INNOVATIVE STRATEGEIS AND DESIGN FRAMEWORK FOR ADVANCING GREEN HYDROGEN-POWERED ELECTRIC VEHICLES

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Introduction:

India, the second most populous country in the world, is home to nearly 300 million of the 1.4 billion automobiles globally, making it a major contributor to transportation-related carbon emissions. With approximately 75% of its electricity produced from coal-based thermal power plants, the nation’s energy profile remains heavily reliant on fossil fuels. This dependency not only exacerbates environmental degradations but also drives up energy import costs, which currently exceeds $160 billion annually -a figure projected to escalate without intervention.

Recognizing this critical challenge, the Government of India has outlined an ambitious objective to achieve energy independence by 2047.Central to this vision is the transition towards green hydrogen, a clean and sustainable energy vector capable of replacing conventional petroleum-based fuels. Fuel cell technologies have recently gained traction in the automotive industry due to their ability to convert hydrogen directly into electricity without combustion.

This process yields only water and heat as by-products, significantly reducing green house gases emissions. Compared to traditional battery electric vehicles (EVs), hydrogen fuel cell vehicles offer longer ranges, faster refuelling, and quieter operation, with lower energy losses and reduced operating costs. Thus, integrating green hydrogen into the transportation ecosystem is a forward-looking approach that combines environmental stewardship with economic resilience.

Objectives:

- To utilize renewable energy sources to produce green hydrogen through electrolysis, supporting clean and sustainable energy systems.
- To design a fuel cell system capable of converting hydrogen gas into electricity to power electric motors in vehicles efficiently.
- To validate the practically of green Hydrogen Electric Vehicles (GHEVs) as a scalable and eco-friendly transportation solution.
- To minimize reliance on fossil fuels and decrease environmental pollution caused by carbon emissions.
- To reduce dependency on conventional battery charging by using hydrogen fuel cells that enable faster refuelling and longer driving ranges.

Methodology:

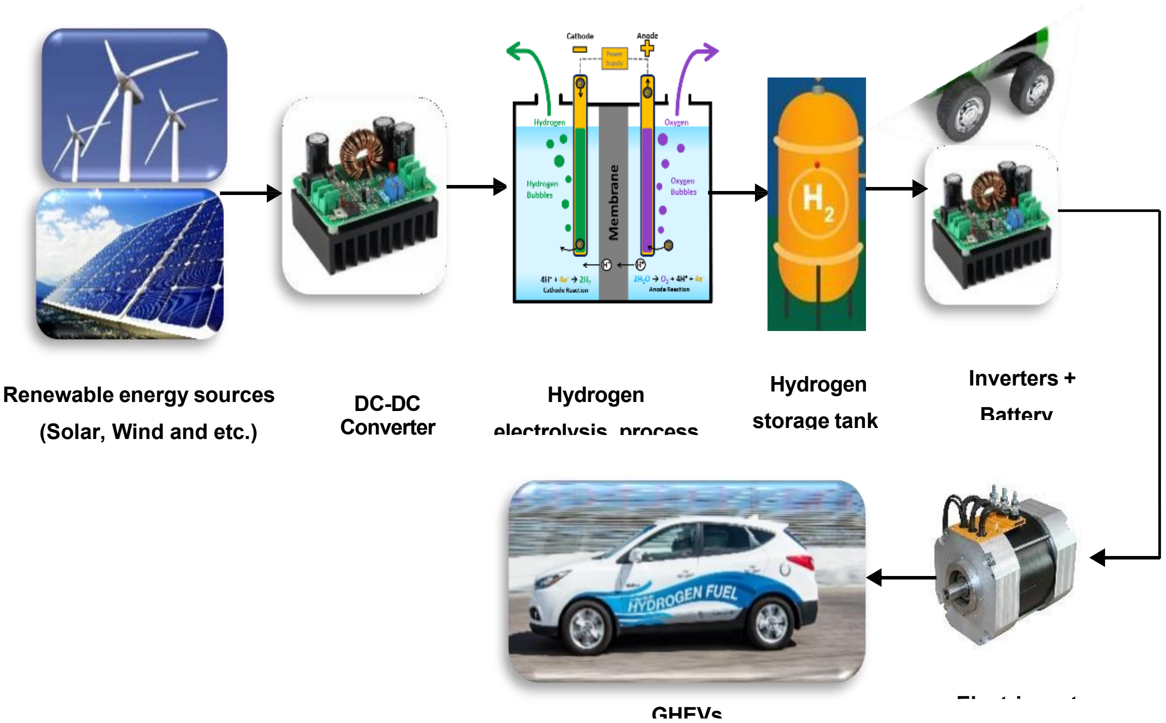

Figure 1: Schematic layout of GHEVs.

1. Renewable Energy source: Renewable energy source such as solar (solar panel-Monocrystalline for energy generation) is harnessed as the initial source of power.
2. DC-DC converter: It stabilizes and regulates the voltage from solar source to suitable levels for electrolysis and storage. For managing output voltage and ensuring safe operation.
3. Hydrogen electrolyser: PEM (Proton Exchange Membrane)-The processed electricity is used to split water into hydrogen and oxygen through electrolysis process. The hydrogen gas is then collected for further use.
4. Hydrogen Storage Tanks: The hydrogen produced is stored in a pressurizes tank, ensuring a steady supply for vehicle.
5. Inverters and batteries: Li-ion battery pack stores energy from the electrolyze or solar for auxiliary systems. DC-AC Inverter converts battery/DC power to AC for motor operation. Battery Management System (BMS)- Protects battery from overcharge or discharge.
6. Supercapacitors (2.7V, 500mF): Supercapacitors are used for rapid energy storage and discharge to assist the inverter in handling load changes efficiently. The inverter converts DC to AC, or stabilizes output for the electric motor.
7. Electric Motor – N20 Gear Motor: The N20 gear motor is used as the driving motor. It is a lightweight, compact DC motor with an integrated gearbox, ideal for small-scale GHEV models. It provides enough torque for wheel movement.
8. Controller and Display System (Arduino + LCD): An Arduino board acts as the central controller to coordinate motor control, sensor inputs, and hydrogen production regulation. An LCD screen displays system parameters such as voltage, hydrogen level, and motor status.
9. Wireless Communication – RF Module: RF modules are used to enable remote monitoring or control of the vehicle parameters, providing a wireless interface between the controller and the user.

Result and Conclusion:

The proposed system successfully demonstrates the practical application of renewable energy to generate hydrogen fuel through electrolysis, contributing to the development of a clean and sustainable energy model.

The generated hydrogen was effectively stored in a mini hydrogen tank and utilized to power the vehicle’s electric motor, showcasing the viability of hydrogen as an energy carrier for electric vehicles.

The integration of supercapacitors (2.7V, 500mF) enhanced the system’s performance by providing rapid charge-discharge capabilities, improving overall energy efficiency and stability during dynamic load conditions.

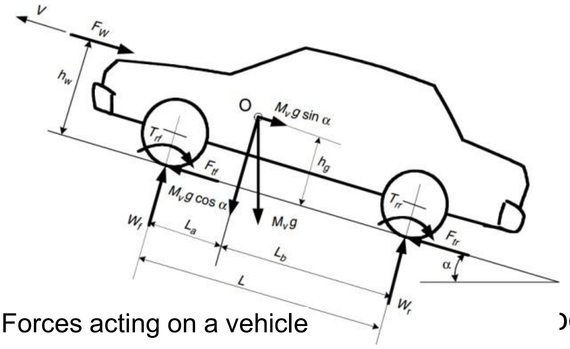

Figure2: Forces acting on a vehicle

The use of an N20 gear motor allow… e vehicle, validating its suitability for small-scale GHEVs.

The Arduino-based control system, supported by LCD display and RF modules, enabled efficient monitoring and control of different subsystems including power flow, electrolysis status, and motor operation.

The entire system worked in coordination with minimal losses, and the prototype model effectively demonstrated the integration of green hydrogen and electric drive technologies.

Conclusion:

This project successfully illustrates a sustainable and environmentally friendly approach to powering electric vehicles using green hydrogen. By utilizing renewable energy sources and efficient energy storage and control mechanisms, the Green Hydrogen Electric Vehicle (GHEV) model offers a promising solution to reduce dependency on fossil fuels and minimize carbon emissions. The practical implementation of components like N20 gear motor, supercapacitors, Arduino controller, and RF communication modules highlights the potential for scaling such systems for future transportation needs. The project aligns with global efforts to combat climate change and promotes the adoption of clean energy technologies in mobility.

Project Outcomes & Industry Relevance:

- The Green Hydrogen Electric Vehicle (GHEV) project demonstrates a sustainable transportation model by integrating renewable energy, hydrogen generation, storage, and electric drive systems.
- A working prototype was developed using solar energy to power electrolysis, with the generated hydrogen stored and utilized via a compact N20 gear motor for vehicle motion.
- Supercapacitors (2.7V, 500mF) were used for quick energy delivery, enhancing motor responsiveness and efficiency.
- Arduino-based control with LCD and RF modules enabled real-time monitoring and wireless communication.
- This system minimizes dependency on fossil fuels and large battery banks, promoting cleaner alternatives for mobility.

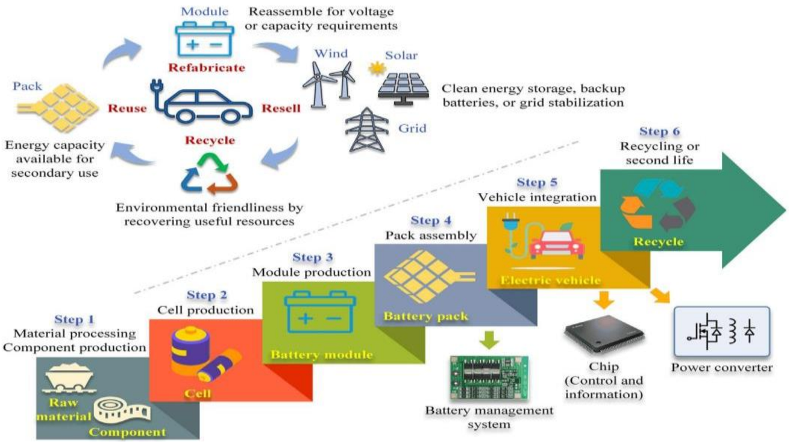

Figure 3: Industrial value chain and circulation of rechargeable batteries for electric vehicle mobility

- The project aligns with industry trends toward green energy, carbon neutrality, and sustainable transport solutions.
- It is relevant for sectors like automotive, renewable energy, embedded systems, and power electronics.
- The modular design makes it suitable for small-scale EVs, last-mile delivery systems, and off-grid power applications.
- It opens avenues for further R&D in hydrogen fuel technology and hybrid energy systems.
- Industries can adopt such models for eco-friendly transportation, especially in

urban and semi-urban areas.

- The interdisciplinary nature of the project promotes innovation in clean tech and energy optimization.
- It can be a stepping stone for startups and enterprises working in the hydrogen economy space.
- The outcomes validate the technical feasibility and scalability of green hydrogen in real-world settings.

Working Model vs. Simulation/Study:

This project involved the development of a fully functional physical working model of a Green Hydrogen Electric Vehicle (GHEV). The prototype was designed and fabricated using real-time components such as a solar panel, N20 gear motor, hydrogen electrolyser, supercapacitors (2.7V, 500mF), an Arduino-based control system, and RF communication modules.

The aim was to practically demonstrate the integration of renewable energy with hydrogen generation and its utilization in powering an electric vehicle. The system architecture, power flow, and hydrogen conversion efficiency were implemented and observed in a hands-on environment.

While theoretical analysis and calculations supported the design phase (such as determining motor torque, energy requirements, and hydrogen production rate), the core emphasis remained on experimental validation through the working prototype.

This approach enabled a more comprehensive understanding of the technical challenges, practical feasibility, and system behaviour under real operating conditions—making the project strongly grounded in practical engineering rather than being limited to simulation or theoretical study.

Project outcomes and learnings:

The Green Hydrogen Electric Vehicle (GHEV) project has resulted in several key outcomes and valuable learnings:

1. Successful Development of a Working Prototype: A compact, functional model was built integrating renewable energy sources, hydrogen production through

electrolysis, energy storage via supercapacitors, and an electric drive using an N20 gear motor.

2. Effective Integration of Interdisciplinary Concepts: The project brought together knowledge from electrical engineering, power electronics, embedded systems, and sustainable energy technologies.
3. Hands-on Experience in System Design and Implementation: Team members gained practical exposure in selecting components, designing circuit layouts, assembling hardware, and programming microcontrollers for real-time control.
4. Improved Understanding of Hydrogen Energy Utilization: The project provided insights into hydrogen generation, storage challenges, and its practical use as a clean fuel in electric mobility.
5. Application of Embedded Systems in Energy Monitoring: Implementation of Arduino, LCD display, and RF communication deepened understanding of real-time system monitoring and control.
6. Problem-Solving and Optimization Skills: Challenges during fabrication and testing encouraged critical thinking, troubleshooting, and iterative improvements in system performance.
7. Validation of Sustainable Transportation Concept: The project proved the technical feasibility of a hydrogen-based electric vehicle model for future green mobility solutions.
8. Team Collaboration and Project Management: Working as a team under time and resource constraints enhanced collaboration, planning, and execution skills essential for industry settings.

This project not only contributed to environmental sustainability but also served as a strong learning platform for future innovations in the field of clean energy and electric vehicles.

Future scopes:

The Green Hydrogen Electric Vehicle (GHEV) project lays the foundation for several potential advancements and real-world applications in the fields of sustainable energy and electric mobility. The following are identified as key areas for future research and development:

1. Scaling for Commercial Applications: The prototype can be expanded into a full-scale model suitable for electric bikes, autos, or small transport vehicles powered entirely by green hydrogen.
2. Integration with Smart Charging Infrastructure: Development of a smart solar-hydrogen charging station can enhance the vehicle's usability and autonomy in remote or off-grid areas.
3. Hydrogen Fuel Cell Implementation: The system can be upgraded with compact hydrogen fuel cells for higher efficiency, greater power output, and extended range.
4. IoT-Based Monitoring and Control: Integrating IoT technology for advanced data logging, remote diagnostics, and predictive maintenance can enhance system intelligence.
5. Advanced Energy Management Systems: Research into hybrid energy storage systems combining batteries and supercapacitors could further improve energy efficiency and vehicle performance.
6. Safety and Storage Optimization: Future work can focus on improving the safety and miniaturization of hydrogen storage systems for broader acceptance in public transport.
7. Environmental and Economic Analysis: A detailed lifecycle and cost analysis can provide insights into the environmental impact and economic feasibility of GHEVs in comparison to conventional EVs.
8. Policy and Industrial Collaboration: Collaboration with industries and policymakers can help in pilot testing, certification, and large-scale adoption of hydrogen-powered vehicles.

This project opens up promising avenues in clean transportation and can serve as a stepping stone for innovative solutions in the green mobility ecosystem.