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Methodology for technical and economic assessment of electric vehicles integration in distribution grid

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Highlights

- A generic methodology is proposed to control Electric Vehicles load.
- A method for obtaining high-performance of Fuzzy–Boolean algorithm was developed.
- The coordination between Electric Vehicles and Wind–Photovoltaic power is performed.
- A co-simulation tool assesses supervision algorithm impacts distribution grid.

Abstract

This paper proposes a methodology to design a supervision system (SS) based on Fuzzy and Boolean logics. In the first stage, a graphical modeling tool is used to facilitate the analysis and the determination of Fuzzy–Boolean algorithm linked to the test system. To improve the performance of the proposed SS a genetic algorithm (GA) is implemented in the second stage. The SS objective is used to control electric vehicles (EVs) load in order to minimize the energy transmission costs (ETC) of the distribution system operator (DSO). To achieve this goal, it is necessary to promote local consumption of wind and photovoltaic (PV) power by coordinating them with EVs load, maximize EVs charging during cheaper energy periods and reduce subscribed power exceeding. The performance of the SS is shown by numerical simulation results using Matlab/Simulink. Finally, a Matlab–PowerFactory co-simulation framework is proposed in order to assess supervision system influence on the technical aspects of a real test grid.

Keywords: Electric vehicles (EVs); Energy transmission costs (ETC); Fuzzy logic; Genetic algorithm (GA); Co-simulation framework

1. Introduction

Several studies have shown that an adequate control of EVs load can provide solutions to problems faced by utilities and especially faced by the Distribution System Operator (DSO) such as: reducing peak power and investment costs, minimizing losses and voltage drops or obtaining some financial profits [3,9,13]. Other studies have shown that EVs

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can be used as a suitable energy storage system to smooth the generated wind power and increase its flexibility to participate in the electricity market [1,11].

In this paper, it is proven that a suitable control of EVs load can minimize the DSO energy transmission costs bill. The proposed SS of EVs load is based on a Fuzzy–Boolean supervisor combined with a GA optimization method. Fuzzy logic control is a suitable tool to manage complex electrical power systems when it is difficult to find a mathematical model or to predict a generated wind/solar power, load consumptions, etc. [6,7]. It is known that fuzzy rules (FR) and membership functions (MFs) have a fundamental impact on the supervision system performance. Usually, the fuzzy rules are given by experts, while MFs are defined by the designer himself. Obviously, this method is more likely to be defective. To enhance the system performance, several studies proposed a GA optimization of fuzzy logic controller [4,14,18]. The aims of applications were to find an optimum trajectory for a truck back upper problem [14], to minimize DC-link voltage variations [4], and to improve the performance of an industrial process [18]. However in [4], the optimization problem assumed symmetrical trapezoidal and triangular MFs and in [18], it supposed an isosceles-triangle MFs. These hypotheses could have an impact on the system performance by preventing MFs full optimization.

In this study, a new method for obtaining high-performance fuzzy MFs was developed. This method uses real encoding in MFs parameters. Trapezoidal MFs are considered to represent the different states of the fuzzy logic supervisor inputs and outputs. Optimization does not take into account assumptions on MFs' shape because it may reduce the chance of finding the best performance of the test system. Furthermore, the optimization problem includes other deterministic parameters related to the system supervision response. Finally, a co-simulation interface is proposed to combine and to coordinate load flow calculation of a power distribution grid together with the simulation of developed SS model. The simulation of the SS system is executed in Matlab/Simulink software, whereas the grid simulation is carried out in PowerFactory software.

This paper is organized as follows: first, in Section 2, a probabilistic model of EVs load is presented. Then, in Section 3, the energy transmission cost function is described. After that, the development of the supervision system methodology is detailed in Section 4. It consists of designing and optimizing the supervision system, and, the performance is shown using numerical simulation results. In Section 5, the impact of the proposed supervision system is evaluated through a co-simulation framework. Finally, conclusions and perspectives are presented in Section 6.

2. Probabilistic EVs load model

This part aims to identify the EVs load profile by considering technical specifications and traffic pattern. To model the energy requirements of the EVs fleet, deterministic and probabilistic parameters defining an EV charging process are taken into account [10]:

- *Charging mode*: from an application standpoint, the normal charging mode (16A/230 V – 3.7 kVA) is the most common one. It has particular relevance to the main parking zones (home, workplace, etc.) where vehicles are parked for a long time. It may provide the majority of EV energy needs according to the first experiments [15].
- *Battery consumption*: "Lithium-ion" has a good performance in terms of energy and power density compared to other batteries. It fits out the majority of EVs/Plug-in Hybrid Electrics Vehicles (PHEVs). In addition, based on a study presented in [15], the average battery (A_{BC}) consumption of an EV/PHEV is estimated at 0.18 kWh/km.
- *Charging losses*: energy loss conversion consists of two main sections: AC/DC and electrochemical conversion. They represent approximately 10% of the total energy demand [10].
- *Penetration level*: according to French forecast scenarios, the EVs/PHEVs market will hold 6%–7% in 2020 and 15% of automotive market in 2030.
- *Daily travel distance*: as reported by INSEE (National Institute of Statistics and Economic Studies), the average distance between the two sites in suburban and rural areas is around 30–35 km. It represents a distance between two successive charging cycles during weekdays. For weekends, EV mobility is reduced and users tend to travel longer distances at different hours during the day. Due to a lack of experimental data, weekend profiles will remain the same as weekdays' [12].
- *Commuting times*: based on the traffic habits of the Deux-Sèvres region in France, during working days, it is found that the majority of French people arrive at their workplace around 8:30 and return home usually at around 18:30 [12]. In this study, it is considered a fleet of vehicles which are commuting regularly between home and work during working days.