IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 4, June 2025
Impact Factor: 7.67

Electric Highway with Pantograph System (EHPS)

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Abstract: *This project, titled* ***"ESP8266-Based Robot for Electric Highway Integration Using Pantograph Mechanism,"*** *focuses on the design and development of a self-operating electric vehicle tailored for highway freight transport. The system incorporates a pantograph mechanism that enables real-time battery charging from overhead electric lines while the vehicle is in motion. Central to the system is an Arduino microcontroller, programmed to autonomously navigate pre-defined routes and avoid obstacles using sensor input. The vehicle is also equipped with sensors to track its speed, monitor battery status, and detect surrounding objects. By combining automation with sustainable power delivery, this solution seeks to offer a viable alternative to traditional fossil-fueled transportation, promoting both energy efficiency and environmental preservation.*

Keywords: electric vehicle

I. INTRODUCTION

With increasing concerns over greenhouse gas emissions and the urgent need for sustainable transportation systems, the **Electric Highway with Pantograph System (EHPS)** has emerged as a cutting-edge solution for long-haul road freight decarbonization. This approach involves the deployment of overhead electric lines along dedicated highway lanes, enabling specially equipped electric trucks to draw continuous power through a roof-mounted, extendable pantograph. This power not only drives the vehicle but can also recharge its battery for use beyond the electrified segments. The hybrid capability ensures that the vehicle transitions smoothly between electrified and non-electrified zones. EHPS draws on established electric rail technologies while addressing the flexibility and scalability required by road-based logistics systems.

II. LITERATURE REVIEW

1. Evolution and Technological Basis

The idea of powering vehicles via overhead lines traces back to electric trolleybuses in the early 1900s. However, the application of this concept for heavy-duty freight gained momentum only in the past decade, led by technological advancements and pilot projects. Siemens and Scania have been at the forefront of these innovations, with Siemens launching eHighway demonstrations in countries such as Germany, Sweden, and the USA. These trials proved the system's capability to maintain stable connections at speeds up to 90 km/h, offering automated pantograph operation and seamless transitions between electrified and non-electrified segments (Siemens Mobility, 2021).

2. Environmental and Energy Efficiency

Life Cycle Assessment (LCA) studies highlight EHPS as one of the most eco-efficient solutions for freight transport when powered by renewable sources. Research by Kasten et al. (2020) reveals that trucks utilizing EHPS can slash carbon dioxide emissions by up to 90% over their operational life compared to diesel-powered counterparts. The **International Council on Clean Transportation (ICCT)** emphasizes that EHPS surpasses hydrogen fuel cells in energy efficiency and demands less extensive infrastructure compared to large-scale electric charging networks.

3. Economic Considerations

Economic analyses show that, while initial investment in EHPS infrastructure is substantial (estimated at €2–3 million per kilometer), long-term operational savings render it cost-effective over time. According to the German Environment Agency (UBA, 2021), electrifying just a portion—around 4,000 km—of Germany's highway network could

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decarbonize more than half of road freight. Lower fuel costs, reduced emissions taxes, and minimal vehicle maintenance contribute to the economic viability of EHPS over a 20 to 30-year timeframe.

4. Field Trials and Deployment

Practical implementations have validated the theoretical potential of EHPS. Germany currently operates three pilot routes (A5, A1, and B462), where hybrid trucks equipped with pantographs demonstrate consistent performance even in challenging weather. Similar findings come from Sweden's **eRoadArlanda** and California's **I-710** corridor trials, proving the adaptability of EHPS to different climates, traffic laws, and fleet types.

5. Integration Barriers and Research Gaps

Despite positive outcomes, several hurdles must be addressed for broader adoption:

Lack of standardization: Variations in pantograph design, voltage specifications, and connector interfaces.

Grid coordination issues: Challenges in managing peak demand and integrating with renewable energy supplies.

Policy and regulatory fragmentation: Absence of harmonized strategies across regions and countries.

III. RESEARCH METHODOLOGY

This study aims to assess the technical, environmental, and economic feasibility of EHPS as a sustainable transport solution. A mixed-methods approach, combining both qualitative and quantitative research, was employed.

1. Research Design

The investigation follows a **descriptive-exploratory framework**. The descriptive part compiles existing data on EHPS infrastructure and operations, while the exploratory aspect identifies trends, technological gaps, and strategic opportunities for future deployment.

2. Data Collection Strategy

2.1 Secondary Sources

Information was compiled from a range of reliable sources:

- Peer-reviewed journals and engineering conference papers (IEEE, Elsevier, Springer)
- Governmental and non-governmental reports (UBA, ICCT, European Commission)
- Technical specifications and documentation from pilot projects (Siemens, Scania)
- Databases related to energy use and emissions modeling

2.2 Case Study Analysis

Three EHPS deployments were examined in detail:

The **A5 eHighway project in Germany**

The **eRoadArlanda initiative in Sweden**

The **I-710 demonstration in California, USA**

Each case was evaluated based on infrastructure layout, vehicle compatibility, real-world performance, and stakeholder engagement.

V. CONCLUSION

The Electric Highway with Pantograph System (EHPS) presents a forward-looking solution to the challenge of decarbonizing freight transport. By leveraging continuous energy supply from overhead lines, EHPS not only increases energy efficiency but also reduces the reliance on large battery packs and minimizes vehicle downtime associated with conventional charging. Drawing from the proven principles of railway electrification and adapting them to modern road transport, EHPS provides a feasible pathway to achieving carbon neutrality in logistics. While challenges in standardization, policy alignment, and grid integration remain, the successful outcomes from global pilot projects reinforce its potential as a scalable and sustainable infrastructure model.

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