ENHANCING THE EFFICIENCY OF HYBRID HYDROGEN FUEL CELL ELECTRIC CARS UNDER ACTUAL DRIVING SITUATIONS: A REVIEW

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Abstract - *The article explores the potential of hybrid hydrogen fuel cell-electric vehicles (H2FCEVs) as a means to reduce greenhouse gas emissions and decrease reliance on fossil fuels in the automotive industry. It begins with an overview of the current state of H2FCEV technology, highlighting the advantages and limitations of electric and hydrogen fuel cell propulsion systems. The article then delves into various optimization strategies, including powertrain designs, energy management systems, and control algorithms, aimed at enhancing the efficiency, range, and overall performance of H2FCEVs in real-world driving conditions. The article discusses the integration of renewable energy sources like solar and wind into H2FCEV systems to enhance sustainability and reduce environmental impact. It also addresses challenges related to the widespread adoption of H2FCEVs, particularly focusing on innovations in hydrogen infrastructure such as production, storage, and refueling technologies. The importance of interdisciplinary collaboration and innovation is emphasized as crucial for realizing the full potential of H2FCEVs in achieving a sustainable transportation ecosystem. The article concludes with a discussion on future research directions and potential advancements in optimizing the performance of H2FCEVs.*

Key Words: Hybrid hydrogen fuel cell-electric vehicles, Performance optimization, Real driving cycles, Control algorithms, Energy management systems.

1.BACKGROUND

The history of enhancing the efficiency of hybrid hydrogen fuel cell electric vehicles (H2FCEVs) has progressed from the early stages of fuel cell technology to the current recognition of hydrogen as a clean energy carrier for transportation. While fuel cells were conceptualized in the 19th century, widespread usage only occurred in the mid-1900s. Hydrogen's availability and low environmental impact have contributed to its recognition as a clean fuel, leading to the popularity of H2FCEVs, combining electric and hydrogen fuel cell technology for zero-emission mobility with extended driving ranges. Challenges in ensuring effective performance in real driving conditions prompted extensive research and development. These efforts focused on refining energy management systems, improving vehicle aerodynamics, enhancing hydrogen storage and distribution systems, and optimizing fuel cell systems. Advances in computer modeling, engineering, and materials science have significantly improved the efficiency of these vehicles. Real-world testing and validation have proven crucial to evaluating performance and identifying areas that still require attention. The persistent innovation and collaborative efforts in the field are driving the development of hybrid hydrogen fuel cell electric car technology, creating new opportunities for sustainable transportation solutions.

2.INTRODUCTION

Alternative vehicle energy sources are receiving a lot of attention as a result of the search for environmentally friendly transportation options, with hydrogen emerging as a viable option. In this field, hybrid hydrogen fuel cell electric vehicles are state-of-the-art because they have the ability to provide longer ranges and zero emissions. Nevertheless, it has proven difficult to realise their full effectiveness in real-world driving situations, requiring targeted research and development efforts. This introduction examines the background and present state of research into improving the practical driving efficiency of hybrid hydrogen fuel cell electric vehicles, highlighting significant developments, obstacles, and the significance of continuous innovation in determining the direction of clean transportation.

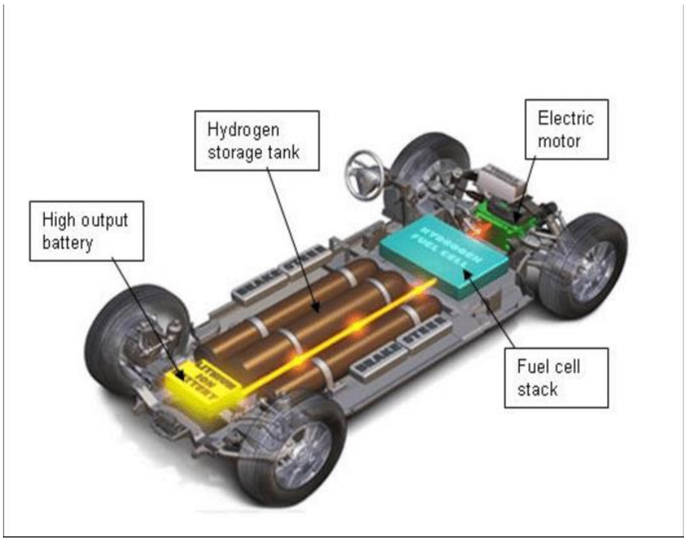

Figure-1: Hydrogen Fuel Vehicle.

2.1.Hydrogen Fuel Cell

Hydrogen fuel cells undergo an electrochemical process converting the chemical energy of hydrogen and oxygen into electricity, heat, and water. This process involves several components: the anode, where hydrogen gas splits into protons and electrons; the cathode, where oxygen combines with electrons and protons to form water; an electrolyte membrane facilitating ion passage while blocking electrons; catalysts, typically platinum, enabling the electrochemical reactions; and an external circuit channeling electrons to create electric current for powering loads. Despite high energy efficiency and water vapor as the primary product, hydrogen fuel cell use is limited due to challenges in economical large-scale hydrogen production, distribution, and safety concerns regarding storage and handling. Nonetheless, ongoing technological advancements aim to address these hurdles, fostering the potential commercialization of hydrogen fuel cells for applications such as transportation and stationary power generation, empowering everyday appliances.

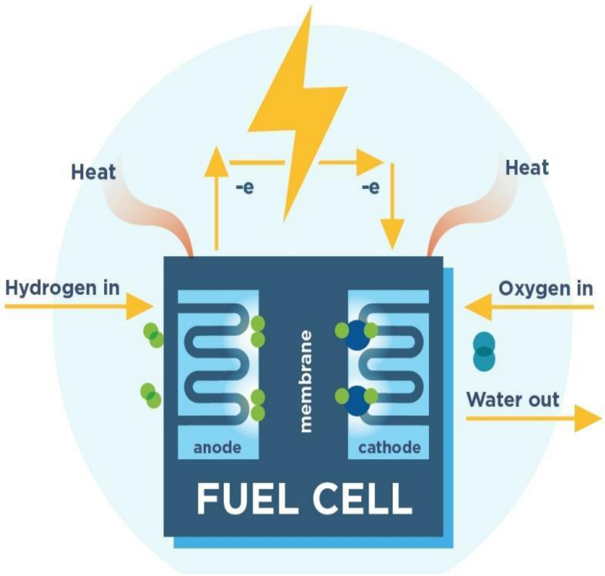

Figure-2: Hydrogen Fuel Cell.

2.2.Principle of Hydrogen Fuel Cell in the Vehicle.

In vehicles, a hydrogen fuel cell converts hydrogen gas into electricity to propel the car, stored within the vehicle and undergoing reactions to generate power. This method is environmentally friendly, as it produces no harmful emissions. Despite its benefits, there are remaining challenges to address before widespread adoption. Nonetheless, utilizing hydrogen fuel cells in cars stands as a promising avenue to contribute positively to the environment and promote sustainable transportation.

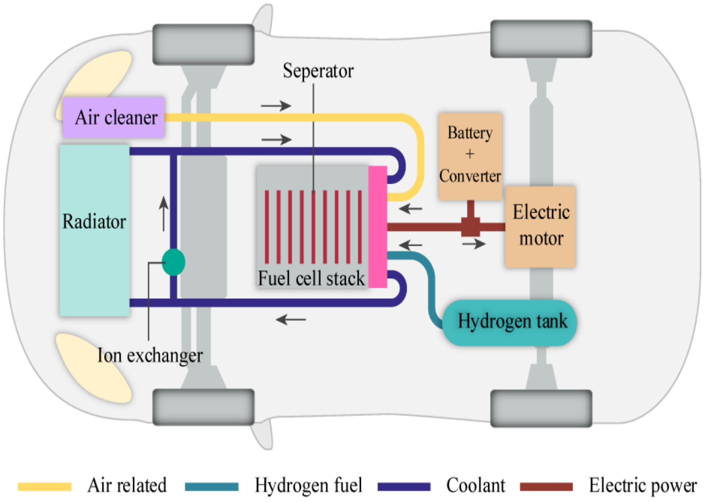

Figure-3: Principle of Hydrogen Fuel Cell in the Vehicle.

3.LITERATURE REVIEW

In the section of the literature review, studied the previous research paper related to the hydrogen fuel cell in the vehicle. The summary of the all previous research paper are given below:

Sasidhar, Sailaja (2019): The optimization of hydrogen production processes aims for simplicity, low cost, and environmental sustainability. Success relies on technological advancements yielding more significant outcomes. Despite progress in storage techniques, a major challenge remains in achieving experimental results that fully meet requirements, hindering the hydrogen economy's viability. Transportation demands careful attention, with efficient storage solutions vital for viable transport methods. Fuel cell selection for vehicles considers factors like efficiency, cost, and consumer preferences among six main types. Yet challenges persist, including high fuel cell costs and durability/reliability concerns.

Jiang et.al (2020): Statistical analysis, conducted on a dataset of one thousand random cycles with identical statistical characteristics, reveals that Stochastic Dynamic Programming (SDP) methods outperform other methods across both evaluation criteria. Specifically, Markov-SDP demonstrates optimal performance with well-centered outcomes and minimal standard deviations. Conversely, Adaptive Equivalent Consumption Minimization Strategy (A-ECMS) shows high sensitivity to tuning parameters, resulting in elevated fuel consumption and inadequate final State of Energy (SOE) control, particularly in diverse cycle scenarios. The complexity of SDP methodologies is justified by their efficacy, with Markov-SDP being the most promising among them. However, A-ECMS stands out for its ease of implementation. Future research should address the computational complexity associated with offline Markov-SDP analysis and the need for online data storage resources.

Qing et.al (2020): This study introduces a new life cycle assessment method for Fuel Cell Electric Vehicles (FCEVs) using MATLAB/Simulink and GREET software. It examines how driving cycles and hydrogen supply methods affect fuel economy and greenhouse gas (GHG) emissions of FCEVs in Korea. The research compares and analyzes findings to understand the environmental sustainability of FCEVs. The NEXO FCEV demonstrates better fuel economy across various driving cycles, making it suitable for urban areas in Korea and beyond. However, in congested cities, improving the regenerative braking system is important. The dominant hydrogen production method in Korea, from naphtha, has high GHG emissions, hindering FCEV market growth. Electrolysis-based hydrogen production has benefits but requires more renewable energy in the Korean electricity grid. On-site hydrogen production from natural gas is potentially more environmentally sustainable, but its scale in Korea is limited. Lifetime GHG emissions from the NEXO FCEV are estimated at 12,500 to 16,000 kg CO2-equivalent, less than one-fourth of an Internal Combustion Engine Vehicle (ICEV) using gasoline. This highlights FCEVs' significant potential in reducing transportation's environmental impact.

Plamen, Tsvetomir (2020): The vehicle's development was aimed at participating in the Shell Eco-marathon's Urban Concept category, focusing on minimizing energy consumption. A simulation model was created, considering vehicle dynamics and real-world efficiency of components like DC/DC converters, motor controllers, and transmission. Five propulsion schemes and driving strategies were evaluated using this model. Fuel cell output parameters were experimentally determined, and energy requirements and hydrogen consumption were estimated for each scheme. Additionally, an empirical investigation into fuel cell output power and hydrogen consumption was conducted for two propulsion schemes, distinguishing between hybrid and non-hybrid power sources. The hybrid scheme involved integrating supercapacitors as energy storage elements, charged from the fuel cell at a constant current rate of 10 A.

Gürsel, Merg (2020): The investigation explores temperature regulation of hydrogen vessels through flow rate control, comparing parallel and successive order strategies. Parallel flow exhibits uniform exponential temperature variations, while successive order control results in variable rates of temperature adjustments, reducing temperature fluctuations by approximately 35.14% compared to parallel flow. A Feedback Linearization (FL) algorithm regulates the Flow Splitting System (FSS) based on vessel temperatures, leading to reduced energy consumption by the Temperature Management System (TMS) by up to 15%, 79.31%, and 58.74% at ambient temperatures of 10°C, 18°C, and 35°C respectively. These results highlight the importance of waste heat utilization and control mechanisms in enhancing overall system efficiency. Efforts to improve electric vehicle (EV) efficiency include strategies to maintain optimal operating temperatures for energy sources. An algorithm oversees temperature regulation for batteries and fuel cells, prioritizing the fuel cell as the primary propulsion energy source when battery temperatures exceed optimal levels, and vice versa. The Energy Management System (EMS) optimizes energy utilization across sources, enhancing overall EV efficiency.

Hossein et.al (2020): A Life Cycle Assessment (LCA) analysis was conducted to thoroughly assess the pros and cons of different bus propulsion alternatives. Electric buses, despite showing superior operational efficiency and minimal energy loss during operation, have a higher environmental impact during manufacturing, consuming nearly double the energy of other options. However, over the total life cycle, their energy consumption differs by only 5% compared to fuel cell and diesel buses. In terms of CO2 emissions, diesel Internal Combustion (IC) buses emit 201 kg per 100 km, with most of this during operation. Fuel cell buses emit 130 kg per 100 km, mainly during the well-to-pump stage, with no emissions during operation. Electric buses produce 78 kg per 100 km during the well-to-pump stage and a total of 121 kg per 100 km. While diesel buses may offer economic benefits, they also have the highest emissions profile, posing a disadvantage despite their economic viability in bus fleet operations.

Akhoundzadeh et.al (2021): A model of a hydrail powertrain was developed based on a specific drive cycle derived from Diesel Multiple Units (DMUs) operating on the Air Rail link tracks in Toronto, Ontario, Canada. The model includes five subsystems: battery, hydrogen fuel cell, vehicle dynamics, power split, and high-level controller. A novel power split subsystem was designed to allocate power demand between the two energy systems, integrating an Infinite Impulse Response (IIR) filter and a rule-based high-level control mechanism for energy flow management. Cost functions related to battery State of Charge (SOC) and available hydrogen levels govern the power split progression. A sensitivity analysis was conducted to evaluate subsystem responses to different parameters. Validation involved comparing outputs from different subsystems against real-world DMU data and benchmarking against similar studies from the literature. The study demonstrated satisfactory agreements with both benchmarks, confirming the model's fidelity.

Gaurav et.al (2021): Recent research and projects have explored various solutions and approaches in hybrid, fuel cell, and electric vehicle technologies. Validating control systems for motors operating as both motor and generator alongside fuel cells through computational simulation requires careful consideration of all hybrid electric vehicle subsystems. This task is complex and time-intensive. Hybrid electric cars are significantly more environmentally friendly than Internal Combustion Vehicles (ICVs). Efforts are ongoing to develop batteries with extended lifespans, enabling economically viable battery recycling once hybrid cars become widespread. Continued research into alternative energy sources like fuel cells and renewable fuels shows promise for the future of hybrid vehicles. The trajectory of Fuel Cell Vehicles (FCVs) and Electric Vehicles (EVs) depends on the quality of their batteries and fuel cells. Advancements in battery and fuel cell technology are crucial for realizing a promising future for these vehicles. If researchers succeed in developing super batteries or super fuel cells, the future outlook for these vehicles is indeed promising.

Ahmet, Mert (2021): Implementing a transmission system in Hydrogen Fuel Cell Electric Vehicles (HFCEVs) can significantly reduce energy consumption compared to alternative powertrain setups by optimizing operating conditions for electric motors. Automated transmission systems are crucial for enhancing energy efficiency, especially when high torque is needed at lower vehicle speeds. Additionally, integrating a Regenerative Energy Storage and Conversion (RESC) system into an in-wheel motor layout improves energy recovery efficiency, resulting in overall lower energy expenditure, except for setups with downsized electric motors and two-stage automatic transmissions. In-wheel architecture with an RESC system offers advantages, particularly on curved roads, leading to significant energy savings. Continuously Variable Transmission (CVT) transmission allows for reducing the peak torque requirement of the electric motor, enabling motor downsizing. This not only reduces motor weight but also that of associated components and power units, ultimately achieving the lowest energy consumption rates among various layout configurations.

Santosh et.al (2022): The simulation of a real-world Fuel Cell Hybrid Electric Vehicle (FCHEV) mid-size automobile model under various Drive-to-Hybrid (DoH) performance scenarios. The hybrid powertrain is accurately modeled using ADVISOR software within a MATLAB/Simulink framework. Results show that increasing the DoH significantly improves the vehicle's acceleration performance. Moreover, higher DoH configurations notably enhance fuel economy, with a marked 16.3 percent performance improvement observed compared to the original DoH setup, even while maintaining consistent fuel economy. Acceleration performance sees significant improvements by reducing fuel cell power and increasing battery modules' pulse power capabilities, leading to smaller fuel cell stack sizes and costs while enhancing vehicle acceleration. Simulation results on an actual Toyota Mirai FCHEV across various driving cycles demonstrate admirable performance under both European and Japanese driving conditions.

Suraj et.al (2023): Hydrogen fuel gas-powered vehicles, producing only water and heat as byproducts, offer a promising solution for reducing pollution and greenhouse gas emissions. With hydrogen's superior energy storage capacity, these vehicles boast shorter recharging times and longer driving ranges. However, a significant challenge lies in hydrogen procurement due to limitations in conventional production technologies, including energy loss and environmental degradation. Ongoing research aims to overcome these challenges through alternative generation techniques like proton exchange membrane technology, with an estimated efficiency rate of 86%. Exploring options such as using surplus energy sources for hydrogen production and developing hybrid hydrogen-lithium-ion vehicles shows promise for advancing hydrogen-powered transportation.

4.CONCLUSION

The review paper titled "Enhancing the efficiency of hybrid hydrogen fuel cell electric cars" highlights the imperative of sustained academic inquiry and collaborative endeavors aimed at advancing the domain of hybrid Fuel Cell Electric Vehicles (FCEVs). Notable strides have been achieved through the integration of fuel cell technology with complementary systems such as batteries or supercapacitors, resulting in enhancements in efficiency, range, and overall performance. However, persistent challenges including cost constraints, infrastructure limitations, and technological barriers underscore the necessity for ongoing research and interdisciplinary cooperation. Future research initiatives should prioritize exploration into novel materials, innovative system integration methodologies, and advancements in hydrogen production, storage, and distribution infrastructure to address existing challenges comprehensively. Furthermore, the establishment of supportive regulatory frameworks and strategic investments is imperative for facilitating the widespread adoption of FCEVs and associated infrastructure. Through concerted efforts from academia, industry, and policymakers, the transition towards a sustainable and efficient transportation landscape centered on hybrid hydrogen fuel cell electric vehicles can be realized.

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