Study on the Potential of EV Smart Charging Aggregation for providing flexibility services for the Smart Grid and Electricity Markets

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Abstract With the great development of electric vehicles and the growing research on the potential benefits that new entrants can bring, both in terms of applications for the smart grid and grid control, it is essential and urgent to resort to an intelligent charging forecasting for direct control and the indirect charging of electric vehicles (EVs). There are already some examples of charging forecasting processes and load control by medium and large enterprises, where the concept Synthetic Reserve arises. The charging forecasting process has to identify those responsible for regulating and connect to the grid, allowing the distribution network operator to respond more effectively to the requirements of the electricity networks and users of such vehicles. Thus, in this dissertation, known parameters like: power requested/provided to the vehicle, charging station location and duration of the charging are used in order to develop an effective method of charging cut. This reduction is intended to respond to load peaks that may occur at certain times of day where power demand may not be satisfied. The latter this method analyzes the EV users from both energy distributor point of view and user point of view (satisfaction and charging speed), trying to understand the best way to meet the demands (control signals) of the smart grid, quickly and in real time. For this, the parameters that influence the cut error in the EV charging are studied through the development, implementation and testing of various methods that can make the error insensitive (in relation to demand requirements). Seven different approaches for EV charging cut are presented, being the method of cutting according to the power outlet's charging history (type curve) the most favorable, optimized for the number of users in Portugal. Such result comes to sustain the focus on flexibility, intelligent charging forecasting, intelligent charging control of EV and its impact on the grid as well as for all its stakeholders.

Index Terms— Flexibility, Customer Energy Manager, State-of-Charge (SOC), Distribution System Operators.

I. INTRODUCTION

In liberalized power systems, different tasks regarding the planning and operation of the power system concern different actors. The flexibility of EV charging (as explained in detail below) also concerns the contribution of several actors. Distribution System Operators (DSOs), for example, have interest in controlling the EV charging process since one of their main tasks is to manage load and guarantee stability. On the other hand, retailers, who buy electricity on wholesale markets, could benefit from lower off-peak wholesale prices if they can postpone EV charging to low price periods. Yet another perspective arises if one considers adjusting EV charging power with regard to the variable output of renewable energy sources.

A new concept has recently emerged, Synthetic Reserve, and with it several variants: Synthetic Frequency Response Reserves, Synthetic Regulating Reserves and Synthetic Ramping Reserves, all of them present in the document [1]. Some renewable energy generators do not have the necessary capacity control to meet the requirements of system frequency regulation. Thus arises the concept Synthetic Frequency Response Reserves in which there is a partial participation of loads in response to system frequency disturbances, a fully automated program that would not cause noticeable changes in most settings. Applications in this area could target technologies that can allow sensitive loads or DRGs to provide any booking service that allows the system to handle the short-term variability in the output of VERs. Regarding the Synthetic Regulating Reserves concept, its basis is the same as that of the Synthetic Reserve concept and it can be applied to various fields such as methods and architectures to optimally schedule and control local energy resources (with flexible loads, distributed generation and storage) at the level of home, weather forecast, and grid reserve. Lastly, the concept Synthetic Ramping Reserves focuses on the technologies that enable responsive loads or DRGs to provide any type of reserve service that enables a system with high penetrations of VERs to better follow high netload ramp rates.

The exponential increase of EV owners coupled with the considerable technological development (both in terms of software and hardware) translates to an opportunity to improve the supply of charging services. If we add the possibility of having access to information taken from EV owners and combine it with the best business scenarios and grid behavior of DSO it becomes necessary to create new services, flexibility and demand control. Hence, there are still many concepts, strategies and organizations to be defined.

I. FUTURE OF THE ELECTRICAL GRID

It is important to understand what the role of the DSO is in the electrical grid. DSOs are responsible for the distribution networks and, since they form a natural monopoly in their core business, their activities are regulated. Some variations in the form of regulation are possible, but generally this means that the competition authority determines the change in tariffs that the DSO is allowed to charge its customers (for a certain period of time), referred to as the regulatory
period. Another actor that is truly important on the electrical grid is the Aggregator. As previously mentioned, an EV aggregator is the commercial middleman between drivers, transmission system operator (TSO), distribution system operator (DSO) and the electricity market (with supply and demand energy bids - application vs response, bidding). Representing also a number of EV owners has the task to charge the EVs while taking into account the driving patterns of EV owners. In the eyes of the System Operator (SO), the aggregator is seen as a large source of generation or load, which could provide ancillary services such as operating reserve or controllable load. The aggregator may contract the ancillary services directly to the SO, but generally these services will be provided in the Day-Ahead (DA) and intraday electricity markets. This influences and creates different scenarios on the electrical grid. A new concept of aggregator agent of EV has been introduced by Brooks and Gage [2] under which all drivers communicate with the aggregator, and it is the aggregator which ultimately manages all the information. The aggregator therefore needs to know the profiles of all drivers. This allows it to create a virtual power plant on account of all the information it holds regarding how many vehicles are expected to be plugged at any given time of the day and how much energy they need. This idea was developed having in consideration that the aggregator receives request signals from the SO and transmits its commands to the EV. This information and communication technology (ICT) allows real-time data transmission, containing the location, SOC and power capacity of interconnection of the EV and would be used to update the expected availability and willing to sell the service. Marra et al. [3] also tested the concept virtual power plant and which results revealed the potential capability of EV to respond in real-time to different charging/discharging requests based on different coordination plans.

Communications-wise, Kielthy et al. [4] offers a very optimistic vision from future internet usage, as it becomes the main communication method in smart grid. This concept relates to a home charge scenario and public or specific charging points. The organization of the grid also undergoes change by using the future internet technologies to balance the load on the grid in cases where unplanned events that causes fluctuations in grid frequency occur. Kielthy also presents a solution where interruptible loads can be used to gain greater advantage on demand side management by including additional loads within users’ homes or through the aggregation of loads within a region in order to provide localized solutions. These breakthroughs are done by remotely controlling the load drawn down by domestic EV charge points.

1) Flexibility grid concept

Flexibility expresses the extent to which a power system can modify electricity production or consumption in response to variability, expected or otherwise. The problem to find the best charging schedule that meets a certain set of criteria can be conveniently described mathematically as a problem of optimization. The potential of this flexibility can initially be treated from the point of view of distribution networks, and then, from the point of view of lower generation costs, either directly, or through the signal provided by the wholesale electricity price.

We note that there are already many possibilities in today’s power system regarding flexibility: bilateral contracts, day ahead markets, intraday trading, balancing markets, interruptible load contracts, etc. However, as flexibility becomes more and more crucial, the notion of some type of market for ‘flexibility products or services’ has to be developed. It was also noted that the development of a market for such products will attract the necessary investments in flexibility enabling technologies. In this PhD thesis, Verzijlbergh [5] suggests the concept of flexible demand quantum, defined as a contract for a certain amount of energy in a certain time frame, regardless of the exact timing.

2) Distribution grid impacts of EVs

The basic principles of each type of load frequency control are the same. In Portugal, regulation reserve (AgC) is the secondary control while spinning reserve is also part of the secondary control and fast tertiary control reserve. In [5] answers are provided for questions such as the following: How can the controlled charging EVs reduce their impacts on the distribution grid, how can controlled EV charging reduce generation costs in power systems with a high share of renewable energy sources and finally how can the costs of EV charging be minimized within distribution grid constraints are answered. The author addresses these subjects more on the computational method based upon a particle swarm optimization, that, on the higher level, impacts and benefits from flexible EV demand. If the controllable conventional generation has to be replaced by less flexible RES and, simultaneously more flexibility on the demand side, it is a logical consequence that a part of the services provided traditionally by the conventional power plants will now be transferred to the demand side.

The EV aggregator will participate in the reserves market under the same rules as generating units. It is important to refer that since the intraday market sessions are close to the operational time, the aggregator must have information for each EV in order to manage the fleet charging process and go to the intraday market, if necessary. This process is more complex than it might appear at first sight.

An important deduction concerning this work is that, due to the EV load diversity, i.e., the randomness in the timing of charging EV (which itself leads to a large smoothing of the EV load), the aggregator is in danger of becoming overloaded, especially ones that have a lower number of customers connected to them.

Taking the above into consideration, it is possible to conclude that controlled charging of EV can potentially reduce network impact.

3) Description of the scenarios

The business scenarios comprise many actors such as the EV customer or EV owner, the distribution system operator (DSO), the transmission system operator (TSO), electricity retailer, the aggregator and a few others. An aggregator needs a good business model to attract and maintain EV owners under the contract. As consequence, there have been several business models introduced over the last few years. The aggregator not only provides free replacement batteries and possibly free or inexpensive charging but also direct payments, subsidized leases, or ownership and/or warranty of the vehicle battery pack. When the aggregator is the retailer company (which buys power from vehicles and sells this power into the electricity market), it does not have any control over the individual vehicles but can provide financial incentives to stay plugged when possible. These contracts allow easy access to charging stations or even choose different and selective access as so through exchange batteries in strategically pre-selected charging points.

Verzijlbergh [5] shows that controlled charging of EV leads to a significant reduction of overloaded network components when compared to the uncontrolled charging scenarios. The implications of these results for DSOs are not straightforward and depend largely on
the institutional setting that the DSO is operating in. One could argue that the results presented in this study give a strong indication that there is a societal benefit in allowing DSOS to apply some form of charge control, something that is not allowed in many regulated electricity sectors. The aggregator primarily performs the optimization without a network tariff and communicates the charging schedule to the DSO. The DSO then evaluates if network constraints are satisfied and, if not, communicates a certain network tariff associated to the moments where network capacity is exceeded. The aggregator recalculates the charging schedule based on the new grid tariff, communicates to the DSO and so on. At this point, the aggregator communicates with and controls the SOC at each charge point. This procedure is then repeated until convergence, which results in a certain grid tariff and a binding charging schedule. Another parameter that will influence the future work is type of charging battery. Battery charging is envisioned to be performed in two ways:

- adjust the charging rate e.g. fast and slow charge;
- charging "ON/OFF" only with the possible of having charging ON or charging OFF constant rate.

The ideal situation is to synchronize EV charging with regulating reserve. As noted by Stefan U¨ bermasser in [6] all recent cars (first start of sale after 2011) have a constant charging intensity (minimum between pole power, cable section and EV capability) up to roughly, 80% of the State of Charge (SOC) (depending on the car). Above 80%, the charging intensity is linearly reduced until the EV is completely charged. One should realize that to disconnect the charging point, which is the studied case in this work, batteries need to be charged with a constant load up to 80% and, thereafter, the charge rate begins to decrease. This helps to detect finishing charges. Batteries can withstand multiple cycles and their lifespan is barely affected by lowering the charging rate. This is depicted in the figure 1:

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Several simulations were done in order to optimally simulate the actual situation in which a DSO takes a decision and imposes a requirement to reduce the percentage of charging of an EV in a particular area at a particular time of day. This decision is made based on the best grid scenario, considering both the economic benefits and capacity of the grid. All simulations were done using real data (the Portuguese power outlets) and their main objective was to find the variables which allowed to make the error more insensitive in relation to demand requirements. This was done by iterating those variables several times until the error reached a reasonable value. In this point, it is important to understand why there is a cutting error associated with the simulations. The figure 2 represents an example of type curve of a regular power outlet after a charge constraint decision (at hour 15 with a 30% cut).

![Figure 2: Charge illustration](image)

There is an error (see in the next equation) associated with each cut decision of an outlet which is different for each performed method. This error arises when the implementation of this decision once the power outlets are randomly chosen and a certain cut is applied. From this stage onwards, there are two hypotheses: the day under analysis has sufficient power outlets and the cut is performed (reduced value is slightly above the desired generating negative error), or there are not enough outlets on this day to fulfill the imposed charge constraint (positive error). Such error variation is represented on the graph by the blue interval and the charge constraint represented in orange.

$$
\epsilon_{cut} = \frac{Expected_{value} - Real_{value}}{Expected_{value}}
$$

Besides this error, there is another associated with time precision since the cut decision is made based on a charging value that is not the actual value, i.e. time lag. So, when the analysis and decision is taken, based on actual value (present), the value will differ when the cut is applied (future). This error is negligible to the methods of this dissertation. Having access to the values of energy applied at each power outlet for periods of one hour allowed to build a possible scenario of demand and make the necessary simulations. For analysis and comparison of different variables of different types depending of the day of the week, it is important to choose a random week and weekend of year 2014/2015. The consumption in both cases is illustrated in the figures 3 and 4.

II. PROPOSED METHODOLOGIES

The proposed methodologies are based on the performance of tests made through simulations using data provided by CEiiA (Centro para a Excelência e Inovação na Indústria Automóvel). The company provided all the data related to the hourly charging state of its Portuguese charging points from all days until June 30th. For this dissertation three data files were used, totaling 72 000 lines of real information.
It is essential to note that each EV owner has access to the vehicle identification number - VIN (on EV owner card), so MOBI.E system has full information of the state of each power outlet. The main requirement and also primary objective of this work is to create ideal conditions such that the DSO can decide which is the favourable charging point with another power outlet already in use, it has no impact on the service time and is a measure for the flatness of the load profile. In addition, the service time is a useful measure to estimate yearly energy losses based only on a measurement of the yearly peak load. Increased interconnection and flexible demand will, on the other hand, have a damping effect on electricity prices. Depending on the exact nature and physical characteristics of the flexible demand it could, for example, be possible to shift a portion of the demand by several days.

After making the base methods (full cut of charging) another series of methods were performed, all of which are crucial to greater development and conclusion result of this dissertation. From all the performed methods we have 5 that stand out. Note that there was a logical sequence for the simulations, but for all of them the following constants were stipulated:

1) Initial hour of the analysis: 15h was the hour chosen since it is one of the daily consumption peaks in Portugal, that is, when a larger number of power outlets is being used and the power consumption is higher;

2) Demand requirement: 3kW at hour 15 for every day of the year under analysis (reduction of daily consumption by 3kW and time 15h is seen as if it was the current time imposed by the requirement). For some simulations the value of the requirement was varied in order to study the error fluctuation but in general 3kW stipulated value to simplify the analysis;

3) Duration 3 hours: After the analysis of hour 15 (and consequently decision in accordance to each method) cutting is done on hour 15, 16 and 17. The cut is made in these three hours realizing its impact and calculating the error uncertainty. But once again, the charging cut decision is taken only based on the current value of the charging at hour 15.

4) Decharacterization of power outlets: there was no distinction of geographical areas, power outlets were treated as a whole. Analysis was done by power outlet and not by charging point. A charging point usually has two power outlets but some have up to four. One could be have chosen to analyze charging point by charging point (summing the final consumption of each power outlet), however, as each power outlet has its typical behavior, independent of the other power outlets of the same charging point, we chose to decharacterize every power outlet. Note that if an EV owner wants to charge its vehicle on a power outlet in the same charging point with another power outlet already in use, it has no impact on the charging requirements of the EV that was already there in the first place.

5) No distinction was made on the type of customer;
6) Data: the data used in the methods covers one year, from July 2014 to June 2015. The large increase verified in EV charging at the beginning of 2015 widely justifies the use of data until the final date of the methods.

B. Method overview

All methods are based upon the logic sequence depicted on figure 5, 6, 7 and 8. In this sequence the rectangular boxes represent actions, the diamond shaped ones represent verifications, the green round boxes the gathering and presentation of the algorithm output and the red one the end of the sequence.

The reference method which was the starting point for all the other methods allowed to realize the importance of having to vary the charge cut (in percentage) accordingly to the power consumption record of the outlet. This reduction on the charging of the EV results from the requirement imposed at hour 15 (simulating a real requirement in real-time by the DSO to respond in real-time to the needs and the best network scenario).

Thus, it is shown below the main and most relevant methods made, in chronologically order, after the reference method:

1) **Method 1 - Dual cut:** In this simulation a power outlet is randomly chosen and analyzed. If this outlet is starting its charging or if it is already charging up to two hours ago then the cut would only be 10% (at the hour 15, 16 and 17), if the power outlet is already charging for 3 hours or more the cut is 30% (at the hours 15, 16 and 17). After the cut, another outlet is randomly chosen until we have a total daily reduction of 3kW (at the hour 15) or until all outlets for the day are used. Logical sequence is shown in figure 5.

2) **Method 2 - Blind cut:** In this simulation a power outlet is randomly chosen and a cut of 30% of its power consumption is applied for the hours 15, 16 and 17. The process of choosing an outlet and its respective cut is repeated until we have a daily reduction of 3kW at hour 15 or until all outlets are used (same as the method above). Logical sequence is shown in figure 6.

3) **Method 3 - Three stage single cut:** An outlet is randomly chosen and it is identified whether the outlet is in the initial, intermediate or final stage of charge. This identification is made upon the comparison of its values. For example, if the charging value at the hour 14 is less than the value of the hour 15, the latter is in the intermediate stage. The identification of the three stages is made in accordance with a battery charging behavior such as shown in Figure 2.5. If is in the initial stage the cut is 10% at the hour 15 and 30% in the hours 16 and 17 (intermediate stage). If at the hour 15 the outlet is in the intermediate stage and if the analysis of the previous hours shows that the outlet is already charging for four hours or more a cut of 30% is applied at hour 15, and in the hours 16 and 17 the reduction is 15% (final stage). There are other possible situations and they are all accounted in this method (even accounting with punctual chargings of only one hour). If the charging at hour 15 is its final stage then the charging value requested at hour 15 is smaller than the value on hour 14, so the cut is 15% at the time 15h, 16h and 17h. If charging has been completed in the meantime, the cut does not affect its value. For example, if the charging value (same as power consumption) is different than zero only at hour 15 the cut is applied within the three hours, however, the only value affected is the one related to the hour 15. Again, the randomization of the power outlet and respective cut is done until 3kW of daily consumption are reduced or until all outlets are used (same as the above). Logical sequence is shown in figure 7.

4) **Method 4 - Three stage cut update:** the only method in which the decision is updated at hourly (between hour 15 and 17, inclusive). In this, a power outlet is chosen randomly, every hour of charging is analyzed and it is identified whether the power outlet is in its initial, intermediate or final stage. If it is in initial stage the cut is 10%, 30% for intermediate and 15% for the final. This method has the same stages of decision that the method “Three stage single cut”, however, the analysis is done for the time 15h, 16h and 17h (decision update). The requirement to lower 3kW on hour 15 remains (as in other methods) and is not applied for the hour 16 and 17. Logical sequence is shown in figure 7.
5) **Method 5 - Three stage curve fit:** In this simulation an outlet is again chosen randomly and analysed at the hour 15 (presumed current time), identifying the charging stage. Using the historical data from the early hours of the power outlet, an historical analysis is done to the average behaviour of the outlet and its type curve (profile) obtained. The decision on the amount to reduce at the hour 15, 16 and 17, is based on that curve type/profile. If the slope at a given point is positive the cut is 10% (corresponds to the initial stage of charging), if the slope is zero the cut is 30% (intermediate stage) and for negative slope the cut is 15% (final stage). This procedure is done until a daily reduction of 3kW for hour 15 or until we run out of power outlets for the day. As we do not have access to the SOC then, the type curve based on historical data is used. Logical sequence is shown in figure 8.

In order to gather the data from all the aforementioned methods, the following Table is presented: 1

### III. Results

#### A. Introduction

Extensive tests were run in order to analyze the performance of different types of charging and different type of cutting decision of the EV charging.

The simulation profiles defined in the previous chapter can be used to represent the demand of a group of EVs if they are scaled appropriately. This means that the shape of the profile is assumed to be independent of the number of EVs, but the magnitude is scaled according to the energy demand.

For a very low numbers of EVs, this approach will not be accurate since the profiles have a more spiky shape. The question is for how many EVs one can assume that the aggregate profile will be a good approximation. It is also important to know the information provided by metering devices and charging point locations. In this work, it is assumed that the EV will be charged at residential areas, at public charging stations and also at workplaces. Nevertheless, it is relevant to emphasize that one of the objectives is to minimize losses and load peak. If the DSO sends signals to the aggregator to amend the SOC, it must always be done with the aim of achieving the best scenario (economic and power grid balance). A number of papers describe how EVs can simultaneously minimize charge costs based on time...
varying electricity prices and provide minute to minute balancing services. It is indeed found that this combination has a higher financial potential than charging solely based on electricity prices.

Using the data provided by CEiiA allowed to build several scenarios of demand and to make the necessary simulations to realize the impact of the algorithm. The simulations were used to scrutinize the impact caused by cutting charge of one or more power outlets in a period and thus, the error associated with estimating and optimizing the desired service. Decisions taken at hour 15 are decisions taken from the point of view of the DSO and the EV owner type is unknown. During the charge and decision event, the aggregator has no access to the vehicle’s SOC (unilateral communication), so the analysis is always done based on the type curve, using historical data. There are some damaged charging points which further reduces the number of data used in the simulations. It is worth noting that each charging is treated as an event.

Before presenting the results it is necessary to mention that since each simulation has randomly chosen power outlets, slightly different results are expected each time the same type of simulation is performed (average error and standard deviation). Given that all simulations behave the same way there is no influence on the results of the analysis.

B. Presentation of the results

For each simulation two chart groups will be presented. They are all essential to the correct analysis of the problem. The Table 9 is a summary table with the values, with the average errors and standard deviation of each simulation.

1) Method 1

For the first method - Dual cut - performed (after the reference method has been made) the results are presented in figure 9.

The output values of this method are shown on table 2:

<table>
<thead>
<tr>
<th></th>
<th>15h</th>
<th>16h</th>
<th>17h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average[%]</td>
<td>1.44</td>
<td>-0.84</td>
<td>-7.33</td>
</tr>
<tr>
<td>Standard Deviation [%]</td>
<td>5.41</td>
<td>18.76</td>
<td>35.28</td>
</tr>
</tbody>
</table>

Table 2: Error output [%] for method 1

2) Method 2

For the second method - Blind cut - the results are presented in figure 10.

![Figure 10: Charging cut error, average and standard deviation](image)

The output values of this method are show on table 3:

<table>
<thead>
<tr>
<th></th>
<th>15h</th>
<th>16h</th>
<th>17h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average[%]</td>
<td>9.77</td>
<td>6.68</td>
<td>2.73</td>
</tr>
<tr>
<td>Standard Deviation [%]</td>
<td>8.45</td>
<td>8.53</td>
<td>8.10</td>
</tr>
</tbody>
</table>

Table 3: Error output [%] for method 2

Comparing the values obtained with the ones from method 1, it is possible to verify that both the average error and standard deviation values increased in absolute value. This is justified by the constant charging cut and by the lack of distinction of charging values. The total cut rate will always be a bit above or below the stipulated requirement (3kW).

3) Simulations with distinction of three charging stages

3.1) Method 3

For the method 3- Three stage single cut - the results are presented in figure 11.
The output values of this method are show on table 4.

<table>
<thead>
<tr>
<th></th>
<th>15h</th>
<th>16h</th>
<th>17h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average [%]</td>
<td>-3.40</td>
<td>-3.33</td>
<td>-8.81</td>
</tr>
<tr>
<td>Standard Deviation [%]</td>
<td>12.92</td>
<td>19.32</td>
<td>41.67</td>
</tr>
</tbody>
</table>

Table 4: Error output [%] for method 3

Throw analyzing the figure it is possible to verify that the errors became negative and that its absolute values were reduced to less than half of the method 2 (at 17h the values reduce to less than a third). The simulations values improved with the distinction of the three charging stages. The standard deviation increased when compared with method 2 and increased when comparing between the three hours analyzed (note the great improvement in the value of 17h).

3.2) Method 4

For the method 4 the results are presented in figure 12:

The output values of this method are show on table 5.

<table>
<thead>
<tr>
<th></th>
<th>15h</th>
<th>16h</th>
<th>17h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average [%]</td>
<td>1.44</td>
<td>-2.77</td>
<td>-9.60</td>
</tr>
<tr>
<td>Standard Deviation [%]</td>
<td>17.52</td>
<td>27.25</td>
<td>66.31</td>
</tr>
</tbody>
</table>

Table 5: Error output [%] for method 4

This simulation was the only one where the update of charging cut was made within the three hours of analysis (15h, 16h and 17h). This was made to understand the impact of the update. Comparing these values to the results of method 3, the average error values in the first two hours are significantly lower (absolute value) but higher at hour 17. The value at hour 15 is positive since it was not possible to meet the requirement of cutting the desired charge. The standard deviation has changed substantially to higher values.

4) Final Simulations

4.1) Method 5

For the final method the results are in figure 13:

The output values of this simulation are show on table 5.

<table>
<thead>
<tr>
<th></th>
<th>15h</th>
<th>16h</th>
<th>17h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average [%]</td>
<td>-3.40</td>
<td>-7.38</td>
<td>-15.90</td>
</tr>
<tr>
<td>Standard Deviation [%]</td>
<td>11.47</td>
<td>22.09</td>
<td>41.79</td>
</tr>
</tbody>
</table>

Table 6: Error output [%] for method 5

It was verified that the average errors are nearly identical to the method 3 ("Three stage single cut"). The advantage of method 5 is that the algorithm can better resemble the behavior of each charging point and adjust the charging cut according to the profile of each power outlet. Due to the logical sequence of the algorithm was necessary to develop a method that excluded the days with reduced number of charges (days that have less than 10 charges at hour 15 are excluded). Thereby, the method 5 was reformulated and the days with low consumption were removed. The results of the "Three stage curve fit" (with removal of the low consumption days) are presented in Figure 14.
The output values of this method are shown on Table 7:

<table>
<thead>
<tr>
<th></th>
<th>15h</th>
<th>16h</th>
<th>17h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average [%]</td>
<td>-0.54</td>
<td>-3.64</td>
<td>-7.83</td>
</tr>
<tr>
<td>Standard Deviation [%]</td>
<td>3.43</td>
<td>9.49</td>
<td>9.16</td>
</tr>
</tbody>
</table>

Table 7: Error output [%] for method 5 with removal of the days with low consumption

In this method the standard deviation and average errors were much lower. In this last method the sample was reduced in order to approximate as closely as possible to the correct type of test sample. In total were removed 37 days of the sample (equivalent to a month and a week of the chosen data). The average daily sample was only 22 EVs, i.e., average outlets used on each day. Since the amount of data is inexpressive when compared with countries with a larger amount of EVs, like Netherlands, it was necessary to use the law of large numbers and comprehend how the average error and standard deviation are influenced by increasing the sample. Before study the law of large numbers is important to present the values in all simulations, summarized in the Table 10.

C. Effect of the sample increase in error and standard deviation

In a nutshell, the Law of Large Numbers (LLN) in [9] says that through the statistical concept that the larger the sample (or the number of observations) used in a test, the more accurate the prediction of the behavior of that sample, and smaller the expected deviation comparing both outcomes. Regarding the variance, if the sample is extrapolated by multiplying it by a scaling factor \(a\), the new value of variance would be calculated by multiplying the variance by the square of \(a\). So for this dissertation where:

\[
\text{Error uncertainty} = \frac{\sigma}{\mu}
\]

Extrapolating for hundred times and for ten thousand times the original sample:

Table 9: Error results

<table>
<thead>
<tr>
<th></th>
<th>Standard Deviation for 100x</th>
<th>Standard Deviation for 10000x</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15h</td>
<td>16h</td>
</tr>
<tr>
<td>Dual cut</td>
<td>0.38</td>
<td>1.99</td>
</tr>
<tr>
<td>Blind cut</td>
<td>0.09</td>
<td>0.13</td>
</tr>
<tr>
<td>Three stage single cut</td>
<td>0.38</td>
<td>0.59</td>
</tr>
<tr>
<td>Three stage cut update</td>
<td>1.22</td>
<td>0.98</td>
</tr>
<tr>
<td>Three stage curve fit</td>
<td>0.34</td>
<td>0.30</td>
</tr>
<tr>
<td>Three stage curve fit with removal of the days of low consumption</td>
<td>0.64</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Table 10: Error uncertainty
IV. CONCLUSION AND FUTURE WORK

In short description, the role of electric vehicles in multi-actor and liberalized power systems is discussed by different authors which have different objectives, translating into different strategies with respect to innovative grid technologies (such as distributed generation and responsive demand). Distribution grid operators generally have incentives through some form of regulation in order to minimize costs, related to asset replacements and energy losses (avoiding peaks in network demand). The controlled charging scenario was chosen in such a way that the ideal was to shift the EV charge to the late night hours, when grid consumption is low. This is convenient for homecharging but very difficult for public charging. One could imagine many different control strategies in a smart grid setting, but in this work, the point of view of the distribution grid operator is chosen. In a regulated environment, DSO will generally aim at minimizing costs associated with reinforcing existing grid assets and energy losses. There have been several studies and the common understanding on many of them is that controlled charging of EVs can have significantly value for various actors in the power system. DSO communicates with the aggregator in order to act according to the most favourable scenario (to lower or not the demand). This is to help with this work estimate this optimal scenario and facilitate the role of aggregator. In respect to the results obtained in the simulations done for this dissertation it was noted a major difference in the results between the simulations where an equal cut rate is applied to the ones where the three stages of charge were distinguished. The distinction of the stages of the EV charging is very important in the decision step. The simulations demonstrated that the more adaptable the algorithm is to the different behaviors from power outlets, the better are the results. In the end, it was possible to reach an average error around 0.5% (in absolute value) with a low standard deviation: value around 3%. Using the extrapolation and the law of large numbers is possible to predict that a larger sample would get better results. The final algorithm developed in this work has a huge potential when applied to a scenario with more EVs, and with access to a greater number of user data. Nowadays we witness an increasing use of Fast Data. This will become very important for the development of the theme of this dissertation and will allow a major advance in the management of real-time data, allowing an optimization of the entire system.

It is also worth mention that a change in the electricity market is expected, in order to include new products such as peak shaving, load response to prices loss reduction at the low voltage level, SOC control and load shedding due to congestion in feeders. To complement these products, the integration of new ICT is needed as a tool to provide grid operators with real-time ability to stabilize the grid frequency by controlling the demand.

A. Future Work

For this dissertation one had access to the location of each charging point but for simplification there was no distinction and descharacterization of power outlets. As future work, it is suggested that simulations should be organized by regions and/or by residential areas (private condominiums, housing developments, among others), business areas, public transportation stations, university areas and recreational areas. Another interesting distinction would be to combine several types of areas with custumer preference of location and timetable (daytime and night-time charging). Real-time calculation of demand of each charging point through an mobile app that each EV owner would have could lead to another interesting distinction. If the owner wanted to charge his car at a given hour the application would give him not only the destination and charging time but also the waiting list for the desired destination and possible "busy” or "on maintenace” status.

REFERENCES