

## EVALUATION OF THE LONG-TERM IMPACT OF EV DEVELOPMENT ON FRENCH DISTRIBUTION NETWORKS: TECHNICAL CHARACTERIZATION AND INTEGRATION COSTS EVALUATION

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### ABSTRACT

*For distribution networks, taking into account electric vehicles' charging will directly lead to grid investment needs in order to create new connection infrastructures but will also imply investments to reinforce existing networks when necessary [1]. In order to assess these potential long-term technical and financial impacts, Enedis decided in 2014 to start working on a study methodology and on a dedicated set of hypotheses to conduct specific analysis. The goal of this paper is to present the status of this work as of today. It will in particular focus on the methodology developed to evaluate network impacts of charging points connected to LV networks.*

*Two major issues were in particular addressed for conducting this work:*

- *Finding a suitable model to integrate mobile loads (electric vehicles) in electrical network studies and taking into account associated existing uncertainties.*
- *Taking into consideration the large heterogeneity of French LV and MV networks.*

*The approach proposed to address these points will thus be described here. Main results of these analysis will also be mentioned.*

### INTRODUCTION

In France, at the end of September 2018, around 170 000 Electric Vehicles (EVs) including Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) were registered [2]. Stimulated by French and European regulation and by a growing collective environmental awareness, electromobility is expected to grow significantly in the coming decades, generating new challenges for the electrical system and for distribution networks [3]. To ensure the development of electromobility in the best possible way and at the lowest price for all customers, Enedis is thus conducting long term studies to anticipate technical and financial impacts on distribution networks. In particular, a characterization of reinforcement needs of existing networks has been made. Conclusions of this study has then especially been used to realize a more global evaluation of EV integration costs including investments for reinforcement but also for connection infrastructures.

Work presented in this paper focus on the methodology developed for this analysis and aims at describing the approach proposed to address the specific challenges of this new type of studies.

### CONTEXTUAL ELEMENTS

#### Framework of this analysis

The analysis detailed in this paper focused on light and light-duty vehicles. Models for electric buses, coaches and trucks will be designed for future studies as technologies and charging modes appear more precisely. Two-wheeled vehicles such as bicycles and motorcycles have also been left aside for now since their impact on electrical network is presumed to be globally modest in comparison with those of the types of vehicles mentioned above.

Furthermore, perception of the way vehicles are used has been supposed close to today's mobility characteristics and disruptive displacement modes (related to the development of autonomous vehicles for example) have not yet been taken into account.

#### Specific challenges

Since vehicles are mobile by nature, the analysis of the impact of EVs on distribution networks presents unique features. Two aspects need in particular to be determined to address this issue:

- Where BEVs and PHEVs are going to charge? More precisely, where charging points will be located on each MV and LV networks and what will be the characteristics of these charging points?
- What does consumption at charging points look like? This question naturally raises the issue of the behaviour of the drivers of electric vehicles.

These points are particularly intricate because strong uncertainties exist. It is thus necessary to develop a dedicated methodology which can take them into account. This is one of the goal of our work. The second challenge tackled here is related to the large heterogeneity of French LV and MV networks. Network impact is indeed local and could be very different from one network to another. Therefore, simulations must be conducted on a large number of networks which increases the complexity of the problem.

### STUDIES PRINCIPLES

#### Input data

Several prospective scenarios have been designed by Enedis to represent different possible futures according to criteria such as environmental awareness or economic and

demographic growth [4]. Studies conducted are based on a median scenario which estimates globally a total number of BEVs and PHEVs in France in 2035 around 9 million. This scenario also gives projections at a local scale for the 35 000 French municipalities. For each of them, probabilities determined for different densities of territory allow to divide the matching number of BEVs and PHEVs into 3 categories: private vehicles, company cars and cars dedicated to shared mobility (car-sharing, taxi services...). Since these categories of cars answer to different purposes, they will not necessarily charge on the same type of charging points. Four types of charging points were thus defined [2]: “residential”, “at workplace”, “dedicated to shared mobility” and “public”. For instance, a private vehicle could charge from case-to-case at home, at work or at a public charging point. Probabilities were also formulated to allocate to one vehicle of each category a fraction of charging points of the four types mentioned above. Those probabilities are different according to the density of territory. For instance, for each private vehicle on rural areas, one charging point was modelled at home but small fractions of charging points at work and at public places were also taken into account.

On a global scale, the set of hypotheses realized led to an estimation of 11.5 million charging points in France in 2035 with the following repartition:

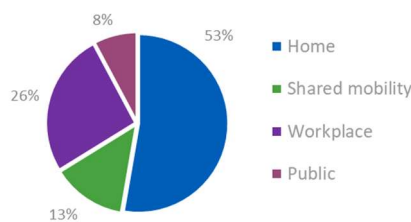


Figure 1: Repartition by type of the 11.5 million charging points for the chosen scenario

### Analysis description

Once a number of charging points of each type has been established by municipality, uncertainties on location on distribution networks, rated power and use of those charging points had to be managed before starting simulations. A set of hypotheses were then formed and a dedicated methodology developed. It is proposed here to focus on the work realized on charging points connected to LV networks. Charging points connected directly to MV networks have been studied with different approaches. This last aspect will not be detailed here but associated main global results will be displayed.

## **FOCUS ON THE METHODOLOGY TO EVALUATE REINFORCEMENT NEEDS FOR CHARGING POINTS CONNECTED TO LV NETWORKS**

### Elaboration of a set of hypotheses

To conduct analysis, four attributes had to be characterized with their uncertainties for each type of charging points:

- Possible locations on distribution networks. Firstly, possible locations on LV networks for this type of charging points were defined (for example, charging points “at workplace” are integrated into existing network models at professional clients’ level). For each family of possible locations, a probability of presence at a given location for this type of charging points was then evaluated for each French LV network by using the number of charging points of this type of the matching municipality. To this end, its charging points of this type were “divided” into every corresponding LV networks according to several parameters like their respective numbers of residential or professional clients. These parameters are of course different from one type of charging points to another.
- Rated power. Charging points’ rated power were defined by assuming vehicles charge at maximum rated power. Thus, charging levels defined are closer to the assumed power capacities of charge of vehicles than to advertised powers of charging points. Public charging points left aside, three rated powers were modelled [2]: 3.7 kVA, 7.4 kVA and 22 kVA. For each type of charging points, probabilities of belonging to one of the configuration described above were also defined to take into account multiple situations on electrical networks.
- Connection’s starting hours. This parameter is declined here as specifications for each hour of the day of probabilities of connection of a vehicle for the relevant categories of vehicles. These probabilities are of course quite different from one type of charging points to another. An illustration of a profile characterizing connection’s starting hours is presented below:

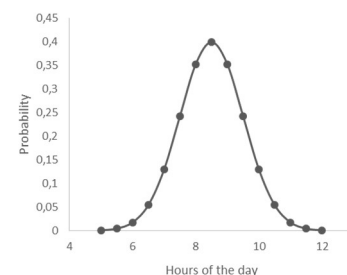


Figure 2: Probability distribution of connection’s starting hours for private cars at work

For residential charging points in particular, three charging scenarios were also defined: unmanaged charging, off-peak hours<sup>1</sup> charging and off-peak hours charging with a 3-hour offset with boilers' start. This last scenario more globally aims at giving a first evaluation of the impact of an optimisation of charge overnight [4].

- Daily connection frequency and energy charged for each category of vehicles using this type of charging points. For instance, we used a mean frequency of connection at home of less than once a day whereas on a charging point dedicated to shared mobility, this mean frequency was well above once a day (especially on urban areas). Mean connection frequencies were evaluated using a model of displacements for each category of vehicles. We could note here that the average daily travel distance considered for this model was quite different from one category of vehicles to another and was distinct between rural and urban areas [6]. Energy to charge at each connection was directly linked to these parameters (for instance, if a private car is connected at home three days after its last connection which was also at home, energy charged is globally equal to the need of three times its average daily travel distance). A mean factor of 20 kWh per 100 km was used for calculation to integrate to our model vehicles' energy consumption and global efficiency [7]. Here the batteries of the vehicles are considered full at the end of each connection.

These elements are the foundation of the methodology implemented for the analysis described in this paper.

### Evaluation of network constraints

To understand the methodology built to analyse the impact of the integration of BEVs and PHEVs connected to LV networks, it seems necessary to give first a few elements on how LV calculations are run for French distribution

networks [8].

In France, network planning is based on a defined risk level. For LV calculation, this aspect is taken into account starting from load model. A specific algorithm is then used to evaluate feeders and substations constraints. More precisely, load profiles are divided into two parts for each hourly step: the first one represents the mean power and the second one the variance of the demand so that the summation of the two components equals the maximum load consumption with a 10 % risk. To determine resulting power on every network elements, a diversity factor is then taken into account to combine the variances of the loads. For our simulations, EVs' consumption profiles at charging points were thus designed to match existing network planning methodology. Uncertainties on connection's starting hours, daily connection frequencies and energies charged were taken into account during the creation of these profiles. Therefore, Monte Carlo simulations were run to simulate EV drivers' behaviours. Around 30 profiles were then produced for the different type of charging points, rated powers, charging scenarios and densities of territory defined. Like traditional loads, those profiles are composed of a mean part and of a part which represents the statistical variability of the power demand. The figure 3 outlines the main principles of their elaboration.

As specified above, since French distribution networks can be extremely different among themselves, the impact of a significant development of EVs on networks constraints needed to be evaluated on every LV and MV networks. Thus, for every primary substations, all matching LV networks were taken into account. Then, for each of these networks, 10 Monte Carlo simulations were realized using the probabilities defined above to allocate charging points of each type with their associated rated power at different locations of these networks. Since 3 charging scenarios for residential charging points were also considered, 30 calculations were realized for each French LV and MV networks. Dedicated scripts developed by Enedis on the PowerFactory software environment [9] and parallel computation were used to this end.

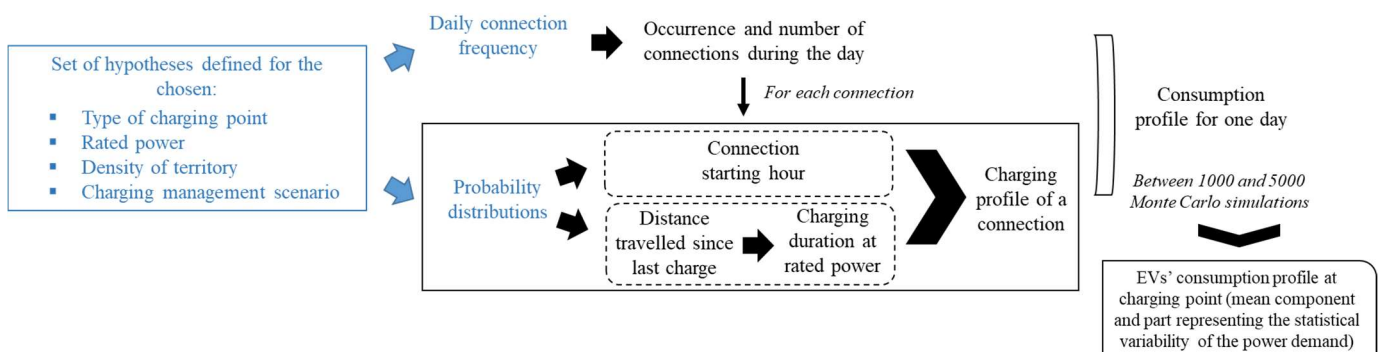


Figure 3: Methodology of elaboration of a charging point's consumption profile according to its type and rated power, the density of territory and the charging management scenario chosen

<sup>1</sup> In France, off-peak hours are defined at a local scale by the DSO to limit network constraints [5].

Firstly, network calculations were conducted without integrating EVs to establish a reference. Then network constraints evaluated thanks to the simulations described above were referenced. They were analysed according to the type of elements in constraint (LV and MV feeders, primary and secondary substations) but also according to different densities of territory.

The graph below displays a graphical view of our methodology:

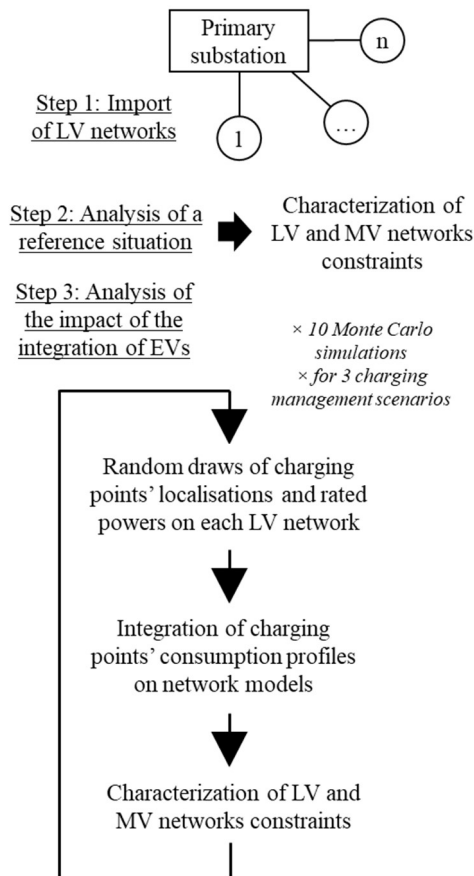


Figure 4: Methodology of characterization of networks constraints due to the integration of EVs

Costs for LV feeders reinforcements and for upgrades or creations of secondary substations were applied afterward to establish the cost of LV reinforcements due to the integration of EVs for the scenario studied.

## MAIN RESULTS AND CONCLUSIONS

This work has already produced a set of results. Analysis detailed here led for example to an estimation of LV reinforcement costs around 1 billion euros for the integration of 9 million BEVs and PHEVs. Studies also showed that a perfect shift during off-peak hours of personal vehicle charging at home could allow a 25 % reduction of this cost. This figure could go up 40 % according to our results if a further optimisation was implemented overnight for personal vehicles charging at

home (for example with a 3-hour offset).

EVs' consumption profiles at charging points and hypotheses designed were also used to give at first an overview of the capacity demand due to EVs at national peak hour. At a global scale, charging management scenarios studied here lead to a division by a factor of 6 of this parameter.

As mentioned earlier, estimation of LV networks reinforcement costs was part of a more global evaluation of EVs' integration costs which will not be described in this paper. Detailed results allowed to understand the contribution to these costs (including the parts related to network reinforcement and to connection infrastructure) of the different type of mobility usages. This analysis also highlighted the opportunity to reduce by more than 30 % these costs with simple charging management system. In absolute terms, we can mention that this impact is far more significant for connection infrastructures costs than for reinforcement costs.

Conclusions of these studies have led in France to the elaboration of several recommendations in order to anticipate and to support the development of electromobility from the distribution network side ([10]).

## PERSPECTIVES

As electromobility is still in its early stages, it is essential to pursue the work initiated on this subject and to improve the existing approach presented here. Firstly, future work will include the update of the set of hypotheses used to take into account the most recent assessments of the electromobility sector. For instance, as battery technologies improve, the average daily charging frequency may decrease. The evaluation of the impact on distribution networks of high power charging (electric buses, fast charging infrastructures on motorways...) will also be one of the main subject of our future analysis.

In addition, our work is today focused on the improvement of our study methodologies. Development of a new methodology to evaluate network constraints for charging points connected to LV networks is in particular in a well-advanced state. It aims at increasing the accuracy of the results and at reducing computation time.

### Overview of the new methodology

The purpose of this new methodology is to avoid using Monte Carlo simulations to take into account the uncertainties in the location and rated power of the charging points. The Monte Carlo method implies indeed to run multiple simulations for the same network, these two uncertain parameters being fixed in each simulation. A correct overview of the different constraints that may happen is obtained when the number of simulations is high, so this method is costly in terms of computation time. The principle of the new methodology is to integrate these uncertainties both in the consumption profiles (different

from the ones used in the main study presented here since they integrate uncertainties on consumption but also on location and rated power) and in the network electrical computation, so that only one simulation is required, which will give all the constraints that may happen at a certain level of risk. This principle is comparable to the algorithm used by Enedis for LV planning, but adapted to the specificities of EV (especially the defined power levels and location uncertainties).

More precisely, for each type of possible charging site, a consumption profile is created by using the different uncertainties and their associated probabilities to determine the different possible load curves (EV consumption only) for these sites, each load curve having a certain probability. From these we can derive, for each hourly step, the probability that this site consumes a given power level.

These data are used in the electrical computation. Like the algorithm used for traditional loads, this computation is not a proper load-flow, as it does not represent a realistic configuration of the network. Instead, we compute for each network element, the situation at a given level of risk. For each line, we search all the possible charging sites downward of this line, and using the probabilities mentioned before, we compute the “upper” power flow due to EVs at a certain level of risk. This power flow is then added to the power flow due to clients’ consumption outside EVs, and finally the voltage variations are computed. The following figure gives a simplified example of how the EV power flow in each line depends on the number of possible sites downward.

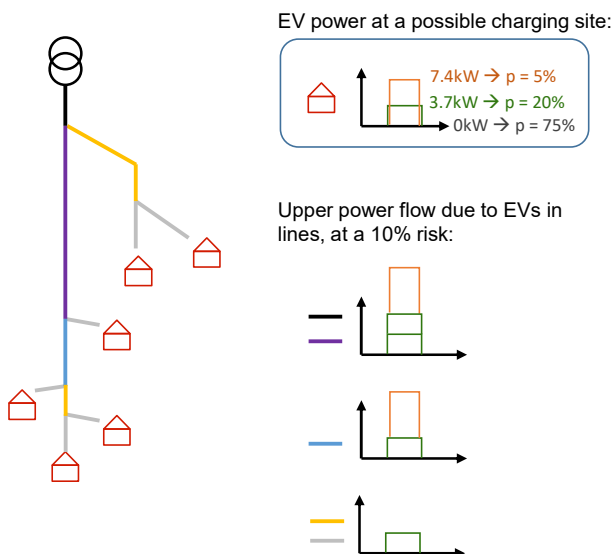


Figure 5: example of EV power flow at a given level of risk. Each small house is a possible charging site, which parameters are defined in the top-right corner. Each color of line corresponds to a certain number of downward sites.

This methodology has been tested in comparison to Monte Carlo simulations. For each network element, we compared the constraints (current and voltage drop)

obtained at a risk level of 10% with the distribution of the same constraints obtained from the Monte Carlo simulations. It showed that the results from the new methodology were very close to the 90<sup>th</sup> percentile of the Monte Carlo distribution, proving the accuracy of this approach.

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