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Data-Driven Evaluation of Plug-In Hybrid Electric Bus Utility Factors

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KEYWORDS

Plug-in Hybrid Electric Bus (PHEB), Utility Factor (UF), Data-Driven Analysis, Energy Management, Sustainable Transportation, Emission Reduction.

ABSTRACT

The increasing need for sustainable and energy-efficient transportation systems has accelerated the adoption of plug-in hybrid electric buses (PHEBs), which integrate electric propulsion with conventional internal combustion engines. A key parameter in evaluating their performance is the Utility Factor (UF), which represents the proportion of distance traveled in electric mode. Conventional UF estimation methods based on standardized driving cycles often fail to capture real-world operating conditions, leading to inaccurate assessments.

This study proposes a data-driven approach for evaluating the Utility Factor of PHEBs using real-time data such as GPS information, battery State of Charge (SOC), and fuel consumption. The system incorporates an energy management framework that optimally distributes power between electric and hybrid modes based on operating conditions. The analysis reveals that UF is significantly influenced by route characteristics, traffic conditions, charging availability, and battery usage patterns.

Results indicate that frequent charging and optimized route planning enhance electric mode utilization, thereby reducing fuel consumption and emissions. The proposed model provides a more accurate and reliable framework for performance evaluation and supports intelligent decision-making in public transportation systems. Overall, the approach contributes to improved energy efficiency, reduced environmental impact, and the advancement of sustainable urban mobility.

1. INTRODUCTION

The transportation industry is a crucial area of concern for sustainable development since it contributes significantly to both global energy consumption and greenhouse gas emissions. The need for greener and more energy-efficient transportation systems has increased due to rapid urbanization and rising public transit demand.

The benefits of both battery-electric and traditional internal combustion engine cars are combined in plug-in hybrid electric buses. They can run in two main modes: charge-sustaining (hybrid mode), which uses an internal combustion engine for propulsion, and charge-depleting (electric mode), which uses energy from the battery.

The Utility Factor (UF) is a crucial metric for assessing the effectiveness and environmental advantages of PHEBs. The percentage of the total distance travelled in electric mode compared to the total distance travelled is known as the Utility Factor. Fuel usage, energy efficiency, and emission reductions are all significantly impacted by it.

II. LITERATURE SURVEY

- Research on Plug-in Hybrid Electric Vehicles (PHEVs) initially focused on standardized Utility Factor (UF) models, such as SAE J2841, which estimate electric usage based on predefined driving patterns.
- However, these models are limited as they do not reflect real-world operating conditions of buses.

Recent studies have shifted toward data-driven approaches that use real-world data like GPS, battery State of Charge (SOC), and fuel consumption to improve accuracy. These studies highlight that factors such as route characteristics, traffic conditions, and charging strategies significantly influence UF.

- Additionally, research shows that opportunity charging and optimized route planning can enhance electric mode usage, reduce fuel consumption, and lower emissions, emphasizing the importance of intelligent and data-driven evaluation methods in modern transportation systems.

III. RELATED WORK

- Early studies on Plug-in Hybrid Electric Vehicles used standardized Utility Factor models such as SAE J2841, based on fixed driving cycles. However, these models are mainly designed for passenger vehicles and do not accurately capture the dynamic conditions of bus operations.
- Recent research focuses on data-driven approaches using real-world data like GPS, battery State of Charge (SOC), and fuel consumption. Techniques such as statistical analysis and machine learning provide more accurate estimation of Utility Factor under varying conditions.
- Studies highlight that route characteristics, traffic conditions, and charging strategies significantly impact Utility Factor. Higher UF is associated with reduced fuel consumption and emissions, emphasizing the need for system-level optimization and intelligent transportation planning

IV. BLOCK DIAGRAM EXPLANATION

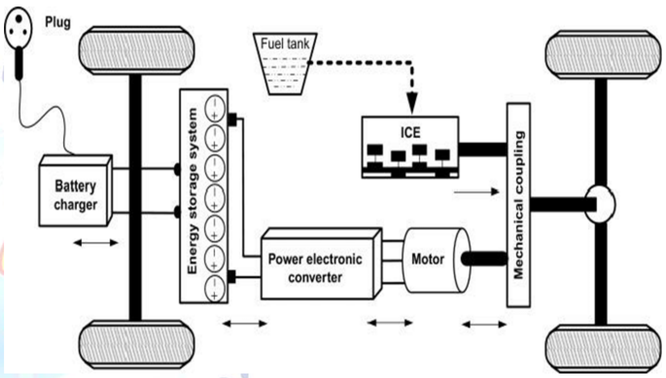

Fig-1: BLOCK DIAGRAM

The system architecture follows a linear data-processing flow:

1. Input Stage: Includes plug, battery charger, and fuel tank. Energy is supplied either through charging or fuel input.
2. Processing Stage: Power electronic converter and energy management system control and distribute power between battery and engine.
3. Feedback Stage: Energy management system monitors battery level, fuel usage, and performance to switch between modes efficiently.
4. Transmission Stage: Mechanical coupling combines power from motor and engine and transfers it to the wheels.
5. Output Stage: Wheels receive power and enable vehicle movement.

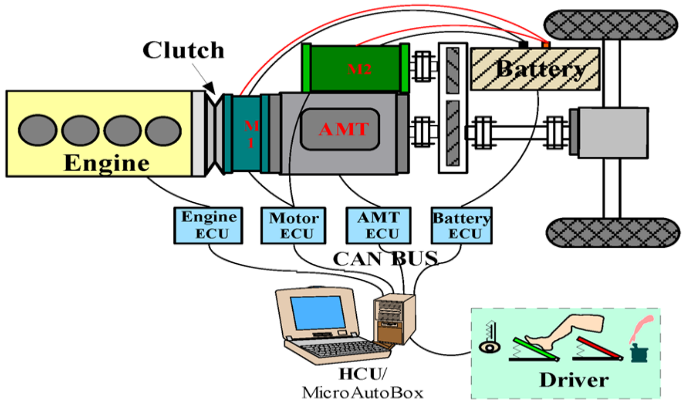

Fig-2: MODEL ARRANGEMENT

V. RESULT AND DISCUSSION

The analysis of real-world data shows that the Utility Factor (UF) of Plug-in Hybrid Electric Buses varies significantly depending on operating conditions such as traffic, route characteristics, charging availability, and battery usage.

The results indicate that traditional methods often overestimate performance, while data-driven approaches provide more accurate insights

It was observed that frequent charging and shorter routes increase electric mode usage, thereby improving and reducing fuel consumption and emissions.

However, increasing battery capacity has limited impact beyond a certain point. Overall, the study highlights that optimizing charging strategies, route planning, and energy management is essential for achieving better real-world performance and sustainability.

5.1 OUTPUT ON ENERGY CONSUMPTION

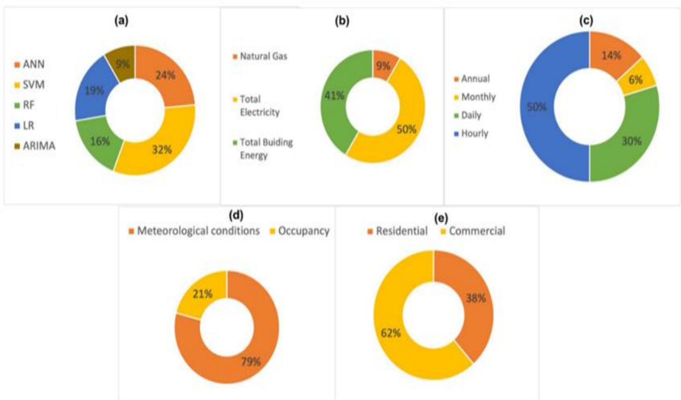

Figure – 3: Results of Energy Consumption

APPLICATIONS

1. Public transportation systems (city buses and smart transit networks)
2. Fleet management and logistics optimization
3. Electric and hybrid vehicle performance monitoring
4. Smart city transportation planning
5. Energy management and charging infrastructure planning
6. Traffic and route optimization systems

VI. CONCLUSION

- The proposed model provides an effective framework for analyzing and predicting the performance of plug-in hybrid electric buses.
- Real-time data integration improves the accuracy and reliability of performance evaluation. Utility Factor (UF) serves as a key metric for assessing electric mode utilization. Operating conditions such as traffic, route type, and battery capacity significantly influence system performance'
- Data-driven analysis enables better understanding of energy consumption patterns. The model supports optimization of route planning and charging strategies Implementation of the model can reduce fuel consumption and operational costs.
- It contributes to lowering emissions and promoting environmentally sustainable transportation. Overall, the approach enhances decision-making for efficient and intelligent public transport systems.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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