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Simulation and Performance Analysis of a Power-Split Hybrid Electric Vehicle Architecture Using MATLAB

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Abstract:
This study demonstrates that simulation using MATLAB is an effective approach for evaluating and enhancing the performance of power split hybrid electric vehicles (HEVs). The system combines an internal combustion engine and an electric motor through a planetary gear mechanism, allowing flexible and efficient power distribution under varying driving conditions. A detailed HEV model is developed in MATLAB/Simulink, incorporating key components such as the engine, motor, battery, transmission, and control strategy. The model is analyzed under standard driving cycles to assess fuel consumption, battery state of charge (SOC), torque sharing, and overall efficiency. An energy management strategy dynamically allocates power between the engine and motor to optimize energy usage and reduce emissions, while regenerative braking is employed to recover energy during deceleration. Simulation results indicate that the proposed power split HEV significantly improves fuel economy and reduces emissions compared to conventional vehicles. This work highlights the importance of MATLAB-based simulation as a reliable tool for the design and optimization of sustainable hybrid vehicle systems.

Keywords: Hybrid electric vehicle (HEV), power-split architecture, MATLAB/Simulink, vehicle modeling and simulation, performance analysis, energy management system, battery state of charge (SOC), power flow distribution, fuel efficiency, drive cycle analysis.

I.INTRODUCTION:

Hybrid Electric Vehicles (HEVs) have emerged as an effective solution for reducing fuel consumption, minimizing harmful emissions, and addressing the increasing demand for sustainable transportation systems. Unlike conventional vehicles, HEVs combine an internal combustion engine with an electric motor, allowing the vehicle to operate more efficiently under different driving conditions. Among various hybrid configurations, the power-split hybrid system has gained significant attention because of its ability to distribute power intelligently between the engine and motor using a planetary gear mechanism. This arrangement improves fuel economy, enhances vehicle performance, and provides smooth operation during acceleration and braking conditions. Recent developments in hybrid vehicle technology have

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mainly focused on improving control strategies, energy management systems, and overall vehicle efficiency. Researchers have investigated the dynamic behaviour of power-split HEVs during important operating conditions such as engine start up, braking, and mode transition. Advanced multimode hybrid powertrain configurations have also been proposed to optimize fuel efficiency and improve the sizing of powertrain components. In addition, several energy management approaches, including predictive and stochastic control methods, have been introduced to ensure efficient power sharing between different energy sources according to changing driving requirements. Battery performance plays a major role in determining the reliability and efficiency of hybrid electric vehicles. Therefore, recent studies have concentrated on battery charging methods, battery health monitoring, degradation analysis, and optimal battery selection techniques to improve system durability and operational safety. Regenerative braking technology is another important feature integrated into HEVs, where braking energy is recovered and stored in the battery to increase overall energy efficiency and reduce energy losses. Simulation and modelling tools are widely used for analysing the performance of hybrid electric vehicles before practical implementation. Among these tools, MATLAB/Simulink provides a flexible and efficient environment for designing, modelling, and testing complex hybrid vehicle systems. It enables researchers to study the interaction between various vehicle components under different operating conditions and evaluate system performance accurately. Using MATLAB/Simulink, engineers can analyse vehicle dynamics, battery behaviour, energy flow, and control system performance without the need for costly physical prototypes. In recent years, the increasing popularity of plug-in hybrid vehicles and hybrid energy storage systems has further highlighted the importance of efficient power management and charging strategies. As a result, advanced hybrid system configurations and intelligent control techniques are being developed to improve vehicle efficiency, charging safety, and energy utilization. In this research, a hybrid electric vehicle model is developed and simulated using MATLAB/Simulink to evaluate its operational performance, energy management capability, and overall system efficiency under different driving conditions.

II.LITERATURE SURVEY:

Several research works have been carried out in the field of hybrid electric vehicles (HEVs), focusing on modelling, control strategies, and energy management techniques to improve overall system performance's et al. [1] presented a detailed modelling and dynamic response analysis of a compound power-split HEV during the engine starting process, emphasizing smooth transition and system stability. Choi et al. [2] proposed a novel multimode hybrid powertrain architecture aimed at improving fuel efficiency and optimizing component sizing. Zhao and Tang [3] focused on controlling the transition from e-CVT mode to electric vehicle mode during braking, ensuring efficient energy utilization. Similarly, Shi et al. [4] developed a stochastic predictive energy management strategy for power-split hybrid buses under real-world driving conditions, demonstrating improved efficiency. Chen et al. [5] introduced a mode transition control strategy using an improved extended state observer to enhance system performance. Tang and Wang [6] investigated advanced energy management strategies considering the dynamic characteristics of multiple power sources. Diazo et al. [7] explored charging safety in electric vehicles using advanced algorithms, while Dias Vasconcelos et al. [8] analyzed the impact of electric vehicle charging on the power grid using predictive indicators. Timilsina et al. [9] provided a comprehensive survey on battery degradation in electric and hybrid vehicles, highlighting its impact on system lifespan, and Akyildiz et al. [10] studied optimal selection of lithium iron phosphate battery cells for improved performance. Furthermore, Eppstein et al. [11] examined consumer adoption of plug-in hybrid vehicles using agent-based modeling, offering insights into large-scale deployment. Gautam et al. [12] proposed an integrated optimal power management strategy for hybrid energy sources, enhancing efficiency and reliability. Eppstein et al. [11] investigated the adoption of plug-in hybrid electric vehicles using an agent-based modeling approach, incorporating real consumer survey data to analyze large-scale adoption patterns and influencing factors. Gautam et al. [12] proposed a hybrid energy source-based electric vehicle configuration with an integrated optimal power management strategy, demonstrating improved efficiency and reliability through effective coordination of multiple energy sources. Yuvaraj et al. [13] presented a comprehensive review on the allocation of electric vehicle charging stations in distribution networks, highlighting the importance of infrastructure planning for supporting large-scale EV integration. Wang et al. [14] focused on enhancing battery power output and reducing mode switching frequency in multi-mode hybrid energy storage systems using a real-time average power method, which improved system performance and operational stability. Zhao and Tang [15] developed a control strategy for smooth transition from e-CVT mode to electric vehicle mode during braking conditions in power-split HEVs, ensuring efficient energy utilization and seamless operation.These studies emphasize advancements in hybrid system control, energy management, infrastructure development, and user adoption. However, there is still a need for detailed simulation-based analysis using tools like MATLAB to further optimize system performance and validate control strategies under different driving conditions.

III.EXISTING SYSTEM:

The existing hybrid electric vehicle (HEV) configurations employ a conventional power split technology with an engine and an electric motor integrated with a planetary gear set. The existing HEV configurations utilize conventional energy management strategies, which are not effective for changing driving conditions. Although regenerative braking and battery storage capabilities are integrated into these configurations, they lack advanced control strategies for optimization. Moreover, these configurations require costly hardware tests with limited flexibility. As a result, simulation software such as MATLAB is required for better performance optimization.

DISADVANTAGES:

- Highway inefficiency
- Complex calibration
- Torque lag
- Cost
- High speed efficiency
- High computation load

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IV.PROPOSED SYSTEM:

The proposed system simulates a power split hybrid electric vehicle (HEV) using MATLAB / Simulink to improve efficiency and performance. It combines an internal combustion engine and electric motor through a planetary gear system for flexible power distribution. The model includes key components such as the engine, motor, battery, transmission, and control unit. An energy management strategy optimally shares power between sources, while regenerative braking recovers energy. The system is tested under driving cycles to evaluate fuel consumption, battery SOC, and overall efficiency.

ADVANTAGES:

- Improve fuel efficiency
- Reduse development cost
- Faster time to market
- Accurate performance and range prediction
- Safe testing of critical scenarious
- Multi domain system

System Architecture

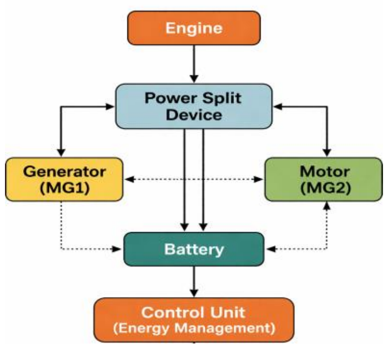

Fig 1: Power-Split Hybrid Electric Vehicle Block Diagram

The architecture of a power split hybrid electric vehicle (HEV) is based on the integration of both mechanical and electrical sources of power for efficient driving. The major components of a hybrid electric vehicle's architecture include an internal combustion engine, an electric motor, a generator, a battery pack, a planetary gear set, and a supervisory control unit. The planetary gear set is the core component of the hybrid electric vehicle's architecture, which enables the flow of both engine and electric motor power for driving in different operating modes. The electric motor assists the engine during acceleration and enables the HEV to operate at low speeds using only the electric motor's power. The generator is used to convert mechanical energy into electrical energy for storage or direct use. The battery pack stores electrical energy for the motor's use and also captures electrical energy during regenerative braking. The control strategy continuously monitors the speed, load, and state of charge for efficient driving.

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MATLAB SOFTWARE

MATLAB is a programming and simulation software that is used for numerical computations, data analysis, and system modeling. It is a high-level programming software that allows a person to carry out complex mathematical calculations. It also allows a person to create algorithms. MATLAB allows a person to generate graphs and plots for visualizing their results. MATLAB uses a matrix-based system that allows it to carry out complex mathematical calculations efficiently. MATLAB has a wide range of tools that allow it to work with different fields such as signal processing, control systems, machine learning, and power systems. MATLAB also allows a person to work with Simulink, a software that allows a person to carry out system simulations using a graphical diagram.

V.RESULT

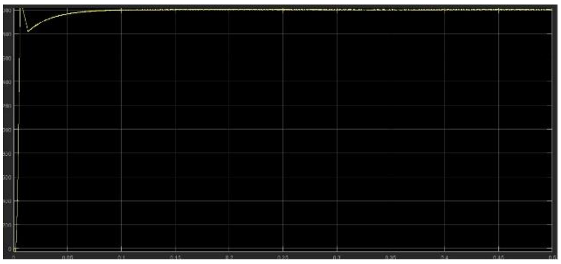

FIG 2: System Response Characteristics of the HEV Model

The above graph is a representation of the system response over time, which indicates that the output is rising rapidly and then gradually stabilizes to a steady value. The smooth curve in this graph indicates that there are minimal oscillations in the system, which in turn indicates that the system is operating efficiently.

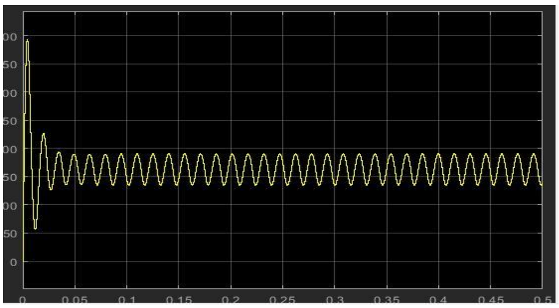

Fig. 3: Battery State of Charge (SOC) Analysis

The above graph indicates the initial transient response with significant oscillations and overshoots. It then gradually approaches a steady-state with an oscillatory waveform. The system seems to have reached a steady state with constant frequency and amplitude. It is assumed that the system has reached a state of equilibrium with the presence of oscillations.

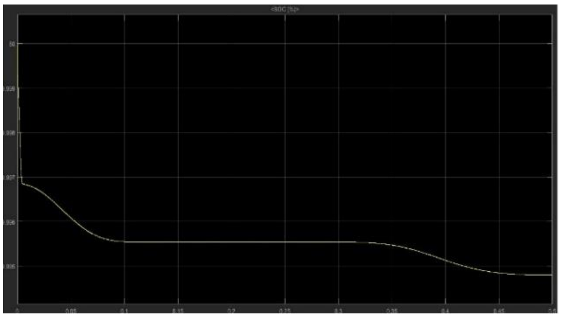

Fig. 4: Electromagnetic Torque Response of the HEV System

The above graph indicates the state of charge of the battery, which is continuously declining. The declining nature of the state of charge indicates the consumption of energy during the operation of the vehicle. The initial sharp decline in the state of charge is followed by a constant rate of decline.

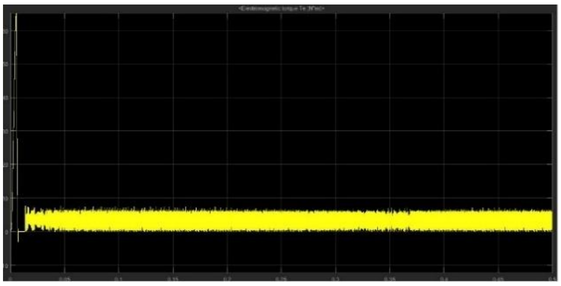

FIG 5: Battery Current Response in Power-Split HEV

The graph shows that the graph represents the electromagnetic torque response, where there is a spike at first, followed by a region of stability. The graph shows that the system has a stable operation as it oscillates within a small range. This shows that it is efficiently regulating the torque.

VI.CONCLUSION:

The simulation results have shown that the proposed power split hybrid electric vehicle (HEV) model can attain better overall performance compared to conventional vehicles. The simulation results have shown that the proposed vehicle can efficiently distribute power from the engine and the electric motor during various driving conditions, thus reducing fuel consumption and emissions. In addition, the state of charge (SOC) of the battery is maintained at an optimal level, thus ensuring proper battery management. The system response is found to be stable, which indicates that the proposed vehicle can operate reliably. Furthermore, regenerative braking is also implemented in this vehicle, which can recover maximum energy during deceleration, thus ensuring improved vehicle efficiency. From the simulation results, it is validated that the proposed vehicle can attain improved overall performance using the proposed optimized approach based on MATLAB/Simulink for developing a hybrid vehicle.

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