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Editorial

Energy Management Control and Optimization for Hybrid Electric Vehicles

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This Issue, Energy Management Control and Optimization for Hybrid Electric Vehicles, was set in motion over three years ago with the objective of addressing the challenges posed by energy management control and optimization in vehicle hybridization. Papers were invited that proposed novel power management methods capable of acquiring optimal power handling, accommodating system inaccuracies, and suiting real-time applications to improve the powertrain efficiency at different operating conditions. Some topics initially proposed included an improvement in rule-based control strategies by optimizing the design of their rules and the suitability of optimization-based methods to real-time application, as well as the proposal of novel control strategies. Experimental results describing real-life applications of novel technologies were also requested. This was my first idea of the themes for the papers in this Issue. However, as articles came in, this initial idea evolved and expanded to other cross-cutting areas that have enriched the initial objective of this Special Issue.

One example of these cross-cutting research areas is related to the charging infrastructure required for plug-in hybrid electric vehicles and electric vehicles in general. The effect of charging EVs for the electric power systems is studied in some of the works presented. In [1], the management of the charging power demand in the charging stations was performed from the point of view of the system operators rather than the user. The system operators influence the route selection of the EVs, changing the price of the charging stations in real time. Specifically, the system operator compiles the charging schedule for the CSs and determines the voltage of the system based on the charging schedule. The operator judges the voltage and detects risk factors in the system in advance, changing the charging price described above. The results showed that operational costs could be reduced because the risk could be predicted in advance and EV users could benefit economically from dynamic pricing. When the charging stations are part of a smart micro-grid, including renewable and conventional generation units, the problem of proper charging management must consider uncertainties. Another study dealing with the topic from the perspective of the user was presented in [2]. Firstly, this paper designed sub-item evaluation indicators, to represent the comprehensive satisfaction of electric vehicle users based on their driving characteristics and charging preferences. Then, a dynamic time-of-use pricing strategy for electric vehicle charging considering user satisfaction degree, which was implemented the day ahead, was proposed to achieve the goal of friendly charging for the micro-grid. It was demonstrated that significant financial benefits were offered to the participants and the cost of EV utilization and the operational cost of the electricity grid were decreased by this strategy. Rasouli et al. [3] presented a new model based on the Monte Carlo simulation method for considering uncertain effective factors on the electric vehicles' charging station's load, including battery capacity, type of electric vehicles, state of charge, charging power level, and response to energy price changes. The results showed that by applying the proposed model for estimation of charging station load, the total operation cost decreased. Taking everything into account, I would like to state that the electric vehicle charging infrastructure presented in these works needs to rely on significant advancements in technology

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in various fields, especially those that contribute to a smart grid infrastructure and real-time communication/pricing—smart meters, advanced information/communication technology, etc. The foundation of these technologies is based on advancements in communication systems and power electronics converters. These power electronics-based solutions are reviewed in [4] from the point of view of the integration of photovoltaic energy sources and smart grid with charging systems for electric vehicles and plug-in hybrid electric vehicles.

Regarding the energy management methods for optimizing the power handling in electric vehicles, some papers presented works whose objective evolved from the initial idea of this Special Issue. Optimized energy management systems will be needed in future microgrids where electric vehicles will to be connected and disconnected at different nodes and times. The work presented in [5] coped with that problem, making use of the concepts of fixed and variable virtual impedances. Fixed virtual impedance is related to the distance from each house to the power inverter and variable virtual impedance is associated with the distance from each electric vehicle to it. The proposed control of the inverter seeks to regulate the voltage where the electric vehicles create variations in the impedances. This novel control is useful for the future microgrids to adapt and share active and reactive power, regardless of the distance where electric vehicles are connected.

In spite of the new research lines opened in this Special Issue, there are works that have been adjusted to the objective of this Special Issue (the design of novel energy management systems for hybrid electric vehicles), with interesting results that should be highlighted. In the work of Zhang and Fu [6], an Energy Management System was presented with the objective of addressing the inherent problems of traditional fuzzy energy management systems: although they are easy to understand and easy to implement in the control chip, they cannot realize self-learning and have poor self-adaptability. Thus, there are previous studies, prior to [6], that improved the adaptability of fuzzy energy management systems to some extent by optimizing fuzzy control rules and membership functions, but they did not consider the impact of driving cycles. The research in [6] showed that the proposed neural network fuzzy Energy Management Strategy was able to perform adaptive optimization of the fuzzy membership function and control rules under different driving cycles. Consequently, the proposed control had strong robustness and practicability under different driving cycles. energy management systems can also be designed to improve the overall efficiency of new powertrain systems, for example, the dual-input coupling powertrain system for pure electric tractors presented in [7]. In this case, the energy management system operation depended on two crucial elements: a good choice of operating mode (dual-motor or single-motor operation) and, in dual-motor operation, a well-selected power distribution. The optimization of its parameters showed an improvement in the overall efficiency of the system by about 9.8%. Another issue that energy management systems must face is a proper regenerative braking performance. In [8], with the aim of guaranteeing comprehensive regenerative braking performance, a revised regenerative braking control strategy was introduced and a method of the multi-objective optimization algorithm for tuning the parameter of the control strategy was proposed to balance the braking performance, regenerative braking loss efficiency, and battery capacity loss rate. The results of the sensitivity analysis showed that after parameter optimization, the revised regenerative braking control strategy was proved to perform better road adaptability regarding the distribution of solutions.

All the proposed energy management systems, independently from the kind of power system they are going to control (hybrid electric vehicles or microgrids), require a proper method to estimate the battery state of charge for their correct operation. Up to now, the most effective approach for battery monitoring was to apply advanced estimation algorithms based on equivalent circuit models. A new cascaded framework for lithium-ion battery state and parameter estimation, which separated the battery equivalent circuit model parameters and battery capacity estimation, was proposed based on theoretical analysis in [9]. Apart from providing a simultaneous estimation of battery open-circuit voltage, more rapid and less fluctuating battery capacity estimation were the main advantages of this new proposed monitoring structure. In [10], a completely different approach to model Lithium-Ion batteries was presented that did not require any prior knowledge of these batteries or theoretical analysis. It was based on training recurrent neural networks, composed of two short-term memory layers and one dense layer with processed data of measurable physical features—current, voltage, and temperature. The proposed battery model could be used in real-time applications, as the model inputs are physically measurable parameters, allowing for the possibility of simple and accurate implementation in battery management systems.

Last but not least, other works that presented results that came to answer some thought-provoking questions related to hybrid electric vehicles and their energy management systems. On the one hand, the effects of the driving torque and capacity (energy density) of the lithium-ion battery on the fuel economy of a parallel hybrid vehicle were studied in [11]. The following conclusions regarding the state of charge characteristics and current balance of the lithium-ion battery were drawn: when the battery capacity is reduced by 20%, by using a variety of strategies (e.g., downsizing, engine operation strategy, state of charge increase) to compensate for the state of charge drop, it will be possible to operate hybrid electric vehicles at lower battery capacities; for efficient battery use, state of charge must be charged to near 50%. On the other hand, a systematic literature review of the more recent works that developed energy management systems for hybrid electric vehicles was presented in [12]. The review was carried out subject to the following idea: although the development of novel energy management systems that seek the optimum performance of hybrid electric vehicles is booming, in the real world, hybrid electric vehicles continue to rely on well-known rule-based strategies. The contribution of this work was to present a quantitative comparison of the works selected. It was concluded that the improvement in the analyzed energy management systems ranges, roughly, between 5% and 10% with regard to commercial rule-based energy management systems and, in comparison to the optimum, the analyzed energy management systems are nearer to the optimum than commercial rule-based energy management systems.

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