



Editorial Special Issue "Plug-In Hybrid Electric Vehicle (PHEV)"

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Abstract: Climate change, urban air quality, and dependency on crude oil are important societal challenges. In the transportation sector especially, clean and energy-efficient technologies must be developed. Electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) have gained a growing interest in the vehicle industry. Nowadays, the commercialization of EVs and PHEVs has been possible in different applications (i.e., light duty, medium duty, and heavy duty vehicles) thanks to the advances in energy-storage systems, power electronics converters (including DC/DC converters, DC/AC inverters, and battery charging systems), electric machines, and energy efficient power flow control strategies. This Special Issue is focused on the recent advances in electric vehicles and (plug-in) hybrid vehicles that address the new powertrain developments and go beyond the state-of-the-art (SOTA).

Keywords: novel propulsion systems; emerging power electronics; including wide bandgap (WBG) technology; emerging electric machines; efficient energy management strategies for hybrid propulsion systems; energy storage systems; life-cycle assessment (LCA)

1. Introduction

In light of the current challenges of climate change, urban air quality, and dependency on crude oil [1–3], this special issue was introduced to collect the latest research on plug-in hybrid electric vehicles. There were 21 papers submitted to this special issue, of which 11 papers were accepted. When looking back to this special issue, various topics have been addressed, mainly on drive trains and energy management (four papers), batteries (five papers), and environmental assessments (two papers).

2. Drive Trains and Energy Management

The first paper, authored by Zheng Chen [4], proposes an energy management strategy for a power-split plug-in hybrid electric vehicle (PHEV) based on reinforcement learning (RL). Firstly, a control-oriented power-split PHEV model was built, and then the RL method was employed based on the Markov decision process (MDP) to find the optimal solution according to the built model. During the strategy search, several different standard driving schedules were chosen, and the transfer probability of the power demand was derived based on the Markov chain. Accordingly, the optimal control strategy was found by the Q-learning (QL) algorithm, which can decide suitable energy allocation between the gasoline engine and the battery pack. Simulation results indicate that the RL-based control strategy could not only lessen fuel consumption under different driving cycles but also limit the maximum discharge power of the battery, compared with the charging depletion/charging sustaining (CD/CS) method and the equivalent consumption minimization strategy (ECMS) [4].

Renxin Xiao and his co-authors compared different energy management methods in their paper [5]. This paper proposes a comparison study of energy management methods for a parallel plug-in hybrid electric vehicle (PHEV). Based on detailed analysis of the vehicle driveline, quadratic convex functions

are presented to describe the nonlinear relationship between engine fuel-rate and battery charging power at different vehicle speeds and driveline power demand. The engine-on power threshold is estimated by the simulated annealing (SA) algorithm, and the battery power command is achieved by convex optimization with target of improving fuel economy, compared with the dynamic programming (DP)-based method and the charging depleting-charging sustaining (CD/CS) method. In addition, the proposed control methods are discussed at different initial battery state of charge (SOC) values to extend the application. Simulation results validate that the proposed strategy based on convex optimization can save fuel consumption and reduce the computation burden noticeably [5].

Duong Tran describes in his paper the development of DC/DC multiport converters (MPC) [6]. These converters are gaining interest in the field of hybrid electric drivetrains (i.e., vehicles or machines), where multiple sources are combined to enhance their capabilities and performances in terms of efficiency, integrated design, and reliability. This hybridization will lead to more complexity and high development/design time. Therefore, a proper design approach is needed to optimize the design of the MPC as well as its performance and to reduce development time. In this research article, a new design methodology based on a multi-objective genetic algorithm (MOGA) for non-isolated interleaved MPCs is developed to minimize the weight, losses, and input current ripples that have a significant impact on the lifetime of the energy sources. The inductor parameters obtained from the optimization framework are verified by the finite element method (FEM) COMSOL software, which shows that inductor weight of optimized design is lower than that of the conventional design. The comparison of input current ripples and losses distribution between optimized and conventional designs are also analyzed in detail, which validates the perspective of the proposed optimization method, taking into account emerging technologies, such as wide-bandgap semiconductors (SiC, GaN) [6].

The last paper in the domain of drive trains and energy management is from Yi-Fan Jia et al. [7]. A drive system with an open-end winding permanent magnet synchronous motor (OW-PMSM) fed by a dual inverter and powered by two independent power sources is suitable for electric vehicles. By using an energy conversion device as primary power source and an energy storage element as secondary power source, this configuration can not only lower the DC-bus voltage and extend the driving range but also handle the power sharing between two power sources without a DC/DC (direct current to direct current) converter. Based on a drive system model with voltage vector distribution, this paper proposes a desired power-sharing calculation method and three different voltage vector distribution methods. By their selection strategy, the optimal voltage vector distribution method can be selected according to the operating conditions. On the basis of the integral synthesizing of the desired voltage vector, the proposed voltage vector distribution method can reduce the inverter switching frequency while making the primary power source follow its desired output power. Simulation results confirm the validity of the proposed methods, which improve the primary power source's energy efficiency by regulating its output power and lessening inverter switching loss by reducing the switching frequency. This system also provides an approach to the energy management function of electric vehicles [7].

3. Energy Storage Systems for Electric and Hybrid Vehicles

Insu Cho introduces an accurate state of charge (SOC) approach [8]. Current optimization strategy for a parallel hybrid requires much computational time and relies heavily on the drive cycle to accurately represent driving conditions in the future. With increasing application of the lithium-ion battery technology in the automotive industry, development processes and validation methods for the battery management system (BMS) have attracted attention. This paper proposes an algorithm to analyze charging characteristics and improve accuracy for determining state of charge (SOC), the equivalent of a fuel gauge for the battery pack, during the regenerative braking period of a Transmission-mounted electrical device (TMED)-type parallel hybrid electric vehicle [8].

Another SOC estimation method is proposed by Chi Zhang [9]. Accurate battery modeling is essential for the state-of-charge (SOC) estimation of electric vehicles, especially when vehicles are operated in dynamic processes. Temperature is a significant factor for battery characteristics,

especially for the hysteresis phenomenon. A lack of existing literatures on the consideration of temperature influence in hysteresis voltage can result in errors in SOC estimation. Therefore, this paper gives an insight to the equivalent circuit modeling, considering the hysteresis and temperature effects. A modified one-state hysteresis equivalent circuit model is proposed for battery modeling. The characterization of hysteresis voltage versus SOC at various temperatures was acquired by experimental tests to form a static look-up table. In addition, a strong tracking filter (STF) was applied for SOC estimation. Numerical simulations and experimental tests were performed in a commercial 18650 type Li(Ni1/3Co1/3Mn1/3)O2 battery. The results were systematically compared with extended Kalman filter (EKF) and unscented Kalman filter (UKF). The results of comparison showed the following: (1) the modified model has more voltage tracking capability than the original model and (2) the modified model with STF algorithm has better accuracy, robustness against initial SOC error, voltage measurement drift, and convergence behavior than EKF and UKF [9].

In the paper of Omid Rahbari et al. [10], two techniques that are congruous with the principle of control theory are utilized to estimate the state of health (SOH) of real-life plug-in hybrid electric vehicles (PHEVs) accurately, which is of vital importance to battery management systems. The relation between the battery terminal voltage curve properties and the battery state of health is modelled via an adaptive neuron-fuzzy inference system and a group method of data handling. The comparison of the results demonstrates the capability of the proposed techniques for accurate SOH estimation. Moreover, the estimated results are compared with the direct actual measured SOH indicators using standard tests. The results indicate that the adaptive neuron-fuzzy inference system with 15 rules based on an SOH estimator has better performances over the other technique, with a 1.5% maximum error in comparison to the experimental data [10].

The impact of ageing when using various state of charge (SOC) levels for an electrified vehicle is investigated in the paper of Evelina Wikner [11]. An extensive test series is conducted on Li-ion cells, based on graphite and NMC/LMO electrode materials. Lifetime cycling tests are conducted during a period of three years in various 10% SOC intervals, during which the degradation as function of number of cycles is established. An empirical battery model is designed from the degradation trajectories of the test result. An electric vehicle model is used to derive the load profiles for the ageing model. The result showed that, when only considering ageing from different types of driving in small depth of discharges (DODs), using a reduced charge level of 50% SOC increased the lifetime expectancy of the vehicle battery by 44% to 130%. When accounting for the calendar ageing as well, this proved to be a large part of the total ageing. By keeping the battery at 15% SOC during parking and limiting the time at high SOC, the contribution from the calendar ageing could be substantially reduced [11].

The aim of this paper of Mahdi Soltani et al. [12] is to investigate the effectiveness of a hybrid energy storage system in heavy duty applications, in protecting the battery from damage due to the high-power rates during charging and discharging. Public transportation based on electric vehicles has attracted significant attention in recent years due to its lower overall emissions. Fewer charging facilities in comparison to gas stations, limited battery lifetime, and extra costs associated with its replacement present some barriers to achieving wider acceptance. A practical solution to improve the battery lifetime and driving range is to eliminate the large-magnitude pulse current flow from and to the battery during acceleration and deceleration. Hybrid energy storage systems that combine high-power (HP) and high-energy (HE) storage units can be used for this purpose. Lithium-ion capacitors (LiC) can be used as a HP storage unit, which is similar to a supercapacitor cell but with a higher rate capability, a higher energy density, and better cyclability. In this design, the LiC can provide the excess power required while the battery fails to do so. Moreover, hybridization enables a downsizing of the overall energy storage system and decreases the total cost as a consequence of lifetime, performance, and efficiency improvement. The procedure followed and presented in this paper demonstrates the good performance of the evaluated hybrid storage system in reducing the negative consequences of the power peaks associated with urban driving cycles and its ability to improve the lifespan by 16% [12].

4. Environmental Assessments of Electrified Vehicles

Benedetta Marmiroli presents a review on vehicle life-cycle assessment (LCA) studies [13]. LCAs on electric mobility are providing a plethora of diverging results. Forty-four articles published from 2008 to 2018 have been investigated in this review in order to find the extent and the reason behind this deviation. The first hurdle can be found in the goal definition followed by the modelling choice as both are generally incomplete and inconsistent. These gaps influence the choices made in the life cycle inventory (LCI) stage, particularly in regards to the selection of the electricity mix. A statistical regression is made with results available in the literature. It emerges that, despite the wide-ranging scopes and the numerous variables present in the assessments, the electricity mix's carbon intensity can explain 70% of the variability of the results. This encourages a shared framework to drive practitioners in the execution of the assessment and policy makers in the interpretation of the results [13].

Nils Hooftman et al. [14] compare the environmental impact of the combination of a 40 kWh EV and a trailer options with a range of conventional cars and EVs, differentiated per battery capacity. In this paper, they distinguish plug-in hybrid electric vehicles (PHEVs), electric vehicles (EVs) with a modest battery capacity of 40 kWh, and long-range EVs with 90 kWh installed. Given that the average motorist only rarely performs long-distance trips, both the PHEV and the 90 kWh EV are considered to be over-dimensioned for their purpose, although consumers tend to perceive the 40 kWh EV range as too limiting. Therefore, in-life range modularity by means of occasionally using a range-extender trailer for a 40 kWh EV is proposed, based on either a petrol generator as a short-term solution or a 50 kWh battery pack. A life-cycle assessment (LCA) is presented for comparing the different powertrains for their environmental impact, with the emphasis on local air quality and climate change. Therefore, the combination of a 40 kWh EV and the trailer options is benchmarked with a range of conventional cars and EVs, differentiated per battery capacity. Next, the local impact per technology is discussed on a well-to-wheel base for the specific situation in Belgium, with specific attention given to the contribution of non-exhaust emissions of particulate matter (PM) due to brake, tyre, and road wear. From a life cycle point of view, the trailer concepts outperform the 90 kWh EV for the discussed midpoint indicators as the latter is characterized by a high manufacturing impact and by a mass penalty resulting in higher contributions to non-exhaust PM formation. Compared to a petrol PHEV, both trailers are found to have higher contributions to diminished local air quality, given the relatively low use phase impact of petrol combustion. Concerning human toxicity, the impact is proportional to battery size, although the battery trailer performs better than the 90 kWh EV due to its occasional application rather than carrying along such high capacity all the time. For climate change, we see a clear advantage of both the petrol and the battery trailer, with reductions ranging from one-third to nearly 60%, respectively [14].

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