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Electric vehicle models for evaluating the security of supply

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ABSTRACT

The future large-scale deployment of electric vehicles (EV) will not only have impact on load growth, but also create opportunities for the electricity sector. Generally, the current methods for security of supply long-term evaluation do not include this new type of load. While the electric components of the generating systems are usually modelled by the Markov process, this paper presents, as its major contribution, an EV model based on the Nonhomogeneous Poisson process, which has been developed in order to better represent the motorized citizen mobility and the EV opportunity to release spinning reserve to electric systems. The simulation procedure lies in combining both Poisson and Markov processes into a sequential Monte Carlo simulation (SMCS) to measure the impact of EV when evaluating the adequacy of generating systems. This evaluation is divided into two complementary concepts: static reserve (generating capacity reserve) and operating capacity reserve. The proposed models are analyzed using a modified version of the IEEE RTS-96 including renewable sources.

1. Introduction

The gradual replacement of internal combustion engine (ICE) vehicles by EV will have impact on the system load growth in the years to come. Furthermore, the requirements from this new load should be covered by ordinary actions linked to the expansion planning of the generation, transmission and distribution systems. Moreover, the large-scale integration of EV in the electric systems may provide new opportunities for the electricity sector. For instance, the possibility of increasing the use of renewable energy sources (RES), as a result of EV integration, makes the generating systems more sustainable.

Two opportunities could be exploited from the generating system point of view, assuming a large-scale deployment of EV, considering them as a component of the electric system. First, the EV is seen as an aggregated load which could be controlled or even moved from one hour to another, stimulating demand side management and/or taking advantage of charging interruption.

This situation could be viewed as a practical scheme in a few years' time. Second, EV could be exploited for vehicle-to-grid (V2G) power injection which takes into account the possibility of having a large amount of EV injecting the electric power stored in their batteries into the grid. Although V2G support has been discussed in the literature [1,2], this situation will not be addressed in this paper.

In recent years, the expansion of the generating system is conducted by market forces, however, these decisions require studies involving the monitoring of security of supply evaluation. The impact of EV will depend mainly on the charging behaviour, which in turn depends on how citizens travel around (mobility behaviour), on the willingness of EV drivers to participate in the management of the grid and on the regulatory aspects, such as the monetary incentives that could be provided by the government and/or electricity companies (charging strategies).

Several studies about the impact of EV in the electric systems have been made, but most of them lie in the distribution system level. Only a handful of studies could be found considering the impact of EV in the generating/composite systems. While in [3] is showed that an adequate charging strategy could support the reduction of CO_2 emissions and increase the expected deployment of EV, and in [4] is presented a study based on the EV impact on the generation mix and transmission network highlighting some aspects such as the increase in natural gas generation and the reduction of the coal-fired generation imports [5] observes that even considering a significant EV penetration scenario it does not have significant impact on its power system operation and on a fossil fuel consumption, on the other hand, from the economic perspective, energy cost and CO_2 reductions are the main benefits.

The benefits of cost and CO_2 reductions due to the large-scale deployment of EV are also presented in [6]. In [7] is proposed a method of examining the impact of plug-in hybrid electric

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vehicles (PHEV) on composite power systems. In [8] is proposed a probabilistic constrained load flow method considering the EV deployment. In [9] is presented an optimization method to improve the daily system load profile through the optimal distributed EV charging load. The impact of EV on a national power demand level is evaluated in [10] where the authors proposed a stochastic model of power demand due to EV.

This paper follows a different point of view introduced in [11], the general idea is to evaluate the impact of EV on security of supply on the long-term perspective. This will make it possible to simulate different scenarios of EV obtaining suitable risk indices which will measure the security of supply of the future generating systems. This methodology extends the current techniques to assess security of supply, through reliability evaluation of the generating systems, considering the uncertainties related to the intermittent characteristics of the current RES [12–16].

Here, the reliability evaluation of generating systems is divided into two complementary concepts: static reserve which means generating capacity reserve (GCR) and operating capacity reserve (OCR) evaluation. Refs. [15,16] address the OCR evaluation in the long-term perspective considering a significant use of RES, mainly wind power.

The main idea of this paper is to present an EV model based on the Nonhomogeneous Poisson Process (NHPP), to be included in the long-term OCR evaluation method. This model aims to better represent the citizens' mobility behaviour in order to analyze the EV impact on the probabilistic evaluation of the generating system adequacy studies.

Section 2 presents the EV models which were incorporated in the SMCS method in order to perform the generation system reliability evaluation, presented in Section 3. Section 4 describes the test system, Section 5 discusses the simulation results and Section 6 presents the conclusions.

2. Electric mobility models

The lack of real data related to EV charging, leads the issue of addressing EV impact on the monitoring of security of supply problem to the use of probabilistic methods which may use real mobility statistical data. The purpose of the mobility models is to estimate the number of EV which proceeds to battery charging based on an arrival distribution according to the mobility patterns of the motorized population. The data used was obtained through a statistical study performed by the National Statistics Institute (INE – Instituto Nacional de Estatística) in Portugal [17]. Then, it is important to highlight that in this paper it is assumed that the use of EV will not change the current mobility patterns, such as: departure time from home, work/school arrival time and return time to home.

As an electric system component, the EV could be understood as a flexible load with their own particular characteristic of lacking any predictable order for battery charging, however, this stochastic feature, where arrivals occur completely random in time, is only true for Poisson arrivals and is called PASTA property (Poisson Arrivals See Time Averages) [18], and a rigorous proof of this property can be found in [19].

From the mobility pattern, the first model is based on the Poisson process (PP) [20] which is a stochastic process that only counts the number of events (arrivals) based on the rate parameter λ for a fixed time period, and represents the expected number of events that occur per hour.

The second model aims at analysing the continuous EV load variation for a time period considering that the EV remaining time, in battery charging mode, follows an exponential distribution [20] and its rate parameter is time dependent given by $\lambda(t)$. This model is based on the NHPP and may be useful to assess possible ramping events caused by EV charging requirements as well as to represent the battery state of charge (SOC) and the remaining time in charging mode for each arrival event.

Fig. 1(a) shows the constant arrival events aggregated in an hourly resolution while in Fig. 1(b) the arrivals are continuously and randomly. Both models are based on the same input data (as seen in Fig. 1), the difference lies, mainly, on how the counting process is calculated which is addressed in Sections 2.1 and 2.2. Therefore, the EV arrivals represent stochastic processes regarding different time resolutions, as shown in Figs. 3 and 4.

A stochastic process $\{N(t), t \geq 0\}$ with λ rate is said to be a counting process if $N(t)$ represents the total number of events that have occurred up to time t [21]. The principle behind these proposed models considers, for instance, that cars arrive at different charging points at random moments of the day in accordance to a Poisson distribution with λ rate. It is also considered that each arrival would correspond either to different types of events, where the EV needs to connect to the grid and proceed to battery charging or to a type of event where the EV does not need to proceed to battery charging. Both types of events may be viewed as a Poisson process.

2.1. Electric vehicle model using the Poisson process

This first approach of EV modelling can be found in detail in [11], however, for the better understanding of the reader, the main characteristics will be summarized here.

The arrival probability distribution of the INE survey provides the desirable information on the λ parameter, given in Fig. 2 for a typical weekday. This input is used to estimate the number of arrivals, which proceed to battery charging, as a random variable at each hour t of the simulated year. Fig. 2 represents the hourly

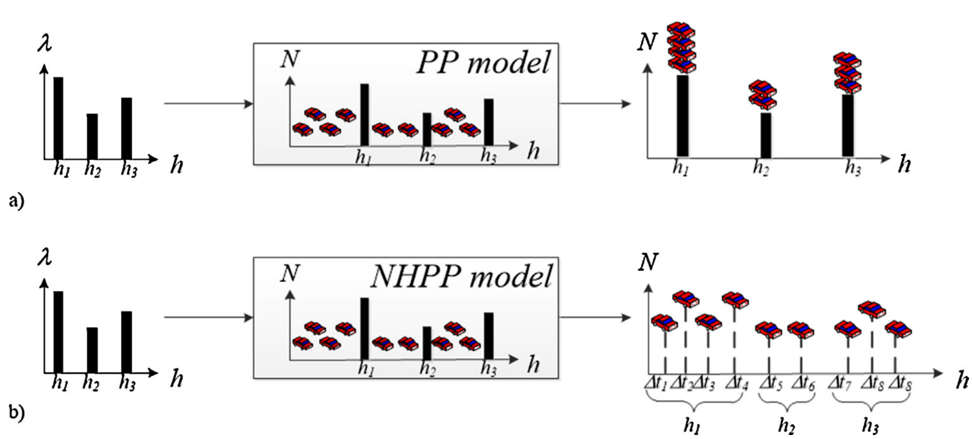

Fig. 1. Concepts of the EV models.