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Multi-criteria fuzzy-logic optimized supervision for hybrid railway power substations

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Abstract

Renewable energy sources and storage units' integration in the railway power substations is an alternative solution to handle the energy consumption, due to railway traffic increase and electricity market liberalization. To integrate this technology change in the railway network, an adapted energy management system has to be established. However, when considering only energy efficiency aspects on the energy management strategy, an economical viable solution cannot be ensured. This paper proposes a supervision strategy based on multi-criteria approach including energetic, environmental and economic constraints. The energy management objectives such as reducing the network power demand, favoring local renewable consumption and ensuring storage availability are treated in different time levels. Economic aspects are first integrated in predictive mode based on forecast data. Then a supervision strategy is developed based on fuzzy logic approach and graphical tool to build it. An optimization study of the supervision strategy is proposed in order to conclude on system performance. Simulation results are discussed for different scenarios cases and the reaction of the hybrid railway power substation is detailed. Results show that this methodology can be successfully applied for hybrid systems energy management in order to improve their energy efficiency.

Keywords: Hybrid railway power substation (HRPS); Supervision design; Fuzzy logic (FL) energy management; Design of experiments (DoE); Genetic algorithm (GA)

1. Introduction

With railway traffic increasing and electricity market liberalization, railway actors are determined to search for techno-economic solutions to face future energy demand increase. Renewable energy sources (RES) and storage

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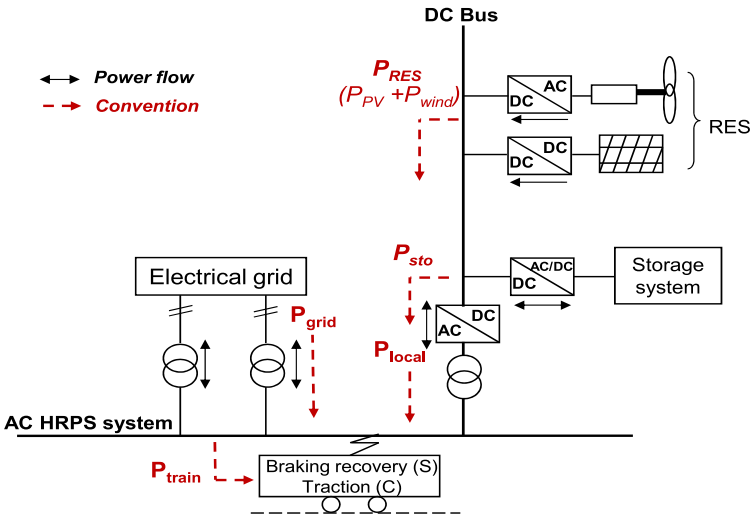

Fig. 1. HRPS electrical configuration.

integration in the railway power substations may contribute to partial independence from energy producers as shown in [6], with adapted energy management strategy. Centralized, distributed and hybrid control strategies for hybrid power generation systems focusing on energy sustainability are listed in [7]. An interesting point is related to the multilevel control framework with additional supervisory level. This aims to make operational decisions for the entire subsystem within seconds to minutes' time frame. Causal, explicit and implicit supervision methodologies of hybrid RES based on storage systems are presented in [9]. A priority is given to implicit methodologies based on artificial intelligence tools like fuzzy logic [2,14,16] or multi-agent systems [5]. It is important to notice that a mix of these methodologies is generally optimal [13,15]. These methodologies are implemented to handle storage system control in order to improve the hybrid power system's energy efficiency. However, when considering only energy efficiency aspects in the energy management strategy, an economical viable solution cannot be ensured.

This paper proposes a supervision strategy based on multi-criteria approach including energetic, environmental and economic constraints. The energy management objectives such as reducing the network power demand, favoring local renewable consumption and ensuring the storage availability, are treated in different time levels. Economic aspects are integrated in predictive mode during the long term supervision. The real time supervision strategy is based on fuzzy logic (FL) approach and graphical methodology to build it. Then, the optimality of the energy management strategy is analyzed within an adapted optimization methodology. In this sense, experimental design and genetic algorithm (GA) are iteratively used in an optimization platform. Finally, simulation results are discussed within different scenarios and the reaction of the hybrid railway power substation is detailed. Initial and optimal solutions are compared within the simulation results and the influence of the optimization procedure on system supervision is outlined.

2. System description and specifications

2.1. Hybrid railway power substation system

The French railway network power supply for electrical traction is a particular system defined by two main voltage levels: 1.5 kV DC and 25 kV 50 Hz AC. For this study, a power flow configuration of the AC railway network was considered in order to analyze the possibility related to the minimization of the power grid consumption. Two generic architectures have been proposed in [8] to illustrate the interconnection between the electrical grid, the railway system and additional sources. The hybrid system composed of photovoltaic (PV) units, wind turbines and storage systems is DC-bus connected to the electrical power substation, allowing isolation mode if necessary. Fig. 1 shows the electrical configuration of the AC hybrid railway power substation (HRPS) studied in this paper. Some assumptions have been established. In order to integrate the fluctuating train consumption, we assume the variable P_{train} is representing the railway power consumption seen by the HRPS. Furthermore, the traction (consumer) and braking recovery (source)