RAILWAY TRANSPORT SYSTEM ENERGY FLOW OPTIMIZATION WITH AN INTEGRATED MICROGRID

Hrvoje Novak, Mario Vašak, Marko Gulin, Vinko Lešić
University of Zagreb, Faculty of Electrical Engineering and Computing, Laboratory for Renewable Energy Systems, Croatia

Abstract
Railway transport system microgrid model is observed from the point of balancing energy flows between accelerating and decelerating trains, hybrid energy storage systems and a single supply substation connected to the main power grid. In this paper, an energy flow optimization of a railway system microgrid is presented. Optimization problem is formulated as a linear program that takes into account energy storage systems with corresponding charge and discharge efficiencies, actual electricity prices and simulated daily train consumption profiles. Performance of the proposed approach is verified through one-day simulation scenario with model predictive control scheme and by considering different prediction horizon lengths.

1. Introduction
Transport systems are considered as large energy consumers that accounted for 31.8% of overall energy consumption and for 1160.2 million tons of CO₂ emission in Europe in 2012 alone [1]. As a part of it, railway transport accounted for 2% of overall energy consumption and 7 million tons of CO₂ emission. For the same year in Croatia, 164.5 GWh were spent on transporting around 27.6 million passengers and 11 million tons of goods through the railway system [2]. Given the European Union climate and energy targets for 2020, also known as the 20-20-20 plan, it becomes important to improve the energy efficiency of the railway systems and market the “green image” of railway applications. Advances in information and communication technologies and electronics, together with more efficient and economically affordable energy storage systems, provide an opportunity for complex technical systems like railway transport to transform from passive loads that consume energy from the grid into more proactive entities with an ability to adapt to changing energy exchange terms and various demands of the power grid. In order to increase the energy efficiency of the railway system, a considerable amount of effort is invested on better utilization and efficiency of braking trains regenerative energy [3]-[13]. Electric trains in braking convert the mechanical kinetic energy to electrical energy and feed it back to the catenary. If another train is accelerating while supplied from the same substation, energy sent back to the catenary will be used for powering its acceleration. If there are no accelerating trains nearby, regenerated energy causes overvoltage that potentially damages the system infrastructure. The energy is then dissipated on train built-in resistors, or it is stored in energy storage devices if available. An opportunity is provided to tune train timetables in order to closely coordinate nearby trains such that the braking trains regenerative energy is immediately reused by accelerating trains [3], [4]. Introduction of onboard and stationary energy storage systems [5]-[13] for storing the regenerative braking energy for later use show that savings of up to 30% of regenerative energy are achievable. In order to further increase the economic effects related to energy flows of the railway system, it is necessary to implement a higher-level control system to take into account the possibility of different electricity prices throughout the day or changing acceptable power exchange levels imposed by the power utility.

The concept of microgrids brought possibility of dynamical optimization of the railway system total power consumption by means of distributed regenerative braking, renewable energy sources and storages, all of which transforms it to active participant in the power system [8], [9]. A clear microgrid structure is formable for each railway system supply substation, where braking trains present distributed sources and the energy storage systems are installed in the substation. The microgrid energy management system balances the energy flows between accelerating trains energy consumption, decelerating trains energy production, energy storages and energy exchange with the grid. It takes into account declared price profile for energy exchange on the grid side, current state of the energy storage and prediction of trains energy consumption, and makes the decision when to buy/sell electrical energy from/to the utility grid and in which amount. Therefore each supply substation along the train route may be observed as an individual microgrid. By making a step-up further, the railway traffic system is observed as a chain of microgrids that can be coordinated in order to attain minimum cost for energy drawn from the grid while all the trains operate according to timetable and operational constraints along the routes.

Previous work on microgrid energy flow optimization is
performed on a DC microgrid that consists of photovoltaic array, batteries stack and fuel cells stack with electrolyser, all connected to the grid via bidirectional power converter. Minimization of microgrid operating costs is formulated by using a linear program that takes into account energy storage devices charge and discharge properties [14], [15]. The improvement in energy consumption efficiency has additional advantages for the railway operator and the power system in general: the use of the grid is more efficient and a smaller capacity is required; the railway operator becomes less dependent on the power grid; decentralization of the power system thus increases its reliability and stability; finally, the amount of power that needs to be contracted is reduced and the operating costs are further decreased [4]. In this paper, a railway system microgrid is considered consisting of a hybrid energy storage system, distributed generation of nearby trains in braking and a bidirectional connection to the power grid through a supply substation. Microgrid energy flow optimization problem is defined as a linear program (LP) and a model predictive control (MPC) scheme with receding horizon philosophy is implemented. The performance of the proposed approach is verified on a one-day simulation scenario considering different prediction horizon lengths. This paper is structured as follows. In Section 2, a microgrid model is presented. In Section 3, the optimization problem and model predictive control scheme are formulated. Performance verification of the proposed approach is given in Section 4.

5. Conclusion
In this paper energy flow optimization in railway system with integrated microgrid is presented. Model predictive control scheme is implemented and the approach is verified for different prediction horizon lengths on a simulation scenario. It is shown that the proposed approach reduces the railway system operation costs through charging and discharging of the hybrid energy storage system, with better performance for longer prediction horizons. Choice of energy storage systems is validated as it is shown that supercapacitors are used for storing the regenerative braking energy, while batteries perform better at utilization of the difference in the electricity price profile throughout the day. Due to inherent complexity, the railway system is observed from two different control levels. The higher-level railway system optimization introduced here optimizes energy flows with respect to external grid conditions, state of the energy storage system and railway traffic. Lower, consumption level optimization, where each train is controlled to achieve least travel costs while maintaining the timetables and passengers comfort can be recomputed such that interaction of both levels is taken into account and the computed energy consumption profile on the lower level directly maximizes the global economic gain of the whole system operation. Price of energy exchange with the grid is for an individual train transformed through the higher coordination system and the economic cost is reduced by cooperative action of all the trains in balancing energy flows.

Acknowledgments
This work has been financially supported by Croatian Science Foundation through project 3CON (94020-2014). This support is gratefully acknowledged.

References


