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# Flexpower3: Significant increase in grid hosting capacity without comfort loss, by smart charging based on clustering and non-firm capacity

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## Summary

A novel Smart Charging strategy, based on low base allowances per charger combined with 1. clustering of chargers on the same part of the grid and 2. dynamic non guaranteed allowance, is presented in this paper. This manner of Smart Charging will allow more than 3 times the amount of chargers to be installed in the existing grid, even when the grid is already congested. The system also improves the usage of available flexibility in EV charging compared to other Smart Charging strategies. The required algorithms are tested on public chargers in Amsterdam, in some of the most intensely used parts of the Dutch grid.

*Keywords: Smart charging, smart city, smart grid, control system, demonstration*

## 1 Introduction

Amsterdam has been the home of smart charging strategies under the name Flexpower since March 2017. Currently, the third iteration of smart charging is in operation. In Flexpower1 and 2, smart charging was enforced through a static capacity profile on a grid connection that had been enlarged from the regular 3x25A size to a 3x35A capacity. The hypothesis was that by charging at higher speeds during non-peak hours, the low capacity in the peak hours would be acceptable to both Electric Vehicle (EV) drivers and Charge Point Operators (CPO's). After two years of experiments, it was concluded [1] that although the desired peak limitation had been achieved, the capacity limitation was in fact too fierce on many days, whilst the benefits of the 3x35A grid connection were very limited for EV users. The latter was mostly due to the restricted charging capacity of the cars [1].

The new strategy consists of a continuous capacity bandwidth on each charging station, much lower than the actual technical capacity of the grid connection and lower than the lowest capacity in Flexpower 1 and 2. Additionally, charging stations are clustered in the backoffice to form a virtual charging plaza, according to the distribution station that supplies the energy to the charger. The CPO is allowed to distribute the total allowed capacity of a cluster over the active charging only. Additionally, the Distribution System Operator (DSO) can decide to add extra dynamic non-firm capacity to the allowed cluster capacity, both day-ahead and real-time, based on actual measurements in the grid. This will allow more charging capacity by more efficient grid usage and local balancing of demand-supply, for instance in periods of high local production or low household consumption.

## 2 Project set-up

The project aims to deliver a scalable, futureproof way of charging, at the lowest possible social impact. The goal is to achieve lower costs for the CPO, lower impact on usage of public space, more charge points on an existing grid and a stimulus to the adoption of EV.

The project is operated on ten clusters of chargers, in which the CPO can redistribute cluster capacity to supply only the active sockets, benefiting from the guaranteed or firm capacity of idle sockets. It must be noted that clustering in this project does not refer to similar types of users per charger as in [2] but is based on the technical connection of the chargers to the low voltage grid. Our hypothesis is that the occupancy rate of chargers connected to the same cable and/or transformer yields possibilities to decrease the power that needs to be guaranteed by the DSO for these connections. Redistribution of guaranteed power from idle stations to active stations ensures a more efficient usage than the traditional system, in which firm capacity is guaranteed for each connection, regardless of whether it is used or not.

Figure 1 illustrates the available capacity per active charging station throughout the day, using the strategy described above. As can be seen, the redistribution of capacity from idle chargers offers an elegant solution to consume all available transport capacity on the grid, while maintaining control over the total grid capacity demand and – as an added bonus- without relying on technology that is not available on the market yet in sufficient numbers, such as V2G [4]. The distributed capacity per active charger will in general be higher than the capacity presented in the figure, because the occupancy rate of the charge points is hardly ever 100%. It can therefore be expected that charging can occur at near-full power during many hours of the day, except during peak hours, even in a grid that is considered "full" from the DSO perspective.

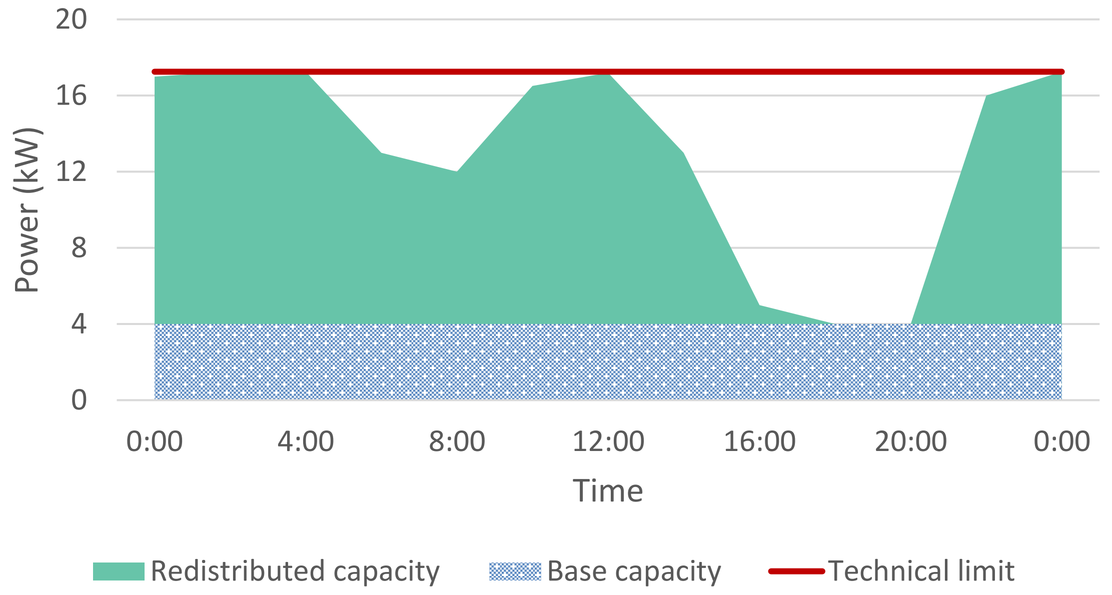


Figure 1: Schematic representation of the available power per charger in the project, with clustering and redistribution of power

This method of charging is different from previous studies, at which a hard capped, all day, bandwidth limit per charger is proposed [3]. An invariable bandwidth on charging power will inevitably negatively affect short charging sessions and will not allow sessions to take up higher amounts of energy when there is an abundance of energy and grid capacity available.

In our operating procedure, we incorporated a second improvement apart from the clustering. The power load that is available for the clusters in the final iteration of the project consists of two parts, both calculated per charger: a guaranteed part (firm capacity; this is guaranteed to the charger 24/7 and which is illustrated above) and a part that is available only after the DSO authorizes the CPO to use it (non-firm capacity). The maximum operational load on the chargers is determined by the technical capacity of the fuse in the charger, which is maintained at the, within Dutch standards, regular 3x25A (17,25 kW) fuse on the grid side. By adding non-firm capacity to the guaranteed base capacity, charging can benefit when local energy production is high, or non-flexible demand is low.

In total we have 63 charge points, so 126 sockets, in the project, divided in ten clusters. A cluster contains at least 6 charge points that are connected to the same medium to low voltage distribution station. Figure 2 gives the average load of our clusters, derived from data of charging sessions in the first four months of 2021. Considering the average power usage of domestic EV's in the Dutch fleet (table 1), it is clear from the average load presented in figure 2 that there is much flexibility available within clusters. Peak demand is in the early evening hours for all clusters, but the average power demand during peak hours is much lower than the average charging capacity of the Dutch EV-fleet. It must be noted that for determining grid capacity, the peak capacity of a (type of) connection is used rather than the average presented here [5][6]. In interpreting figure 2, we also need to consider that the Netherlands were, as was the rest of the world, suffering from covid restrictions. This enforces some prudence in using historic charging as a reference for future behavior. However, even when increased mobility is considered, the figure and table show that as a starting point, there is plenty of flexibility potential in our system for all clusters.

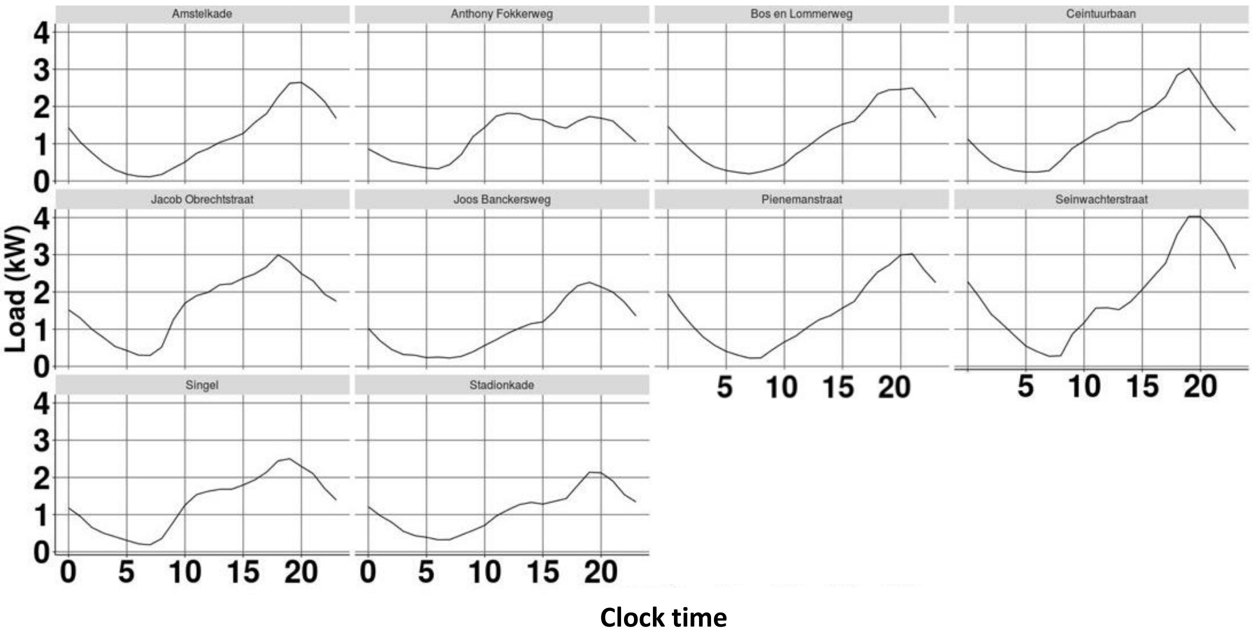


Figure 2: Average load per charger for selected mid voltage stations in Amsterdam, in the period 01-01-2021 to 30-04-2021. This data has been used to gain insight in the expected average occupancy of the clusters of chargers

Table 1: Top 10 EV's in the Netherlands as per February 28, 2022, with their charging capacity. Data retrieved from Rijksdienst voor Ondernemend Nederland [7]

| *Top 10 brands* | *# of cars* | *kW* |
|---|---|---|
| *Tesla model 3* | 41.401 | 11 |
| *Kia Niro* | 16.326 | 11 |
| *Hyundai Kona* | 15.477 | 11 |
| *Volkswagen ID.3* | 14.375 | 7 |
| *Tesla Model S* | 11.713 | 16,5 |
| *Nissan Leaf* | 11.538 | 7 |
| *Renault Zoe* | 11.252 | 22 |
| *Volkswagen Golf* | 10.173 | 7 |
| *Audi E-tron* | 9.402 | 11 |
| *BMW i3* | 8.397 | 11 |
| | | |
| ***Total of top 10*** | **150.054** | |
| *Total number of full EV's* | 253.743 | |
| ***Average Power top 10*** | | **10,6** |

In order to operate the clusters, charging profiles have to be recalculated each time a vehicle joins a cluster or finishes charging. In a charging station, the following statuses are used to indicate the actual charging behavior per socket:

- Available: Charging socket is available
- Preparing: EV is connected, but session has not started
- Charging: Session is in progress; vehicle is being charged
- SuspendedEVSE: Session is in progress, charging is paused by the charging point
- SuspendedEV: Session is in progress, charging is stopped by vehicle
- Finishing: Session has ended, vehicle is still connected

These statuses can be used by the CPO to determine the power distribution.

For the control algorithm, our first version recalculated the charger profile every time a socket within the cluster changed its status to Preparing, Charging or Suspended EVSE. However, we found that the addition of Preparing resulted in unexpected loss of active power and in an excessive number of commands returned to the charger. This was caused by the fact that statuses can change within a matter of seconds when a new vehicle is connected. Repeated commands can result in malfunction of the algorithm, since it will not be able to finish a profile calculation. Therefore, we removed Preparing as a trigger for the charger profile recalculation, after which the system performed as expected.

The first phase of the project focused on charging on the firm capacity only. Through stepwise decreases, the goal was to find the lowest possible firm capacity, at which cars were still charged to satisfaction of the drivers.

Based on the data shown in figure 2, the hypothesis tested is that it is possible to go as low as 1 kW per charger per phase using this way of charging, without affecting the observed charging by drivers or the CPO. Based on our statistical analyses, using a very low firm capacity will result in occasional actual power allowances per car below the limits set in IEC 61581-1, when cluster occupancy is high. This will occur approximately 1% of the time per day (figure 3), which may seem negligible. However, when it occurs it will result in a "sleep" situation for all connected vehicles, with no means to "wake", other than the departure of a car. In order to prepare for the event in which "never-ending sleep" would occur, the CPO in this project (Vattenfall) programmed a carrousel scheme for the chargers, that kicks into action when the calculated power per active session drops below the threshold of 7A. In this case, the scheme sends a sleep command (following IEC 61851-1) to alternating vehicles every fifteen minutes, starting with the vehicle that has the longest connection time. Through this procedure, all other vehicles will continue to receive power and a fair distribution of grid capacity is ensured.

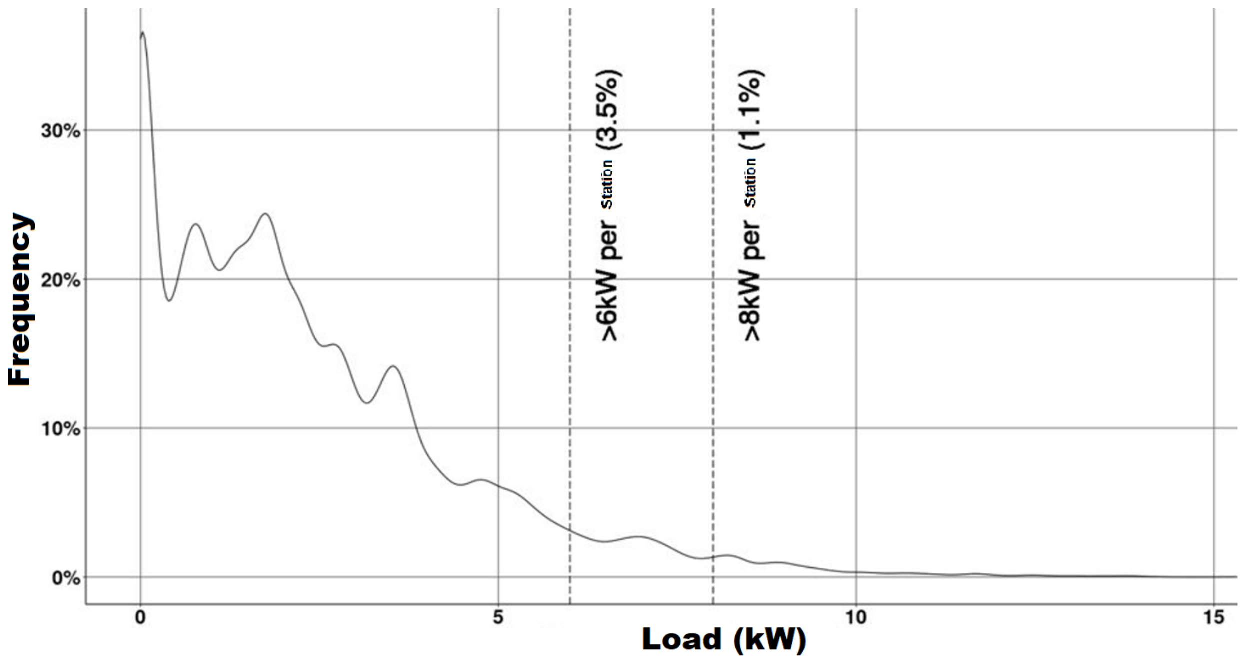


Figure 3: average charging power per charger for all involved medium voltage stations. An average charging power of more than 8kW is demanded of the chargers during 1,1% of the day (= approximately 15 minutes per day)

In the second phase of the project, the DSO sends non-firm capacity day ahead, with near real time updates, to the CPO. This added capacity is expected to allow even lower firm capacity. A lower firm capacity can be beneficial for CPOs, since it might (once it becomes a standard procedure) be translated into a cheaper grid connection tariff whilst still allowing vehicles to be fully charged. A lower firm capacity is also beneficial for the municipality, with respect to the number of charge points that the DSO can host on the LV grid in a neighborhood.

In the final phase of the project, the CPO will be given the opportunity to add prioritization to the redistribution of power within a cluster, based on their knowledge or estimation of driving behavior. This enables new propositions towards the EV driver. This phase is not discussed in this paper.

Starting November 2021, all distribution stations in the project have been equipped with real time measuring devices on each LV cable and transformer feeder. The ten clusters of chargers started operating under the Flexpower3 regime at 10A per charger per phase (instead of 25A) on December 1st, 2021, and decreases in power were implemented every 2 to 3 weeks, ending February 2nd, 2022.

During this period, Dutch mobility was influenced by measures from the Covid-19 pandemic response of the Dutch government. Fortunately, Dutch EV drivers maintained the same driving and charging routine during the project period. All periods were comparable in occupancy (number of cars present) and kWh charged per session. Therefore, we did not need to compensate for effects of the varying covid-19 restrictions.

# 3 Results

## 3.1 Phase 1: guaranteed firm cluster capacity

Figure 4 shows an example of the response of the total power per cluster (green) to the addition of cars (red). In interpreting the results, it is important to keep in mind that the delivered power per connected vehicle can vary, due to differences in car batteries (capacity, state of charger, onboard transformer). For this reason, the delivered power for the same amount of cars charging is not a constant value. The blue line in the graph is a calculation of the power that would have been delivered to the charging cars if smart charging would not have been applied. In this calculation, State of Charge of the battery could not be included because it is an unknown factor during charging. The calculated blue line is thus based on adding each nominal socket charging capacity separately, ignoring the possibility of technical limitations due to dual occupancy of a charger. The blue line thus indicates the estimated impact of the clustering on the power supplied per charger, at that specific moment in time. The overlap in blue and green lines in periods of low occupancy shows the positive impact of clustering during times in which only a limited number of cars is charging. The cars that are present can charge at normal speed, even though they are under a smart charging regime.

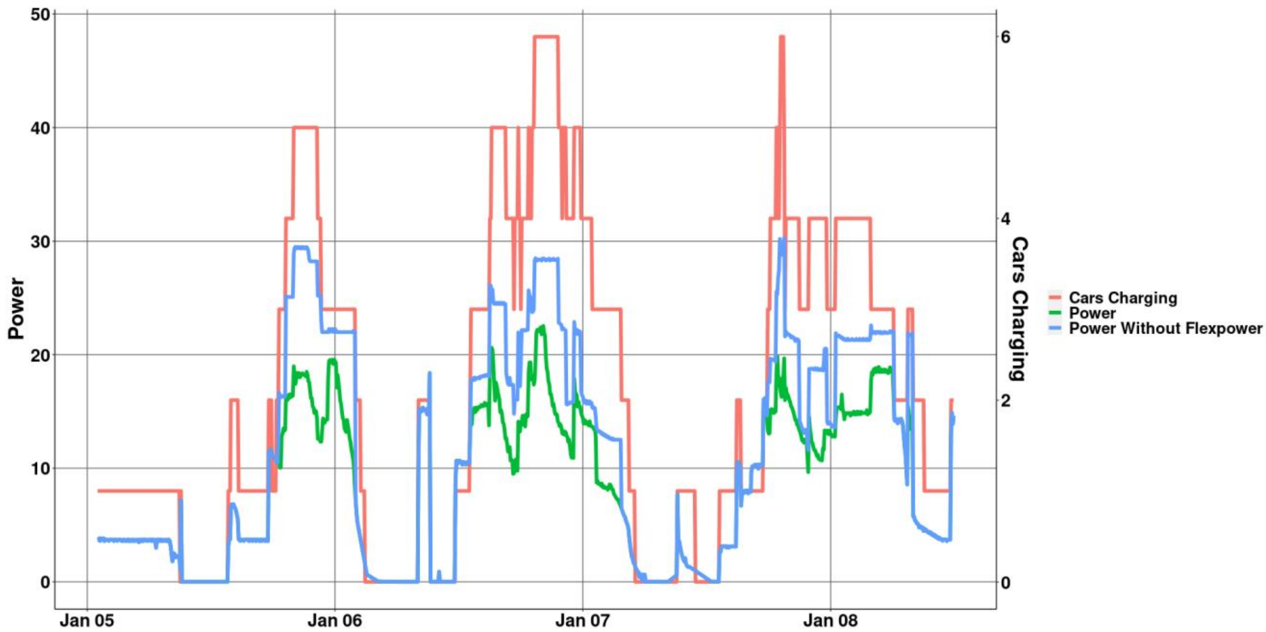


Figure 4: Actual delivered charging power per charger for distribution station Seinwachterstraat, consisting of 6 chargers. The allowed capacity of chargers was 6A per phase per charger, resulting in a maximum allowance of 25 kW for the cluster

When plotting the average charging power for all successive settings (original setting of 25A; 10A, 8A, 7A, 6A, 5A), the results on average distributed power per charger can be compared. This is shown in figure 5. A slight increase in charging power was observed for the 10A limit due to increased charging demand during wintertime and COVID-19 restrictions being lifted. The overall demand was much higher in this period (see also the daytime increase). The 10A limit did not often pose a limit to the charging sessions as it allows multiple charging sessions on a single cluster without the smart charging interfering. In lower settings, the impact of our smart charging becomes visible. The entire charging profile has been peak shaved and load shifted, resulting in prolonged charging at night for all settings below 10A. As expected, there is hardly any difference in delivered power during the daytime hours between 7:00 and 15:00h.

Because charging is occurring with a constant maximum power allowance, there is no “hard coded” increase in power during the day. In accordance with our design hypothesis, this resulted in the absence of unwanted rebound peaks after peak time that occurred in the previous Smart Charging projects Flexpower1 and Flexpower2 [8]. An average peak reduction of 29% was achieved.

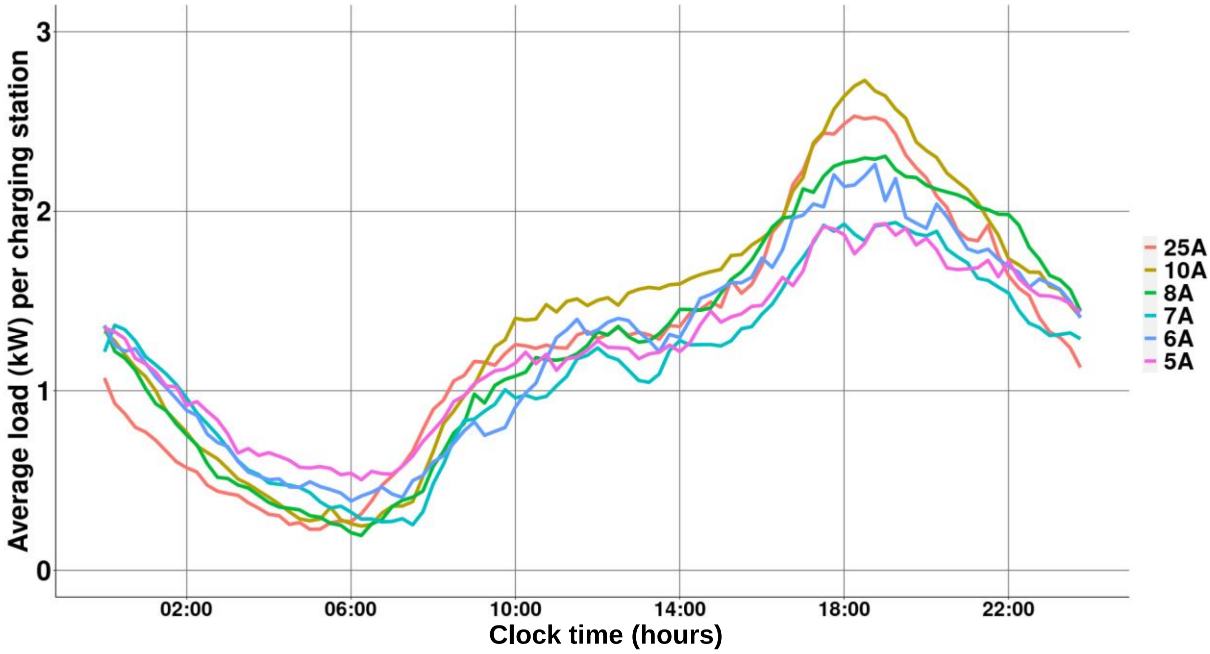


Figure 5: Actual delivered average charging power per charger during different settings. Under the strictest regime, charging continues longer at night, but during daytime all settings show approximately the same charging power.

With respect to the delivered energy per vehicle, we looked at the average distributed energy in kWh for the sessions in the subsequent phases of the project (63 chargers) and compared this to the average distributed energy in all other 8000 chargers in Amsterdam (figure 6).

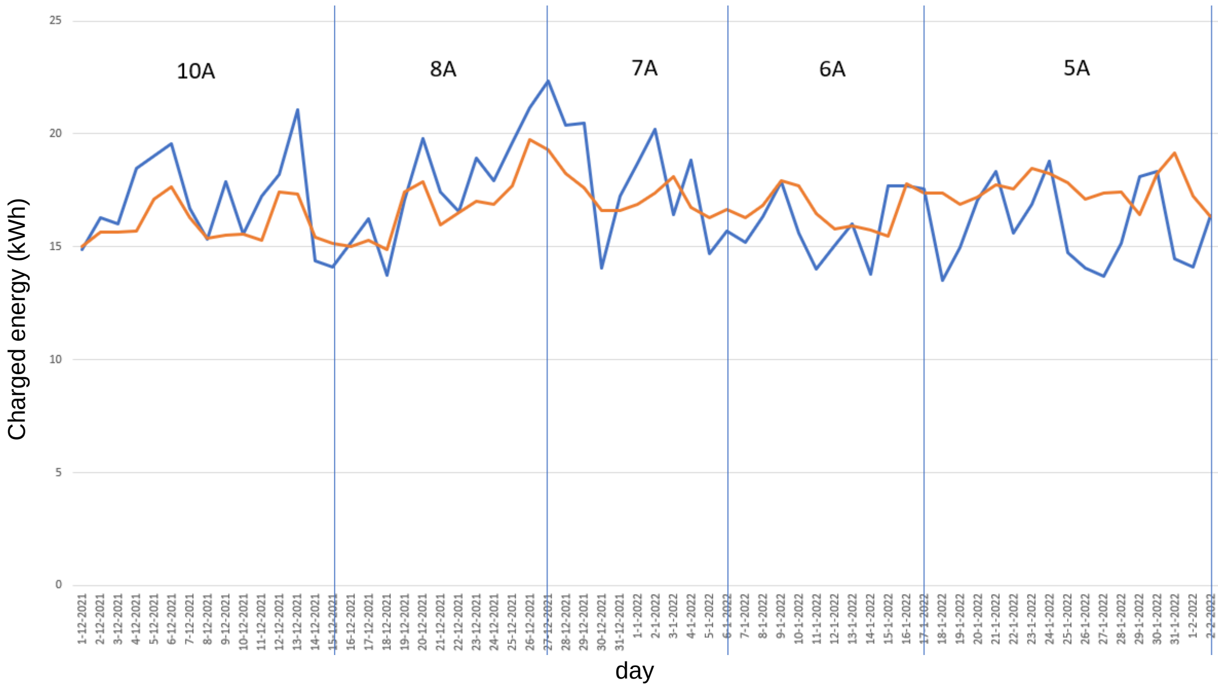


Figure 6: Comparison of the average delivered kWh per session, for the 63 chargers (126 sockets, blue) of the Flexpower3 project compared to the 8000 other chargers (orange) in Amsterdam

We found an apparent decrease in delivered energy for the settings of 6A and 5A. This resulted in approximately 3% less charged energy per charging session, when compared to the rest of the population. We did not do a deep dive into the comparability of the two populations, to exclude outliers. Still, it seems unlikely for users of the Flexpower3 chargers to have noticed different charging behavior to such an extent that their mobility needs were impacted. Even at the lowest setting tested, the overall delivered energy was very close to the average of the total population of chargers. Of course, we included a series of consumer surveys to validate this quantitative assumption and have included questions on our approach in the national Dutch Charging enquiry, which is held from April 11th to the end of June 2022. Results of both surveys are expected in September 2022.

During the first project period (December 1st 2021 to April 2nd 2022) in which we tested the base setting, we received no customer complaints. However, we witnessed a few incidents in which chargers were not responding to charging profiles sent by the CPO but instead operated on factory settings. In our project set-up, such incidents do not result in overloads, regardless of the time of day or the occupancy level at which they occurred, because the grid is not actually at its limit yet. However, for future scenarios in which the grid is reaching its technical limit, the statistics of such incidents do need to be considered.

### 3.2 Phase 2: Adding non-firm capacity to the cluster

The addition of non-firm capacity is new for both the DSO and CPO and communication had to be established between both parties. This was done by building an mTLS secure API, through which OCPP2.0 commands can be sent and received. The CPO translates these commands into OSCP2.0 charging profiles per active charger.

At the DSO, measurements from the distribution stations had to be translated in non-firm capacities. For research purposes, we needed to prevent output that would always allow 100% charging, since this would not be a demonstration of the smart charging concept. Since the local LV grids of our clusters are not yet fully congested, we analyzed the daily household consumption and adjusted the grid safety limits to a level at which the clusters are expected to have 2 to 4 hours of minimum capacity (i.e., only firm capacity) per day.

The developed procedure for determining the total capacity that can be send to the CPO is to first calculate the unused capacity day ahead, in fifteen-minute intervals. This calculation is performed by combining continuous flow measurements from the grid with forecasts for solar production and historic data of domestic power usage. The capacity that is send to the CPO is determined by subtracting the non-EV prognosis from the fictive grid safety limit of the low voltage distribution station. The prognosis is part of a self-learning system in which past prognoses are validated with actual grid performance every week, for 120 days of data. In future, we plan to use (near) real time measurements to improve the prognosis intraday. Figure 7 graphically shows the basic procedure for determining the charging capacity. Figure 8 shows how the unused capacity is communicated to the CPO, in terms of firm and non-firm cluster capacity. In the project, we can always deliver the firm capacity, even when the grid measurements result in a negative amount of unused capacity, this can occur because the actual capacity limit of the system is higher than what we have implemented in our reduced grid capacity settings.

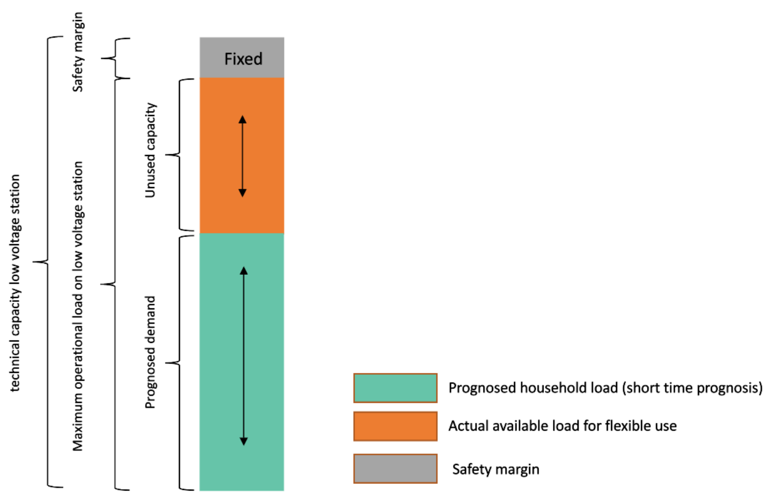


Figure 7: Every fifteen minutes, the amount of available capacity in the local grid for charging electric vehicles is calculated, based on grid measurements and a fixed safety margin

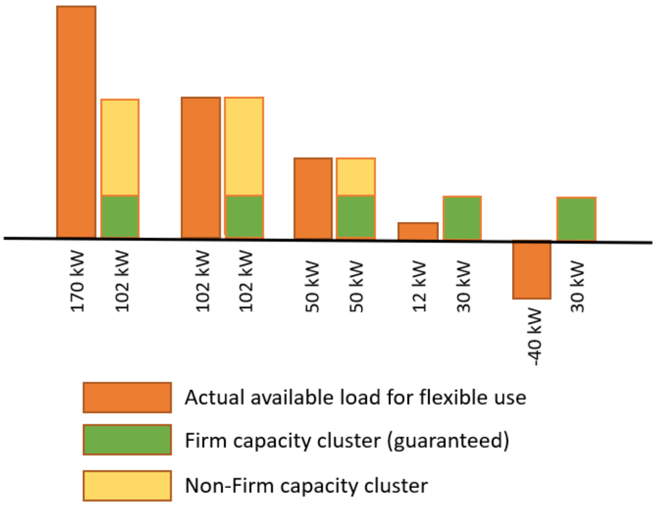


Figure 8: The available capacity is compared with the uptake capacity of the cluster. The cluster will never receive a charging profile that exceeds its technical capacity. In this example, the technical capacity of the cluster is 102 kW and the guaranteed firm capacity is 30 kW

We built in several checks for the reliability of the non-firm capacity response of the total chain. With these checks, we aim to develop a smart charging product that can be depended upon by the DSO and that is considered reasonable and fair by the other stakeholders (municipality, CPO and EV driver). A clustered firm/non-firm grid connection is beneficial to the DSO only if all the response performance has a limited and predictable margin of error. In this pilot project, we incorporated a fictive fixed safety margin, and we measure the occurrence and severity of overshoots of the system into this safety margin. Based on an evaluation of the performance, several mitigating strategies are possible, such as improvements in the prediction of available energy at the DSO side, performance KPI's on the CPO side or a standard agreement for the acceptable margin of error.

On April 12$^{th}$, 2022, we finished the development and acceptance testing of the algorithms for phase 2 and started adding the extra capacity to the charging clusters. The systems perform as expected and, as in phase 1, no customer complaints have been filed yet. We expect to see an improvement with respect to the delivered kWh presented in figure 6, and opportunities to lower the firm capacity even further.

# 4 Conclusions

Clustering chargers and allowing only a low firm capacity per charger resulted in a steady and predictable low grid impact, without negatively affecting driving possibilities. Clustering already yields a valuable proposition for charging, even without adding the more complex functionality of near real time non-firm capacity.

We calculated the amount of extra grid hosting capacity that is released through flexible charging. For this calculation, we used simultaneity calculations based on a simultaneity curve, the method generally used by grid companies to determine the expected grid impact of new connections [5][6][9]. The simultaneity of charger loads is based on the Strand Axelsson curve, which gives the average expected power demand of a specific connection, depending on the number of these connections. For charging stations, DSO Alliander uses the Strand Axelsson curve presented in figure 9. The curve shows that for our prevailing cluster size (6 chargers), the DSO designs on an average power demand per charger of 11.4 kW to be able to guarantee sufficient grid capacity for each charger of 25kW to use its maximum capacity without limitations. As present used firm contracts are based on a 24/7 guaranteed maximum capacity, the Strand Axelsson curve value is used by the DSO to determine if the grid can handle extra connections of this type, prior to allowing a new connection. It has to be adjusted for all existing connections of the same type once extra connections are realized, in order to keep the predicted grid load up to date.

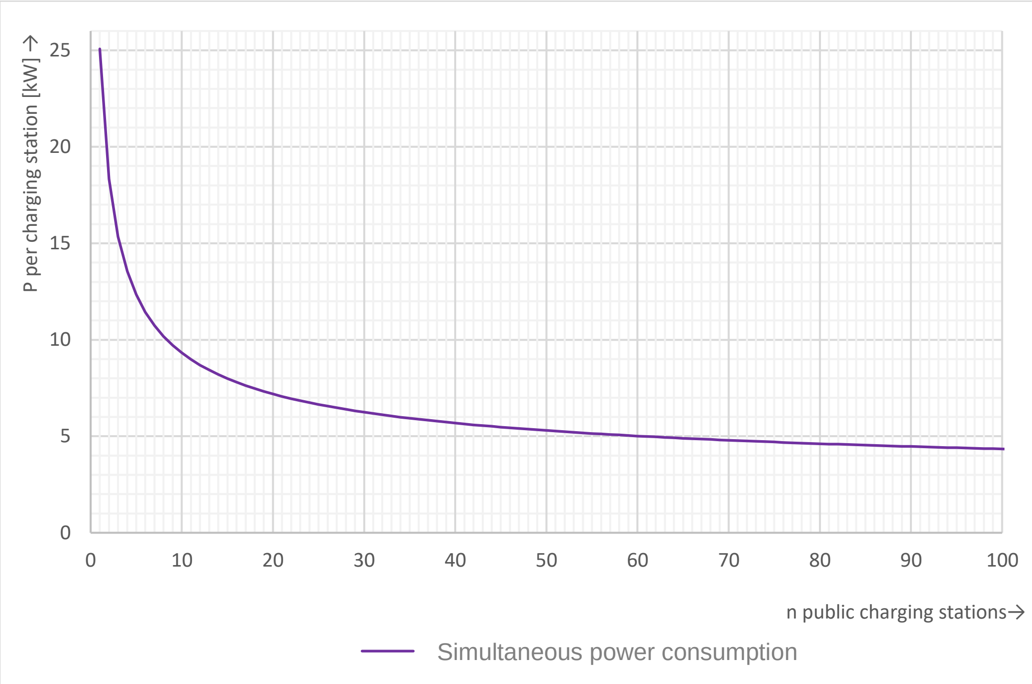

Figure 9: Strand Axelsson curve of maximum simultaneous power consumption per metering point, used to determine P per charger for grid configuration purposes

By operating the chargers on 5A and clustering capacities, the actual maximum guaranteed power demand is only 3.5 kW per charger. Due to the systems design, it is not possible to exceed this setting and there is no need to update the expected grid load once new chargers are added. As a result, more 3.2 times more chargers can be operated without causing an overloading effect on the grid load at the distribution station. In the near future, no grid reinforcements will be needed in neighborhoods that would otherwise be considered congested, when public chargers are operated as clusters instead of as individual connections. Also, no adjustments in the power load calculations will be needed: the addition of extra chargers has a constant impact on the peak grid load. This will make grid calculations less complex and more reliable. The effect we found is of almost equal proportion on a higher grid level (medium voltage).

One footnote to this result is that we have not analyzed the per day performance of chargers in detail, but have found some incidents that correspond with our setup of determining the margin of error in the system. In particular the data communication between CPO backoffice and chargers seems to be an important parameter for further research, because loss of communication will result in the charger affected to allow default maximum charging instead of charging according to the desired smart charging profile. The incidence of occasional nonresponsive chargers is valuable input for the calculation of the expected impact of clustering at low base capacity on fully booked grids and to specify the product proposition for the DSO-CPO contract.

Because the overall impact of our approach to smart charging is very promising, we aim to calculate a full product proposition for this type of grid usage shortly, to allow municipalities and CPOs to start charging the Flexpower way. We expect this will result in a substantial number of extra chargers per grid area, with a very predictable impact on the grid and without unwanted side effects.

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# Presenter Biography

Marisca Zweistra, PhD MSc, studied bioprocess engineering at Wageningen University where she obtained her PhD in 2007. Since then, she has worked in the energy business. First as a general consultant and since 2019 as a specialist program manager on smart charging of electric vehicles.