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Editorial

Advances in Electric Traction System—Special Issue

Adam Szeląg [1,*] and Mladen Nikšić [2]

[1] Electric Traction and Electrical Power Economy Division, Power Engineering Institute, Warsaw University of Technology, Koszykowa Street 75, 00-662 Warsaw, Poland
[2] Department of Railway Transport, Faculty of Transport and Traffic Engineering, University of Zagreb, 10000 Zagreb, Croatia
* Correspondence: adam.szelag@pw.edu.pl

1. Introduction

Transportation does not produce goods by itself but is a service of moving people or goods that allows societies to thrive and develop. The development of the wheel, railways, cars and planes has determined our current development level. That is why transportation is sometimes called the "lifeblood" of the economy.

The 19th century was a "golden age" of railways, peaking at the beginning of the 20th century, when locomotives achieved speeds of more than 200 km/h. Further development of railways was possible due to technological advances in electric traction. However, in the 20th century, railways faced competition from road (automobiles) and air (airplanes) transport following the development of the internal combustion engine. Consequently, after World War II, buses and passenger cars pushed rail transport (trams) away from towns. The development of motorways and airports resulted in falling shares of railways in long-distance passenger transport. In Europe, the share of railway passenger transport fell from 10% in 1970 to 6% in 2000, and cargo transport from 21% to 8% in the same period. However, since the 1970s, the interest in electric traction has picked up again due to road traffic jams and environmental pollution [1]. Past data and current EUROSTAT statistics have shown a slow trend in this regard. In 2016, the share of railway traffic (in passenger km) in Europe varied between several percent (7% in Poland, an average value for Europe) to 10% in the Netherlands and Austria, to 20% in Switzerland. In 2017, the average share of railway cargo transport (in tonne km) in EU-28 was 5%, ranging from a fraction of one percent in Ireland to 20% in Poland, and to more than 60% in Lithuania and 70% in Latvia (in the Baltic States, transit railway transport has played an important role, which might have changed due to the attack of Russia on Ukraine).

The "drive" typically means the transfer of mechanical energy from various types of engines or motors to the actuating machine. Electric drive is when the motor is supplied with electrical energy. Electric drives are called electric traction drives if they propel traditional rail or road wheeled vehicles along a dedicated route, unconventional vehicles such as maglev, or even aerial vehicles (drones). Electrical motors can be driven by an on-board energy source (self-propelled vehicles with diesel engines or batteries) or an external source, such as special AC or DC power supply systems, i.e., from traction substations via catenary (overhead or third-rail) [2]. Modern solutions, specifically in electromobility, can use innovative energy sources (fuel cells, hybrid energy storage devices with batteries and ultracapacitors). Currently, due to development of power electronics [3], automation and digital control, electric motors in electric traction can be supplied from various energy sources, and the choice of specific solution depends on the purpose of service (required traction characteristic), costs, efficiency, as well as reliability, availability, maintainability and safety (RAMS). This is accompanied by new methods of analysis [4], diagnostics and provision of redundancy in the subsystems, especially the braking ones. Modern electric traction vehicles are complex engineering systems equipped with high-end solutions in electromechanics, electronics, automation and IT, especially in high-speed railways which

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have achieved record speeds of up to 574 km/h in France (AGV in 2008), with trains in China travelling at 380 km/h in regular service. The application of AC motors makes it possible to apply electric braking more effectively [5,6].

Constant dynamic development of societies, especially in Asia, has significantly increased demand for transportation. Electrified catenary systems are limited to dedicated lines, which reduces their availability for passenger transport in less populated areas and makes it less competitive to road transport based on liquid fuels. It is estimated that more than 90% of energy used for transport is consumed by road vehicles. Environmental pollution has brought the need to replace vehicles based on internal combustion engines with electric ones. Shortages of fossil fuels due to the attack of Russia on Ukraine and decreasing availability of fossil fuels have resulted in a new push towards electric transport. However, the insufficient capacity of batteries and low use of alternative energy sources provide an opportunity for catenary-supplied transport to increase its share of the economy. In countries without significant reserves of crude oil, rail electric transport could play strategic role in long-distance and urban transport as electrical energy [7] could be generated from other sources, with increasing share of renewables or nuclear plants. Therefore, the maintenance and development of electric-traction infrastructure and vehicles should be considered not only from the economic point of view but also as a means to increase strategic autonomy of a country, especially when transportation could be energized mainly by renewables [8].

2. Overview of Contributions to This Special Issue

Modern electric transportation systems have constantly applied new technologies. As effective electromobility is an essential component of sustainable societies, electrified transportation systems (e.g., railways, metro, trams) make a huge contribution in this respect. Mass rail transport can be complemented with individual solutions that solve the "last mile problem" and enable door-to-door delivery, which is convenient for passengers in less populated areas. Due to efforts to decrease greenhouse gas emissions, electrified transportation has been gaining advantage over systems and means of transport based on combustion engines. Moreover, the integration of electric traction (vehicles and power supply) with renewable energy sources and energy storage is an important topic of the 'European Green Deal' policy.

The papers presented in this Special Issue cover a wide range of selected problems of advances in electric traction systems [1–8], electric drives for ground and air transport [9–11], DC [12,13] and AC [14,15] power supply used in network traction, automation and control [16,17], and energy savings that help the environment [18].

In [9], the authors present the results of research on the adoption of running gear and a drive solution for low-floor tram vehicles with independently rotating wheels, and the outcomes of simulation analysis of the drive control in such system, using mathematical models of the mechanical system (running gear) and the electrical system (motor drive control system). The Vector Control Method used in that paper makes it possible to simultaneously control rotational speed and electromagnetic torque of the motor, which provides better dynamics of the drive system compared to control with scalar methods. The innovation of the proposed solution consists of building a mathematical model of the electromechanical system, later used in the simulation model and then used in the construction of a prototype of a low-floor tram vehicle.

Paper [10] presents a conceptual design of batteries which could be applied in a hybrid training plane used for pilot training of students. Due to the high weight of batteries and their low specific energy compared to aircraft fuel, it was important to choose and design the battery to meet specific restrictions. The authors have concluded their research with the coverage of the hybrid drive ratio (the ratio between a conventional ICE and electric motor—0% means only ICE drive and 100%–only electric drive) and operating costs for different ranges of flights.

Paper [11] addresses important issues involved in the initial application of AC motor drives supplied by inverters, i.e., the problem of the reduction in torque harmonics caused by distorted voltage delivered by inverter to a machine's terminals. Extensive literature in this area and applications of different methods of inverter control in multilevel inverters are presented. The paper proposes a selective harmonic elimination technique (SHE-PWM) and compares it with the synchronized carrier pulse width modulation technique (SCPWM). In order to show efficiency and the superiority of the proposed elimination method, simulations with MATLAB/Simulink and laboratory verifications were performed. More research in this area is discussed in papers [19,20].

Paper [12] presents research on decentralized supply of a 3 kV DC railway system using low-power supplying modules (SM) instead of traditional high-power traction substations. The modules make up a kind of smart grid and consist of energy storage devices with DC/DC converters connected to catenary, that can be supplied by local RES (photovoltaic, wind generators), and connected to local distribution networks. Technical and economical outcomes of a case study involving the proposed solution are benchmarked against a traditional 3 kV DC supply system with rectifier substations. The main advantages of the proposed solution include: lower energy consumption by the line due to better usage of recuperative energy, higher reliability, better stability of catenary voltage, opportunity to use green energy from RES, opportunity to connect the SM to local weak distribution networks if microgrids could be organized [21]. Such solutions are easier to apply in urban transport when the power demand is lower [22].

Short-circuits in DC traction supply lines has been an important issue in traditional systems with rectifier substations, and the problem has been additionally complicated by new solutions using energy storage devices as in [12], which is comprehensively discussed in [13]. A simulation Matlab model was applied for the calculation of short-circuit currents, and the results were compared with theoretical calculations standardized in EN 50123-1. A study case was then presented for a 1.5 kV DC light rail system in order to verify protection against short-circuits and required breaking capacity of high-speed breakers. The proposed method may be applied as a useful tool for designing protection of DC traction supply systems equipped with energy storage devices. More details on short circuits in DC traction are provided in [23].

Paper [14] addresses research on the application of non-intrusive load monitoring to AC traction power substations. Various time domain and frequency domain aspects of AC traction load were analyzed based on the results of past measurements taken in Switzerland, Germany and France. The comparison and assessment of the applied methods helped the authors to describe the specifications of AC traction load in different operating conditions (traction and braking) taking into account: voltage–current time domain trajectories; current, active and reactive power harmonics in the low-frequency range. Results of measurements in European AC supplied railway are presented in [24].

Another approach to the analysis of AC traction supply is presented in [15] which discusses a new method for the estimation of losses of active power based on electromagnetic field analysis. Analytical description of a section of AC power supply and formulas for active power losses derived from Maxwell's equations are presented. Example calculations of active losses in all conductive elements, not only in the conducting circuits (rails, catenary), showed that the proposed "field" approach to active losses is more complex and takes into account losses in locomotives and wagons. Another approach to electromagnetic processes in electric transport systems is presented in paper [25].

Paper [16] presents a Markov-chain-based method for the synthesis of high-sampling-rate (HSR) driving cycles for buses that satisfy statistical features extracted from low-sampling-rate (LSR) vehicle-tracking data over trip segments. The proposed HSR driving cycle synthesis method was validated against the LSR recorded data in terms of micro-cycle mean velocity and stopping probability. A large set of realistic HSR synthetic driving cycles can be generated in a numerically efficient way to faithfully characterize the features of a transport system represented by LSR tracking data.

Two strategies for the delivery of goods by electric vehicles are presented in [17]: with partial and full battery recharging. Optimization of routing for the delivery of goods includes: minimizing the required number of vehicles and routing costs (depending on distance, energy consumption, travel times, GHG emissions, battery charging costs, etc.). The partial recharging strategy was able to reduce the total number of vehicles, total distance traveled, total time and total recharging amount compared to the full recharging strategy, at the expense of an increased number of visits to charging stations. The partial recharging strategy turned out to be more robust regarding battery degradation costs, non-linear charging function and daily charging costs, but the compliance rate must be high for this to be efficient in real-world applications. Advantages of mobile-charging in transport systems where trolley-buses with battery are in service is discussed in [26].

Excessive global CO_2 emissions have led to climate problems, and emission reduction policies require calculations of carbon footprint in every sphere of human activity, including transportation. Although electrified railways are known for their high energy efficiency, emissions resulting from the generation of electric power used for transportation depends on the type of power plants dominant in a specific country. Paper [18] studies energy consumption and CO_2 emissions by comparing the operation of different types of trains along the same routes: new seven-unit high-speed trains ED250 and traditional trains with a 6 MW locomotive and 10 passenger wagons. Energy consumption shows that high-speed trains are significantly more environmentally friendly than locomotive-driven trains. Additionally, CO_2 emissions from the operation of ED250 trains are lower than from traditional trains. The goal of the paper has been to present selected aspects (energy efficiency, environmental load, etc.) of putting into service traction units with ED250 as an example of modern trains compared to locomotive trains previously used by Polish railway operators. The study employed simulation methods for running ED250 and equivalent locomotive passenger trains to compare the parameters of service on main railway lines where ED250 trains operate. Results of simulations have demonstrated the superiority of an electric traction unit over a locomotive train in terms of energy consumption, which, coupled with a spike in energy prices in 2022, makes an additional case for modernization of the rolling stock. More research on this topic can be found in items [27–29] of the References, with an interesting assessment of the possibility to accomplish the target of 100% of energy for transport purposes delivered from renewable sources [8].

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