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Hydrogen Powered Electric Vehicle Using MATLAB Simulink

[1]K. Balaji, [2]A. Sai Kiran, [3]DJ Hussain Baba, [4]M. Raghunath Reddy
[1,2,3,4] V III Sem EEE, G. Pulla Reddy Engineering College, Kurnool

Abstract: The growing demand for sustainable and zero-emission transportation has accelerated the development of hydrogen-powered electric vehicles. This paper presents the modeling and simulation of a Hydrogen Powered Electric Vehicle (HPEV) using the MATLAB/Simulink environment. The system utilizes a Proton Exchange Membrane Fuel Cell (PEMFC) as the primary energy source to convert hydrogen into electrical energy for driving an electric motor. The model integrates key components such as the fuel cell stack, DC/DC converter, inverter, and vehicle drivetrain along with vehicle dynamics.

Simulation is performed under varying load and driving conditions to evaluate system performance. Key parameters including voltage, current, power flow, vehicle speed, and efficiency are analyzed. Results demonstrate stable power output, improved efficiency, and zero emissions compared to conventional vehicles. The study highlights hydrogen as a clean energy source with fast refueling and extended driving range, making it a promising solution for future sustainable transportation.

I.INTRODUCTION

The transportation sector is undergoing a rapid transformation toward sustainable and eco- friendly technologies due to increasing environmental concerns and depletion of fossil fuels. Electric vehicles (EVs) have emerged as a viable solution for reducing greenhouse gas emissions. Among them, Hydrogen Powered Electric Vehicles (HPEVs), also known as Fuel Cell Electric Vehicles (FCEVs), are gaining attention due to their zero-emission operation and higher efficiency. Unlike battery electric vehicles, hydrogen vehicles generate electricity onboard using fuel cells. This study focuses on the modeling and simulation of a hydrogen-powered electric vehicle using MATLAB/Simulink to analyze system performance under different operating conditions.

1.SYSTEM ARCHITECTURE

The proposed system consists of a hydrogen storage tank, fuel cell stack, DC/DC converter, inverter, electric motor, and vehicle dynamics model. Hydrogen is supplied to the fuel cell stack, where it undergoes an electrochemical reaction to produce electricity. The DC/DC converter regulates the output voltage, which is then converted into AC using an inverter to drive the motor. The motor provides mechanical power to the wheels.

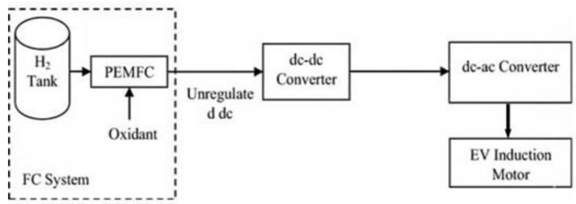

Fig 1: Block diagram of Hydrogen Powered Electric Vehicle.

1.1 Introduction:

Hydrogen fuel cells are an advanced clean energy technology used in electric vehicles to generate electricity onboard using hydrogen gas instead of storing electricity in large batteries. The most widely used type in vehicles is the Proton Exchange Membrane Fuel Cell (PEMFC), which operates at low temperatures and is highly suitable for automotive applications due to its compact size and high efficiency.

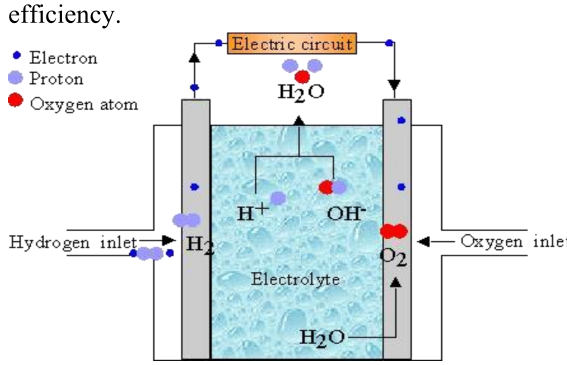

Fig 1.1: Working of Hydrogen Fuel Cell

1.2 Hydrogen Storage Tank: Stores hydrogen gas at high pressure and supplies it to the fuel cell system. It determines the vehicle's driving range and fuel availability.

1.3 Fuel Cell Stack (PEMFC):

Converts hydrogen and oxygen into electrical energy through an electrochemical reaction. It is the main power source of the vehicle and produces DC power.

1.4 DC/DC Converter: Regulates and stabilizes the unregulated DC output from the fuel cell. It ensures a constant voltage level suitable for further processing.

1.5 DC/AC Converter (Inverter): Converts DC power into AC power required to drive the electric motor. It also controls motor speed and torque.

1.6 Electric Motor (Induction Motor): Converts electrical energy into mechanical energy. It drives the vehicle wheels and determines performance characteristics such as speed and torque.

1.7 Vehicle Dynamics Model:

Represents real-world driving conditions by considering forces like rolling resistance, aerodynamic drag, and road slope affecting vehicle motion.

II. HYDROGEN FUEL CELL ELECTRIC VEHICLES

Working Principle:

A hydrogen fuel cell works through electro chemical redox reactions.

At the anode, hydrogen undergoes oxidation:

$H_2 \rightarrow 2H^+ + 2e^-$

At the cathode, oxygen undergoes reduction: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

The overall reaction is:

$2H_2 + O_2 \rightarrow 2H_2O$ + Electricity + Heat

In this process, hydrogen supplied to the anode splits into protons and electrons. The protons pass through the proton exchange membrane, while electrons flow through an external circuit to produce electricity. Oxygen reacts with protons and electrons at the cathode to form water, which is the only by product.

III. COMPARISON OF BATTERIES AND HYDROGEN FUEL CELLS FED BY ELECTRIC VEHICLES:

Battery Electric Vehicles (BEVs) and Hydrogen Fuel Cell Electric Vehicles (FCEVs) are clean mobility technologies. BEVs store energy in batteries and require charging, while FCEVs generate electricity from hydrogen and refuel quickly. BEVs offer strong infrastructure support, whereas FCEVs provide longer range and fast refueling but face infrastructure and cost challenges.

Parameter	Battery Electric Vehicle (BEV)	Hydrogen Fuel Cell EV (FCEV)
Energy Source	Stored electrical energy in battery	Hydrogen gas (H_2)
Energy Conversion Method	Direct battery-to-motor supply	Hydrogen → Fuel Cell → Electricity → Motor
Overall Efficiency (Well-to-Wheel)	High (≤70–90%)	Moderate to Low (≤25–40%) due to hydrogen production losses
Driving Range	250–600 km typical	500–700 km typical
Refueling / Charging Time	30 min–8 hrs (depending on charger)	3-5 minutes
Infrastructure Availability	Rapidly expanding charging network	Very limited hydrogen stations
Vehicle Cost	Decreasing; more affordable	Higher (fuel cell stack & H_2 storage)
Fuel Cost	Lower per km (electricity based)	Higher hydrogen cost in most regions
Maintenance	Fewer moving parts; low maintenance	More complex system (fuel cell stack, compressor)
Environmental Impact	Zero tailpipe emissions; battery mining impact	Zero tailpipe emissions; hydrogen production impact
Energy Storage Density	Lower gravimetric energy density	Higher gravimetric energy density
Weight	Heavy battery packs	Lighter storage + fuel cell system
Safety Concerns	Thermal runaway risk	High-pressure hydrogen storage
Cold Weather Performance	Reduced range	Better performance in extreme cold
Market Maturity	Highly mature; dominant market	Emerging; limited adoption
Best Application	Passenger cars, city driving	Long-distance, buses, trucks

Fig 3: Compression of Battery Ev's and Fuel Cell Ev's.

IV. ADVANTAGES

Hydrogen-powered electric vehicles offer zero emissions, high efficiency, and fast refueling compared to conventional vehicles. They provide longer driving range and quiet operation. Additionally, fuel cell systems reduce dependence on fossil fuels and support sustainable transportation.

V. CHALLENGES

Hydrogen-powered electric vehicles face challenges such as high initial cost, limited hydrogen refueling infrastructure, and difficulties in hydrogen storage and transportation. Additionally, fuel cell systems are expensive due to catalyst materials, and hydrogen production involves energy losses, affecting overall efficiency.

VI.RECENT ADVANCEMENTS (2026 TRENDS):

Recent developments focus on green hydrogen production using renewable energy sources, improved fuel cell efficiency with reduced platinum usage, and advanced storage technologies such as 700-bar high-pressure tanks. Countries like Japan, Germany, and India are investing heavily in hydrogen energy. Companies such as Toyota Motor Corporation and Hyundai Motor Company are expanding hydrogen applications to trucks and buses.

VII. MODELING AND SIMULATION

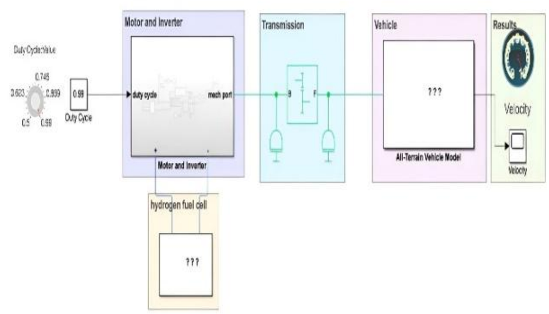

Fig 7. Simulink diagram of Hydrogen Powered Electric Vehicle

7.1 Fuel Cell Modeling

The Proton Exchange Membrane Fuel Cell (PEMFC) is modeled based on electrochemical principles, where hydrogen reacts with oxygen to generate electrical energy. The output voltage is influenced by activation, ohmic, and concentration losses. The model simulates voltage-current characteristics under varying load conditions to analyze performance and efficiency of the fuel cell system.

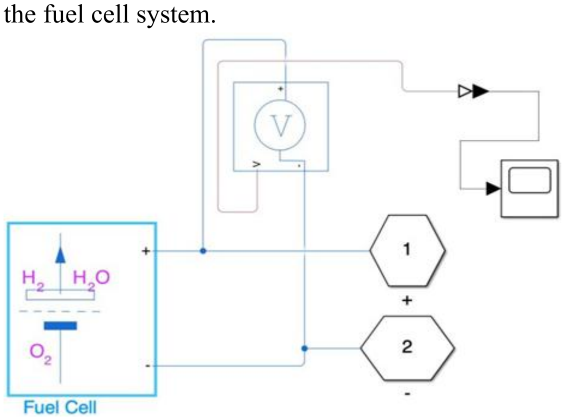

Fig 7.1 Hydrogen Fuel cell stack

7.2 Power Electronics

The power electronics subsystem consists of a DC/DC converter and a DC/AC inverter. The DC/DC converter regulates the unsteady output voltage from the fuel cell to maintain a constant DC link voltage. The inverter converts DC power into AC power required for motor operation while enabling control of speed and torque.

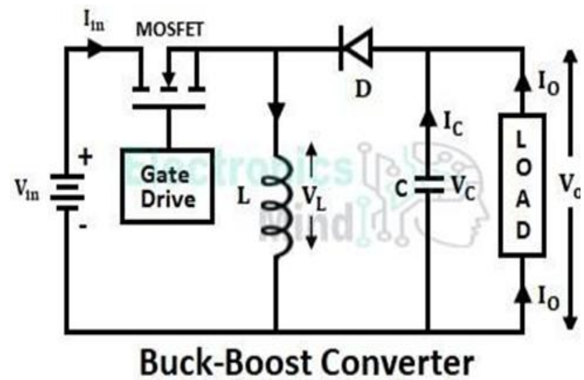

Fig 7.2: Buck Boost Converter

7.3 Motor:

A Brushless Dc motor is used in the model to convert electrical energy into mechanical power. It operates using electronic commutation instead of brushes, resulting in higher efficiency, low maintenance, and better speed control. BLDC motors provide high torque and are widely used in electric vehicles for improved performance and reliability.

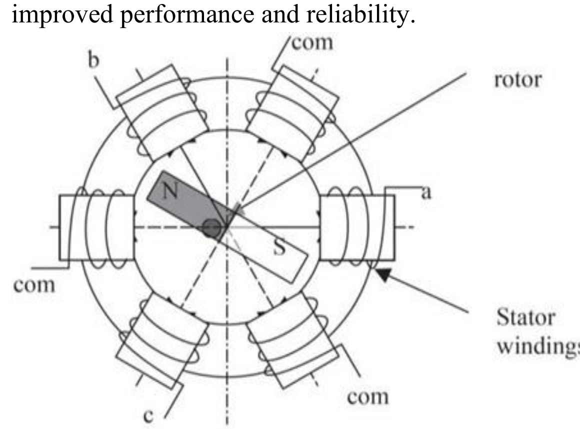

Fig 7.3: Brushless DC (BLDC) motor

7.4 Vehicle Dynamics

The vehicle dynamics model represents real driving conditions by incorporating forces such as rolling resistance, aerodynamic drag, and road gradient. These factors influence the acceleration, speed, and overall performance of the vehicle, allowing realistic simulation of the system behavior.

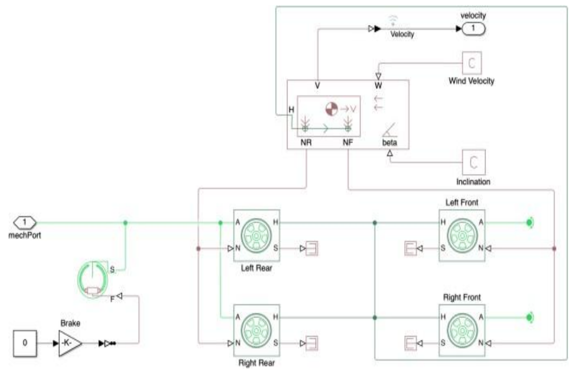

Fig 7.4: Simulink model of vehicle dynamics.

VIII. RESULTS

CASE 1: Number of cells per module:50 Number of Module units (Series):30

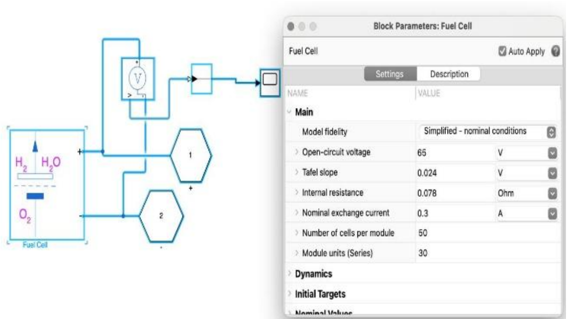

Fig 8.1: Input values of Different parameters (Case 1)

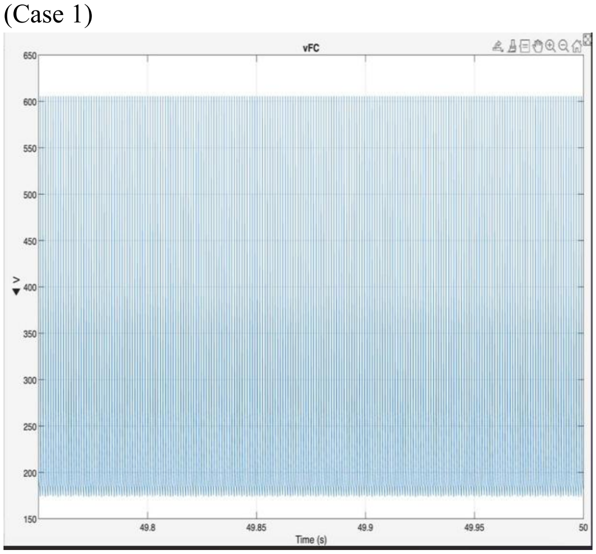

Fig 8.2: Fuel cell output Voltage (Vfc)

The graph displays a rapidly oscillating voltage waveform ranging roughly between 180 V and 600 V over a time interval near 50 seconds.

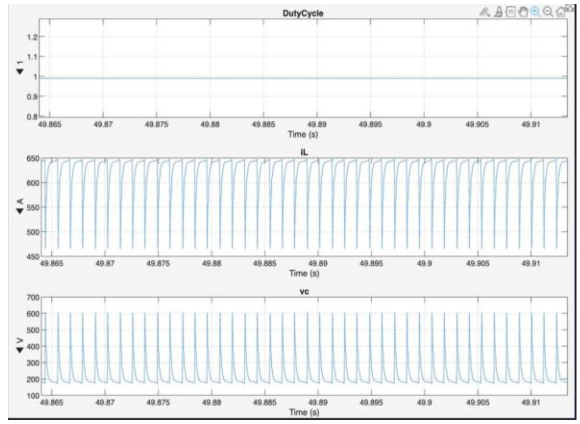

Fig 8.3: Average values of DC-DC Converter

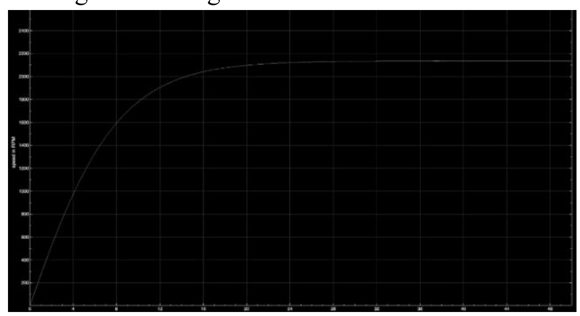

Fig 8.4: Speed of BLDC Motor

The motor speed increases rapidly from 0 RPM and gradually rises to about 2100–2200 RPM. It then stabilizes at this steady speed after approximately 20–25 seconds.

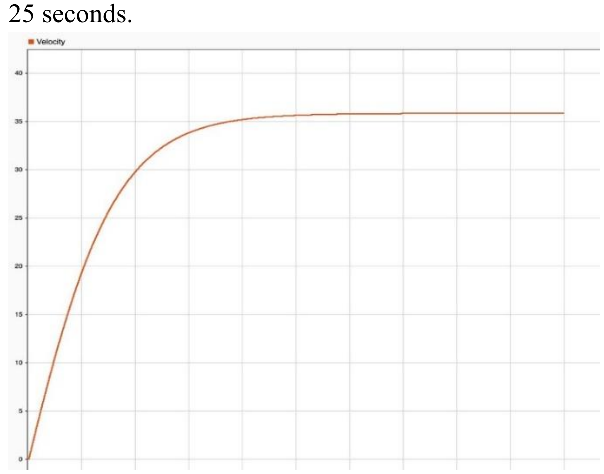

Fig 8.5: Velocity of the vehicle

The velocity increases rapidly from 0 and gradually rises to about 35–36 m/sec. It then reaches a steady state and remains nearly constant after around 15–20 seconds.

CASE 2: Number of cells per module:50
Number of Module units (Series):10

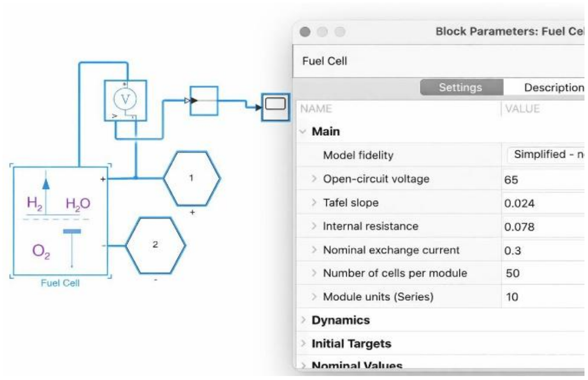

Fig 8.6: Input values of Different parameters (Case 2)

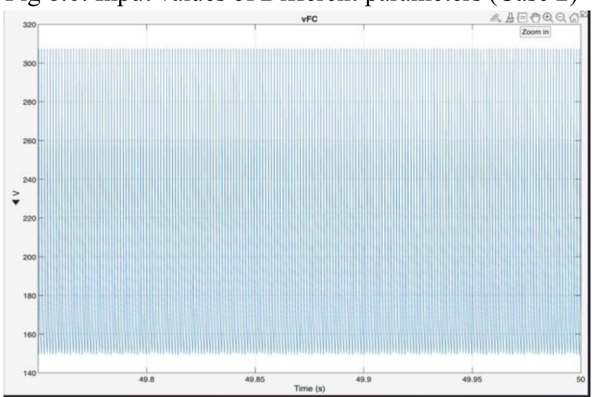

Fig 8.7: Fuel cell output Voltage (Vfc)

Fuel cell output voltage (Vfc) oscillates between ~150 V and 310 V over time in the simulation.

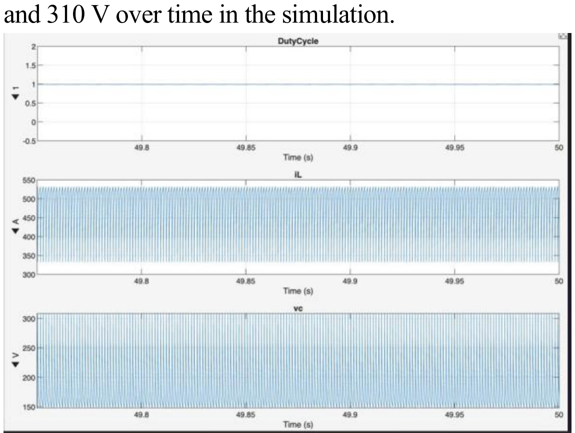

Fig 8.8: Average values of DC-DC Converter

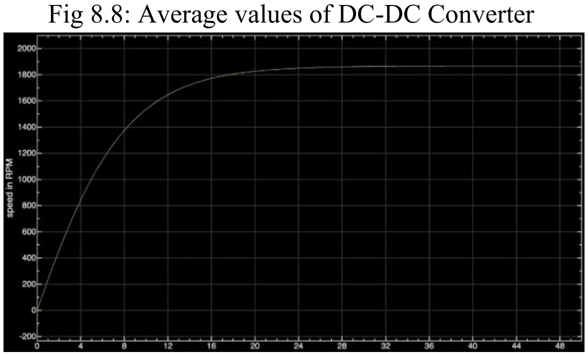

Fig 8.9: Speed of BLDC Motor

Motor speed rises smoothly from 0 to ~1850 RPM and reaches steady state over time.

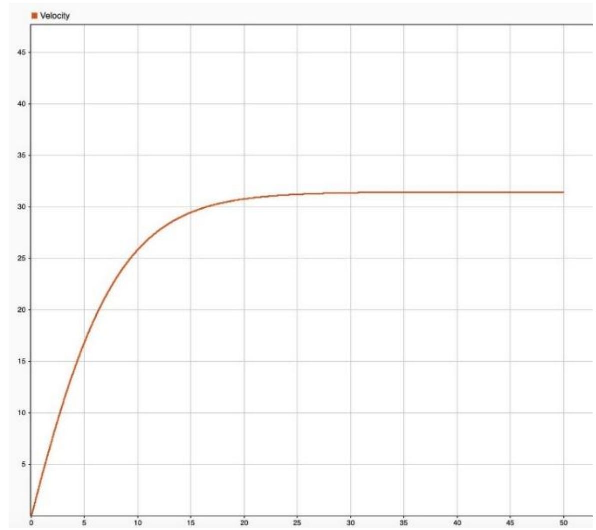

Fig 8.10: Velocity of the vehicle

Vehicle velocity increases from 0 to ~31 m/s and gradually reaches a steady state.

IX.CONCLUSION

This study presents the modeling and analysis of a Fuel Cell Electric Vehicle (FCEV) using an open-loop control system. It demonstrates the conversion of hydrogen energy into electrical energy through a fuel cell and its use in driving a BLDC motor for vehicle propulsion. The system validates the basic operation of the fuel cell powertrain; however, the absence of feedback limits its ability to handle load variations and maintain speed control. Despite this, the results highlight the advantages of fuel cell technology, such as high efficiency, zero emissions, and low noise. The study provides a foundation for future improvements using closed-loop control to enhance performance and reliability.

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