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Development a new power management strategy for power split hybrid electric vehicles

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ABSTRACT

Reduction of greenhouse gas emission and fuel consumption as one of the main goals of automotive industry leading to the development hybrid vehicles. The objective of this paper is to investigate the energy management system and control strategies effect on fuel consumption, air pollution and performance of hybrid vehicles in various driving cycles. In order to simulate the hybrid vehicle, the combined feedback–feedforward architecture of the power-split hybrid electric vehicle based on Toyota Prius configuration is modeled, together with necessary dynamic features of subsystem or components in ADVISOR. Multi input fuzzy logic controller developed for energy management controller to improve the fuel economy of a power-split hybrid electric vehicle with contrast to conventional Toyota Prius Hybrid rule-based controller. Then, effects of battery's initial state of charge, driving cycles and road grade investigated on hybrid vehicle performance to evaluate fuel consumption and pollution emissions. The simulation results represent the effectiveness and applicability of the proposed control strategy. Also, results indicate that proposed controller is reduced fuel consumption in real and modal driving cycles about 21% and 6% respectively.

Introduction

Nowadays due to the transportation sector has been one of the top contributors in increasing air pollution and fuel consumption, a significant interest in hybrid electric vehicle (HEV) has arisen globally to reduce fuel consumption and pollution emissions. According to the U.S. Department of Energy (USDE), about 15% of the total fuel energy is consumed to run a car and its other accessories. The main concern in vehicle emissions is CO_2 which is related to fuel consumption linearly (Chau and Chan, 2007). In order to overcome these problems, HEVs incorporates two power drives including an internal combustion engine (ICE) and an electric motor (EM) which results in optimal energy management. HEV's reduce Green House Gas (GHG) emissions, and displace petroleum energy by utilizing both powertrains to increase vehicle efficiency. The conventional vehicle engine is typically sized to meet high power demands, while the hybrid electric vehicle powertrain is sized

Abbreviations: HEV, hybrid electric vehicle; USDE, U.S. Department of Energy; ICE, internal combustion engine; EM, electric motor; FLC, Fuzzy Logic Controller; FCHV, fuel cell hybrid vehicle; SOC, state of charge; MPC, Model Predictive Control; PHEV, plug-in hybrid electric vehicle; NEDC, New European Driving Cycle; GHG, Green House Gas; THS, Toyota Hybrid System; EVT, electronically variable transmission; DP, dynamic programming; EMS, energy management strategy; QP, quadratic programming; MG, motor/generator; UDDS, Urban Dynamometer Driving Schedule; FTP-75, Federal Test Procedure; Teh-car, Tehran Car.

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to enable engine start/stops, regenerate during braking. In order to make more significant reductions in pollution emissions and petroleum energy usage vehicle architectures also need to be considered.

There are many different hybrid configurations currently proposed by vehicle manufacturers (Fan, 2007; He et al., 2012; Zhang, 2011, Liu, 2013; Murphey et al., 2013), most configurations can be categorized into three hybrid systems: Series, Parallel and Power-split. In this paper, power-split hybrid vehicle is considered, which it combines the advantages of series and parallel hybrids by utilizing two electric machines and a combustion engine as shown in Fig. 1.

With the potential for achieving higher fuel economy, power-split HEV has been seen as one of the hybrid powertrain architecture to improve fuel economy when their power-management algorithms are properly designed. Most of the attention has been given to designing energy management control systems in power-split HEVs which is responsible for selecting operating points of the subsystems to achieve better vehicle fuel efficiency (He et al., 2012; Zhang, 2011; Liu, 2013; Murphey et al., 2013; Zheng and Mi, 2009).

The power-split hybrid configuration can switch between the parallel and series which, according to driving condition the high efficiency range of each one is selected. Depending on the situation, both power sources (electrical and mechanical paths) can also be used simultaneously to achieve the maximum power output efficiency. The biggest advantage of the planetary gear mechanisms is that high rotational ratios can be produced by using small number of relatively small dimensioned gear systems. Also the input and output shafts are coaxial so the mechanism is extremely well assembled (Liu, 2007; Macor and Rossetti, 2013). Other advantages are eliminated radial loads, working silently and the facility of using planets in steps.

Power split powertrains can be divided into single (Toyota Hybrid System (THS)) and multi-mode systems (Allison Hybrid System) which uses two or more planetary gears and has two electronically variable transmission (EVT) modes. Trade-off between multi-mode powertrain complexity and fuel consumption has been performed in Kim et al., 2010 to provide a detailed review of the benefits and drawbacks of the single and two-mode systems, the three-mode and four-mode vehicles. It was found that the multi-mode system has more fuel economy advantage during the high-speed cycle due to the relatively higher system efficiency. In this paper due to complexity, high cost and additional weight of multi-mode systems, single mode configuration of Toyota Prius has been considered.

One of the most significant factors in the performance of hybrid vehicles are control strategies, which play an important role in improving energy management of HEVs. Different strategies has been used in previous studies which mainly are classified into rule based and optimization approaches (Tie and Tan, 2013). Majority of the proposed solutions for the power management control logic can be classified under two types: rule-based approach and optimization-based approach.

Rule-based control strategies consist of deterministic and fuzzy logic rule-based methods, while optimization-based approaches typically utilized global optimization when determining the control strategy (Salmasi, 2007). In Zahabi et al. (2014) the effect of different factors on fuel efficiency including road driving conditions (link type, city size), temperature, speed, cold-starts and eco-driving training is compared for HEVs and conventional gasoline vehicles. Results demonstrated that winter time significantly increased the fuel consumption of HEVs.

Delprat et al. (2004) and Mansour and Clodic (2012) proposed a global optimal strategy based on dynamic programming (DP) methods for parallel HEV and parallel-series HEV, respectively. An overview of the controllers was given in Wirasingha and Emadi (2011), and an analysis on which strategy is more suitable to maximize HEV performance in different drive cycle conditions was provided. They presented a new classification for HEV control strategies based on the operation of the vehicle and verified through simulation results. Kim et al. (2009) proposed nonlinear model predictive control algorithm based on DP procedure for the vehicle control system to maximize fuel economy while satisfying constraints on battery state of charge, relative position and vehicle performance. One of the disadvantages of this control is approximation/transformation that may not be applicable in complicated drive train system. Power-split hybrid vehicles have two degrees of freedom in the

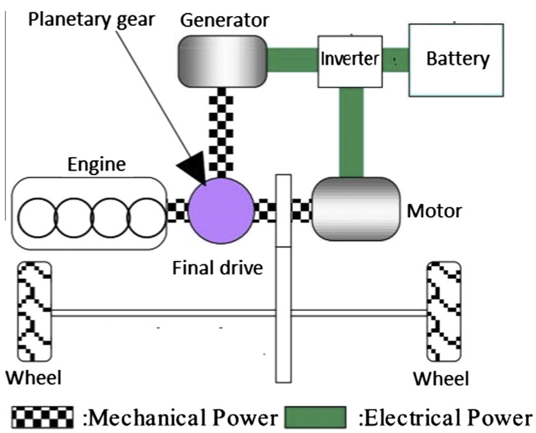

Fig. 1. Power-split hybrid vehicle modeling.