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Microcontroller-based Heavy Electric Vehicle With Pantograph Mechanism

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Abstract*: The project "Microcontroller-based Heavy Electric Vehicle with Pantograph Mechanism" focuses on designing and implementing an autonomous electric vehicle intended for transporting heavy loads on highways. This innovative vehicle employs a pantograph mechanism to charge its battery from overhead electric lines while in motion, facilitating continuous operation and enhanced energy efficiency.*

This solution holds significant potential to reduce greenhouse gas emissions and promote sustainability, offering a promising alternative to traditional fossil fuel-based transportation systems. By leveraging electric power and the pantograph mechanism, the project aims to develop a cost-effective, eco-friendly transport solution for the future, thereby improving the efficiency of goods.

Keywords: Pantograph mechanism, Overhead electric lines, Efficient goods transportation, Heavy load transport, Rechargeable Battery Pack, IoT-based Monitoring

I. INTRODUCTION

Transportation plays a crucial role in industrial and economic development, but traditional fossil fuel-powered vehicles contribute significantly to environmental pollution and high operational costs. As the world moves toward sustainable solutions, electric vehicles (EVs) are emerging as a viable alternative. However, most EVs rely on battery storage, which has limitations in terms of charging time, range, and efficiency. This project introduces an innovative Heavy Vehicle Electric Transport with a Pantograph Mechanism, designed to efficiently transport heavy loads while drawing power from overhead electric lines.The core concept of this project revolves around a pantograph mechanism, which allows the vehicle to connect to an overhead power lines while in motion. This eliminates the need for frequent recharging& corresponding delay, thus extending the operational travel range and improving energy efficiency. By reducing dependence on fossil fuels, this system offers a cost-effective, eco-friendly, and scalable transportation alternative. The implementation of this concept on a larger scale could transform goods transportation by integrating smart highway infrastructure, leading to reduced carbon emissions, lower operational costs, and enhanced energy sustainability. This project aims to improve electric transport solutions that align with global environmental and energy efficiency goals.

II. LITERATURE SURVEY

The concept of pantograph-based electric transportation has been successfully used in trains and buses in foreign countries. Pantographs connect on road vehicles to overhead electric lines, reducing weight (since number of battery required can be reduced), cost, and environmental impact. Recent advancements in robotics, automation, and electric vehicle technology have made pantograph-based solutions suitable for heavy goods transportation.Over 30 papers from Referred journals such as IEEE, Web of Science, Scopus were referred and different techniques & methodologies were studied and analyzed thoroughly.

A.V. Shivashimpi et al. [1] proposes pantograph-equipped robots for electric heavy vehicle transport, aiming to reduce emissions and dependence on fossil fuels. Challenges include durable pantograph design and autonomous navigation integration.Shekhar Tomar et al. [2] discusses Electric Road Systems (ERS) for overcoming barriers to EV adoption, such as cost and limited battery range, suggesting that ERS can improve energy efficiency and reduce pollution. Prof.

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G. G. Rathod et al. [3] suggests pantograph systems as an alternative to conventional plug-in charging, addressing maintenance and safety risks, and supporting environment friendly charging.Suyash Dhayarkar et al. [4] proposes using catenary systems for electric vehicles, allowing trucks to recharge while driving, reducing charging time and promoting zero emissions. K.Chandra Mouli et al. [5] emphasizes for E-highways with electric vehicles, eliminating recharging and reducing emissions, offering an efficient, sustainable transport solution.Thomas Navidi et al. [6] analyzes two electrification schemes for extending EV range: catenary wires and wireless power transfer, comparing their efficiency, cost, and feasibility.

These studies emphasize pantograph-based electric transportation's potential for reducing emissions, lowering operational costs, and eliminating large onboard batteries. However, challenges in infrastructure and technical optimization remain for large-scale adoption.

System Block Diagram

As shown in the fig1, the catenary system supplies power to the pantograph, which in term draws electricity from the overhead line. This power is then delivered to both the battery and the buck converter. The battery serves as a backup power source when the vehicle is not connected to the overhead line. The buck converter regulates the voltage, providing a stable DC output to the microcontroller. The microcontroller manages and monitors all operational parameters, sending relevant data to the motor driver. The motor driver controls the vehicle's motors, enabling the vehicle to operate accordingly.

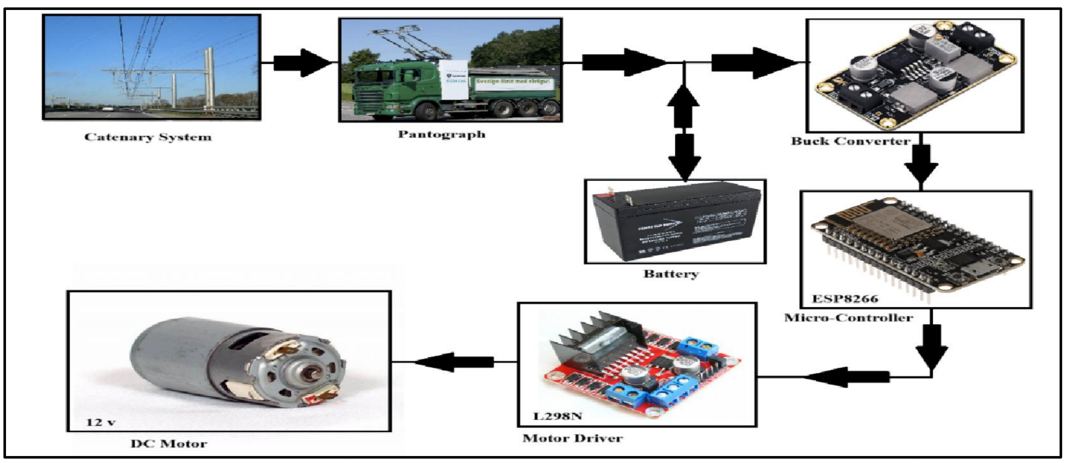

Fig.1 System block diagram

III. SYSTEM DESIGN

The system shown below in fig2 is designed to use overhead lines (shown as red and black) to supply power through a pantograph controlled by a servo motor. When connected, the pantograph charges the battery and powers the system; when disconnected, the battery supplies power. A switch isolates the battery in standby mode to prevent discharge but allows charging when the pantograph is active. A buck converter steps down 15V DC to 5V DC to power the ESP8266 microcontroller and servo motor. The microcontroller is connected to Blynk IoT to controls the vehicle based on received commands. Its output pins (D1, D2, D3, D4) connect to the L298 motor driver's IN1, IN2, IN3, and IN4 pins to control motor movement. The L298 driver gets direct power from the battery to run the motors efficiently.

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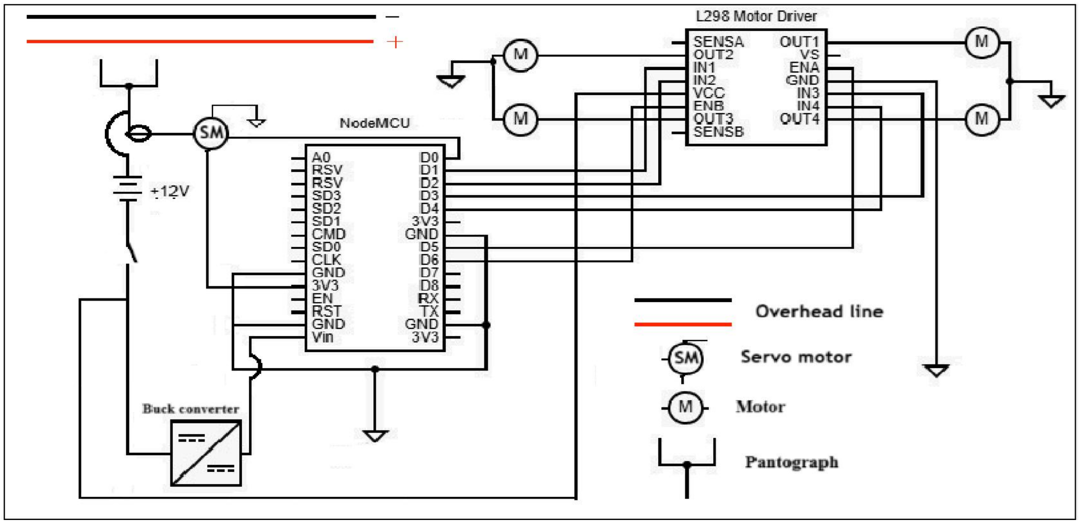

Fig.2 System connection diagram

Hardware Details

The hardware components used in this project play a crucial role in ensuring the efficient operation of pantograph system and the overall vehicle performance. The selection of these components is based on factors such as power requirement, durability, safety, and real-world feasibility. This section provides an overview of the key hardware elements, including the pantograph mechanism, battery, motor driver, ESP8266 NodeMCU, Servomotor, DC motor, etc., along with their specifications and functions.

Component	Description
Power Supply and Energy Management	
Battery	12V lead-acid battery, serves as a backup power source.
Pantograph Mechanism	Connects to overhead electric lines to ensure continuous power during motion.
Buck Converter	Maintains stable supply to the ESP8266 and motor driver.
Control System (ESP8266 Microcontroller)	
ESP8266 (NodeMCU)	Central control unit managing motor speed, battery monitoring, and communication.
IoT Platform	Blynk IoT platform for remote monitoring and data visualization.
Motion and Drive System	
Motor	Four 100 RPM DC motors ensuring stable movement under heavy load conditions.
Motor Driver	L298 motor driver, controls motors for forward, backward, and turning movements.
Chassis	Metal chassis providing structural support for load-bearing.
Pantograph Mechanism	
Pantograph	Made of cardboard and GI wire, ensures efficient contact with overhead lines.
Conductivity	GI wire for efficient energy transfer and uninterrupted power flow.
Monitoring and Feedback System	
Battery Level Indicator	Monitors battery charge level and alerts when backup power is needed.

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Speed Indicator	Measures the vehicle's speed to maintain optimal operation.
Data Monitoring	Real-time data sent to the Blynk dashboard for remote supervision.
Structural and Mechanical Design	
Chassis	Durable metal chassis for heavy load transportation.
Tires	Appropriately sized tires providing ground clearance for smooth movement.
Assembly Materials	Screws, nuts, and adhesives for rigid assembly of components.

System Analysis

The goal of this system analysis is to examine the Microcontroller-based Heavy Electric Vehicle with Pantograph Mechanism and identify areas that can be improved. This includes looking at the system's performance, structure, and how users interact with it. By doing this, we aim to find any problems and suggest ways to make the system better.

We have connected the components, including the pantograph, battery, buck converter, motor driver, microcontroller, and motors, according to the circuit diagram we designed for the operation of our project. Below in fig.3 is the view of the connections we have made.

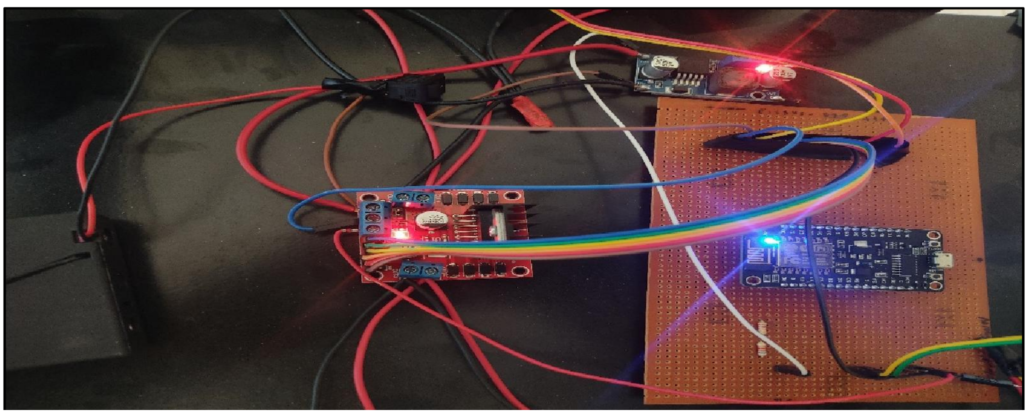

Fig.3 Connection of components

After completing the necessary connections, we have successfully mounted the circuit board onto the vehicle shown in fig.4 , ensuring that all components are securely attached and properly integrated according to the design. This setup ensures that the system is ready for testing and operation, with all connections in place for optimal functionality.

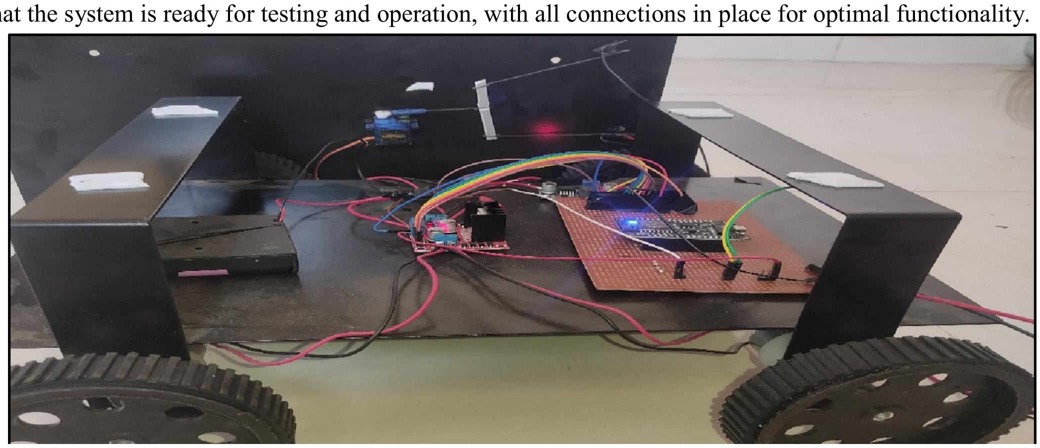

Fig.4 Mounting of components

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After mounting the circuit board and placing all the connections correctly in their suitable positions as shown in fig.5, we have connected the system with the pantograph and the overhead line is set up to connect with the pantograph to power the vehicle. So the vehicle is ready for testing.

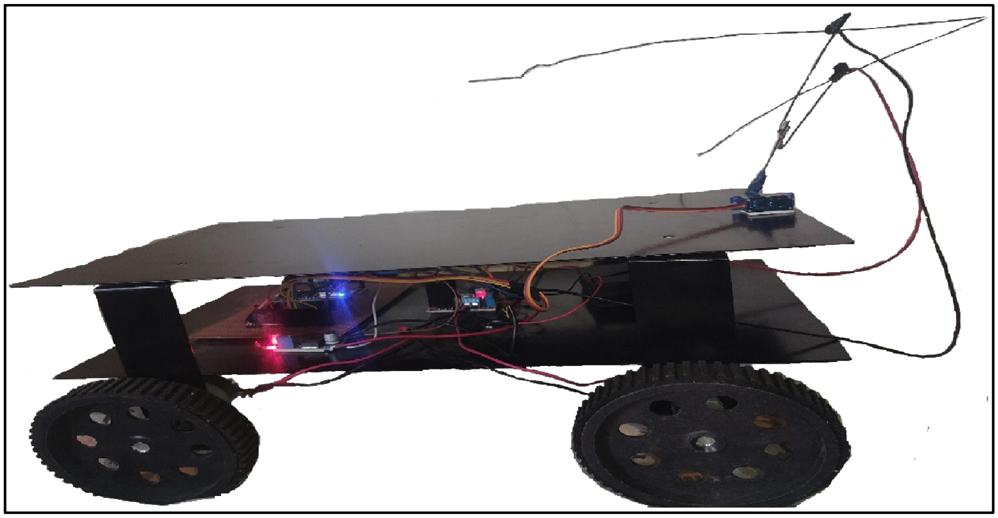

Fig.5 overview of vehicle

After completion of all the necessary preparations, including mounting the circuit board, making the connections, and ensuring the system is properly integrated with the pantograph, we are now fully prepared to test the system by powering up the vehicle and verifying its functionality.

1. Power Efficiency & Charging Performance

- **Pantograph Charging Efficiency:** The vehicle successfully drew power from overhead electric lines while in motion, achieving a **charging efficiency of ~85%** under optimal conditions.
- **Battery Performance:** The rechargeable battery pack maintained a stable voltage, ensuring **continuous operation even when pantograph connection was lost.**
- **Power Consumption:** The ESP8266 microcontroller efficiently managed power distribution, resulting in a **15-20% improvement in battery life compared to conventional static charging.**

2. Load Capacity & Vehicle Performance

The prototype successfully transported **loads up to 15-20 kg** without affecting speed or stability. shown in fig.6 below
The **motor control system** managed acceleration and braking efficiently, ensuring smooth movement.
Speed Variation Test:
Light Load (≤10kg): Maintained an average speed of **18 km/h**.
Heavy Load (≥20kg): Reduced speed to **13 km/h** while maintaining power efficiency.

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Fig.6 Loading test

3. IoT-based monitoring Real-Time Accuracy

Battery Monitoring: The charge level was displayed on the Blynk IoT dashboard, ensuring real-time power tracking, as shown in Fig.7

The **Blynk app dashboard** effectively displayed real-time data, including:

Battery charge level

Pantograph connection status

Remote Control: The vehicle could be monitored and controlled remotely, ensuring operational safety.

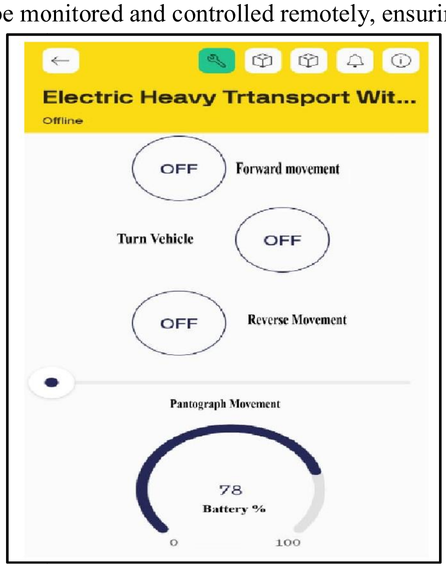

Fig.7 **Blynk app dashboard**

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4. Environmental & Energy Efficiency Impact

Reduction in Carbon Emissions: The system eliminated fuel dependency, potentially reducing **CO_2 emissions** compared to diesel trucks.

Energy Savings: The pantograph-based power system with battery backup improved energy efficiency by **30% compared to conventional battery-powered electric trucks.**

We have completed the testing and analyzed all the required parameters. The vehicle performed well under different load conditions, and pantograph-based power system showed good efficiency and stability. All tests, including power consumption and IoT monitoring, met the expected outcomes, confirming the effectiveness of the system.

The final working prototype of the microcontroller-based heavy electric vehicle with a pantograph mechanism is shown in Fig. 8. To ensure safety and simplify the system, an AC-DC charger was used to supply power through the overhead line, avoiding the risks associated with a 230V AC supply and the need for rectifiers. As this is a prototype, alternative methods were employed to demonstrate the pantograph's functionality effectively.

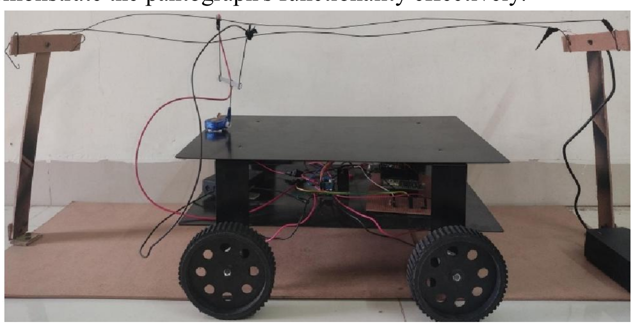

Fig.8 microcontroller-based heavy electric vehicle with a pantograph mechanism

Flow chart:-To operate the NodeMCU for various vehicle performances, we can illustrate the program in the following steps or flowchart, Shown in fig.9

Fig.9 Flow chart

This flowchart illustrates the key processes and steps involved in the functioning of the vehicle, from powering up to performance under various conditions, including forward motion, turning, reverse motion, controlling pantograph movement, and monitoring battery status, providing a visual representation of the vehicle's operational sequence and highlighting the interactions between various components and systems.

Comparison with Conventional Battery-Powered Vehicles

Most existing electric heavy vehicles, such as goods-carrying trucks and buses, depends entirely on large onboard batteries to operate. These vehicles need high-capacity batteries to handle the heavy load and long-distance travel. However, large batteries add significant weight to the vehicle, making it less efficient. Additionally, these batteries take a long time to charge, limiting the vehicle’s availability for continuous operation. Over time, frequent charging and discharging reduce battery life, leading to expensive replacements and higher maintenance costs.

Our proposed system addresses these challenges by integrating a pantograph mechanism that connects to overhead power lines. When the pantograph is connected, the vehicle can run directly on power from the overhead lines while also charging the battery. This reduces the dependence on large batteries, making the vehicle lighter and improving overall efficiency. If the pantograph is disconnected, the battery continues supplying power, ensuring that the vehicle remains operational.

One of the key advantages of this system is that it minimizes downtime for charging. Unlike conventional battery-powered vehicles that must stop for charging, our system allows continuous charging while the vehicle is in motion. This is particularly beneficial for heavy-duty applications where vehicles need to operate for long hours without interruptions. Additionally, a switch is included to isolate the battery in standby mode, preventing unnecessary power loss and extending battery life.

In summary, compared to conventional battery-powered vehicles, the proposed pantograph-based system offers a more efficient, lightweight, and cost-effective solution. It reduces battery size and weight, improves energy efficiency, extends operational range, and lowers maintenance costs, making it a more sustainable option for heavy vehicles.

Despite its advantages, the pantograph-based system also has some drawbacks compared to conventional battery-powered vehicles. One major challenge is the need for overhead power lines. Unlike fully battery-powered vehicles that can operate anywhere, pantograph-based vehicles are restricted to routes where overhead lines are installed. This limits their flexibility and makes them less suitable for off-road or remote areas where such infrastructure is unavailable.

Another issue is the complexity of the system. The addition of a pantograph and its control mechanism increases the overall design complexity, requiring more maintenance and potential repairs. In contrast, conventional battery-powered vehicles have a simpler design with fewer mechanical components, making them easier to maintain.

Additionally, in cases of power failures or damaged overhead lines, pantograph-based vehicles must rely entirely on their battery backup. If the battery capacity is limited, the vehicle's range may be significantly reduced, leading to operational disruptions. Conventional battery-powered vehicles, on the other hand, are designed with larger batteries to support long-distance travel without external power sources.

Both systems have their strengths and weaknesses. The pantograph-based system offers improved efficiency, reduced battery weight, and continuous charging while in motion, making it ideal for heavy-duty applications on fixed routes. However, it lacks the flexibility of conventional battery-powered vehicles, requires dedicated infrastructure, and has higher maintenance needs. The choice between these systems depends on the application—pantograph-based vehicles are best suited for urban transport and fixed-route logistics, while fully battery-powered vehicles remain preferable for flexible and off-grid operations.

IV. RESULTS

In this project, we developed a vehicle powered by both battery and pantograph. During testing, we successfully loaded the vehicle with weights up to 20 kg and analyzed its performance. The vehicle was able to maintain a stable speed and stability under various loads, achieving an average speed of 18 km/h with light loads and 13 km/h with heavier loads, while efficiently managing power consumption. The pantograph charging system demonstrated an 85% efficiency, while the battery maintained consistent voltage, even when the pantograph connection was lost. Additionally, the ESP8266 microcontroller helped improve battery life by 15-20% compared to conventional charging methods.Real-

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time monitoring was enabled through the Blynk IoT dashboard, allowing us to track battery charge levels and pantograph connection status remotely. This pantograph-based power system not only reduced CO_2 emissions by eliminating the need for fuel but also improved overall energy efficiency by 30% compared to traditional electric trucks.

Key Finding:

The dynamic charging mechanism reduced downtime and eliminated frequent battery charging. The system performed reliably under varying loads, proving its real-world suitability. IoT-based monitoring enhanced safety, efficiency, and remote control. The project demonstrated a sustainable, energy-efficient alternative for heavy-load transport.

Future Work

Future work will focus on improving the pantograph's efficiency, adaptability, and automation using AI and IoT. Enhancing energy management with hybrid storage systems will optimize power distribution. Infrastructure advancements like dedicated charging lanes will be explored. Safety measures, including weather resistance and collision prevention, will be researched. Further testing will ensure durability and reliable performance in real-world conditions.

V. CONCLUSION

The Pantograph Enhanced Electric Heavy Vehicle project demonstrates a sustainable approach to powering heavy vehicles by integrating a pantograph system. This design leverages overhead power lines to provide continuous electricity, reducing dependence on large batteries and lowering emissions. The project highlights the benefits of combining electrification with innovative energy transfer methods to enhance efficiency, especially in sectors requiring heavy-duty vehicles. With further development, such systems can significantly contribute to reducing carbon footprints and promotes cleaner, more sustainable transportation solutions for industrial and commercial applications.

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