Abstract

Energy management is critical for improving energy efficiency, reducing fuel costs, and extending battery life as well as electric range in Parallel Hybrid Electric Vehicles (PHEVs). This work presented in this thesis explores various approaches to manage energy flow among the motor, the Internal Combustion Engine (ICE) and the wheel in PHEVs to optimize performance indicators, such as fuel/energy consumption, emission, drive quality as well as time to travel for a trip.

The work particularly focuses on optimizing energy consumption and State Of Charge (SOC) tracking while maintaining drivability, considering physics-based dynamic or steady-state models of the powertrain. The literature on Model-based Energy Management of PHEVs can be categorized into three main groups. Short-Range Predictive Energy Management (SRPEM) strategies aim to minimize energy consumption during traction and maximize energy regeneration during braking by optimally controlling the Torque Split Ratio (TSR) of the ICE, the electric motor, and the mechanical brake at a given point on the trip. Trip Level Predictive Energy Management (TLPEM) strategies determine the optimal SOC reference trajectory for the battery to be tracked and hyper-parameters of the performance criteria of SRPEM over the whole trip using macroscopic traffic data, etc. Finally, ADAS (Advance Driver Assistance System) based Energy Management (AEM) optimizes the vehicle's information, such as terrain information, velocity reference set by the ADAS and the TSR, to minimize energy consumption while ensuring a safe distance from other vehicles. The major motivations and contributions of this thesis are described below.

Conventional SRPEM for PHEVs typically utilizes only local information but not trip-level information, which limits their energy performance and leads to constant violation. To overcome this limitation, a modified SRPEM method is developed to meet trip level constraints imposed by Zero-Emission Zones (ZEZs) and High Gradient Zones (HGZs). The algorithm enables the PHEV to perform energy optimization while ensuring enough SOC to operate in EV mode during the ZEZ or to provide necessary assist torque during HGZs.

SRPEM involves the prediction of system states over the prediction horizon for optimization using a dynamic model. Conventionally used nonlinear MPC (NMPC) approaches are computationally complex for improved state prediction and optimisation. This thesis has described a computationally efficient implementation of the NMPC-based SRPEM for real-time implementation. In addition to that, a systematic and efficient approach to choosing the optimal tuning hyperparameters used in SRPEM performance criteria is proposed.

The methods in the current literature on AEM compute speed set points only based on vehicle dynamics, safety and comfort. To improve the vehicle speed advise various performance objectives in turns of energy as well as travel time, the work described in this thesis takes into account trip-level terrain, traffic and traffic signal information along with HEV powertrain characteristics. Methods in the existing literature on AEM do not blend the objectives of energy-optimality (Eco mode) and time-optimality (Sports mode) for generating optimal speed set points. To address this gap, this thesis has developed a novel, real-time energy management framework that can incorporate trip-level information and ADAS functionalities while optimizing energy efficiency and travel time performance criteria.

Overall, the works reported in this thesis have attempted to address some key limitations of existing energy management strategies reported in the literature. Encouraging results are obtained using realistic vehicle simulation over standard drive cycles. This shows clear motivation to take up validation of this performance by the energy management strategies discussed in this thesis on real PHEVs over real drive cycles in the future.

Keywords:- Energy Management, Fuel Economy, Hybrid Electric Vehicle, Supervisory Controller, Model Predictive Control, Advanced Driver Assistance System (ADAS)