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Editorial

Safe and Effective Smart Urban Transportation—Energy Flow in Electric (EV) and Hybrid Electric Vehicles (HEV)

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1. Introduction

Electric vehicles (EVs) and hybrid electric vehicles (HEVs) are the most appropriate alternatives for conventional vehicles (internal combustion engine (ICE)-based) for smart urban transport—as an element of sustainable modes of transportation. Moreover, HEVs are a good solution because they allow for a smooth transition from conventional vehicles to EVs and reaping the benefits of both vehicle types.

The Guest Editor of this Special Issue of *Energies* entitled "Safe and Effective Smart Urban Transportation—Energy Flow in Electric (EV) and Hybrid Electric Vehicles (HEV)" has personally found out about the specific aspects of energy flow while using an HEV. When carrying out measurements of traffic flow on road sections in a city network—together with an assessment of the energy demand, operating parameters of a hybrid drive system, and identification the driving mode of the HEV—the vehicle's inverter was damaged. The inverter failure was caused by insufficient cooling of the inverter IGBTs (insulated gate bipolar transistors) during the fast discharge of the HEV traction battery during fast acceleration on a hot summer day. It should be emphasized that the inverter transistors are cooled by a separate cooling system in their own cooling liquid, and despite this, the rate of current rise caused permanent damage to the IGBTs, which additionally confirms the importance of the issues raised in this Special Issue. During this incident, the HEV showed an additional beneficial property that is very rarely mentioned and not found in EVs. This was due to the very well-designed power management system of the HEV model, which allowed for driving in emergency mode with significantly reduced power and speed. This event, among others, was the inspiration for the development of this Special Issue.

The key point for the proper operation of hybrid electric vehicles (HEVs) is the energy management system that aims to find the most suitable power split between the multi-source energy systems that are available onboard [1], i.e., the conventional internal combustion engine (ICE)-based powertrain, the fully electric powertrain using an electric motor generator (EMG), and the available energy in the onboard battery storage (traction battery pack).

The classic traction battery pack consists of a large number of battery cells connected in a series and in parallel in order to meet the energy and power requirements of the vehicle, but the useful capacity of the battery pack is limited by the lowest capacity parallel string of cells (i.e., a bottle neck) due to the lack of charge exchange between the serial rows of cells during discharge [2]. Therefore, the use of modular battery system with a multilevel inverter (MLI)—for example cascaded IGBT (insulated gate bipolar transistor) H-bridge converter topology—is a proposed solution that eliminates the bottle neck problem. The research question is: can the energy efficiency of EVs with an MLI be improved by using pulse width modulation (PWM) and/or fundamental selective harmonic elimination (FSHE)?

The long charging time of most popular wired chargers and their limited availability in only specific locations raises the need for developing other charger technologies. Currently, there are different technologies associated with wireless power transfer (WPT) as an alternative technology to improve user perception of the charging process for electric vehicles [3]. Therefore, it is worth reviewing these technologies in terms of their suitability for use in smart urban transportation.

Battery state-of-charge (SoC) estimation is a key feature of a battery management system (BMS) in electric vehicles (battery EVs). The development of advanced and intelligent SoC estimators for lithium-ion batteries (LIBs)—as the fastest growing technology of energy storage systems (ESS) in EVs—is a recent research topic [4]. Therefore, a very important issue is the accurate modeling and estimation of SoCs to enable optimal battery performance and appropriate safety supervision. The abovementioned issues constitute the basis for a review of the modeling, estimation, and SoC BEV LIB methods.

An essential component of EVs is an energy storage system (ESS), and a reliable thermal management system (TMS) is essential for such an ESS to guarantee safe and reliable high-current operation. This TMS uses powerful modeling tools including 1D electro-thermal models and 3D computational fluid dynamics (CFD) models. Related to this is the need to validate the combination of 1D–3D models in real high-current applications [5].

Lithium-ion batteries in EVs and HEVs generate a relatively large amount of heat, especially during the fast charging/discharging processes. Therefore, designing and building the right TMS with active and passive cooling systems is critical for keeping the battery temperature within a safe temperature range [6,7].

Electric vehicles are often equipped with multiple battery cells; therefore, an appropriate BMS is essential for the safe and reliable operation of battery systems. The main causes of accidents related to the safety of the battery system were either internal short circuit or external short circuit of the battery caused by electrical abuse and mechanical damage. Therefore, a fault tolerance check should be performed after faults are detected and isolated to reduce potential safety risks [8].

The following key functional aspects of hybrid electric vehicles (HEVs) has been presented as introductory issues and problems in the operation of electric vehicles (EVs): wheel load management of HEVs between the internal combustion engine and the battery powered electric motor [1]. Hybrid electric vehicles (HEVs) have been deliberately chosen because they are vehicles that combine the characteristics of internal combustion vehicles—much better known in the automotive field and in common use—with those of electric vehicles (EVs)—whose operating principles are better known in the field of electricity. HEVs are currently being treated in some respects as a transitional technology to the introduction of EVs. However, in many respects, HEVs, despite their apparent complexity (they use two different powertrains technologies), are seen as a very beneficial long-term alternative to the total electrification of urban transport systems.

The problems presented in the next three papers of this Special Issue concern the flow of energy in electric vehicles (EVs) including discussion of the efficient use of energy stored in batteries to the drive of EVs [2]; the effective supply of energy to these vehicles [3]; and a review of modelling, estimation, and methods of smart state-of-charge (SoC) for EVs with lithium-ion batteries (LIBs) [4].

The problems presented in the next three papers focus on the issue of the safety of EVs from the point of view of cooling electric vehicle batteries. Therefore, the following issues are presented: a passive thermal management system (TMS) for lithium-ion capacitor (LiC) technology and cell with a cycled continuous fast charge/discharge 150 A current rate [5]; the thermal performance of different passive cooling systems for a lithium-titanate-oxide (LTO) li-ion battery cell/module [6]; and a hybrid thermal management system (TMS) including natural convection, heat pipe, and air-cooling-assisted heat pipe (ACAH) for EVs [7].

The review of the issues ends with a paper on the diagnosis of batteries and electric vehicles regarding a fault-tolerant voltage and current sensor control strategy for EV batteries [8].

2. A Short Review of the Contributions in This Special Issue

Brief summaries of the eight selected papers featured in this Special Issue of *Energies* titled "Safe and Effective Smart Urban Transportation—Energy Flow in Electric (EV) and Hybrid Electric Vehicles (HEV)" are included in the next subsections.

2.1. Problem of the Wheel Load Management of Hybrid Electric Vehicles (HEVs) between the Internal Combustion Engine and the Battery Powered Electric Motor

Hybrid electric vehicles (HEV) enable lower emissions of exhaust and noise, significant energy savings, and improved driving characteristics, which are all typical benefits of an electric powertrain. An essential condition for the proper operation of HEVs is the energy management system, which aims to select the most appropriate power split between the multi-source energy systems available onboard an HEV. This paper [1] presents the design and verification of an optimized controller for the HEVs parallel energy management system, based on the dynamic programming (DP) and receding horizon (RH) approach. The proposed solutions were tested in a simulation environment and the performance of the control algorithm was assessed based on the fuel consumption of the Worldwide Harmonized Light Vehicle Test Cycle (WLTC) with different control characteristics (e.g., horizon length and update distance).

The energy management strategy (EMS) is responsible for the immediate assessment of the optimal power ratio between the internal combustion engine (ICE) and the electric motor generator (EMG), in relation to the power required by the drive and the energy available in the battery (i.e., its state of charge—SoC), in order to minimize fuel consumption and exhaust emissions.

To estimate the power demanded by the wheels, the optimal vehicle speed for a given driving path is taken into account, and the power demand of the wheels is calculated from the model of the longitudinal dynamics of the vehicle. The specific problem goal of these studies can be defined as the identification of the optimal power profile (or optimal power split between the battery and the thermal engine) to be used according to the driving path profile to minimize the overall fuel consumption of the vehicle. In real applications, it is generally not possible to know the whole driving horizon, especially for long journeys, due to factors such as alternative routes and traffic. In this work [1], the combination of the DP method with the receding horizon (RH) approach to find sub-optimal solutions with respect to those achieved with the knowledge of the entire driving path (full horizon—FH) is presented.

The optimization problem has been solved by combining a DP algorithm with a receding horizon (RH) approach, imposing partial mission horizons and updating the solution at given time steps. The authors [1] emphasize that their method allows for the overcoming of the critical issue of predicting the whole driving path (i.e., full horizon—FH) and enables the exploitation of advanced driver assistance systems (ADAS) and V2X technologies for the knowledge of the short-term driving path profile. Moreover, the proposed method solves the problem of optimal control in conditions of reduced dimensionality; therefore, it reduces computational requirements and enables implementation in real time.

2.2. The Problem of Improving Energy Efficiency at Lower and Higher Speeds of an Electric Vehicle (EV) with an Inverter of a Modular Battery System

The aim of the preliminary research presented in [2] is to determine whether the use of pulse width modulation (PWM) can improve the energy efficiency and current quality of electric vehicles (EV) with an inverter of a modular battery system at lower speeds and fundamental selective harmonic elimination (FSHE) at higher speeds. For the innovative inverter of the modular battery system, i.e., the seven stage Cascade H-Bridge (CHB) inverter, two modulation techniques were compared—PWM and FSHE—considering the wide torque-speed range of electric vehicles.

The analysis takes into account the ohmic losses of the battery. Drive cycle losses are quantified and the dominance of high FSHE speed is demonstrated by an inductive load experiment. The inverter and battery losses, and the inverter-induced current THD, were modeled using a simulation. In order to assess the effectiveness of each method (PWM and FSHE) in relation to the torque-speed of the small passenger vehicle, losses in the drive system (battery and inverter losses) and THD of the total harmonic distortion current were used as reference parameters.

The authors of [2] conclude, inter alia, that the hybrid technique of modulating the output voltage in the operation of the CHB inverter is the most preferred at low speed and when stationary when the driveline must be operated with multi-level PWM, but when driving at higher speeds, FSHE should be selected. The use of a multi-level PWM or FSHE depends on the modulation rate and the relative pitch frequency. The key result of the analysis is that the absolute, simulated cycle efficiency of small EVs was improved from 0.29% to 0.42% by using the optimized hybrid technique compared to using only PWM.

2.3. Problems of Technologies Used for Wireless Charging of Electric Vehicles (EVs)

This paper [3] presents an overview about wireless power transfer for electric vehicles (WPT) technology. The most relevant advantages provided by WPT are the following features of quasi-dynamic and dynamic charge:

– Automatic operation without the driver's intervention and without the presence of the driver in the scheduled mode; this function is related to the use of EVs in V2G (vehicle-to-grid) networks;
– This technology is safer from the driver's point of view because no cable is needed to carry the high electrical current, which in cable charging poses a risk especially in unfavorable weather conditions; however, it is required that the magnetic or electric fields involved in energy transmission must be limited to safe and controlled levels;
– The EVs can be charged in more situations, especially while moving and temporally stopped, such as when waiting in a parking lot, for a traffic light, at a bus stop, etc.; therefore, there are three modes of wireless charging: static, stationary or quasi-dynamic, and dynamic;
– Modes of wireless charging: static WPT takes place when the EV is parked and the engine is turned off, which can go to a full charge—this is a charging mode in public parking lots or at homes; static WPT is similar to conventional conductive charging—considering infrastructure and charging time. Stationary WPT occurs when the EV is stationary but the engine continues to run and for a short time not sufficient enough to reach a full charge; example include when stopped at a toll plaza, when a public transport vehicle stops at passenger stops, or when stopping at traffic lights; dynamic WPT enables wireless charging of an EV equipped with an on-board WPT receiver while driving on a road with sections equipped with WPT transmitters;
– The EV vehicle battery can be charged more often including when driving on more sectors of road infrastructure equipped with WPT transmitters and therefore the battery can be smaller and, therefore, cheaper.

The research results presented in [3] concern the electromobility in the context of four main technologies for wireless chargers with use of following power media: induction—magnetic resonant WPT; capacitance—capacitive-based WPT; radiofrequency—microwave-based power transfer; and optical—laser-beam powered WPT. The authors of this study took into account, inter alia, the following criteria for WTP technology:

– Power is transmitted in the following ranges: up to 1 kW for light EVs, 1–100 kW for medium-power EVs, over 100 kW for high-power EVs;
– V2X-enabled (vehicle-to-everything) power transfer; this applies to bi-directional energy flow in the grid of electrical devices, i.e., energy flow from the power supply system to the electric vehicle battery, but also to the discharge of electric vehicle battery to support the grid, another EV, or another device;
– Gap is the distance between the receiver and the power source—for EVs, the Society for Automotive Engineering (SAE) defines three types of classes according to gap as vehicle coil ground clearance, i.e.: Z1-class (100 mm < gap < 150 mm), Z2-class

(140 mm < gap < 210 mm), and Z3-class (170 mm < gap < 250 mm). The WPT system consists of two components called assemblies. A ground assembly (GA) that includes charging equipment that is connected to the grid and a vehicle assembly (VA) that includes the vehicle's equipment [3];

– Capability to work with misalignment; conventional use of the charger occurs when the transmitter and/or receiver are not at a predetermined location and therefore the WPT must reconfigure the transmitter to adapt the power beam to the receiver's current position;
– Possibility of intermediate objects; security problems may then arise due to disturbances in energy transmission through intermediate objects that will be in the gap;
– Stationary/mobile receiver, i.e., when the WPT system is required to be able to transmit energy when the receiver is in an undefined position before or during the charging process; this feature is important for charging while on the move.

In summary [3], the authors indicate, inter alia, that the most mature technology of the wireless charger for EVs is the one based on the WPT magnetic resonance technology, which also enables cooperation with V2G networks. In contrast, WPT capacitive technology has some significant limitations such as limited efficiency, low power density, intense electric fields, and parasitic capacities. Microwave WPT and laser WPT technologies have similar limitations, and the efficiencies of these two technologies are lower than that of magnetic resonance or capacitive WPT. Additionally, microwave WPT for high power levels is not practical as it requires bulky antennas, while WPT laser beam technology is in turn limited to low power levels due to the potential risk to humans.

2.4. Problems of Modelling, Estimation and Methods of Smart State-of-Charge (SoC) for Electric Vehicle (EV) with Lithium-Ion Batteries (LIBs)

The article [4] discusses the current battery state of charge (SoC) modeling methods and their estimations in predictive analysis for vehicles with lithium-ion batteries (LIB). In the discussed methods, the main physical parameters used to estimate the SoC are current and voltage. The authors of [4] present battery models with an emphasis on data-driven models and electrical equivalent circuit models, along with information on their application and comparisons between them.

Machine learning techniques (e.g., neural networks, support vector machines, and fuzzy logic) are used in most data-driven models for online SoC estimation. It should be emphasized that while data-driven techniques work well for nonlinear problems, they can be significantly affected by the dataset and methods used for training. Therefore, the use of these methods may require high overall computational costs due to the need to use a large dataset in order to cover all possible operating conditions.

Models of electrical equivalent circuits that use electrical components to mimic the behavior of the LIB can be categorized into integral and fractional order models. In integral order models, the most commonly used online parameter discovery technique is recursive least squares because it has a simple structure that can be implemented in real-time applications. In contrast, fractional-order models are also widely used because of their fractional characteristics.

The authors of [4] also referred to physical electrochemical models, pointing out that such models are difficult to implement due to the very large number of variables that need to be defined.

In summary [4], the authors indicate that the current and voltage parameters are used as parameters for the SoC estimation using physical electrochemical, data-driven models, and electrical equivalent models. At the same time, the authors point out the low accuracy of these approaches, which may be a problem in optimal monitoring of the LIB status. Therefore, based on a review of the issues discussed in the article, the authors list some alternative methods, such as methods based on lookup tables, ampere-hour integrals, and estimation algorithms based on filters, observers, or data-driven.

The conclusion ending the review of the models [4] indicates that the research should be focused on reducing the computing power in relation to the current required in the SoC estimation processes.

2.5. Problem of Passive Thermal Management System (TMS) for Lithium-Ion Capacitor (LiC) Technology and Cell with Cycled Continuous Fast Charge/Discharge 150 A Current Rate

A lithium-ion capacitor (LiC) is an energy storage system (ESS) technology for electric vehicles (EV) with a higher energy density than supercapacitors (SC) and a higher power density than lithium-ion (LiB) batteries. However, the performance of LiC is highly temperature dependent and, therefore, a reliable thermal management system (TMS) is essential for the LiC to guarantee safe and reliable high-current operation.

The authors of [5] present an innovative passive temperature management system (TMS) consisting of a heat sink (HS) and phase change materials (PCM). It is a TMS for lithium ion (LiC) capacitors with 150 A cyclic fast charge/discharge. This TMS uses a 1D electrothermal model and a 3D computational fluid dynamics (CFD) model with the output variables of temperature and LiC power loss. The 1D model output was combined with a CFD model to create a suitable 1D–3D model capable of determining electrical and thermal parameters and simulating a CFD model. Such a coupled 1D–3D model enables the determination of the following electrical parameters, e.g., open circuit voltage (OCV), polarization capacitance, and resistance as well as internal series resistance and thermal parameters, e.g., cell temperature and power loss. Such model capabilities are necessary in its application for LiC, because LiCs operate at high dynamic currents when the cell temperature exceeds a safe limit (+40 °C) and requires a solid cooling system.

The article [5] also partially takes into account the method of passive LiC cooling, which uses a system of passive elements, including heat pipes, heat sinks, and phase change materials (PCM). This passive system absorbs large amounts of latent heat through a phase change. However, the use of only PCM is insufficient as PCM cannot release all the absorbed heat due to its very low conductivity temperature. To increase the intensity of heat release, additional material should be added to the PCM, e.g., aluminum or copper mesh, nanoparticles, heat pipes, heat sinks, and even active systems such as liquids or fans. Bearing in mind the abovementioned issues regarding passive cooling systems, the article [5] proposes a hybrid HS-assisted PCM TMS for cooling LiC 2300 F prismatic cell, i.e., using pure paraffin as a phase change material (PCM) assisted by two aluminum heat sinks on both sides cells. Then, tests of passive cooling of LiC batteries were carried out for the following passive systems: under natural convection (NC TMS) conditions, using the system only with PCM TMS, and hybrid HS-assisted PCM TMS. The results of these tests showed that HS-assisted PCM TMS reduced the maximum temperature by 38.3% compared to NC TMS and by 16.4% compared to PCM TMS. These results confirm the high thermal efficiency of the HS-assisted PCM TMS hybrid [5].

2.6. The Problems of the Thermal Performance of Various Passive Cooling Systems with Lithium-Titanate-Oxide (LTO) Battery

Lithium-ion (Li-ion) batteries are the most popular energy source in electric (EV) and hybrid electric (HEV) vehicles. The advantages of Li-ion batteries include high specific energy, large capacity and power, high durability, and no memory effect. To ensure the listed advantages of Li-ion batteries, an appropriate temperature management system (TMS) is required because such batteries generate a large amount of heat, especially during the rapid discharge process that occurs when accelerating or high climb EVs and HEVs.

In [6], natural convection (NC), aluminum mesh (Al), copper mesh (Cu), phase change material (PCM), and graphite PCM on a lithium-titanate-oxide (LTO) cell/module at discharge rate of 8C (184A) were considered. Experimental and numerical studies were carried out to investigate the cooling efficiency of various passive TMSs. The results of the experiments confirmed that the PCM and PCM-graphite cooling methods maintain a safe battery temperature. Furthermore, the results show that the cell spacing has a great influence on lowering the module temperature. The authors [6] indicate that further research should be carried out in order to increase the thermal conductivity of PCM through the use of additional materials, e.g. the construction of passive hybrid systems such as an HS-assisted PCM TMS hybrid [5].

2.7. The Problems of the Hybrid Thermal Management System (TMS) with Natural Convection, Heat Pipe and Air-Cooled Heat Pipe (ACAH) for EVs

The heat generation of lithium-ion batteries is an unavoidable phenomenon, especially for profiles with high discharge currents, which occur when an EV is driven at high acceleration and/or on an uphill road segment.

The article [7] presents the concept of a hybrid thermal management system (TMS) for EVs, which uses a natural convection heat pipe called an air-cooling-assisted heat pipe (ACAH).

In the experimental tests, the battery was discharged from 100% to 0% of state of charge (SOC) under the 8C discharging rate in 446 s. The tests were performed at a constant room temperature of 22 °C, started with a status check of the battery cell, and the natural convection was used as an initial cooling method that benefits no cooling energy consumption, but the maximum temperature of the cell reached 56 °C, demonstrating that the natural convection cooling method is not successful at controlling the cell temperature within the appropriate range. Therefore, a cooling concept using the six heat pipes as superconductors was designed to increase the heat transfer efficiency. In order to enhance the cooling target, an experimental air-cooling-assisted heat pipe (ACAH) was designed. In this design of a hybrid cooling system, the cell equipped with heat pipes is affected by forced convection—the fan with an inlet velocity of 3 m/s directly affects the cell, evaporator, and condensers of the heat pipes. The mathematical models were solved by COMSOL Multiphysics®. The authors [7] describe their obtained results: first, the maximum temperature of the cell reached 38.3 °C at the 31% and 17.2% reduction compared with natural convection and heat pipe cooling system, respectively. The cooling effect of ACAH is extremely dependent on its coolant inlet velocity, temperature, and flow path. Despite this, studies have confirmed that ACAH is an effective method of LTO cell temperature management in fast discharge conditions.

2.8. The Problems of the Fault-Tolerant Control Strategy for a Voltage and Current Sensors for Batteries in Electric Vehicles (EVs)

The work [8] presents a model of a hybrid sensor for failure diagnostics and a failure tolerance control strategy for batteries in electric vehicles (EV).

An innovation of this fault identification and fault-tolerant control strategy is that the fault values of the voltage sensor and the current sensor are derived from the residual open-circuit voltage (OCV) and the residual capacity, respectively [8].

An estimated capacity derived from the accumulated charge-to-state difference (SOC) ratio at different non-contiguous sampling times is used to generate residuals for detecting sensor failure. Active fault-tolerant control after fault detection is essential in order to improve the safety of battery systems, and an exact fault identification value is the basis of the fault-tolerant control. However, this method is only suitable for faster sample rates.

Summarizing the obtained research results, the authors indicate further directions of their research related to selection the appropriate capacity residuals to meet EVs application conditions. It is related to different sensitivity of different residuals to faults, which was observed in the research presented in the paper [8].

3. Conclusions and Future Works

The papers in this Special Issue of *Energies* titled "Safe and Effective Smart Urban Transportation—Energy Flow in Electric (EV) and Hybrid Electric Vehicles (HEV)" highlight a variety of problems related to the power split between multi-source energy systems, cascaded IGBT H-bridge converter, wireless power transfer (WPT), smart state-of-charge (SoC) estimators for lithium-ion batteries (LIBs), a thermal management system (TMS), and fault-tolerant control with fault detection. An extension of the problems of EV operations can be found in papers [9,10] that present selected problems of using EVs in the energy networks of smart cities that share their energy resources with renewable energy sources and energy storage and present an economic model of electric bus implementation.

The scientific content of this Special Issue should inspire researchers from different research areas to consider the problems that are discussed in the eight included papers, as well as from the many other research areas related to electromobility [11,12] and decarbonization of transport and logistics [13,14].

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