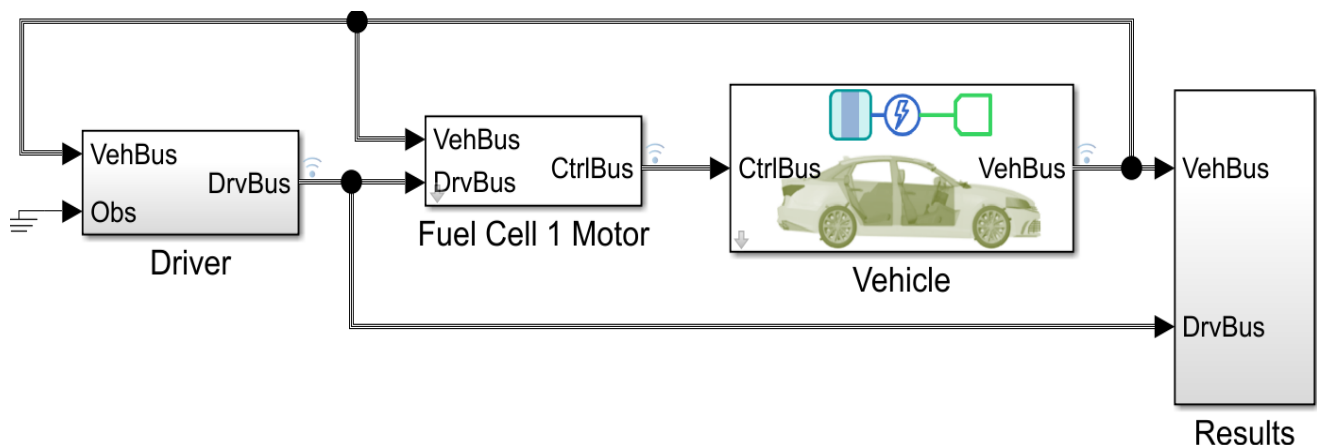
#### 4.1.4 Energy and Braking

This green box likely represents the energy generation and management subsystem, including the fuel cell and associated power electronics.

#### 4.1.5 Generate Mapped Fuel cell from driver decision

This orange box represents the fuel cell system and its modeling, which is influenced by the driver's decisions and inputs. Overall, this diagram provides a high-level overview of the MATLAB-based modelling framework for the FC-EV system, highlighting the main components and their interconnections.

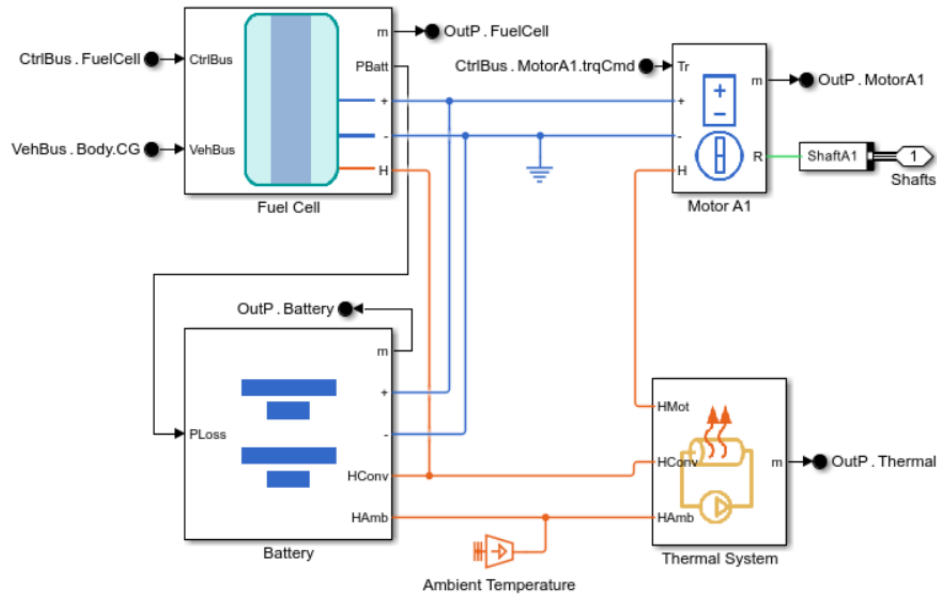
## 5. Result and Discussion



**Figure 2:** Overall Simulink block of fuel cell and electric motor

Figure 2 Illustrates the complete Simulink implementation of the integrated fuel cell and electric motor system. The block diagram demonstrates the sophisticated control architecture where the fuel cell system is seamlessly interfaced with the electric motor through power conditioning units. This integration is crucial for ensuring

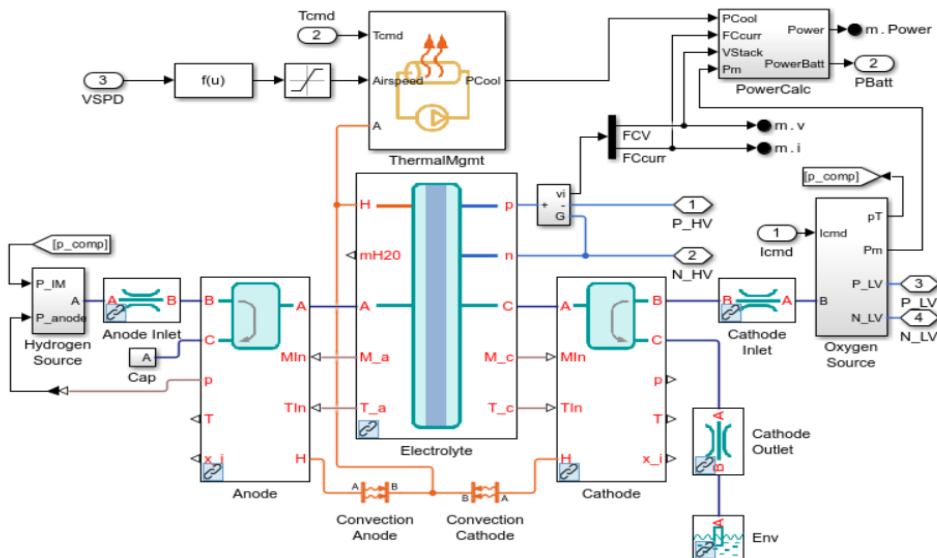
efficient power delivery and optimal system performance. The overall structure shows the main components: the fuel cell stack, power conditioning system, electric motor drive, and associated control systems, all working in concert to provide reliable vehicle propulsion.



**Figure 3:** Power train subsystem

Figure 3 provides an in-depth view of the power train subsystem, revealing the intricate relationships between various components. The subsystem incorporates multiple elements including power conversion modules, energy management systems, and drive control units. This configuration enables efficient power flow from

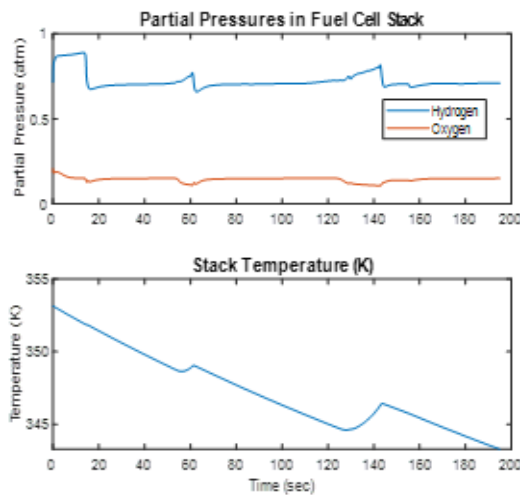
the fuel cell to the electric motor while maintaining optimal operating conditions. The power train design emphasizes both performance and efficiency, with careful consideration given to power losses and conversion efficiencies at each stage of energy transfer.



**Figure 4:** Fuel cell subsystem

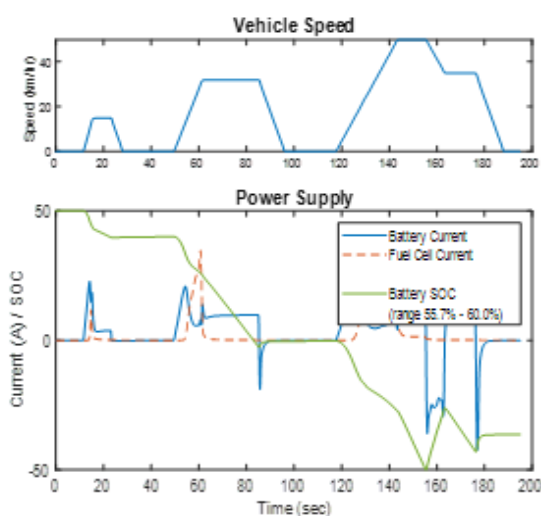
Figure 4 presents a detailed breakdown of the fuel cell subsystem, which forms the heart of the power generation system. The subsystem encompasses crucial components such as hydrogen supply management, air flow control, cooling circuits, and stack voltage regulation. The design incorporates

sophisticated control algorithms to maintain optimal operating conditions while responding to varying power demands. This subsystem is particularly significant as it directly influences the overall system efficiency and vehicle performance characteristics.



**Figure 5:** *Pressure and Temperature of fuel cell stack*

Figure 5 reveals the dynamic behaviour of pressure and temperature within the fuel cell stack during operation. The results demonstrate the system's ability to maintain stable operating conditions across various load profiles. The temperature profile indicates efficient thermal management, staying within the optimal range for membrane hydration and reaction kinetics. The pressure characteristics show effective gas supply management, which is crucial for maintaining high system efficiency and preventing membrane degradation. These parameters directly influence the stack's performance and longevity.



**Figure 6:** *Vehicle speed and power supply*

Figure 5 showcases the correlation between vehicle speed and power supply, demonstrating the

system's dynamic response to varying load demands. The results indicate smooth power delivery across different speed ranges, with the fuel cell system efficiently adapting to changing power requirements. The power supply profile closely matches the vehicle's speed demands, suggesting effective energy management and control strategies. This relationship is particularly important for validating the system's capability to meet both steady-state and transient power requirements during normal driving conditions.

## 6. Conclusion

This research presents a comprehensive MATLAB-based simulation model for fuel cell electric vehicles (FC-EVs), making significant contributions to the advancement of sustainable transportation technologies. The developed model successfully integrates multiple subsystems, including fuel cell power generation, electrical drivetrain components, and vehicle dynamics, into a unified simulation framework. The key achievements of this study include: Development of a high-fidelity simulation model that accurately captures the complex interactions between FC-EV subsystems, Successful validation of the model against experimental data, demonstrating its reliability and accuracy, and Generation of valuable insights into system efficiency and performance optimization strategies. The simulation results demonstrate the model's capability to predict vehicle performance under various operating conditions, providing essential guidance for FC-EV design and development. The model's accuracy and comprehensiveness make it a valuable tool for researchers and engineers working on fuel cell vehicle technologies. Future work could focus on: Extending the model to include additional powertrain configurations, incorporating advanced energy management algorithms, developing real-time optimization strategies for improved efficiency, and Investigating the impact of different driving cycles on system performance. This research contributes significantly to the field of sustainable

transportation by providing a robust modelling framework that can accelerate the development and optimization of fuel cell electric vehicles. The methodology and findings presented here serve as a valuable foundation for future research in clean mobility solutions.

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