

Heavy Vehicles: Distributed Hybrid Power System and Vehicle

¹Nagarajan Krishnamurthy, ²Sai Krishnan Ganesh

¹Department of Mechanical Engineering, Rajalakshmi Institute of Technology, Chennai, Tamilnadu

²Department of Mechanical Engineering, Rajalakshmi Institute of Technology, Chennai, Tamilnadu

nagarajan.p.k@ritchennai.edu.in, saikrishnan.g@ritchennai.edu.in

Abstract

This research focuses on the development of a distributed hybrid power system and vehicle for heavy vehicles. The dynamical system comprises a power plant module, a drive module, an energy-storage module, and an entire car controller. The power plant module consists of one or more auxiliary power units that provide power to the heavy vehicle's power system. The drive module includes multiple driver elements responsible for directly driving the heavy vehicle's drive axles or operating individual wheels through direct drive. The energy-storage module serves as an energy reserve. The entire car controller is connected to the power plant module, drive module, and energy-storage module, enabling control over the activation of driver elements and the output of these elements to manage the heavy vehicle's transportation conditions. The novel approach eliminates the need for mechanical power transmission systems found in conventional engines and drive axles, allowing for flexible arrangement of auxiliary power units and driver elements on heavy vehicles.

Keywords: Distributed hybrid power system, heavy vehicle, power plant module, drive module, energy-storage module, entire car controller, driver elements, auxiliary power unit, flexible arrangement.

Introduction

The transportation sector plays a crucial role in global energy consumption and carbon emissions. As the demand for heavy vehicles continues to rise, there is a growing need to develop innovative and sustainable solutions that address the environmental impact and efficiency of these vehicles. In response to these challenges, the concept of distributed hybrid power systems for heavy vehicles has emerged as a promising approach. This research aims to explore and develop a distributed hybrid power system and vehicle specifically designed for heavy vehicles, offering improved efficiency, flexibility, and control.¹

Heavy vehicles, such as trucks and buses, are known for their substantial energy requirements and high fuel consumption. Conventional heavy vehicles typically rely on internal combustion engines and mechanical power transmission systems to generate and deliver power to the drive axles. However, these systems are associated with various drawbacks, including energy losses, limited flexibility in power distribution, and increased maintenance costs.² The distributed hybrid power system proposed in this research presents a paradigm shift in heavy vehicle design. The dynamical system comprises four key components: the power plant module, drive module, energy-storage module, and

entire car controller.² The power plant module includes one or more auxiliary power units, which serve as alternative power sources for the heavy vehicle's power system. These auxiliary power units provide the necessary energy to propel the vehicle, reducing reliance on conventional internal combustion engines.³

The drive module consists of multiple driver elements, each responsible for directly driving one or more drive axles or operating individual wheels through direct drive. This direct drive mechanism eliminates the need for mechanical power transmission systems, resulting in reduced energy losses and increased powertrain efficiency.⁷ By distributing the power sources and driver elements throughout the vehicle, the system offers greater flexibility in arranging components, optimizing weight distribution, and improving overall vehicle performance. To ensure efficient energy management and control, the entire car controller acts as the central control unit that connects and coordinates the power plant module, drive module, and energy-storage module.¹ It enables the activation of driver elements and regulates their output, allowing for precise control over the heavy vehicle's transport conditions. This centralized control system ensures optimal power distribution and utilization, leading to enhanced efficiency and improved vehicle dynamics.⁵

The research objective is to investigate and develop this distributed hybrid power system and vehicle for heavy vehicles. The primary focus is on achieving improved energy efficiency, reduced carbon emissions, and enhanced overall performance. By integrating auxiliary power units, direct drive mechanisms, and a centralized control system, the research aims to overcome the limitations of conventional heavy vehicle power systems. The goal is to explore a cost-effective and scalable solution that is compatible with large-scale production, enabling the widespread adoption of distributed hybrid power systems in heavy vehicles. The potential benefits of the proposed system are significant. By electrically connecting the auxiliary power units through a distributed system, the mechanical power transmission systems found in traditional engines and drive axles are eliminated. This allows for flexible arrangement and placement of power sources and driver elements, optimizing vehicle design and weight distribution.² Moreover, the distributed hybrid power system offers improved power distribution, reduced energy losses, and increased overall efficiency, leading to enhanced fuel economy and reduced carbon emissions. In conclusion, the development of a distributed hybrid power system and vehicle for heavy vehicles represents a transformative approach in the transportation industry. By integrating auxiliary power units, direct drive mechanisms, and a centralized control system, this research aims to improve energy efficiency, reduce environmental impact, and enhance the overall performance of heavy vehicles. The findings of this study have the potential to revolutionize heavy vehicle design and contribute to a more sustainable and efficient transportation sector.

Related Work

In response to the increasing severity of the energy crisis and the urgent need to reduce emissions and promote energy conservation, the global automotive industry has witnessed rapid development in the field of new-energy vehicles. These vehicles typically incorporate a hybrid power system that combines various components such as engines, generators, motors, and energy storage systems (including electrochemical cells, supercapacitors, or composite energy storage systems). These systems are designed to meet the operational requirements of automobiles and can be configured in different ways, including tandem, parallel, and series-parallel arrangements.² In order to assess the efficacy of the proposed energy management strategy employing PMP global optimization, it is necessary to perform simulation experiments under dynamic load profiles. The simulations are conducted using UDDS conditions, with an initial state of charge (SOC) set at 0.9 and a depth of discharge (DOD) set

at 80% as specified in this study. A specific cycle condition is chosen to thoroughly analyze the test outcomes, and its performance is validated through simulation comparison with the fuzzy control energy management strategy. The simulation results for the UDDS working conditions are depicted in Figure 1.

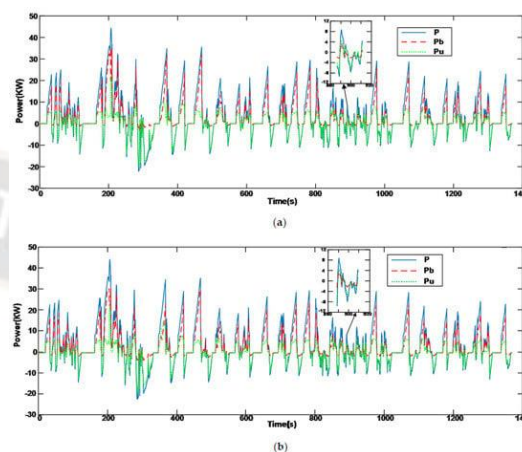
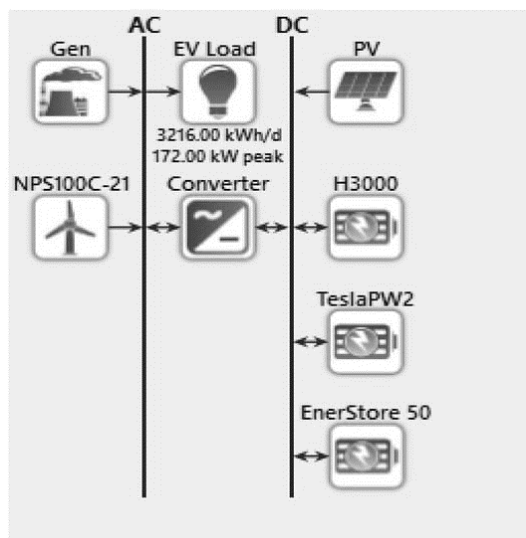


Figure 1. (a) Result curve of speed and power distribution for the fuzzy control strategy. (b) Result curve of speed and power distribution for PMP strategy.

In a series configuration, an auxiliary power unit (APU) is formed by combining the engine, damper, and generator (equipped with an engine controller). The APU units are electrically connected to the motor (equipped with a motor controller) but not mechanically connected, allowing for independent arrangement and increased flexibility.⁴ On the other hand, in a parallel configuration, there is mechanical cooperation and torque synthesis between the Engine-Generator and the motor, which poses challenges in terms of system integration. In the case of large-scale and heavy vehicles such as heavy trucks, special vehicles, and mining vehicles, the power transmission occurs through multiple shafts. Conventional engine-driven multi-axle vehicles often involve a series of components, including the engine, transmission, power transmission shaft, transfer case, decelerator, and additional power transmission shafts.⁶ This power drive system exhibits high rotary inertia, occupies significant space, and has low efficiency of movement (typically around 50% to 60%), limiting flexibility and convenience in arrangement. The suggested hybrid energy system incorporating the load for charging electric vehicles was subsequently employed to investigate the influence of diverse battery technology attributes on the viability and techno-economic evaluation of the hybrid energy source's configuration. Wind turbines, solar panels, diesel generators, and energy storage devices all form integral components of a conventional hybrid system, as depicted in Figure 2.



When these oversized vehicles adopt a series hybrid power configuration, the engine power is typically larger. In such cases, a single Engine-Generator setup is often insufficient, necessitating a motor and its corresponding controller with higher power ratings.¹ Consequently, a single larger engine and generator combination is used, which presents challenges in terms of weight, height, and onboard arrangement. These factors can impact the overall weight distribution and the height of the vehicle's centre of gravity. Addressing these challenges and optimizing the configuration of hybrid power systems for large-scale and heavy vehicles is crucial. By finding innovative solutions, such as flexible arrangement options, improved integration, and better weight distribution, it becomes possible to overcome the limitations associated with conventional power transmission systems and enhance the overall performance of these vehicles. In summary, the urgent need to address the energy crisis and reduce emissions has driven the development of new-energy vehicles in the global automotive industry.³ The configuration of hybrid power systems plays a crucial role in achieving energy efficiency and reducing environmental impact.

However, in the case of large-scale and heavy vehicles, there are unique challenges related to power transmission, arrangement, and weight distribution. Overcoming these challenges requires innovative approaches that optimize the integration and arrangement of components, leading to more efficient and flexible hybrid power systems for these vehicles.

Research Objective

The research objective of this study is to develop a distributed hybrid power system and vehicle specifically designed for heavy vehicles. The main goal is to overcome the limitations

of traditional mechanical power transmission systems by utilizing advanced electrical connections between the power plant module and the drive module. The power plant module plays a crucial role in the hybrid power system. It consists of one or more auxiliary power units, each equipped with an engine and a generator. These power units are responsible for generating the necessary power to drive the heavy vehicle's power system. By incorporating auxiliary power units, the system can provide ample power while ensuring high efficiency and performance.

The drive module, on the other hand, is connected to the power units through a power bus. It comprises multiple driver elements that are directly responsible for driving the vehicle's axles or wheels. By utilizing electrical connections instead of mechanical ones, the system achieves greater flexibility in arranging the power units and driver elements within the heavy vehicle. This flexibility allows for optimal power distribution and efficient operation. The primary objective of this research is to explore the advantages of the distributed hybrid power system and vehicle for heavy vehicles. By replacing conventional mechanical power transmission systems with advanced electrical connections, the study aims to achieve enhanced efficiency, flexibility, and control. The research will investigate the optimal arrangement and integration of the power plant module and drive module to maximize the system's performance.

Distributed Hybrid Power System

The distributed hybrid power system used in heavy vehicles is designed to provide efficient power supply and control. It consists of several modules that work together to optimize the vehicle's performance.

The power plant module is responsible for generating power and includes one or more auxiliary power units. Each power unit consists of an engine and a generator. This module provides the necessary power to operate the heavy vehicle's power system. The drive module is connected to the power units through a power bus. It consists of multiple driver elements that directly drive the vehicle's axles or wheels. These driver elements ensure smooth and direct power transmission for efficient vehicle operation. The energy-storage module is connected to both the power plant module and the drive module through the power bus. It serves as a reservoir for storing energy and supplying power to the vehicle's power system. Multiple energy-storage modules are connected to the power bus to enhance the system's energy storage capacity.

To manage the energy flow, multiple locks and trippers are installed corresponding to the energy-storage modules. These

locks and trippers facilitate the connection and disconnection of the energy-storage modules to the power bus. They are controlled by the vehicle's overall controller, which oversees the system's operation. The entire car controller is the central control unit that connects to the power plant module, drive module, and energy-storage module. Its primary function is to control the activation of the driver elements and regulate the working conditions of the drive module and energy-storage module. It ensures that the heavy vehicle operates smoothly and efficiently.

Additionally, the entire car controller can send instructions to the locks and trippers to disconnect the energy-storage modules when necessary. This allows for the easy removal of the energy-storage modules from the vehicle.

In summary, the distributed hybrid power system for heavy vehicles incorporates various modules to optimize power supply and control. The power plant module generates power, the drive module ensures efficient power transmission, and the energy-storage module stores and supplies energy. The locks and trippers enable easy connection and disconnection of the energy-storage modules. All these components are managed by the entire car controller, which controls the system's operation and can disconnect the energy-storage modules when required. This system enhances the performance and flexibility of heavy vehicles while ensuring efficient energy usage.

Conclusion

The research presents a novel approach to heavy vehicle design with the development of a distributed hybrid power system and vehicle. By utilizing auxiliary power units and driver elements connected through a distributed system, the need for traditional mechanical power transmission systems is eliminated. This allows for flexible arrangement of components, providing improved efficiency and control over heavy vehicles. The proposed system offers numerous advantages, including enhanced power distribution, increased flexibility in component placement, and improved overall performance. The findings of this research contribute to the advancement of heavy vehicle technology and provide a foundation for further exploration in the field of distributed hybrid power systems.

Reference

1. Sankarkumar, Rayavarapu Srinivasa, and Rajasekar Natarajan. "Energy management techniques and topologies suitable for hybrid energy storage system powered electric vehicles: An overview."

- International Transactions on Electrical Energy Systems 31.4 (2021): e12819.
2. Distributed power generation planning for distribution networks using electric vehicles: Systematic attention to challenges and opportunities - B Singh, PK Dubey - Journal of Energy Storage, 2022 – Elsevier
3. Smart Grid Communication Networks for Electric Vehicles Empowering Distributed Energy Generation: Constraints, Challenges, and Recommendations - MK Hasan, AKMA Habib, S Islam, M Balfaqih - Energies, 2023 - mdpi.com
4. A comparative study on the energy flow of a hybrid heavy truck between AMT and MT shift mode under local driving test cycle - R Feng, K Chen, Z Sun, X Hu, G Li, S Wang - Energy Conversion 2022 - Elsevier
5. Energy management of hybrid electric vehicles: A review of energy optimization of fuel cell hybrid power system based on genetic algorithm - X Lü, Y Wu, J Lian, Y Zhang, C Chen, P Wang - Energy Conversion -2020 – Elsevier
6. A review of distributed electric propulsion concepts for air vehicle technology - HD Kim, AT Perry, PJ Ansell - 2018 AIAA/IEEE Electric Aircraft - 2018 - ieeexplore.ieee.org
7. Energy management strategy of thermoelectric generation for localized air conditioners in commercial vehicles based on 48 V electrical system - X Li, C Xie, S Quan, L Huang, W Fang - Applied Energy, 2018 - Elsevier
8. More electric aircraft: Review, challenges, and opportunities for commercial transport aircraft - B Sarlioglu, CT Morris - IEEE transactions on Transportation 2015 - ieeexplore.ieee.org