European Distribution System Operators for Smart Grids

Smart charging: integrating a large widespread of electric cars in electricity distribution grids

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Contents

Key Messages

1. **Enable DSOs to use smart charging of electric vehicles (EVs)[1].** DSOs should be able to access smart charging in order to manage local grid congestions and reduce costs whenever this is cost-efficient – either through smart capacity network tariffs, variable capacity contracts and/or services procured via a flexibility market.

2. **Make charging infrastructure ready for flexibility.** Charging infrastructure should be equipped with the necessary technical and communication devices to manage the charging process particularly at the low-voltage level, where most of the charging is taking place. The additional electricity consumption (kWh) from charging EVs is not the challenge, but the instantaneous capacity demand (kW) on low-voltage grids.

3. **Engage in smart grid planning and development.** DSOs need to actively engage in the planning and development of LV/MV networks to effectively forecast and integrate electric vehicles' loads and other flexible resources. DSOs need increased visibility about charging stations' location and electric vehicle capacity requirements in order to predict when and to which extent they can use smart charging.

4. **Invest in new grid tools and methods.** DSOs will need new instruments and grid tools to increase the visibility of network constraints, enable flexibility markets and thus operate their networks efficiently. DSOs need more investments in advanced metering/sensors, distribution automation and dynamic charging technology to monitor the grid in near real-time through smart meters and other control devices.

5. **Ensure interoperable ICT standards for smart charging.** Interoperability of data and coordination between all charging infrastructure and e-mobility management systems is critical to communicate with all parties. A key issue is communication on available capacity between the DSOs' and, respectively, the charging point operators' control systems, as defined in open standard interoperability protocols[2].

6. **Empower customers to participate in smart charging.** Customers' benefits may include an opportunity to reduce their mobility costs by trading time flexibility with

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[1] CEN-CENELEC definition of smart charging 'when the charging cycle can be altered by external events, allowing for adaptive charging habits, providing the EV with the ability to integrate into the whole power system in a grid-and user-friendly-way. Smart Charging must facilitate the security (reliability) of supply and while meeting the mobility constraints and requirements of the user.' CEN-CENELEC-ETSI Smart Grid Coordination group, Smart Charging of Electric Vehicles in relation to Smart Grid, May 2015

[2] OCPP (Open Charge Point Protocol), OSCP Open Smart Charging Protocol), OpenADR, ISO / IEC 15118, IEC 63310

service cost savings. Financial incentives can be offered through smart network tariffs/variable contracts when shifting charging outside peak/congestion hours.

7. **Set the right standards to reduce power quality issues.** The effects of AC and DC loads of EVs related to harmonics, asymmetry and voltage impacts need to be further assessed in order to maintain the integrity and balance of the distribution system. DSOs should initiate standardised requirements aligned with regulation governing the electricity network to reduce and mitigate power quality issues.

8. **Optimise high power charging for users' convenience.** In case of quick and ultra-fast chargers (>350 kW), the impact on the network can be considerable. A proactive dialogue with DSOs could speed up the installation of these chargers at MV connections, as well as maximise renewables and/or integrated storage capacity.

Introduction

The energy transition has a profound impact on electricity distribution networks which have been designed several decades ago, largely based on the principle ‘generation follows demand’. Changing from predictable demand and stable power flows in electricity networks, to more dispersed and decentralised loads and generation is challenging this traditional approach.

On the supply side, variable decentralised generation causes more fluctuations and even reversed flows in electricity networks. On the demand side, high demand loads such as electric vehicles (EVs) which tend to have coincidental effects on distribution grids may cause sharper instantaneous capacity needs at certain times. This means that local grid congestions and voltage constraints will occur more often, while DSOs are required to maintain the system at least as stable and as robust as it is today.

The result is an increasing need for flexibility in distribution grids. In their role as neutral market facilitators and active system operators, DSOs should be able to use all forms of flexibility and facilitate markets, including smart charging in the context of electro-mobility and be rewarded for its use. Flexibility on the EV demand side, or smart charging, is a precondition for electro-mobility to fully take off, and for grid users to remain within the boundaries of their (smart) capacity connection.

By adjusting the charging to periods of lower electricity demand, or supply peaks from renewables production, smart charging has the potential to minimise new investments and upgrades in electricity grid infrastructure, while facilitating electro-mobility markets and customers’ participation.

Whereas this paper focuses on electro-mobility, many of the challenges and solutions described are generic for all high load applications and should be implemented accordingly. The paper’s findings build on the results of a survey carried out among EDSO members in 2017. It includes responses from 17 DSOs from 14 countries: AT, BE, CY, CZ, DE, ES, FI, GR, IT, NL, PL, PT, RO, SE.

Netz Niederösterreich	AT
Eandis	BE
Ores	BE
EAC	CY
ČEZ Distribuce	CZ
PRE Distribuce	CZ
Netze BW	DE
Stromnetz Berlin	DE
Iberdrola España	ES
Caruna	FI
HEDNO	GR
Enel	IT
Enexis / ElaadNL	NL
Energa-Operator	PL
e-distributie Muntenia	RO
E.ON Sverige	SE
EDP	PT

I. Electric vehicle market developments

In recent years, electric vehicles[3] saw a rapid growth when facilitated by policy support, mostly due to their multiple benefits in the areas of transport decarbonisation, air pollution and energy efficiency improvements. Falling battery costs and longer driving ranges, more vehicles available with fully or partly electric motor, and the deployment of charging infrastructure compounded this trend. EVs are also soon expected to be cost competitive with fossil fuel cars even without tax reliefs[4].

Current and future developments of EV market shares

In addition to being emission-free when driving, electric vehicles produce less carbon dioxide than diesel or petrol cars, even when considering today's energy mix and car production[5]. Additionally, EVs are already more energy efficient than combustion engine cars which have an efficiency of up to 40% on the highways, and of only about 10% in cities – with the rest being lost as heat.

Responses from EDSO members show that current EV shares vary between 0% and 2%. This is in line with the average PEV market share in Europe standing at about 1.4% in terms of new car registrations[6]. While EV adoption remains nevertheless small, almost half of EDSO's survey respondents believe this would grow to at least between 10% and 20% or more by 2030. Stricter CO_2 emissions regulations and recent bans on fuel vehicles announced in cities are likely to prompt a faster EV uptake[7].

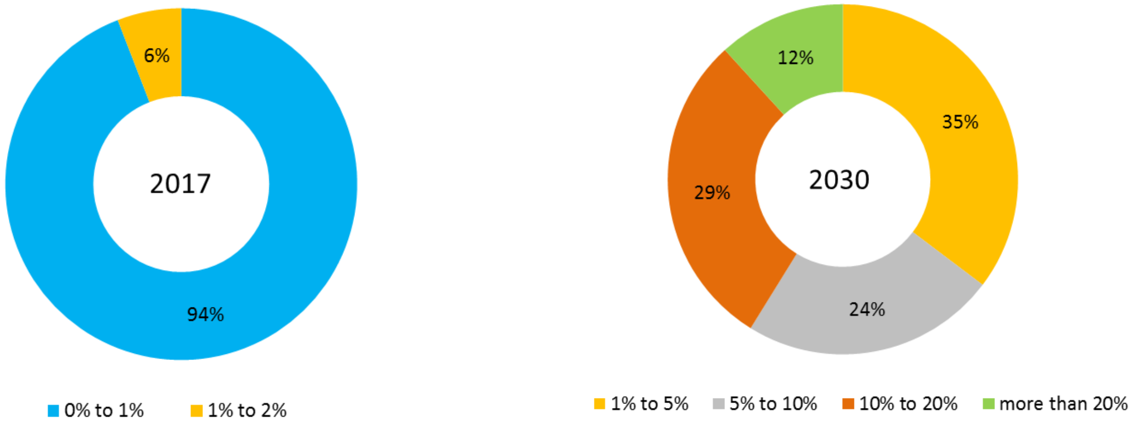

Figure 1: Electric vehicles market shares in 2017 and 2030 (estimated) (%)

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[3] In this paper, EVs are considered as battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs)
[4] Electric car costs forecast to hit parity with petrol vehicles, Financial Times, May 19, 2017
[5] http://www.theicct.org/global-ev-2050-ghg-mitigation-potential
[6] http://www.eafo.eu/europe
[7] France to ban sales of petrol and diesel cars by 2040, The Guardian, July 6, 2017

II. Charging infrastructure needs for electric vehicles

Whenever they are connected to the electricity grid, electric vehicles are dependent on a charging station - at home, at work or at a public charging station. As most of the charging will be carried out in private areas, distribution grids at the low-voltage level will be mostly affected by the uptake of electric vehicles. In the future, different options for load management should become possible concerning charging with normal and medium power in both residential and commercial areas.

a. Overview of charging power levels

The charging of electric vehicles will therefore depend on the power supply from the distribution grid i.e. the voltage levels and the numbers of phases from the mains, as well as the current and future capacity levels of the vehicles' battery. The table below shows a default category of maximum power levels for recharging electric vehicles existing today across EU countries.

A) Normal power Private and semi-public	**AC**	< 3.7 kW (10 - 16 A) 1phase
B) Medium power Private and semi-public	**AC**	3.7 kW (16A) – 22 kW (32 A) 1 or 3phase
B) High power AC Public and semi-public	**AC**	> 22 kW (> 32 A) 3phase
C) High-power DC Public	**DC**	> 22 kW (> 32 A)

Table 1: Charging power levels (kW)[8]

Domestic chargers (1 phase, AC) usually start with 3,7 kW and can be even up to 7 kW or 9 kW in some countries. As for on-board EV chargers that carry a power higher than 3.7 kW, they should be 3-phase to avoid power quality issues. In Belgium and the Netherlands, the most common charging power is 11 kW for one-charging connection used for private, workplace and public locations. By 2030, AC power levels are expected to be only slightly increasing as they will be limited by the existing connection points. DC fast chargers will however grow to more than 150 kW (~up to 300 kW).

Year	Fast power DC chargers
2016	60 kW (300 km/h)
2020	100 kW (500 km/h)
2025	200 kW (1,000 km/h)
2030	250 kW (1,250 km/h)
2035	300 kW (1,500 km/h)

Table 2: Estimated development of fast charging capacity (Source: Ecofys)

b. Private and public charging today and in the future

According to our survey's results, EV drivers will rely on home and office chargers for more than 80% of the time. The rest will take place in the publicly accessible domain at public AC stations and charging plazas, and at faster speeds available to drivers charging at petrol pumps and service stations equipped

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[8] Charging power levels based on PlanGridEV, Final Report, February 2016 and as defined by M/468

with DC charging facilities. Charging in private parking lots and office buildings is consistent with a large majority of users' needs, as this falls within the short distance trips of European drivers (40 km, 80 km two-ways) which can already be managed by state of the art EVs today.

This, combined with lower costs for charging, explains why charging in private areas is a more cost-effective solution for charging electric vehicles. By 2030, as owning an EV will become more commonplace even for those drivers without the possibility to have a charging point installed at their home, it is expected that the demand for (semi-) public charging will rise. The lack of access for home charging i.e. parking facilities such as private garages or driveways is a practical limitation which can differ from country to country, rural versus urban, or even from district to district[9].

The need for (semi-) publicly accessible charging is further intensified by an increasing trend towards using more battery electric vehicles (BEVs) instead of plug-in hybrids (PHEVs), which are more dependent of being able to charge at locations when parked. Moreover, as the BEV will become the primary car of a household, high power charging may provide an additional option to satisfy customers' mobility needs (i.e. for day trips and holiday travel). In the further future, the uptake of electric car sharing and autonomous vehicles, relying on dedicated charging infrastructure, may also affect the growth of public (fast) chargers to provide electricity for a larger number of cars[10].

Although the first batch of EVs will be owned by people who own a private parking location, to ease the conversion of the rest of the vehicles will require a massive deployment of recharging points. This will enable most people to charge each time the vehicle is parked, every day at night or at work without having to wait for fast charging to deliver full charge. In the long-run, it is more convenient to have a large number of normal/medium power chargers, than having a low number of high power chargers.

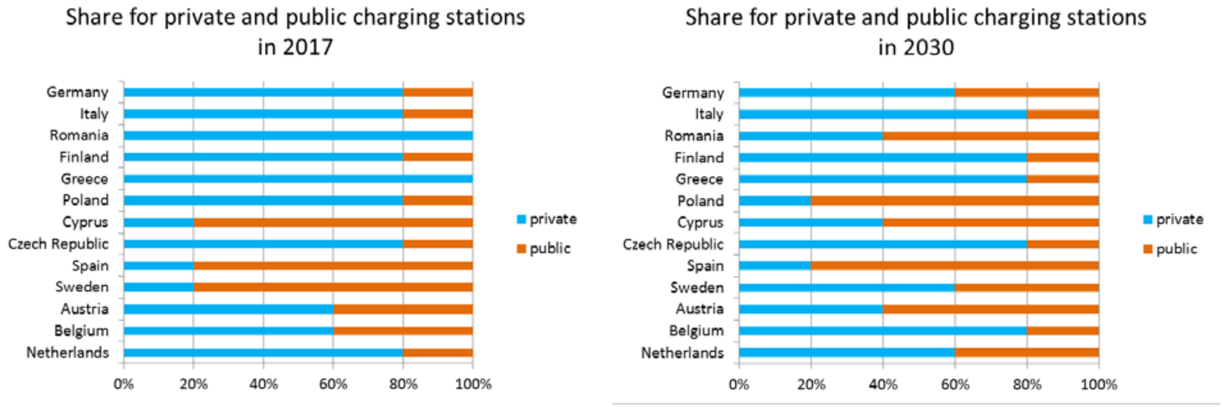

Figure 2: Share of private vs public charging stations (%)

Today, more than 80% of EV charging is carried out at residential and workplace premises. Charging at home, parking lots near home and office buildings every time the vehicle is parked during the day and night is often the most convenient and cost-effective solution. AC charging with normal/medium power opens up more possibilities for smart charging than DC charging.

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[9] Ecofys, Eindrapport Toekomstverkenning elektrisch vervoer, December 2016

[10] Ecofys, Eindrapport Toekomstverkenning elektrisch vervoer, December 2016

c. Market models for public charging

In most countries, the ownership and the operation of public charging stations is carried out by a number of players on a competitive basis (i.e. e-mobility service providers, charging point operators (CPO), municipalities owning the stations but outsourcing the operation to independent charging station operators)**.** However, DSOs still play a significant role in those countries where they can help to kick-start the EV market by deploying charging infrastructure as a regular distribution network asset.

In these cases, DSOs may technically operate the charging infrastructure, including owning the assets and providing the metering service. But the commercial operation and the electro-mobility service (electricity and roaming services) are a clear retail activity. The DSO ownership model is relevant in nascent markets, or where commercial parties are reluctant to install a sufficient number of charging stations (i.e. low-density/wide geographical areas, or those with underdeveloped public transport).

In Cyprus and in Greece, where the regulatory framework is not yet completely defined, DSOs have been responsible for rolling-out publicly accessible charging infrastructure in private areas. Italy tested a DSO ownership model mixed with a market approach, but it is expected to move towards competitive markets. In Spain and Portugal, the infrastructure has mostly been based on public subsidies, where charging is usually provided free of charge as part of pilot projects[11]. In Spain, most DSO are proposing a model where they deploy the charging infrastructure while the commercial operation is open to every retailer. In the Czech Republic public chargers are built, owned and operated by competitive markets mostly pushed by the three biggest energy utilities. DSOs are only asked for connection.

In the Netherlands, the market is fully tested for both private and public recharging, combined with tenders of cities and regions. Investors were generally more successful in fostering sustainable business cases in the private and semi-private terrain rather than in public areas. The aim is to foster the creation of a two-way business model: charging stations which can deliver both charging and smart charging/flexibility services to multiple parties (self-balancing for the owner of the building/terrain, congestion management services for the DSOs, frequency services for the TSOs, and portfolio balancing for balance responsible parties). In the public domain, as a valid business model has not yet reached maturity due to the higher costs of infrastructure (e.g. due to yearly connection charges), most regional governments are tendering for public charging stations.

In case of market failure for the provision of basic infrastructure or insufficient geographical coverage, member states should be able to commission DSOs with the installation and technical operation of charging infrastructure. This might also include owning the assets.

Irrespective of the ownership model in place, however, DSOs must be able to manage the impacts on their networks in an active way through the use of smart grids.

III. Electric vehicles' impact on distribution grids

The impact of EV charging will mostly affect the low-voltage distribution networks, as drivers will mostly rely on domestic or semi-public charging environments to charge their cars. As these networks were designed without predicting the arrival of the new EV loads, DSOs might need to invest in

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[11] In Portugal, an Electric Mobility Business Model is planned in 2017. Charging in the Mobi.E Network with a planned pilot network consisting of about 1,250 charging stations is free of charge.

conventional grid reinforcements if no load management is considered. This implies increasing the existing hosting capacity of transformers, LV lines and feeders to meet the increase in peak demand.

Cost calculations for LV grid investments can be different, and depending on the local situation, traditional grid reinforcements can be between four and ten times more costly than smartening the grid. However, conventional grid investments can still remain a viable option for certain LV networks that might anyways need reinforcements even without considering the uptake of electric vehicles (weaker rural networks or urban networks in the oldest districts of cities which were electrified first).

a. Expected demand and peak load from EVs today and in the future

Today, the low numbers of EVs across Europe do not yet pose significant problems in distribution grids. As their share will be rising in the coming years however, DSOs will need to improve their network operations to meet a higher instantaneous (peak) capacity demand. This will be needed particularly as most of the charging will be performed at the low-voltage levels. The limiting factor for the LV grid is the capacity of cables and transformers and other parameters such as voltage levels or asymmetry.

The additional demand from EVs measured in total consumption of energy over time (kWh) will not represent a critical factor for the DSOs, as this can be handled with the existing grid and generation capacity. However, in terms of power demand (kW) the additional loads can cause a significant higher peak load i.e. in case of charging resulting in simultaneous power demand on distribution networks.

The impact on the peak load will be critically dependent on how congestion is managed: if all EVs start to charge at the same hour (i.e. cars charge as soon as the drivers plug in on arrival at their destination or at a specified timeframe in case of large differences in the cost of energy at night), the impact will be much higher than in those cases where the charge is spread more evenly on the low demand period. The figures below represent the aggregated national increase by 2030[12] but the increase at already existing peak periods in local areas, per feeder, will be much higher as explained in section III b.

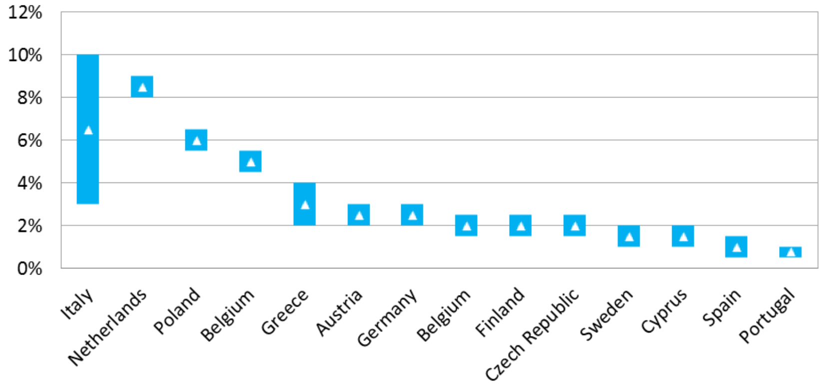

Figure 3: Estimated range of EV consumption vs. total electricity consumption in 2030 (%)

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[12] Figures 3 and 4 represent a representation of aggregated national increase in global consumption and peak demand as provided by EDSO respondents according to own methodologies.

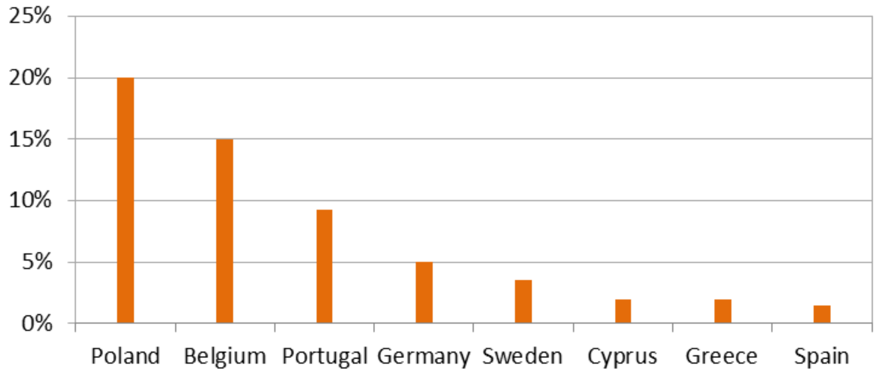

Figure 4: Estimated EV peak demand vs. overall country peak demand in 2030 (%)

Higher peak loads cause (relatively short-time) congestions on distribution grids, adversely impacting on voltage and network capacity. Overloads of network equipment can reduce the life expectancy of grid components. These can also lead to voltage fluctuations outside their designated margins causing consumers' devices to stop working. From the balance responsible point of view (TSO), a significant number of new quick start power plants may need to be ramped up to provide ancillary services.

Home recharging can have a significant impact on the low-voltage grid, as an electric vehicle can increase (peak) power demand within a twofold. The same goes for public AC chargers and charging plazas connected to the low-voltage grid. These stations show a high level of simultaneous usage, which causes increases in peak power demand in LV grids. If the charging power of publicly available AC chargers increases, DSOs will need more understanding and monitoring of their grid impact.

The challenge of congestion is not so direct/obvious for (ultra) fast chargers when connected to the MV grid which, in normal situations, contains enough capacity. The costs of these connections are based on the actual costs of making the connection. Thus, grid connections/extensions to facilitate (ultra) fast chargers are, in most countries, fully paid by the requesters of the connection. Since (ultra) fast chargers will in most cases have their own transformer, there are no other users that will be negatively affected by possible voltage fluctuations when charging starts at full capacity. The impact on the other side of the transformer (MV side) will be limited due to the high capacity of this grid.

DSOs will nevertheless need to be properly engaged and consulted to coordinate and facilitate the connection of (ultra) fast charging stations to the MV grids. Depending on the specific grid conditions, an impact might be considerable if there are several ultra-fast chargers with dedicated transformers close to each other and attached to the same MV connection/or in case of powering multiple electric buses at around the same time. This can also be an issue in networks where gas stations on the roads and motorways are connected to low-powered transformers (up to 250 kVA). In these cases, DSOs will have to upgrade transformers or even the whole MV feeder to handle the additional power.

The additional EV demand (kWh) can be handled with the existing grid capacity. The impact on peak demand (kW) is more critical, which happens in case of simultaneous power demand.

Since most congestions caused by EVs are expected to happen at the lower voltage grids, this might have a lesser impact on grid capacity at the medium-voltage level.

b. Impact of electric vehicles at the low-voltage (household) level

In the past, DSOs were able to estimate network capacity margins, and predict fluctuations in demand as aggregated load profiles of households and commercial sectors were highly predictable. Individual loads are hard to predict but aggregated demands are fairly constant which has led to a system where standardised load profiles were used to calculate the capacity needed for transformers and cables. With the uptake of variable renewables and electric vehicles, a growing and changing demand in network capacity is expected, as well as higher volatility in supply and demand curves.

As EVs are a large load in comparison to other household loads, they will increase overall power demand in low-voltage grids. EVs tend to have a higher simultaneity factor as drivers are likely to plug in their cars at the same time with existing loads, during evening or morning peaks, or when low tariffs start to apply (as most EVs have the capability to schedule the start time of the charge). For households, EVs can even double the peak, depending on the timeframe and the travel distance. The result is a higher coincidence factor on power demand that is different than for other household appliances.

The current tariff systems in most countries are not designed for a sharp increase of peak capacity demand to generate sufficient income for the necessary conventional grid extensions. While the available technical capacity of the DSOs' network could perhaps meet the demand for a few households, it will not be possible for all households on the same cable. Tariff systems for household connections (partly) based on a fixed calculated capacity (connection capacity based on historical standardised load profiles) and not the actual delivered power will no longer be sufficient in the future.

Example of a Dutch household

An average household in the Netherlands (electricity use of 3,500 KWh/year) with a three-phase connection of 25A each has a technical peak capacity of 17.3 kW, an average calculated peak capacity[13] of 4 kW and an average peak power demand[14] of 0.8 kW to 1.3 kW. This means that the aggregated load of a typical EV and the base load of households combined will lead to a peak capacity demand which is much higher than was foreseen (based on the grid planning rules of the past) and the underlying network can (in the future) not accommodate a lot of EVs with this charging pattern.

Average power demand

The average power demand of a Dutch household is 1.3 kW. Assuming an average charging capacity of 5 kW, 1 million EVs require 5 GW of charging power where the total Dutch power demand is 8 - 9 GW (with the potential of seven million EVs in the Netherlands, the power required is 35 GW).

Average usage of car

In the Netherlands, a car drives on average 37 km a day and thus stays still for an average of 23.5 hours. A 37 km trip requires about 8 kWh or about 2.5 hours using the lowest charge speed (single phase 16A, 3.7 kW). If the car stays still for 23.5 hours and 2.5 hours is needed to charge the car to achieve the average distance, a lot of variation in the charging time (starting time of charging) and speed (power level) is therefore possible. *(Source: Enexis)*

As seen above, EVs sharply increase the existing (household) peak demand particularly in residential areas. However, during the off-peak periods, which means most hours of the day and night, there is

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[13] With calculated peak capacity is meant the capacity that is calculated for net planning purposes including the coincidence factor, this calculated capacity is based on 70 households or more.

[14] Used peak capacity = the aggregated capacity used by households/ total number of households

enough capacity available on the grid. Different opportunities of spreading the EV peak demand (whether the EV is connected to a public charging station or behind a household connection) are now researched by DSOs. The potential for peak shaving / shifting is also investigated from the point of view of the existing tariff system. This exploration of 'regulatory flexibility' sets the limits for diversifying the current tariff system. Considering the impacts above, DSOs need the rights on flexibility management, and DSOs should be allowed to develop the tariff system in such a way that the right incentives are given with this new system. This can result in the following two options:

- Direct load control
- Incentivising customers by adapting the current tariff system and (in)direct control: adjusting tariff systems to come to flexibility agreements with customers, as well as correct and standardised ICT interfaces to activate (in)direct control based on the actual (congestion) situation in the grid. Buying services from a flexibility market can also fall in this option.

The realisation of both options is preferable considering the different circumstances in which flexibility is needed and rewarded. Customers' consent and acceptance of the different possible solutions of demand response/smart charging is also important, as this will be a voluntary process.

IV. Power quality issues related to EV charging

As with other electronic devices, EVs can cause power quality (PQ) issues for distribution networks. These need to be minimised by using advanced technology and the right standards. Power quality issues include harmonics distortion and voltages deviations that can overload distribution system components if not properly designed to mitigate these problems. Their effects will nevertheless strongly depend on several factors such as the charging location, and transformers and lines' capacity.

Power is delivered by voltage and current: everything concerning the quality of voltage of the grid is the responsibility of the grid operator. Everything that has to do with the current is the responsibility of the manufacturer of the product. When the disturbance in the current is high enough, it can have an effect on the voltage in the grid. For this reason, network operators are testing the power quality effects of EVs to investigate future impacts. EV charging must at minimum comply with harmonics and voltage levels as defined by existing norms EN 50160 and IEC 61000-3-2.

Product (Current, manufacturer responsible)

- **Reactive current.** An electric vehicle stores energy in a DC battery, thus energy needs to be converted from the AC of the grid to the DC for the battery. A general rule for convertors is that the cos phi value is not lower than 0.95 in order to avoid inefficient reactive power flows. The lower the cos phi value, the higher the amount of reactive current. Reactive current has to be tempered because it cannot be used to deliver power, but has to be transported via the grid (which causes (heat) losses and reduces the lifetime of equipment).
- **Harmonic currents:** Converting the energy from AC (energy in the network) to DC (energy in the battery) can cause harmonic currents. This type of distortion results in multiple sinus waves of frequencies higher than 50 Hz being distributed upon the 50 Hz sinus wave of the current, see figure 5. The higher the frequency of these harmonics, the more energy intensive they are and the more heat they generate in components. This can reduce the lifespan of grid assets, can make components like RCDs heating up and starting to "whistle" and (if strong enough) can influence the grid voltage (for which the DSO is responsible). CENELEC's band A (UNE EN 50065-1:2012) should be reserved for DSO communications purposes at low voltage networks and frequencies between 3 kHz - 148,5 kHz.

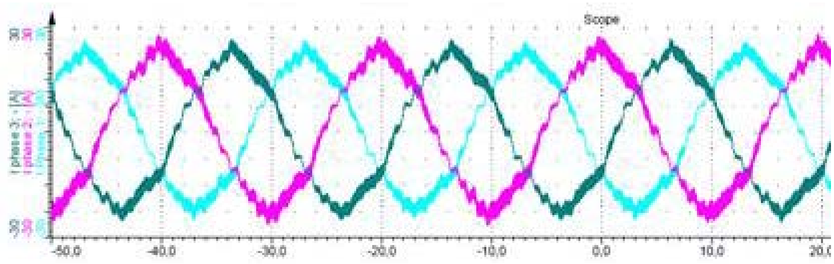

Figure 5: Harmonics effects of EV charging (Source: ElaadNL)

- **In-rush current:** some EVs are known to draw high amounts of current for a few milliseconds at the start of the charging process. If the in-rush current exceeds the capacity of the DSO's connection, the manufacturer is responsible for any issues this might cause. If this causes voltage issues, the DSO can demand a soft starter to resolve this.

Grid (Voltage, DSO responsible)

- **Slow voltage variations:** the voltage margins may vary between +/- 10% (207-253 Volt). This is measured by ten-minute averages over a week. Depending on the level of impendence in the grid (the lower the better) a high current can bring the voltage down. In residential areas this in general happens on a single phase of the grid, a so called **phase imbalance or asymmetry**. This can be caused or increased by multiple EVs charging on a specific single phase of the grid (most of the current existing EVs have usually only single-phase design).
- **Fast voltage variations**: when a current is being asked it may not result in a dip in the voltage of more than 3% of the nominal voltage on the LV and MV grid.
- **Harmonic distortion of the voltage:** When the current harmonics are high enough, and/or the grid impedance is high enough, the harmonics in the current can have a noticeable effect on the voltage in the grid. Harmonics in the voltage can lead to (consumer) electronics behaving strangely or even breaking down.

Grid (Frequency, TSO responsible)

- **Frequency stability:** TSOs are responsible for balancing the supply of electricity with demand on a minute-by-minute basis. High demand of simultaneous charging of EVs could require fast power ramps of generators that may exceed current grid capabilities.

Power Quality impacts of Ultrafast Charging

Ultrafast charging means charging with speeds of 350 kW and higher. Ultrafast charging is meant for the quick charging of EVs, including electric cars, trucks and buses. In the case of buses, the most extreme charging speeds are expected during opportunity charging, when a bus will be given a quick boost of energy at a bus stop. Because of the sudden and high energy demand ultrafast charging will possibly have a noticeable impact on power quality (depending on the grid structure). Nevertheless, these chargers should be connected directly or close to the MV/LV substations.

Asymmetrical charging

Asymmetrical charging is caused by phase imbalance, which can be problematic for phase loads expecting equal phase voltages. Experience from the GRID4EU project and ČEZ Distribuce show the following power quality issues in LV grids that might arise from asymmetrical charging of EVs.

- Most of the existing EVs are equipped with DC and AC charging options.

- DC charging is usually used for high power charging (power over 22kW). DC charging station connectors are usually powered symmetrically by 3-phases on AC side of the charging station.
- AC charging stations are usually equipped with single-phase 230V, 16A domestic or Schuko sockets (max. power 3.7 kVA) or by 3-phase AC Mennekes connectors (usually with charging power of 11 kW (16A, 3-phase), 22 kW (32A, 3-phase) or 43kW (63A, 3-phase).

However, internal AC chargers in most of the existing EVs usually have only single-phase or two-phase design which means that EVs are not able to use the charging stations' full potential[15]. This can triple the charging time. Further, single-phase design of internal AC chargers means increased voltage imbalance/asymmetry in distribution systems and risks of higher costs for the DSOs because of the need for strengthening the distribution networks. In case more EVs are charging from AC charging stations from the same single phase at the same time, the power quality standard EN 50160 could be breached in many cases. On the other side, symmetrical three-phase charging of EVs mitigates the risk of voltage imbalance. Other technical solutions include the usage of phase selectors.

Similar issues with voltage imbalance can also be caused by asymmetrical charging of three-phase AC internal chargers in EVs due to the software control of the charger. Currently, existing EV models that allow for AC 3-phase charging include Tesla Model S (dual chargers feature 16 kW or 22 kW) and Renault Zoe (22 kW or 44 kW).

As the price difference of single-phase and symmetrical 3-phase internal AC chargers is expected to be minimal[16], EDSO strongly recommends designing future EVs with symmetrical AC three-phase internal chargers in case that AC internal charger carries power of over 3.7 kVA. This can significantly reduce costs of deploying charging infrastructure connected to DSOs' grids, and benefit EV drivers to make use of much faster charging of EVs. Charging infrastructure operators can also enable the simultaneous charging of more EVs resulting from the higher charging power provided by a three-phase AC charger.

Examples of EV charging processes (ČEZ Distribuce)

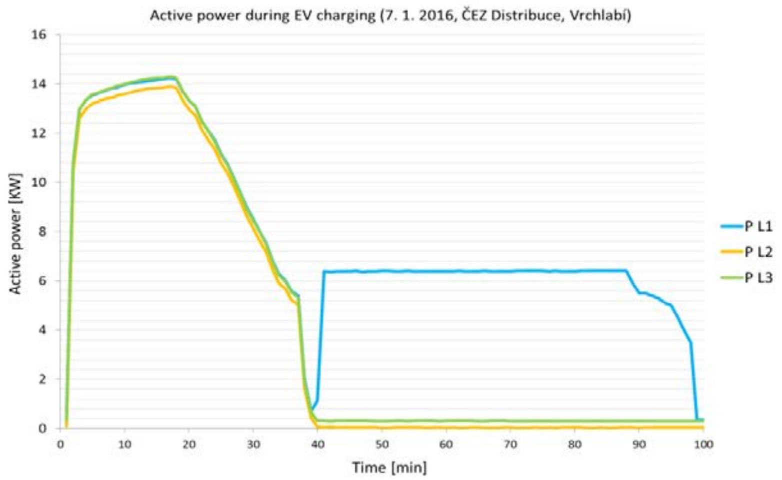

Figure 6: DC charging – symmetrical load in all 3 phases, AC charging – asymmetrical load in phase L1

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[15] For example 3-phase AC charging stations with powers of 22kW, 32A, 3-phase could provide only approx. 7.3 kW to the EVs with internal single phase AC charger with power 7.4 kW

[16] An example of an inexpensive car is Renault Zoe which has a three-phase AC internal charger

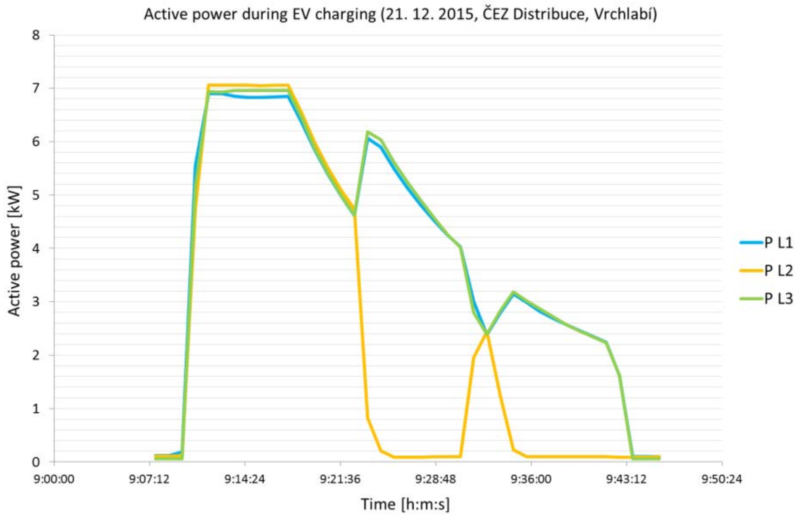

Figure 7: AC charging – asymmetrical load in single phase L1 and L2

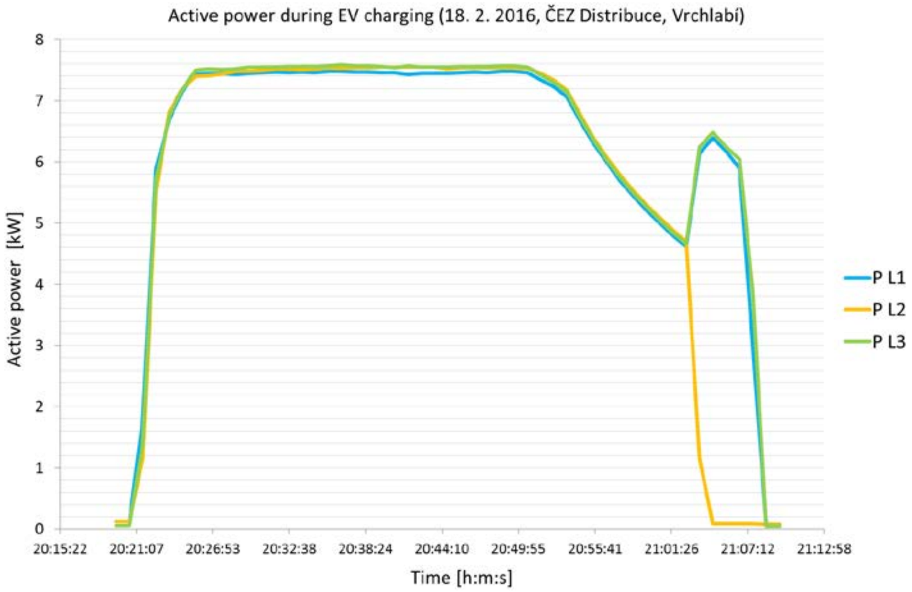

Figure 8: AC charging – asymmetrical load in single phase L1 and L2

Gridlab electric fleet - (Netze BW)

Another example of asymmetrical charging can be seen in measurement results from Netze BW's Gridlab electric fleet. Figure 10 shows the effects of asymmetric charging with about 34 electric cars, most of them VW e-Golf charging at 3.7 kW, resulting in a phase imbalance of about 17 kW. In addition, it also shows the start-stop load profile of one car with a 2-phase charger (7.2 KW). Phase unbalance can nevertheless be significantly reduced when using 3-phase AC-charging or direct DC charging for lower demands (11 kVA). A DC solution can additionally be recommended because it offers the possibility to use intelligent charging methods like Q(U) control.

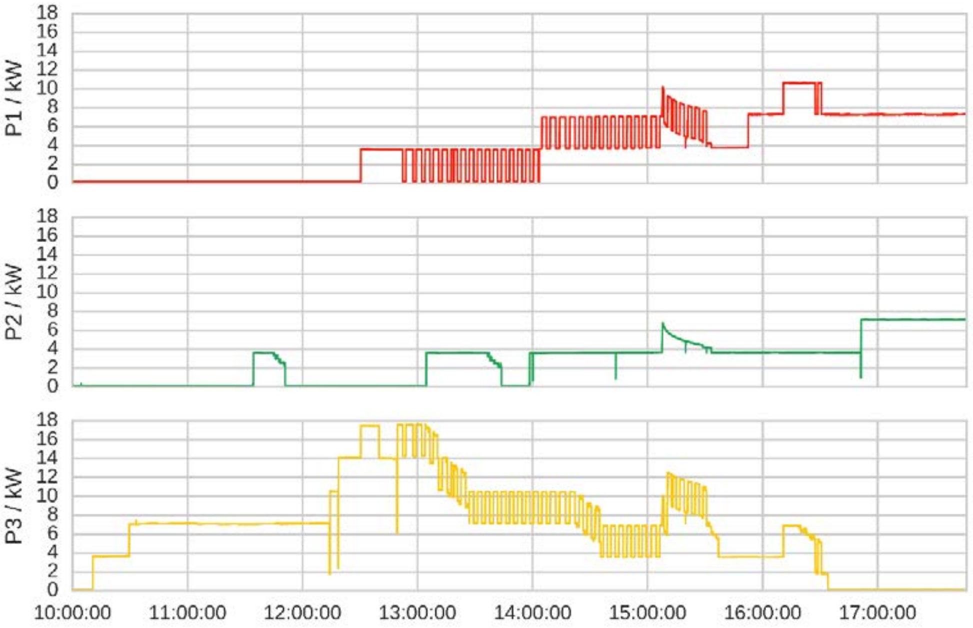

Figure 9: Netz BW assymetrical charging

Power quality issues can be reduced if manufacturers of charging stations adopt emission requirements for their converters. European standardisation bodies should set standardised requirements in the relevant European norms, similar to EN 504338 for photovoltaics.

DSOs should initiate the update of European standards in order to set a requirement for three-phase symmetrical AC internal chargers in EVs with a charging power over 3.7 kVA.

V. Paving the way for large scale EV integration: smart charging

As described above, the new expected loads from EVs can cause a higher instantaneous peak demand. The aggregated load of, for example, an EV together with the baseload of households can be higher than the available capacity of the current household connection. The current solution to tackle this investment challenge is conventional grid reinforcement which can be a capital intensive alternative.

But network improvements could very well consist of solutions based on a smarter handling of the existing capacity demand and distribution assets. Smarter charging solutions can make better use of the available technical capacity which is a risk for the DSOs because this is available for one (or a few) household(s) but is not possible for all households on a cable because of the used coincidence factor.

a. Smart charging as a necessary precondition for all parties

Smart charging can help to streamline demand for energy (and thus capacity) by adjusting the charging profiles with the supply for energy and grid capacity. This means that the power level to charge an electric vehicle can be reduced at times where there is high demand for energy and / or less available grid capacity. Energy stored in car batteries can even be used to feed electricity back to the distribution network (vehicle to grid technology) or lower demand from the customer's side (vehicle to home).

To realise this, the following three levels will be needed:

1. Smart charging (technology)
2. Smart contracts/tariffs
3. Smart regulation

In general, for the DSOs it is crucial that smart charging infrastructure is equipped with all the necessary technology to manage the charging process. This must include both a communication and a control link. The charging process should be controlled according to tradeoffs between DSOs' constraints and customers' needs. The decision of whether this can be directly controlled by the DSO or by an intermediate actor (aggregator, e-mobility service provider) should be left to the market decisions.

Smart Charging Technology

The starting point is that the charging station must be 'connected' to be able to communicate and be managed by a back-end system (of the Charge Point Operator (CPO)). This communication should include smart charging messages to be exchanged through standardised communication protocols. For example, the Open Charge Point Protocol (OCPP), in addition to other standards (IEC 63310), forms the basis for this communication between the charging stations and their back-end systems. But to fully enable smart charging, standardisation of data and coordination between all charging infrastructure and e-mobility management systems is needed beyond those requirements set in the OCPP. The whole electro-mobility 'chain' – starting from the electric vehicle itself, the charging station and the grid should seamlessly communicate with each other.

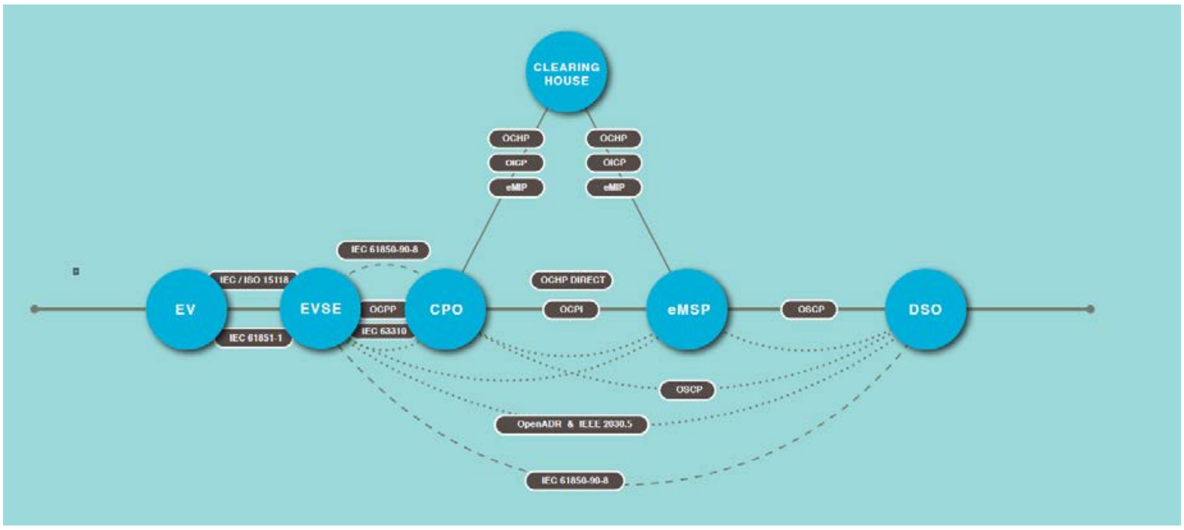

Figure 10: Overview of protocols and standardised interfaces (source: ElaadNL)

The graph above shows standardised interfaces that need to be defined in the future. On smart charging, the major interfaces to focus on are represented in the graph below in relation to the different electro-mobility stakeholders. The development of these interfaces – for instance, a crucial link between the DSO and the charging stations' management system necessary to communicate on available capacity of charging points which is currently missing, should be subject of next (integration) studies and pilots to technically activate dynamic and advanced smart charging.

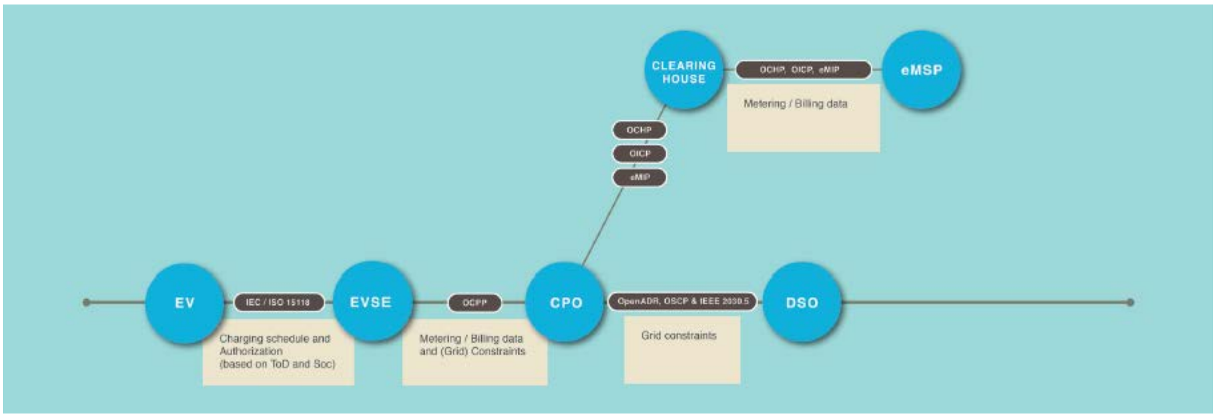

Figure 11: Standardised interfaces needs for smart charging (source: ElaadNL)

Smart contracts / tariffs

Existing solutions to incentivize drivers to shift their consumption to off-peak periods through price incentives (ToU tariffs, critical-peak-pricing) can be applied to EV charging. This is called 'open loop' smart charging; where a customer may decide to take the offer or not. In this case, the DSO cannot be sure about the acceptance and effectuation of smart charging beforehand. A ToU tariff implies a basic 'delayed charging' strategy to move the charge at a certain timeframe outside the peak. This is a fairly static approach with the drawback that EVs can still cause off-peak sharp demand increases when a large number of EVs will start the charging process simultaneously when the low tariff begins.

While these basic strategies may be effective in the short-term (charging at night to avoid network stress), they might still result in grid reinforcements in networks with large EV shares. In the long-term, full flexibility of EV charging with more dynamic and advanced smart charging strategies is necessary. Grid operators could make offers to EV customers to modulate the power, or shift the EV charge (time and power) to avoid high peak load. Such smart charging has to happen based on agreement between DSOs and customers. Even for the dynamic option, there needs to be a variable capacity contract in place between the DSO and the customer, allowing the DSO to manage the capacity within the limits of the agreed variable capacity. An example of a variable capacity contract is found below.

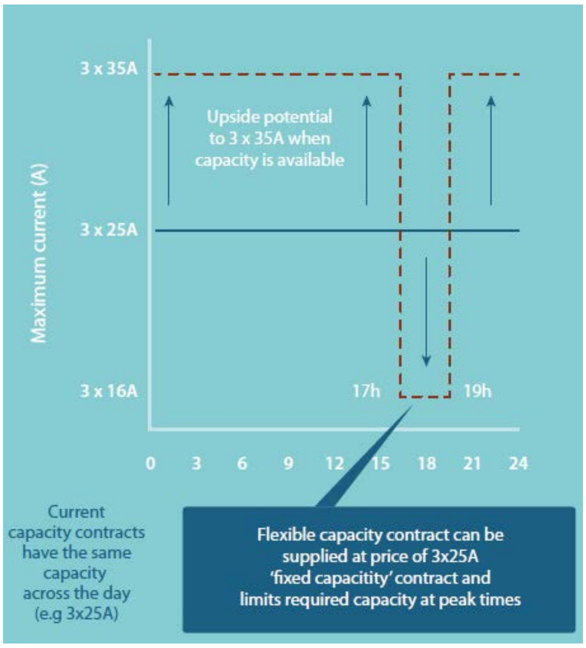

Figure 12: Example of a variable capacity contract

Smart charging could be done directly by the DSOs if there is a communication channel available from the DSO to the charging station. It is more likely that the DSO communicates directly with the CPO - or, depending on the technical architecture, the site owner through an energy management system. The CPO then delivers the requested smart charging profile on the charge stations managed by that CPO, within the predefined contractual settings between the DSO and the customer.

The smart charging process could also follow a route via a centralised system – in which case the local nature of the congestion challenge should be taken into account. A straightforward aspect is to include mandatory registration of charging stations (also behind the household connection) when smart charging is carried out through a more centralised platform. In this case the ICT-route is different but smart charging is still effectuated within the contract between the DSO and customer.

Other solutions whereby flexibility is extracted without a direct contract are also explored. Examples of market-based solutions include the possibility of a 'flexibility market place' where customers can offer their flexibility through a third-party, usually an aggregator. DSOs placing their request on the 'flexibility market place' would match an aggregator's offer. In this case, the contract is between the DSO and the aggregator, an option which can also allow to solve a specific local challenge. Unlike for the TSO and BRPs, the congestion challenge is a very local challenge. Given the local nature of the DSOs' challenge, the liquidity (in this case the number of consumers/connections with flexible loads on that specific LV cable) can be too limited to create a market place for managing DSOs congestion.

Where the regulation allows it, direct dynamic smart charging through the use of a variable capacity contract combined with the right tariff represents a viable and cost-efficient form of local load management. The dynamic smart charging option (within the limits of the contract) is effectuated through the use of standardised ICT protocols (from the DSO to the CPO, and to the charging station).

Smart regulation
The regulatory framework should include the possibility for the DSOs to offer smart contracts (variable capacity contracts) and use smart charging (signals). It is important that DSOs take part in dynamic network control as part of their responsibility for maintaining a stable and efficient network operation. A critical aspect here is that DSOs' challenges are locally bound whereas TSOs' challenges are not.

As current possibilities to apply flexibility in DSO contracts differ from country to country, a higher degree of comparability of the different experiences would be useful. Considering the diverse regulatory starting points across EU member states, and customers' experience with different tariff schemes, a potential comparison should not too straightforwardly neglect commonalities.

In support of this, almost half of EDSO members respondents believe that applying smart charging mechanisms could help reduce grid peak load at least for 30% or more. This mainly concerns private household AC charging. Smart charging was found to have a medium potential in the semi-public domain (car parks, business parking), and small potential in public fast DC charging as EV drivers will want to charge their car in a fairly short period of time.

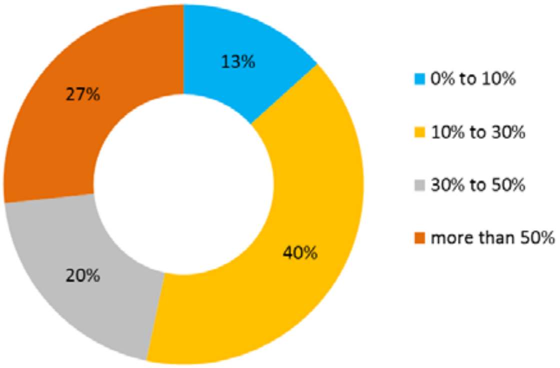

Figure 13: Smart charging potential to reduce peak demand compared to uncontrolled charging (%)

Managing the charging processes (time and power control) will be necessary to optimise the distribution system and mitigate network costs. Smart charging can be designed, implemented and managed by multiple actors, either DSOs or third parties (aggregators, services providers).

Smart regulation should enable DSOs to use smart charging, including dynamic smart charging to incentivise users through the use of variable capacity contracts/network tariffs, or procuring services from a flexibility market via a third party (aggregator).

b. Multi-actor optimisation for EV smart integration

As seen above, consumers, through third parties such as charging point operators and/or managers of e-mobility management systems can provide flexibility. The DSO could extract this flexibility by using variable capacity contracts and standardised smart charging protocols to carry out dynamic smart charging (when there is an actual congestion in place). This can possibly be routed via a centralised platform, still within the contractual relationship between the DSO and the customer. The DSO could also buy a service from an aggregator via a 'flexibility market place' through an indirect contract.

In addition to the DSOs, flexibility from EV customers can be used by different regulated and commercial parties. The DSO is interested in preventing, managing congestion and voltage drops.

- **Managing congestion and voltage drops:** managing EV charging (time and/or power) together with the DSOs depending on the network status and EV forecast conditions**.** Voltage regulation and reactive power regulation are also services that can be provided to DSOs in this context.

Besides the DSO the prosumer (being an individual or commercial party) is increasingly interested to locally optimize its own generation and consumption. This is partly based on financial incentives for balancing and partly due to their own strive for using own renewables in the best possible way.

- **Local optimization of (own) renewable,** including own production and site/building/house capacity and back-up power solutions: services for prosumers

Next to the DSO, the TSO and BRP are also interested in flexibility (of the EV user):

- **Frequency regulation** services to be requested by TSOs or by BRPs (in most EU countries only BRPs have access to the ancillary markets for frequency regulation)
- **Portfolio optimization:** services for commercial parties (supplier, aggregator, BRPs), including passive imbalance management and opportunities on short-term wholesale markets

The roles of these actors, which will most likely evolve in the future, can be broadly understood as ‘flexibility requestors’ in the context of EV flexibility. The role of an aggregator, which could be the charging point operator, or e-mobility service provider, could be added (comparable with the BRPs’ roles in flexibility) which could ‘extract’ flexibility arising from aggregated EVs loads.

Smart charging also aims to incorporate matching the needs of these different stakeholders for an optimal management of EVs. This so-called ‘multi-actor-optimization’, which is dependent on applicable regulation/market organisation related to flexibility is researched in different EU projects.

In such a multi-player market the DSOs will be enablers of interoperable services for smart charging. There is thus a need to adopt the regulatory framework in regard to the role of DSOs in demand response and by deploying specific incentives (e.g. variable capacity contracts). At least in the early adopters’ phase of introducing demand response technology, taking into account the very local nature of congestion challenges and the lack of liquidity to solve the challenge in a market-oriented approach.

In enabling direct dynamic smart charging, DSOs will need more investments in advanced metering/sensors to reach visibility of congestions in LV grids, where smart meters can play a major role to monitor the grid in real time. Investments in new methodology and grid tools will also be needed to assess the potential of congestion management / peak shaving and the value of smart charging. It is crucial that DSOs have a smart grid in place where most of the LV/MV networks are remotely monitored and controlled to detect congestions in real time and avoid network constraints.

Moreover, DSOs need to actively participate in the future grid planning and development of LM/LV networks, needed to address the new realities in distribution systems. Smart charging will rely on advanced ICT infrastructure, smart metering as well as interoperable protocols between the EV, charging station and the grid, which are currently not considered in distribution planning tools. DSOs also need visibility about charging station location and EV capacity requirements, in order to design an optimal use of the LV network and predict to which extent they can use smart charging.

c. Potential to integrate distributed energy resources

One of the main consequences of the energy transition is the decentralisation of energy production. This means that distributed generation will be injected at lower levels in the electricity grid: at medium- and low- voltage levels. Wind energy is usually injected at HV or MV grids, solar is mostly injected at LV levels unless it is a solar farm connected to the MV/HV grid.

A large share of DER in the distribution system can cause overload of conductors and transformers, as well as increase voltage levels. In the medium-term, smart charging can be a solution to maximise local DERs integration by adjusting the charging profiles to the supply from renewable energy generation (i.e. EV driver with a household solar panel installation). Such local DER optimisation can help DSOs with grid (congestion) challenges, with an additional longer-term option including the possibility for reverse flow of energy from the EV (Vehicle to Home).

As more than 90% of decentralized renewables are connected to the distribution grids, EV charging will represent an interesting case to counteract renewables peak production. For example, in Sweden almost all PV is connected to the LV grid. This opens the possibility for providing EV charging with locally generated solar power at semi-public chargers (mainly on workplace parking) during daytime.

It also paves the way for charging EVs at home during evenings and at night from PV installations placed on residential buildings. Yet charging at home with solar power often involves some kind of storage solutions. This means that offerings of PV installations could be combined with offerings for home charging and storage, with possible benefits for both the customer and the DSO. The challenge is to form these services in a way they benefits all parties and comply with local regulations.

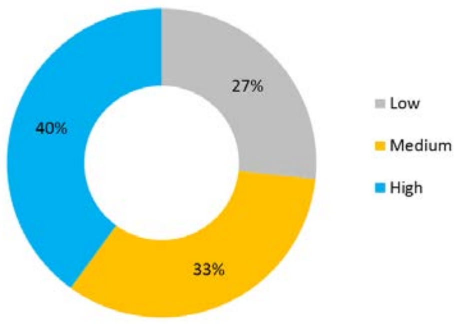

Figure 14: Estimated potential of EV charging to integrate renewables by 2030

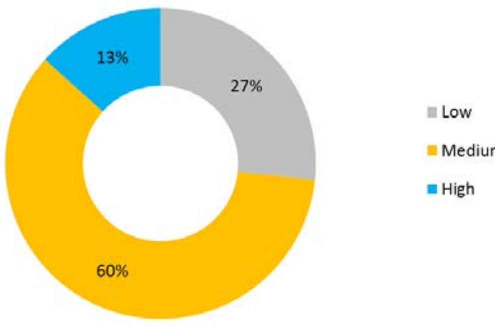

Figure 15: Estimated flexibility and storage potential of EVs in terms of V2G by 2030

d. Gaining customers' consent and acceptance

Smart charging will ultimately depend on meeting customers' needs. DSOs will first need to develop a better understanding of charging processes and customers' behaviour when developing charge management strategies tools and methods. This will help raise customers' acceptance and awareness of related benefits and risks, including overcoming anxiety concerns of losing control over their car.

With the right charging strategy in place, customers' benefits may include an opportunity to reduce their mobility costs by trading time flexibility with service cost savings. This may also reduce the need for increasing the contracted power and related connection costs. Financial benefits such as offering attractive discounts on electricity tariffs and savings on mobility bills will play a clear role. But other factors such as guaranteeing technical reliability and operation, or environmental benefits of load management (i.e. option for a green provider), will also be critical for changing customers' attitudes.

Nevertheless, the decision to participate in load management will ultimately rest with the customers. Charging management must meet customers' preferences about their desired charging schedule and the level of charge. The vehicle can automatically maintain the control by managing the amount of energy and the constant power flow needed throughout the charge[17]. Range anxiety can be further overcome by allowing customers to use a 'direct charging option' overriding 'delayed charging'.

For this to happen, DSOs need to work out best strategies to incentivise customers with active (variable capacity agreements) and passive (price signals, critical peak pricing) demand response schemes. Compounding this trend, smarter regulation will be needed to overcome existing bottlenecks by stimulating the right smart charging strategy, flexible tariff structure and technology adoption. And finally, common interoperable interfaces between the electricity distribution grid, the charging station and the electric vehicle itself will ensure the required safety and security level for the customers.

Smart charging Pilot NB (Enexis)

The pilot showed a clear displacement of charging transactions outside the grid peak load. The number of off-peak sessions increased the amount of kWh charged by 60%. In total, 66% of the charging sessions between 16.00 and 19.00 were moved off-peak due to delayed charging.

The drivers were positive about the 'delayed charging' option during off-peak hours as it entitled them to benefit from lower energy prices and no restriction of use. The drivers saw as additional benefit the possibility to freely choose their energy supplier. A 'Charge me now' app enabled participations to override the 'delayed charging' option at any time. However most of them chose not to use this option. The reason for using the 'direct loading' app was that the car was needed earlier than the next morning. On the downside, more than half of the participants believed that the discount on current tariffs (€0.02/kWh) was too low to permanently use delayed charging.

DSOs need more experiments with active (variable capacity agreements/network tariffs) and passive (price signals, critical pricing, ToU) to incentivise EV drivers to participate in smart charging. Customers can benefit from savings on their mobility costs when agreeing to shift the charging during cheaper, more grid-friendly times i.e. outside the peak/congestion hours.

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[17] Green eMotion, D4.2 Recommendations on grid-supporting opportunities of EVs

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