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Control Technique for Plug-in Hybrid Power Buses to Distribute Energy

[1]Nagarajan Krishnamurthy, [2]G.Vinod

[1]Department of Mechanical Engineering, Rajalakshmi Institute of Technology, Chennai, Tamilnadu
[2]Department of Computer Science and Engineering, Rajalakshmi Institute of Technology, Chennai, Tamilnadu

[1]nagarajan.p.k@ritchennai.edu.in, [2]vinod.g@ritchennai.edu.in

Abstract

This research focuses on the development of a control method for plug-in hybrid power buses, specifically aimed at optimizing energy distribution in urban environments. The method utilizes GPS navigation and a digital map to obtain real-time vehicle position information and assess road congestion levels. By considering factors such as congestion, vehicle position, and battery electric quantity, the method enables dynamic optimization and adjustment of energy distribution. The objective of this research is to reduce fuel consumption, minimize pollutant emissions, and enhance fuel economy in plug-in hybrid power buses operating on fixed routes.

Keywords: Plug-in hybrid power bus, energy distribution, control method, GPS navigation, road congestion, fuel economy.

Introduction

Plug-in hybrid power buses have gained significant attention in recent years as an innovative solution to address energy shortages and reduce environmental pollution in the automotive industry. These vehicles combine the advantages of electric propulsion and internal combustion engines, offering improved fuel economy and lower emissions compared to conventional buses. As the world seeks sustainable transportation alternatives, plug-in hybrid power buses have emerged as a promising option. Efficient control of energy distribution plays a crucial role in optimizing the performance of plug-in hybrid power buses. By effectively managing the utilization of electric power and fuel, these vehicles can achieve enhanced fuel economy, reduced pollutant emissions, and improved overall efficiency. Developing advanced control methods specifically tailored for plug-in hybrid power buses is essential to fully realize their potential benefits.[1]

This research focuses on the control method of plug-in hybrid power buses, with a particular emphasis on buses operating on fixed routes in urban environments. The aim is to develop a control strategy that optimizes energy distribution in real-time based on various factors such as road congestion levels, vehicle position, and battery electric quantity. By considering these factors, the control method can dynamically adjust the energy distribution to achieve the best possible performance and minimize environmental impact.[5] The integration of GPS navigation technology and a digital map allows for accurate determination of the vehicle's position and assessment of road congestion levels. This information serves as a crucial input for the control method, enabling it to make informed decisions regarding energy distribution. By continuously analyzing the real-time data, the control method can adapt to changing traffic conditions and optimize the energy allocation accordingly.

The research objective is to develop a control method that effectively reduces fuel oil consumption, decreases pollutant emissions, and enhances fuel economy in plug-in hybrid power buses operating on fixed routes. By achieving these goals, plug-in hybrid power buses can contribute to a more sustainable and environmentally friendly transportation system. The significance of this research lies in its potential to revolutionize the operation and performance of plug-in hybrid power buses. With optimized energy distribution, these vehicles can play a vital role in reducing carbon emissions, improving air quality, and conserving energy resources. The findings from this research can inform the development of advanced control systems for plug-in hybrid power buses, contributing to the advancement of sustainable transportation solutions.[4]

In the following sections, we will delve into the methodology, analysis, and results of the control method for plug-in hybrid power buses. By examining the effectiveness and feasibility of the proposed control strategy, we aim to provide valuable insights and recommendations for the implementation and future development of plug-in hybrid power buses in urban transportation systems.[2]

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Related Work

The operation of hybrid power buses in various cities has demonstrated their significant impact on energy savings and emission reduction, garnering widespread approval. However, due to limitations in battery technology, conventional hybrid power passenger cars still have ample room for improvement in terms of fuel consumption and emission performance. Plug-in hybrid passenger cars, as an upgraded version of conventional hybrids, offer the opportunity to fully utilize inexpensive clean energy by accessing grid charging during low power consumption periods, particularly at night. This allows for increased electric-only travel, leading to significantly improved fuel economy.[6]

However, the complex traffic conditions in large and medium-sized cities necessitate the development of effective control policies to efficiently distribute electricity and fuel. This becomes a key objective in designing energy distribution strategies for plug-in hybrid passenger cars. In plug-in hybrid car energy strategies, two common approaches exist: charge-depletion mode and charge-sustaining mode. The former is more suitable for maximizing electric energy utilization in plug-in hybrids. However, the current battery capacity of domestic plug-in hybrid buses can only cover 60%-70% of the daily distance traveled by public transportation, with the remaining portion relying on the internal combustion engine for power.[1] If electric energy is not distributed reasonably, it can result in the battery's state of charge (SOC) depleting to its lower limit, leading to increased fuel consumption and pollutant emissions due to frequent engine start-stop cycles, thereby compromising fuel economy goals.[1] A parallel PHEB model with a single shaft is established, depicted in Figure 1. The engine and motor are affixed to the same axle and rotate synchronously. By combining their torques, the gearbox and final gear enable the vehicle to operate by decreasing speed and increasing torque. In a fully charged state, the power battery supplies electric energy to the motor. In instances where the battery's remaining power is insufficient, the motor converts mechanical energy into electrical energy to recharge the battery. As a result, the PHEB operates in four distinct modes: pure electric mode, engine-only mode, hybrid mode with both engine and motor, and brake recovery mode.

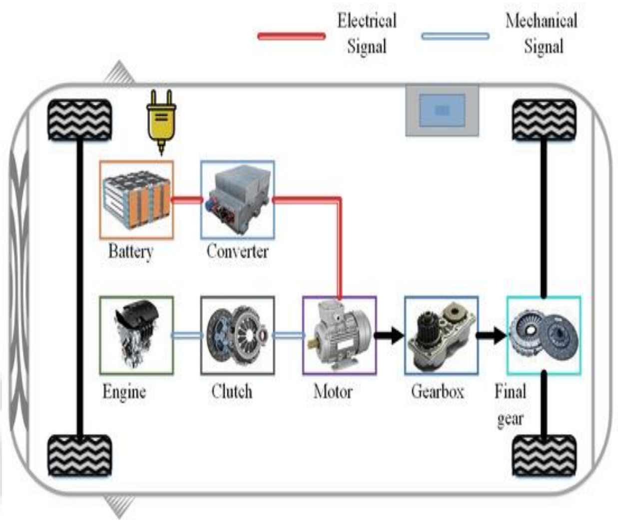

Figure 1. The architecture of the PHEB powertrain

Currently, the energy distribution strategies employed by hybrid power buses remain static and do not consider the specific traffic conditions of individual bus networks within a city. As a result, the equipped energy distribution strategies fail to ensure optimal allocation of electric and fuel energy based on the daily operational scope of fixed bus routes.[7] However, the widespread use of GPS navigation and on-vehicle information units in bus networks presents an opportunity to achieve optimal energy distribution. GPS, or Global Positioning System, allows for accurate vehicle positioning and, when coupled with digital maps, provides precise information about the vehicle's location within a city. It is undeniable that the traffic flow between each bus stop on fixed urban bus lines follows certain statistical patterns. The congestion levels between two stops on the same fixed line are generally similar at the same time each day. The average velocity of bus operations characterizes the congestion level between stations in the public bus network.[2] Figure 2 presents the fuel consumption and computing time for 200 episodes (DRL). According to the table, the PPO-Penalty algorithm requires 1435 seconds to complete 200 training sessions, which equates to 200 repeated driving cycles. Therefore, the average time for one driving cycle is approximately 7.175 seconds (1435 divided by 200). This time standard meets the criteria for real-time online control of HEV's EMS. In contrast, the DP algorithm consumes 9504 seconds to complete one driving cycle.

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Figure 2. The simulation results in 4 × UDDS

Algorithm	Terminal SOC	Battery Temperature (K)	Computing Time (s)	Equivalent Fuel Consumption (L/100 km)	Saving Rate (%)
DP	0.293	313.369	9504	17.481	-
DQN	0.310	314.495	1657	19.231	−10.01
DDPG	0.304	313.921	2296	18.917	−8.21
PPO-Clip	0.280	313.778	1449	17.779	−1.70
PPO-Penalty	0.287	313.854	1435	18.205	−4.14

This statistical information is stored in the on-vehicle information unit. By combining GPS, digital maps, and current time information, the on-vehicle information unit can search for historical traffic flow data and analyze road categories in advance. It can then determine the congestion levels based on the current position, thereby selecting the appropriate energy distribution strategy and enabling real-time adjustments of control policies.[3] This approach allows for better adaptation to fixed bus routes, further reducing overall fuel consumption and promoting fuel economy.

Research Objective

The objective of this research is to develop a control method that effectively and reasonably distributes energy in plug-in hybrid power buses running on fixed routes. By utilizing real-time vehicle position information, road congestion levels, and battery electric quantity, the aim is to optimize energy distribution and achieve reduced fuel oil consumption, lowered pollutant emissions, and enhanced fuel economy.

Control Method for Energy Distribution in Plug-in Hybrid Power Buses

The control method for a plug-in hybrid passenger car involves the following steps:

1. Obtain historical traffic speed-time information of the public bus network from the urban traffic control center. Classify road sections based on congestion levels: high congestion, medium congestion, low congestion, and no congestion.

2. Set the real-time energy distribution method based on the congestion level:
   - High congestion: Use pure electric drive and disengage the clutch. The motor runs on electric power from the battery.
   - Medium congestion: If the vehicle's torque is less than or equal to the maximum torque of the motor (T1), use pure electric drive. If the torque is greater than T1, engage the driving engine and combine its output torque with the motor's torque.
   - Low congestion: If the vehicle's torque is less than the optimum torque of the engine (T2) and the battery's current electric quantity is below a set limit, engage the driving engine and supplement electric power to the battery. If the electric quantity is above the limit, use pure electric drive. If the torque is greater than or equal to T2, disable the motor and use engine drive.
   - No congestion: Use pure electric drive if the vehicle's speed is below or equal to a set threshold value (v). If the speed exceeds the threshold, engage the driving engine and deactivate the motor.

3. Control the plug-in hybrid passenger car's energy distribution based on the determined strategy:
   - Initialization: If the battery's current electric quantity is below or equal to a lower limit, use motor-powered vehicle mode. Otherwise, proceed to the next step.
   - Vehicle navigation initialization: When the vehicle's speed exceeds a specified time (t_s), initialize the vehicle navigation system to

determine the current location using digital maps.

- Vehicle control unit: Based on the historical statistics of the vehicle's current location and time, determine the current congestion status.
- Control the vehicle: Depending on the congestion status and the predetermined energy distribution method, control the clutch, battery management system, engine control unit, and motor control unit accordingly. This ensures proper coordination between the engine and motor for efficient energy distribution and usage.

The control method described is designed for plug-in hybrid passenger cars to efficiently manage energy distribution based on traffic conditions. Plug-in hybrid cars are an upgrade to conventional hybrid cars, as they can be charged from the electrical grid during low power demand periods, such as at night. This allows them to make better use of inexpensive and clean energy sources. The objective of this control method is to address the complex traffic patterns found in large and medium-sized cities. It aims to distribute electric energy and fuel oil in a reasonable and efficient manner, considering the specific characteristics of the public bus network and daily traffic flow. The method utilizes information obtained from the urban traffic control center, including historical data on traffic speed and time for the public bus network. By analyzing this information, the control method classifies road sections into different congestion levels: high congestion, medium congestion, low congestion, and no congestion.

Based on the congestion level, the control method sets specific energy distribution strategies for the vehicle. In high congestion situations, the vehicle operates in pure electric drive mode, with the motor being powered solely by the electric battery. In medium congestion, if the vehicle's torque is within a certain range, it continues using pure electric drive. If the torque exceeds the limit, the driving engine is engaged, and the motor and engine work together to provide the necessary torque.

For low congestion, the method considers the vehicle's torque in relation to the optimum torque of the engine. If the torque is below the optimum and the battery's electric quantity is below a specified limit, the driving engine is engaged to generate power and charge the battery. If the electric quantity is sufficient, the vehicle continues in pure electric drive mode. When the torque exceeds the optimum, the motor is disabled, and the engine takes over the vehicle's propulsion. In situations where there is no congestion, the control method determines the vehicle's speed in relation to a set threshold value. If the speed is below or equal to the threshold, the vehicle continues in pure electric drive mode. Once the speed exceeds the threshold, the engine is engaged, and the motor is deactivated.

The control is performed by the car's control unit, which communicates with various components such as the transmission control unit, battery management system, engine control unit, and motor control unit. The control unit ensures that the energy distribution strategy is applied in real-time, optimizing the vehicle's fuel economy and overall performance.

By implementing this control method, plug-in hybrid passenger cars can effectively respond to traffic conditions, reduce fuel consumption, and minimize pollutant emissions. The method takes into account the specific characteristics of the public bus network, allowing for an optimized allocation of energy resources.

Conclusion

The control method proposed in this research presents a viable solution for optimizing energy distribution in plug-in hybrid power buses. By leveraging GPS navigation and road congestion information, the method allows for real-time adjustments in energy distribution based on the vehicle's position and battery electric quantity. This approach leads to reduced fuel consumption, minimized pollutant emissions, and improved fuel economy. Implementing this control method in plug-in hybrid power buses operating on fixed routes has the potential to contribute to a more sustainable and environmentally friendly transportation system. Further research and development in this area can continue to refine and enhance the performance of plug-in hybrid power buses, paving the way for a greener future in urban transportation.

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