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Editorial

Special Issue on Frontiers in Hybrid Vehicles Powertrain

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1. Introduction

The urgent need to reduce greenhouse gases and toxic emissions is fostering a rapid shift towards more sustainable transport. In this respect, hybrid electric vehicles (HEVs) emerge as a sustainable solution to increasingly adopt on a large scale very shortly. In HEVs, the internal combustion engine (ICE) efficiency is significantly improved by cooperating with an electric unit, consisting of one or more electric machines and a battery pack, that supports the engine during transient operations and enables regenerative braking. As a result, a significant reduction in fuel consumption and emissions can be achieved while maintaining high vehicle performance and driving comfort. A wide variety of hybrid electric powertrains is currently available on the market, ranging from various degrees of electrification, i.e., mild, full, and plug-in hybrid, and different driveline architectures, i.e., series, parallel, and power-split hybrid [1]. The main challenges of HEVs lie in the powertrain design, not only in terms of thermal, mechanical, and electrical components but also of energy management strategy. Consequently, effective research efforts in this field should integrate contributions and knowledge from several scientific areas, such as mechanical, electrical, controls, chemical, and energetic. In this respect, the Special Issue succeeded in collecting nine research articles coming from the sectors mentioned above, providing a broad perspective on open challenges for HEVs.

2. Hybrid Electric Vehicles: A Multidisciplinary Challenge

Although the hybrid electric powertrain is potentially more efficient than the traditional ICE-based one, implementing an effective energy management strategy (EMS) is crucial to achieve an actual reduction in fuel consumption and emissions without compromising vehicle performance. Several EMSs have been proposed in the literature [2], but this is still a major research issue. In this respect, Dimauro et al. [3] investigated the transient dynamic response of a parallel hybrid electric truck. The parallel hybrid layout includes only one electric machine that can boost the tractive power during the acceleration phases or recover energy during the deceleration phases, while a direct mechanical link between the ICE and the wheel is maintained. The authors proposed a control strategy based on torque allocation to split power between the engine and the electric motor. The results showed a satisfying trade-off between vehicle drivability and NOx emissions, reduced by limiting the ICE transient operations.

Another critical issue in HEVs concerns the battery lifetime, which should be considered in the development of the EMS. Anselma et al. [4] introduced an optimization-driven methodology to tune the parameters of thermal and energy on-board rule-based control approaches of a parallel through-the-road plug-in HEV. They used particle swarm optimization to minimize energy consumption and battery degradation by considering various ambient temperatures, driving conditions, payload conditions, and cabin conditioning system states. The obtained results suggested that pure electric operations should be reduced as the ambient temperature progressively increases beyond 30 °C, proving that temperature significantly affects the battery state of health and, consequently, the fuel

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consumption. Preserving the battery life was also pursued by Li et al. [5], who proposed an EMS for a series hybrid electric air-ground vehicles that can both run on land and fly. Series hybrid includes an electric generator directly linked to the ICE, which is mechanically uncoupled from the wheels, and another electric machine providing the power coming from the generator or the batteries for the propulsion or performing regenerative braking tasks. The EMS presented by the authors involves Pontryagin's minimum principle-based model predictive control framework where speed information from intelligent network technology predicted the reference trajectory for the battery state of charge. Compared with more traditional EMS, fuel efficiency was improved and battery temperature was reduced.

As the latter contribution suggested, a hybrid powertrain can be effectively adopted in those applications where the complete disposal of the ICE in favor of a pure electric powertrain appears less practicable. In this regard, Mocera and Martini [6] developed a power-split hybrid electric layout for an orchard tractor. The power-split hybrid architecture merges the advantages of both series and parallel hybrid and overcomes their drawbacks. Indeed, the ICE is kinematically decoupled from the wheels, such as in the series hybrid. However, some of its power can still be delivered for vehicle propulsion without any intermediate electric conversion, such as in the parallel hybrid. Consequently, the ICE could always operate within the most efficient operation and a significant downsizing of both the engine and the electric unit can be realized. The authors presented two control strategies: a charge depleting mode to use full power for the most power-intensive scenarios and a charge sustaining mode to optimize efficiency and battery use throughout the whole working day. Promising results in terms of peak power capabilities and fuel savings were obtained.

In the power-split hybrid architecture, the ICE, two electric machines and the output shaft are coupled by a power-split unit consisting of one or more planetary gear sets, as well as ordinary gear sets. Furthermore, embedding a clutch system enables multimode operations to increase powertrain adaptability in various road conditions. Nonetheless, the high constructive complexity of power-split transmissions requires proper mathematical tools for the analysis and the design. Castellano and Cammalleri [7], taking the Voltec multimode power-split transmission as a case study, described a procedure to evaluate a global efficiency map in various battery scenarios that can be exploited to extract data to implement a real-time EMS. The contribution is based on a universal parametric approach that can be applied to any power-split transmission. Besides the ICE and electric machines efficiency, it also considers the transmission meshing losses, which are rather challenging to evaluate, especially for multimode architecture with multiple planetary gearing, and thus often neglected. In the same regard, Esmail et al. [8] proposed general and reliable formulas to compute the mechanical efficiency of a planetary gear set. The new formulation exploits the concept of potential or virtual power and highlights the dependency between kinematics and efficiency. Mantriota et al. [9] evaluated the power flows and the efficiency of a power-split transmission with two planetary gear sets, showing that adopting this solution would be more advisable if included in a multimode framework. The study aimed to provide designers with the advantages and disadvantages of implementing this topology within a complex compound powertrain, paving the path for developing an optimization tool that identifies the most efficient configuration for each working condition.

The last two contributions foresee the embedding on HEVs of some of the most cutting-edge advancements towards zero-emission mobility. Beccari [10] proposed the implementation of a hydrogen-fueled engine in a power-split hybrid vehicle. By supposing that the ICE always operates at its most efficient point, numeric simulations were performed in order to compare the gasoline-fueled engine with the hydrogen-fueled one in terms of the thermal efficiency and total energy consumed during a driving cycle. The results showed a mean engine efficiency increase of around 17% and an energy consumption reduction of around 15%. Ramshanker et al. [11] investigated greenhouse gas emissions when a floating solar photovoltaic system is used to recharge the vehicle. In this case, land exploitation is reduced and the decrease in evaporation saves water. The results showed a promising reduction in CO_2 emissions.

3. Research Trends for HEVs

The contributions collected in this Special Issue effectively reflect the challenges that prevent the desirable widespread uptake of HEVs. Prediction-based real-time energy management strategies are crucial to reduce fuel consumption and emissions while maintaining high vehicle performance. This is true especially for the most promising layout, the power-split hybrid, whose higher constructive complexity enables more efficient operations but requires proper mathematical tools for an effective control strategy and a conscious design. Moreover, HEVs share similar battery issues with pure-electric vehicles related to battery performance optimization and battery life safeguard. Lastly, if the transition towards pure-electric ground mobility seems to become a reality soon, there are other fields (i.e., agricultural machinery, aircraft, and air-ground vehicles) where the replacement of the thermal unit looks less forthcoming. More efforts towards the development of hybrid electric powertrain beyond light-duty vehicles are advisable, along with the integration of the latest innovations in green fuel and renewable energy.

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