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Building a Smart Charging Ecosystem in Amsterdam

Getting ready for mass market of (next generation) EVs

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Summary

Keywords: smart charging, mass market, mobility system, standardization, regulation

In order to be prepared for the mass market of next generation EVs, Amsterdam executes a smart charging pilot on 200 key public charging points. Different market parties, together representing the complete smart charging ecosystem, test and validate the concept of a variable local capacity profile for the grid connection, increasing the power output during off-peak hours combined with decreased power output in short periods of local peak demand. If the concept is proven successful, the results of the project will be discussed with regulation bodies to adapt law regulations for grid connections.

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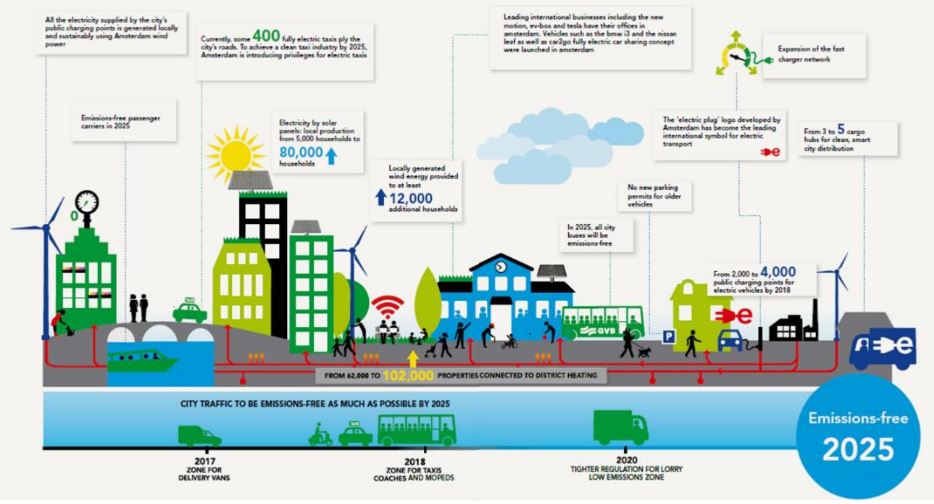
1. Amsterdam, the world leader in electric mobility

No city in the world is as far ahead in the transition to electric transport as Amsterdam. This was once more confirmed in June 2016 at the World Electric Vehicle Symposium in Montreal, where the city council of Amsterdam received the E-visonary award for the second successive year.

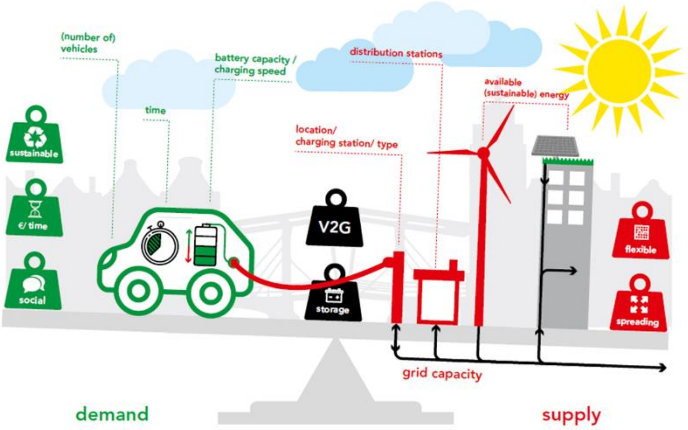
Over the past few years Amsterdam has developed into a true Living Lab for research institutes, innovation businesses and start-ups in the field of electric transport. Now is the time to benefit from the knowledge found and push through revolutionary changes in the city's transport and electricity system. Accordingly, Amsterdam has set ambitious targets in order to show that electric transport can be the norm, rather than the exception. The unique and still emerging charging infrastructure will, together with the implementation of local renewable energy resources, provide the backbone for achieving an emission free transport system in Amsterdam in 2025.



The contemplated increase of EVs and the rapid diffusion of local solar and wind power will have a significant impact on the energy system. In recent studies concerns have been raised regarding the effects of these trends on grid functionality, particularly in urban areas. Extensive grid infrastructure might be needed to support the growth of EVs in the city will increase electricity demand. Previous research has shown that the shift to a sustainable transport system is expected to almost double the electricity demand of households. This poses a threat on grid functionality and reliability, which is enhanced as residential and EV charging peak demands overlap. This risk is considered to be the greatest in densely populated urban areas, like Amsterdam, where EVs are adopted fast and older grids are found with limited capacities.

Furthermore, large scale penetration of in particular locally integrated PV systems have the potential to induce local grid overloads, due to temporary excess of electricity production. This affects both, the grid reliability and the potential of sustainable energy production.

In order to mitigate the mentioned risks, Amsterdam is exploring the implementation of smart charging solutions. These solutions include EV charging outside peak hours and sustainable charging. Successful implementation of these energy solutions has the ability to balance grid loads, postpone or avoid grid reinforcements and create a genuine sustainable electric transportation system, while considering costumer wishes. As a result, the implementation of smart charging solutions has the potential to become an essential component in future energy systems. The true beneficial of this innovation will be the driver as he will directly profit from improved charging service for lower cost while making a direct personal contribution to the energy transition.



1.1 Building a future-proof Smart Charging EcoSystem

In order to be prepared for the mass market of next generation EVs, Amsterdam is currently executing the next step in the development of smart charging solutions. This step considers a smart charging pilot on 200 public charging points that runs from October 2016 until October 2017. The pilot is established in order to create a Smart Charging EcoSystem. Subsequently, it will demonstrate a solution for local smart charging which anticipates a mass market for EVs. In addition, the project aims to optimize the benefits for the EV driver, create a competitive business-to-business market and allow for sustainable charging while considering the grid constraints. The innovation being realized in this project will also exploit results of two European subsidized projects, namely Seev4City (http://www.northsearegion.eu/seev4-city/) and CityZen (http://www.cityzen-smartcity.eu/). Consequently, the project will provide the latest research results of this practical innovation of the Smart Charging Ecosystem.

1.2 Pilot specifications of the Smart Charging Ecosystem

The unique Smart Charging EcoSystem being realized in Amsterdam consists of the following key elements:

1. Grid connection which has a variable capacity profile which releases substantial extra capacity during off-peak periods and a decrease of capacity during short periods of peak demand. The amount of energy (kWh) that can be transferred increases with about 90% on a working day and even more in weekends.
2. An Intelligent Charge Station which manages (via software) the maximum power output (35A) opposed to the existing hardware solution being a fuse (20A), while respecting the selectivity of the grid connection. Desk research shows an potential utilization improvement of the grid connection for the CPO up to 75%.
3. Intelligent Charge Station which dynamically optimizes the actual power output of both sockets of the charge station.
4. An intelligent meter infrastructure collecting usage data per 15 minutes of both the LV-Grid as of the Charge Stations.
5. An advanced communication infrastructure (based on open protocols) for interaction between DSO, CPO, Driver (MSP) and Charge Station

The project will run on 200 key locations of the Amsterdam charging infrastructure. Historic data shows these charge stations are repeatedly used by the Tesla Taxis and Car2Go electric vehicles. The study locations will be intensively measured and monitored to determine the benefits for the user, CPO & MSP (Nuon), DSO (Liander) and City of Amsterdam. Based on the large historic dataset, Amsterdam is uniquely qualified to make predictions for mass market effects and impact. When proven successful, the results of the project will be discussed with regulation bodies to adapt law regulations.

2. Preliminary results

At moment of writing of this paper, the pilot is still work-in-progress. As a result, in this paper only the first preliminary results can be shared. During EVS30 conference in October, the project team will share the latest available results.

2.1 Problem definition

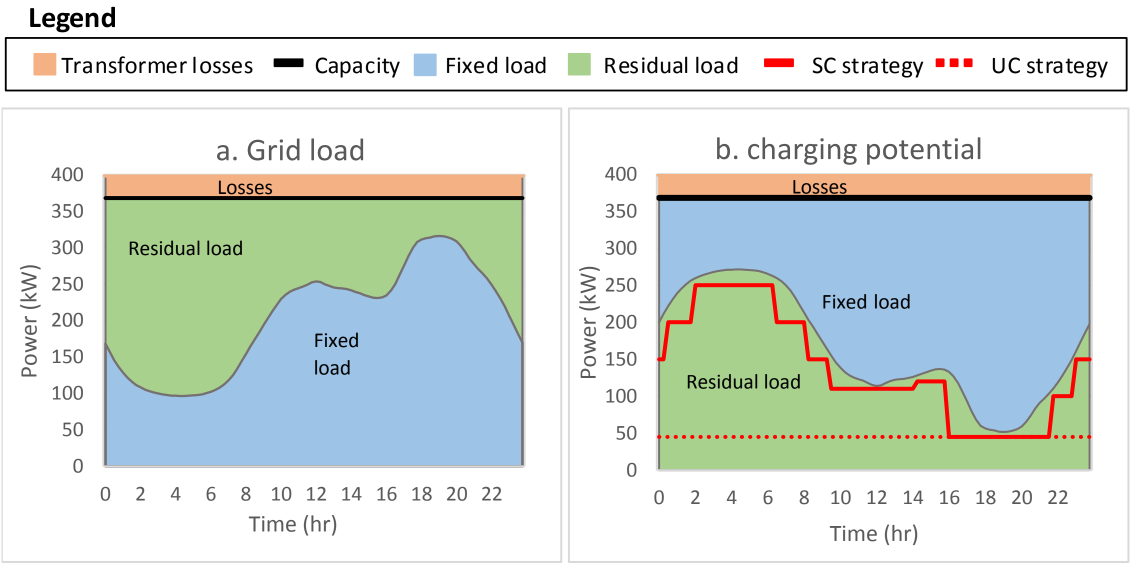
In recent studies, concerns regarding grid functionality due to the rapid diffusion of PV capacity and EVs in urban areas have been raised (Mwasilu, 2014). However, the implementation of smart charging measures has the potential to mitigate these risks, and postpone or avoid grid reinforcements (Eising, van Onna & Alkemade, 2014). De Haas (2016) has identified that in residential areas in Amsterdam increasing numbers of EVs will lead to grid congestion within a few years, whereas the diffusion of PV may lead to grid overloads on the long term.

Since electricity demand and charging patterns differ per neighbourhood, the implications and potential of the introduction of controlled charging also varies per location (see info box 1). Moreover, the opportunity exists here to vary controlled charging schemes per charging point in order to optimize the local grid management. These schemes comprised of local static smart charging profiles, and are in the remainder of this research be referred to as smart charging (SC). In addition, the application of SC will enable the opportunity for effects on the electricity demand and, therewith, sets a first step towards a supply-driven electricity system.

Info box 1. The potential of smart charging

To illustrate the potential of smart charging, an example of the grid load on a transformer substation found in a typical neighbourhood is represented in figure 2.a (NEDU, 2016; WEBGIS, 2016). Here, the fixed load represents the daily electricity demand in the neighbourhood. The residual load is the unused grid capacity, which is the difference between the capacity and the fixed load. When an UC strategy is applied in this neighbourhood the maximum charging power is bounded by the minimum available capacity during the day. However, when a SC strategy is managed the charging point power changes during the day. Consequently, this allows one to tap the unused grid capacity and use the grid more effectively (figure 2.b).

Figure 1. Potential of smart charging



The potential of SC to charge EVs depends on grid constraints and EV driver demands. In this research the impact of the implementation of SC on the grid and the EV driver is considered. Moreover, the potential of SC is assessed by comparison with the current EV charging strategy applied, which is uncontrolled charging (UC). Subsequently the aim of the research is to answer the question:

What is the potential of SC to meet increasing EV charging demands, while considering LV grid constraints in three different typical residential neighbourhoods in Amsterdam; and what is the consequent impact on different EV driver groups?

The research focuses on three specific neighbourhoods in Amsterdam. At these locations the impact of EVs on the local grid and the potential of SC to prevent grid overloads is assessed. On the basis of the results, more general recommendations are given that apply to other neighbourhoods as well.

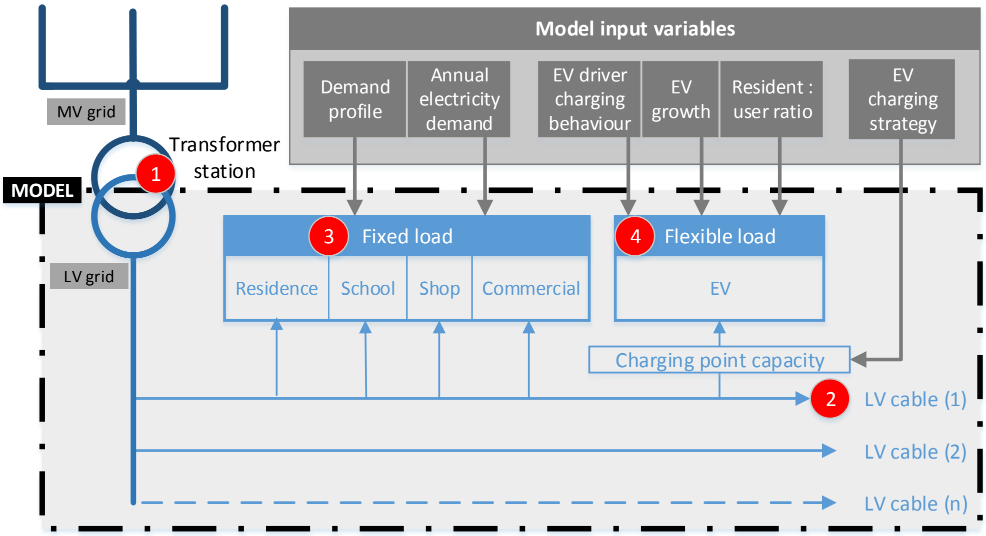
The research focuses on the potential of SC on the LV grid and the electricity supplying transformer separately. The potential impact on higher voltage level grids is not considered.

In this research all EVs are considered. However, as the market share of FEVs is expected to increase significantly in the next few years, whilst the market share of PHEVs is expected to decrease (Liu, Dow & Liu, 2011), emphasis is laid on FEVs. The number of PHEVs are already found to be decreasing in the Netherlands (RVO, 2017). Moreover, focus is laid on the consumer impact of FEVs as PHEVs do not require a charged battery in order to drive (EV Database, 2017).

The EV charging data that is employed in this research is derived from the available data gathered by the Amsterdam University of Applied Sciences (EV Dataset, 2016). This database includes the charging sessions of all EVs at all public charging points in Amsterdam, Den Haag, Utrecht, Rotterdam and the Amsterdam metropolitan area since January 2014.

2.2 Methodology

Find below a schematic overview of the methodology.



This research will focus on the grid impact of EV charging on the LV cable and the MV to LV transformer station. As a result, the parent MV and HV networks are not considered, and therefore not included in the model. In this section the basic model components and principles are discussed first. This is followed by a description of the input variables of the non-static model components. The mathematical method applied in this model is linear programming (LP). This method is applied since the key operating functions describe linear relationships. Moreover, LP is considered to be adequate to deal with the provided data, the LV grid and all load components (Richardson, Flynn & Keane, 2011).

2.3 Neighbourhood selection

The research aims to examine the impact of the implementation of SC by considering three different neighbourhoods in Amsterdam. At this moment, the city has over 1,000 charging points. Since each study location considers the LV cable and transformer substation that is connected to a charging point, multiple charging points can be present in one study location. Hence, there are hundreds of potential study locations. The first research step was to select three adequate and representative locations. Based on academic literature and consultation with experts from ElaadNL, the Municipality of Amsterdam, Liander and Nuon, two requirements and three criteria have been set to complete this selection.

Next, all potential study locations were tested on these two requirements. This was achieved by considering literature and the EV charging history (EV dataset, 2016). Thereafter, the neighbourhoods that met both requirements were examined on the three criteria set. This evaluation was done by consulting the EV dataset (2016), data available from WEBGIS (2016) and academic literature. The final step in completing the neighbourhood selection considered a discussion of the criteria scoring with the experts from ElaadNL, Municipality of Amsterdam, Liander and Nuon.

The districts with the highest EV charging demand at this moment and that show the strongest potential for a demand growth in the next few years are Apollobuurt, Museumkwartier and Nieuw-West (Van den Hoed et al., 2013; & Geerts et al., 2016). The selected study locations are:

1. Raamplein, Centre
2. Van Eeghenstraat, Museumkwartier
3. Baden Powellweg & Willem Heselaarsstraat, Nieuw-West

2.4 Data input

This chapter presents the data input of the model used.

2.4.1 Fixed load

In order to determine the fixed grid load on the LV cables and the transformer substations, the electricity demand profile per user type must be known. This profile is established by considering the average annual electricity demand of the consumer and the corresponding electricity demand patterns available from NEDU (2016). The average annual electricity demand per consumer can be found in table below

Consumer	**Annual electricity demand (kWh)**
Residence	2,970
Small business	10,000
Shop	35,000
Hospitality	9,360
School	35,000

The demand patterns drafted by NEDU (2016) are employed to set fixed daily electricity demand profiles per user type. These profiles are drafted every year for residences and commercial users. The electricity demand profile per user is considered for the winter and the summer period in order to establish the maximum fixed grid load that would be experienced throughout the year. Based on the annual electricity demand and the electricity demand profiles presented above, a daily electricity demand profile for winter and summer days is composed per user type. the limitations of the grid are more likely to be reached or will be reached sooner during the winter. Since this research aims to explore the limitations of the grid, in the remainder of this study only the fixed electricity demand found in the winter will be considered.

2.4.2 EV characteristics

At this moment battery capacities of PHEVs and FEVs differ significantly between different vehicle models (see table 5). In this research the assumption is made that all future PHEVs charge with a power of 3.7 kW and the FEVs charge at 11 kW. This is supported as anno 2017 virtually all PHEVs charge with a maximum power of 3.7 kW. The share of FEVs that are capable to charge with a power of 11 kW on public charging points is between 60 and 70% (RVO, 2017). However, this share is expected to increase in the coming years (Cuijpers et al., 2016).

2.4.3 EV charging behaviour

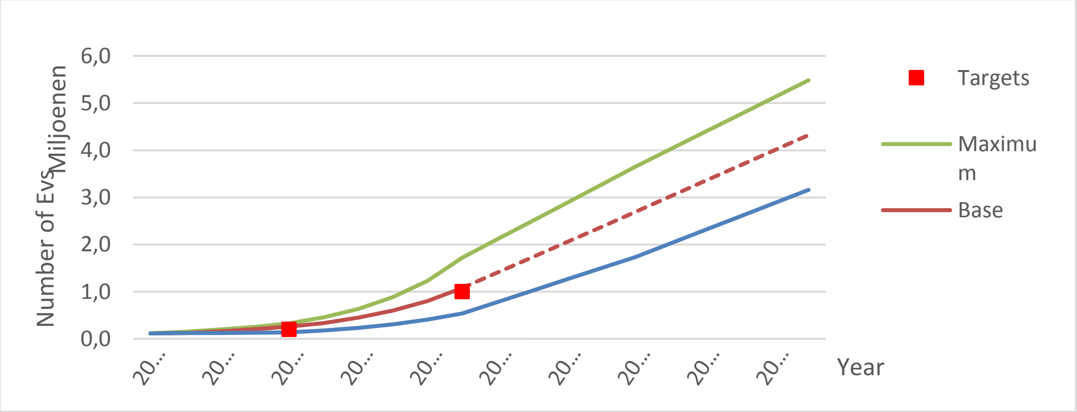
The characteristics of the charging behaviour of every EV driver is unique. However, in research EV drivers are often categorised into typical EV driver groups (Helmus & Van den Hoed, 2015). To establish the impact of SC on the EV driver, it is paramount to make a distinction between these EV drivers (Geerts et al., 2016). Helmus & Van den Hoed (2015) identified five different types of typical EV drivers, residents, commuters, visitors, taxis and car sharing. For both taxis and car sharing no consistent charging patterns can be identified from the dataset. Consequently, these groups are not individually considered in this research and included in the EV driver group others. On the basis of this information, each driver in the EV Dataset (2016) is allocated to one of the four EV driver groups.

EV driver	Arrive between	Leave between	Session duration (hr)
Resident	17:00 – 22:00	7:00 – 12:00	Approximately 14 hours
Commuter	7:30 – 9:00	17:00 – 20:00	Approximately 8 hours
Visitor	9:00 – 16:00	10:00 – 19:00	Less than 8 hours
Other	All day	All day	-

2.4.4 EV growth

In this research three different scenarios for EV growth are considered, a base growth scenario, a minimum growth scenario and a maximum growth scenario. In all the scenarios the number of FEVs and PHEVs at the 31st of December 2016 forms the starting point (RVO, 2017). Per scenario the estimated number of EVs is subdivided into the amount of FEVs and PHEVs. However, more information regarding the charging and battery characteristics of these vehicles is unknown. In general, it is expected that an increasing number of EVs will charge on three phases and the capacity of EV batteries will grow (Cuijpers et al., 2016).

EV growth scenarios



In this research the EV growth estimated by Steinbuch (2017) is considered as the base scenario. This is supported as the EV growth predicted by Steinbuch meets multiple targets set by the Dutch government. These targets include an EV fleet of 200,000 and 1,000,000 vehicles in 2020 and 2025 respectively (ECN, 2016). The minimum scenario is based on the minimum EV growth scenario presented in the Ecofys report “Toekomstverkenning Elektrisch Vervoer” (appendix III; Cuijpers et al., 2016). The scenario is described as the business as usual scenario and considers a slow energy transition and a limited car sharing economy. The maximum scenario is also obtained from the Ecofys report. This scenario considers a fast energy transition and experiences the most extreme EV growth according to Cuijpers et al. (2017).

2.4.5 Smart charging strategies

In order to establish the grid impact caused by the introduction of SC at this moment, the grid impact due to the implementation of standardized SC profiles is reviewed. In accordance with the Smart Charging Project Amsterdam, in this research two different SC profiles are considered (see table).

Time span			**Neighbourhood with low fixed load (Amperage per phase)**		**Neighbourhood with high fixed load (Amperage per phase)**	
			Week	Weekend	Week	Weekend
00:00	-	07:00	35	35	35	35
07:00	-	08:30	30	35	20	25
08:30	-	17:00	35	35	35	35
17:00	-	17:30	20	30	12	12
17:30	-	19:30	20	30	6	12
19:30	-	20:00	20	30	12	12
20:00	-	00:00	35	35	35	35

In consistency with the project the first profile is drafted for neighbourhoods with a relative low fixed grid load, whereas the second profile is assigned to neighbourhoods with a relative high fixed grid load. This distinction is made as neighbourhoods that experience a relative high fixed grid load have a greater need to reduce peak loads compared to so called low load neighbourhoods.

2.5 Preliminary Outcomes

2.5.1. theoretical EV charging

The theoretical EV charging potential considers the amount of EVs that can be charged without causing an overdemand on the LV cable nor the transformer substation. Moreover, this defines the boundary for EV charging on the local grid.

The theoretical charging potential in terms of number of FEVs that can be charged at week and weekend days can be found in table below. In general, the results in the table imply a significant potential for SC. For the theoretical charging potential of SC it is important to note that an average EV charging demand of 16.8 kWh per day is considered per EV.

Table: Number of FEVs that can be charged considering grid constraints at weekdays

Case study		All day (0:00-23:59)		Resident 17:00-8:00		Commuter (9:00-17:00)	
		UC	SC	UC	SC	UC	SC
Raamplein	LV cable	13	217	13	93	13	62
	TS	70	1,381	70	632	74	374
Van Eeghenstraat	LV cable	9	177	9	80	10	48
	TS	7	387	7	249	10	56
Nieuw-West	LV cable (BP)	2	125	2	62	6	33
	LV cable (WH)	9	188	9	83	11	54
	TS	20	665	20	305	23	195

Table:. Number of FEVs that can be charged considering grid constraints at weekend days

Case study		All day (0:00-23:59)		Resident 17:00-8:00		Commuter (9:00-17:00)	
		UC	SC	UC	SC	UC	SC
Raamplein	LV cable	13	219	13	93	13	63
	TS	73	1,416	73	631	74	390
Van Eeghenstraat	LV cable	9	180	9	80	10	49
	TS	14	492	14	253	15	114
Nieuw-West	LV cable (BP)	2	121	2	61	5	30
	LV cable (WH)	9	187	9	82	10	52
	TS	19	637	19	300	19	167

For the study locations Raamplein and Nieuw-West it is found that the transformer substation can charge a multitude of the FEVs that the LV cable can host. However, this does not apply at the Van Eeghenstraat where the number of FEVs that can be charged by the LV cable and transformer station are very similar, especially during weekdays.

Finally, the table shows that the FEV charging potential is very similar for week- and weekend days. However, the transformer substation at the Van Eeghenstraat is an exception to this, as the charging potential is significantly higher during the weekend. This is explained by the relative high share of businesses and shops that are connected to the substation

2.5.2 EV charging in the future

In this section the local grid impact of an increasing number of EVs will be presented for the period 2016 until 2035. As expected, for all the study locations it can be found that the occurrence of an overdemand will be postponed if a SC strategy would be managed instead of a UC strategy.

Table: Year when local grid load exceeds grid capacity for UC and SC

		Min scenario		**Base scenario**		**Max scenario**	
		UC	SC	UC	SC	UC	SC
Raamplein	LV cable	2035	>2035	2031	>2035	2029	>2035
	TS	2034	>2035	2030	>2035	2028	>2035
Van Eeghenstraat	LV cable	2035	>2035	2031	>2035	2029	>2035
	TS	2025	2035	2022	2031	2021	2029
Nieuw-West	LV cable (BP)	2024	2033	2021	2029	2020	2027
	LV cable (WH)	>2035	>2035	2032	>2035	2029	>2035
	TS	2026	>2035	2024	>2035	2023	2034

2.5.3 The impact of smart charging on the EV driver

The overall impact of the introduction of SC is presented per location in table below. From the table it can be observed that the implementation of SC has an effect on about half of all the charging sessions.

Table. Share of affected sessions due to smart charging

	Raamplein		**Van Eeghenstraat**		**Nieuw-West**	
Sessions affected (% of all sessions)	51.2		44.2		58.4	
Faster/slower (% of all sessions)	23.2	28.0	10.4	33.8	24.9	32.5
Advantage/disadvantage (% of all sessions)	4.2	5.0	2.2	3.6	0.9	5.2
Advantage/disadvantage (% of all FEV sessions)	8.9	5.5	14.9	4.9	0.5	4.6

The amount of users that experience a disadvantage due to the implementation of SC is found to be significantly greater than those that experience an advantage. However, when the FEVs are filtered, at the Van Eeghenstraat and Raamplein a greater amount of EVs is observed to encounter an advantage. There are two main reasons for this.

1. First of all, the increasing power capacity of the charging point will only directly benefit the EVs that are capable to charge fast, which holds that the EV is able to charge with a power of 22 kW. This effect is evident although at this moment only a limited number of FEVs can charge with a power of 22 kW.
2. The second reason is supported as other EVs will only profit from the increasing power capacity when two EVs, from which one is able to charge on three phases, are simultaneously charging at the same charging point.

The positive impact of SC on EV charging is expected to increase in the next few years as the number of FEVs that are able to charge on three phases will increase. Consequently, more EV drivers will experience an advantage. Moreover, as the share of three phase charging FEVs increases, the magnitude of the advantage per session is also expected to increase. This would especially benefit those that have relative short sessions at any time during the day (until 17:00) and after 20:00, as here the extra available charging power capacity at the charging point can be deployed.

On the other hand, the absolute negative effect of the implementation of SC may also increase, especially on the long term. This is explained as three phase charging EVs will experience a higher absolute decrease in the charging speed when the charging power is reduced.
Finally, an increasing amount of EVs directly leads to an increasing grid load for EV charging. Consequently, over the years the relative amount of EVs from which the charging demand will be postponed and the amount of time with which charging is postponed is expected to increase. Especially among those that charge between 17:00 and 20:00. However, it is important to keep in mind that when this moment dawns, grid failure would already have occurred when an UC strategy would have been maintained.

2.6 Conclusions

This research results show a significant theoretical potential for SC compared to UC. Moreover, in theory the implementation of SC has the ability to increase the number of EVs that can be charged on the local grid with at least a factor 5 during the day (commuters) and a factor 9 at night (residents).
The EV charging behaviour is found to differ significantly per case study. Nevertheless, at this moment three distinctive peaks in the EV charging demand have been identified. The first peak is mainly caused by commuters and visitors, and observed at the Raamplein and Van Eeghenstraat around 10:00 in the morning on weekdays. The second peak is in varying degrees found at all locations and overlaps with the existing evening peak on both week and weekend days. Here, the EV charging demand is mainly caused by residents, with a smaller contribution by visitors and others. Around midnight a third peak can be observed. This peak is found at both locations in Nieuw-West on week and weekend days and induced by the EV driver group others. In Nieuw-West this peak is assumed to be induced by taxi drivers.

An increasing number of EVs in these neighbourhoods is expected to cause grid overloads at both the LV cable and the transformer station. Nevertheless, adequate grid design would cause the transformer station to experience overloads first at all study locations. Moreover, at each location these overloads are most likely to occur first during the evening peak at week or weekend days.

From the results it is obtained that SC has the ability to postpone grid reinforcement with at least seven years depending on the location. This can be achieved by effectively deploying the local residual grid capacity. Nevertheless, it is found that this comes at a cost of the EV driver. More specifically, the EV drivers that encounter these effects are merely visitors and others. Commuters and residents do not experience an advantage or disadvantage due to the introduction of SC. These two EV driver groups dispose of a significant potential for SC by postponing the EV charging demand.

When considering the charging demands of the EV driver groups, the potential for SC decreases. Nevertheless, without causing any disadvantages for any EV driver, SC still has the potential to postpone the need for grid reinforcements with two to three years at the location considered. This number may be expected to increase, as the SC affects the FEV drivers more positively and less negatively compared to the average EV driver.

In conclusion, successful implementation of smart charging has the potential to postpone the need for grid reinforcements by at least seven years. However, this is found to cause almost 5% of the EV drivers to encounter charging delays. At this moment, adequate implementation of a smart charging strategy that prohibits this effect has the potential to postpone the need for grid expansions by two to three years. Additionally, a changing charging behaviour of visitors and others due to increasing battery capacities reduces the EV charging demand during peak hours. This would increase the potential of smart charging without affecting the EV driver.

Authors

Frank Geerts is Digital Innovator eMobility at Alliander and program manager Smart Charging at ElaadNL. He realizes IT innovations and solutions to facilitate and accelerate eMobility. He is currently engaged in the development of several Smart Charging solutions, fe in Amsterdam testing a new Grid Connection with flexible capacities and in the Utrecht area with Smart Solar Charging based on V2G. Before, Frank was project leader within the Mobi Europe project, which among other things has realized a smart charging plaza in the Amsterdam ArenA. At that time he was also IT manager at Allego. Frank plays an active role in the open standardization of e-mobility at national and international level. He is regular speaker on conferences throughout the world. He has more than 15 years in the energy sector, in different roles and for several energy companies in the Netherlands.

Bart Vertelman is working as a Program Manager Electric Mobility for the City of Amsterdam. On behalf of the city council, he received the E-visionary award in June 2016 at the World Electric Vehicle Symposium in Montreal. Bart and his team have been promoting the use of electric vehicles in the city, putting an effective public charging infrastructure in place and promoting the transition to electric mobility. Amsterdam wants to be an attractive and healthy, sustainable city. The ultimate goal is to become a zero emissions city by 2025, with opportunities for everyone to adopt electric transport. Bart focusses currently on the rapid increase of EVs and local solar and wind power. These two developments can have a significant impact on the city's network but may also reinforce each other and thus contribute to the necessary energy transition.

Marjolein Kelder is working as Project manager at Nuon Vattenfall. She has been active for the Emobility department since 2013. Nuon Vattenfallinvested more than 125 million euro's in electric transportation since 2009. Nuon offers charging solutions to private/leasedrivers at home, businesses and municipalities and is leading when it comes to public solutions and service. Every month about 11.000 electric drivers use the over 2.700 charging points that are being managed by Nuon and installation partner Heijmans. Because of these charging points 3,2 million emission-free kilometers per month are made.