MODEL FOR THE EVALUATION OF THE IMPACT OF ELECTRIC VEHICLE INTEGRATION ON THE ADEQUACY OF GENERATING SYSTEMS

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Abstract. The present study evaluates the adequacy of the Portuguese generating system under different scenarios of battery electric vehicle penetration and recharging conditions. The Portuguese mobility pattern and a modified version of the IEEE Reliability Test System 1996 are used in the analyses. In the worst scenario of EV integration considered, the loss of load expectation index is increased from 0.3449 hour/year to 5.22963 hour/year. However, it is shown that, if adequate recharging criterion is used, the increase in the LOLE index can be significantly mitigated.

Key-words: *Electric Vehicles, Recharging Conditions, Adequacy.*

1. INTRODUCTION

Electric vehicles (EVs) can be categorized based on the vehicle hybridization rate. Today, there are three main types of EVs, according to Young et al. [1] and Tie et al. [2]: hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs).

Ref. [1] and Ref. [2] say the HEVs propel through a combination of internal combustion engine and an electric motor. HEVs generally have a low capacity battery, which is charged by a system of regenerative braking or by the internal combustion engine. These EVs cannot be recharged from the distribution grid. As the HEVs, the PHEVs have an internal combustion engine and an electric motor. However, a PHEV can recharge its battery pack with energy from the distribution grid. On the other hand, the BEVs are electric vehicles that are solely propel by an electric motor.

According to the International Energy Agency [3], 2.5 million EVs were sold across the world by the beginning of 2011. In the same period, the EVs reached a market share of 2% in the USA and 9% in Japan. Ref. [3] estimates that by 2020 the BEVs and PHEVs sold worldwide each year will be about 2.5 million and 5 million EVs, respectively.

The rapidly growth of the EV market presents a challenge to the adequacy of the generating systems, which will have to cope with an increasing peak load and introduction of more load uncertainty.

2. ASSESSMENT METHOD

The electrical system used in this study was a modified version of the IEEE Reliability Test System 1996 that accounts for the increasing presence of renewable energy in the generating system. Leite da Silva et al. [4] details the electrical system used in this study.

Furthermore, the electrical system used here is similar in size to the Portuguese electrical system.

The following sections detail the modelling of the EVs, charging parameters and mobility patterns.

2.1 BEV penetration and charging parameters

This study considers three levels of BEV penetration, namely low, moderate and high penetration for the year 2030, according to Hasset et al. [5]. In the low penetration scenario, BEVs replaced 2.64% of internal combustion engine (ICE) vehicles, which corresponds to 209,254 vehicles. In the moderate and the high penetration scenarios, the number of BEV were 446,700 and 870,955, respectively. Moreover, the battery capacity of the BEVs used in this study was 30 kWh and the BEV efficiency was 6.0 km/kWh, according to the BEV efficiency reported by Ref. [3].

It is assumed that the BEVs will recharge as soon as they arrive home if the recharging criterion is met. Taylor et al. [6] and Yilmaz et al. [7] describe the EV home charging levels. At home, BEVs can recharge at the levels 1 or 2. Level 2 charging requires from 4 kW to 19.2 kW of power from the grid, while Level 1 maximum charging power is 1.9 kW. In this study, each BEV will require 4 kW from the grid. Moreover, based on Sears et al. [8], the charger efficiency is assumed to be 90%.

2.2 Mobility pattern

Azevedo [9] used data from vehicle inspections in Portugal to develop a method for estimating the national traffic volume. Among other results, Ref. [9] synthesized the 2004 daily driving distance probability distribution of light-duty vehicles in Figure 01:

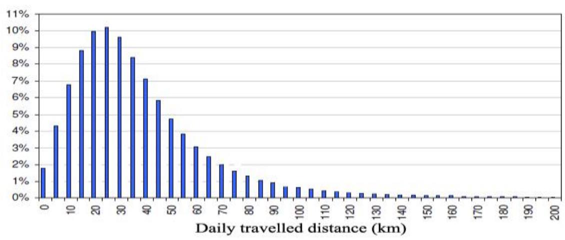

Figure 01 - Daily travelled distance distribution

Then, in order to find a probability density distribution that reflects the Portuguese driving behaviour, the probability distribution curve found by Ref. [9] was here approximated by a gamma probability distribution. The MatLab distribution-fitting tool was used to find the parameters of the gamma distribution. The parameters found were a scale factor of 17.6404 and a shape fact of 2.2836, which give an average daily travelled distance of about 40 km.

The probability density distribution of the home arrival time and departure of light-duty vehicles, demonstrated in Figure 02, in used in this study was obtained from a national mobility pattern survey conducted by the Portuguese National Institute of Statistics [10].

Furthermore, it is considered that, regardless the level of EV integration Portugal, the driving behaviour of the Portuguese population will not be affected.

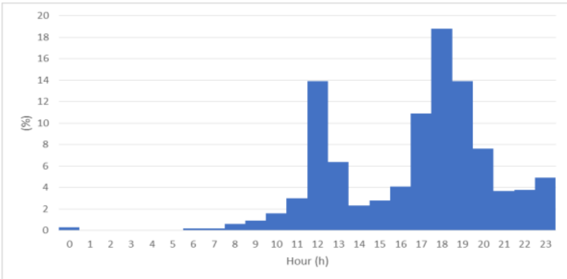

Figure 02 - Probability density distribution of the home arrival time of light-duty vehicles in Portugal

2.3 Computational model

Firstly, it was assumed that a BEV could be in one of three modes: (1) discharging mode, (2) charging mode and (3) connected mode. In mode (1), the BEV is on the road and its battery pack is being depleted. In modes (2) and (3), the BEV is connected to the grid at home, but the BEV is charging only when it is in mode (2). In mode (3), the BEV is connected to the grid but they do not exchange energy.

Three scenarios of recharging criteria were considered. The first one, scenario A, is the scenario where the BEVs proceed to recharge as soon as they arrive home. The second scenario, B, considers that the BEVs will start charging when they arrive home only if their battery's state-of-charge (SOC) at that time is below a 50% level. Finally, similar to the second scenario, in the third scenario, C, the BEVs will start recharging only if their present SOC is below the necessary SOC to propel the BEV through the driven distance assigned to them in the next day.

In the three scenarios, the recharge happens when the BEV arrives home, regardless of the well-being of the generating system. This recharging strategy is known as dumb recharging strategy.

The home arrival time, the departure time and the daily driven distance distributions, along with the BEV and the charging parameters were used to generate a profile of the percentage of BEVs charging during each hour of the day.

This hourly distribution was obtained after simulating the charging behaviour of a 10,000 BEVs in a 10-year period.

In this simulation, each day a driven distance and a departure time were assigned to each BEV by sampling those variables from their respective probability density distributions. The departure time must happen after the previous last hour that the BEV was connected to the grid. Similarly, a home arrival time was sample from its probability distribution, taking into consideration the previous departure time.

The methodology used in this study to sample values from their probability density distributions carries the following steps:

1. Sample an abscissa value, x, using the uniformly distributed numbers generator developed by Bremermann [11];
2. Sample an ordinate value, y, from the range [0, 1) using the previous methodology;
3. Get the probability g(x) from the probability distribution function;
4. Check if g(x) is equal or less than y;
5. If step 4 is true, define x as the distance travelled by the EV or as the home arrival time and go to step 7;
6. If step 4 is false, go back to step 1;
7. End of the methodology.

Subsequently, a yearly profile of charging behaviour for each BEV was obtained. Then, after calculating how many BEVs were charging during each hour of the year, an average number of the BEVs charging during each hour of a day was evaluated. The same steps were followed for all 10 years and the final average for each hour was the average of the 10 years.

It was necessary to obtain this charging distribution before the adequacy evaluation due to restrictions in computer processing capacity.

Then, the BEV power demand was estimated by sampling the number of BEVs charging during each hour of a year from the charging distribution previously calculated. This process was carried for every year of the adequacy simulation.

Therefore, it was possible to efficiently simulate the integration of a large-scale penetration of BEVs in the test systems used in this study.

3. RESULTS AND DISCUSSION

The generation adequacy index used was the loss of load expectation index (LOLE). The LOLE is described by Billinton et al. [12] as the expected mean time for which the system load is greater the system generating capacity, the index is given in hour/year.

Leite da Silva et al. [4] estimates that the LOLE for the modified RTS-96 test system is 0.3449 hours/year, under the scenario of no EVs integration.

Table 01 shows the LOLE for the three BEV penetration levels considered here, low, moderate and high, and for the three recharging criteria.

Table 01. LOLE under different recharging conditions and different BEV penetration.

Recharging condition	Low Penetration	Moderate Penetration	High Penetration
A	0.556053	1.19654	5.22963
B	0.48428	0.792704	1.99495
C	0.481319	0.841654	2.21221

The LOLE index is higher when there is lack of recharging criteria. The worst case is under recharging condition A, where the BEV starts recharging as soon as it arrives home. In B, the most restrictive condition, the LOLE is significantly lower than in recharging conditions A and C.

The results show that under certain recharging conditions, the impact of large BEV integration into the power system used in this study can be greatly reduced. However, despite the benefits of applying recharging criteria, it is noted that the large-scale integration BEVs into the power system will require investments in infrastructure in order to maintain acceptable levels of adequacy.

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