# Deliverable 2.2

# Specification of grid constraints

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## SUMMARY SHEET

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| Key words | Grid constraints; high power charging |
| Short description | The objective of the ASSURED project is to produce interoperable high power charging points for heavy duty vehicles. This document explains the grid constraints and requirements that should be considered in the design of such high power charging points. Existing reports have been reviewed, as well as the experience and opinion of experts of concerned departments, coming from external and internal DSOs. |

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## DOCUMENT CHANGE LOG

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| V 1 | 12/24/2017 | IBERDROLA, ENGIE-LAB, ENEXIS, VUB, SCHOLT, IDIADA, FEV | First draft, additions, and corrections. Contents provided by T2.2 partners. |
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| V4 | 30/03/2018 | RINA-C BE, IBERDROLA | Quality Check |
| Final Version | 06/04/2018 | VUB | Version ready for submission |

## ACRONYMS

| | |
|---|---|
| **AMI** | Advanced Metering Infrastructure |
| **AMM** | Automatic Meter Management |
| **AMR** | Automatic Meter Reading |
| **BPL** | Broadband power Line |
| **CB** | Circuit Breaker |
| **DCS** | Distribution Control System |
| **DRES** | Distributed Renewable Energy Sources |
| **DSO** | Distribution System Operator |
| **EU** | European Union |
| **EV** | Electric Vehicle |
| **FD** | Fault Detector |
| **FH** | Feeder Head |
| **GPRS** | General Packet Radio Service |
| **HD** | Heavy Duty Vehicles |
| **HTTP** | Hypertext Transfer Protocol |
| **HTTPS** | Hypertext Transfer Protocol Secure |
| **IEEE** | Institute of Electrical and Electronics Engineers |
| **IP** | Internet Protocol |
| **IPSEC** | Internet Protocol Security |
| **KPI** | Key Performance indicators |
| **LCC** | Life Cycle Cost |
| **LV** | Low Voltage |
| **MDC** | Meter Data Collector |
| **MDM** | Meter Data Management System |
| **MV** | Medium Voltage |
| **OH** | Over Head |
| **PCKM** | Protocol Change for Key Management |
| **PT** | Public Transport |
| **PTA** | Public Transport Authority |
| **PTO** | Public Transport Operator |
| **QoS** | Quality of Service |
| **RTU** | Remote Terminal Unit |
| **SCADA** | Supervisory Control And Data Acquisition |
| **SS** | Secondary Substation |
| **TCO** | Total cost of Ownership |
| **TCP** | Transmission Control Protocol |
| **THD** | Total Harmonic Distortion |
| **TSO** | Transmission System Operator |
| **UC** | Use Case |
| **UG** | User Group |
| **WP** | Work Package |

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# Executive Summary

ASSURED project aims to develop and test an interoperable high power charging point for heavy-duty vehicles. Buses could charge in 30 seconds, 5 minutes or 30 minutes using powers up to 600 kW. High power systems and short charging times imply special grid operation conditions that should be taken into account.

The objective of this deliverable is to establish a basic context and a set of requirements coming from electricity grids to influence positively the high power charging system design in order to grant an easy and smooth integration of this kind of equipment into electricity distribution systems.

In order to understand the “State of the Art” of electric-HDV (e-HDV), the real on-going exploitation experiences are reviewed, to continue with a brief analysis of existing roadmaps, technical press recommendations and European projects learnings.

The deployment of e-HDV is still starting, but a representative set of these experiences in cities has been reviewed to understand the “state of the art”. Several aspects are briefly reviewed: the number of e-buses, the number of charging points installed, the charging policies (overnight, opportunity charging) used in each city, the technologies that have been employed (pantographs, etc.), the power of the current systems, the expectations and plans of the cities on the electrification of public transport, etc.

China is the clear leader in the use of e-buses with the 98 % of the world total, while USA and Canada could be the next in the list with a few hundreds of electric HDV. In Europe, UK is the first in the list with 213 e-buses, followed by Germany, Belgium and Netherlands.

This study gives an overview of the status of e-HDV, but it necessarily should be completed with an overview of the tendencies of deployment of other types of electric vehicles and the charging infrastructure as well as the energy and power required.

Looking at the drivers of transport electrification progress, the evolution of electric cars has been significant in Norway where has been incentivized with tax exemptions, and it is expected a relevant progress in the next years in Germany, France and U.K.

Different studies show that there is a real risk of an important increase of power peaks in the consumption profiles due to the introduction of EVs with special impact on the LV grids. Several studies about the evolution of EV market are presented. For 2030, some studies foresee an increase of battery-EVs that will cover 50% of cars’ market while diesel vehicles, that nowadays cover more than 50% of the European market (depending on the source), will reduce its share below 30%. The tendency for urban buses is quite similar with a market prediction even higher for e-buses.

In terms of global energy demand, an increase is also expected, but the impact in the system can be easily maintained under control. The only consideration about it is that EV load repartition strongly affects the peak load and the required capacity to fulfil the system needs.

The point of view of the European Association of Green Vehicles (EGVI) extracted from their roadmap is presented, focusing on the charging and grid related aspects. They raise the importance of the charging infrastructure and the regulatory efforts made by EU to encourage Member States to expand the network of charging points. They also recommend public education, vehicle sharing and increasing the autonomy of EVs. In the longer term, they foresee the need of bidirectional smart charging to implement vehicle to grid (V2G) services.

Reviewing other technical information and research projects, interesting inputs can be found. For example, the use of stationary batteries to reduce the peaks of fast charging or bus-high power charging, or the suggestion to connect the high power chargers to MV grid.

A proper management of the electrical loads to reduce the impact on the grid is becoming a key topic. For example, the "overnight" and "opportunity charging" offer possibilities to accommodate the needs in a cost-effective way and with different impact on the grid, for e-HDV, while "Smart charging" can allow a penetration of 50% of EV without grid reinforcement.

In order to understand the reasons that explain the slow pace of transport electrification, and the limitations that prevent or delay the process, the point of view of DSOs, electricity providers, electricity service providers, bus operators and manufacturers has been obtained, sometimes through their European associations.

DSOs consider that flexibility should be taken into account when deploying the charging infrastructure. They identify the power as the challenge and propose the use of "Smart charging", regulation and tariffs to activate it, and the involvement of the DSO in planning and control of charging points assets (not the exploitation of the service).

Energy and Energy Service Providers detect a set of technical, environmental and economic limitations. They consider that the roles of the involved stakeholders should be analysed, especially in a context of access limitations to the cities, growing of EV fleet and lack of charging infrastructure that has to be deployed to foster the EV market.

For the automotive industry, the cost reduction and compatibility are key drivers. They foresee a growing in the electrification of public bus transport in the cities that should be pushed by standardisation and interoperability. They observe important advantages in the electric powertrain technology (operation speed, torque, noise, vibrations, gases emission, etc.) but the technology should be robust, reliable and safe to receive the bus-operators investments. The cost, efficacy, need of raw materials, and other aspects are reviewed as well. They remark that electric vehicle is still not emission free.

Bus operators discuss the possibility of eliminating diesel from the cities, and claim for a legislation on clean air. Public transport should offer comfort, service and good prices. Consequently, when investing they take into account the cost of ownership (including maintenance) and the expectation of satisfaction of their customers. When analysing the investments on e-buses, they consider the different possibilities of charging and consequences in type of charging, size of battery, battery aging, space for passengers, difficulty of moving existing bus-stops, etc.

The impact of charging infrastructure on generation and transmission grids is possible, but it is clearly higher on Distribution grids. The needs of DSOs for the expansion and operation of grids are analysed. The expectations of EDSO4SG for 2030 is an increase of 1% to 10% in energy, which can be easily managed and an increase of up to 20% in peak load which should be properly treated.

A massive deployment of EV could require LV (typically <1kV) grid reinforcement or larger LV grid connection(s), for example in charging zones. Traditionally, LV grid has been poorly supervised or controlled, but "Smartening the LV grid" will be necessary in the short medium term. On the other hand, at MV (<66kV), the impact of high power charging systems on the most common grid constellations and extensions must be assessed.

The grid side requirements for the design of a high power charging point and the reasons for these needs have been reviewed arriving to conclusions that are summarised at the end of this document. The needs of a transformer inside the enclosure of the charging point or the relevancy of connecting it to MV grid are some of these conclusions.

The main limiting factors at LV level and at MV level have been analysed. The first conclusion is that a direct, short-term congestion challenge is not expected with AC-chargers for cars, but the capacity and power quality could be main challenges, especially dealing with e-HDV in urban areas.

The needed measurements in the charging point and the parameters to be considered as well as the limits to be respected have been detailed in the study. The IEC 6100 standard and the European Standard EN 50160 are the main sources of these guidelines. ASSURED solutions should respect the limits emerging of these norms.

The main aspects to be considered when connecting charging stations to the distribution grid have been explained: grid overloads, grid voltage drops, consumption peaks, N-1 needs, reactive power, harmonics, in-rush current and voltage unbalance. Congestion, voltage drops and consumption peaks are the most frequent issues are developed more in deep.

As far as ASSURED project plan to design high power (up to 600kW) installations to be placed in the cities where citizens walk around, appropriate safety and security measures should be implemented. The main problems that may appear and suggestions about the ways of avoiding incidents have been developed.

To conclude, the future of the EVs, and cities have been explored as a source of additional requirement, given that new services may appear. Some of them could be related to electric car uses, but also bus-stops and bus infrastructures may be involved and the future has to be considered at least in terms of potential modular expansions of the systems. A shared use of infrastructures will probably be compulsory for electricity system optimization and general infrastructure cost reduction, leading to a few additional requirements related to payment, identification of vehicles and roaming understood as interoperability among European retailers.

Attainment of the objectives and explanation of deviations:

The objectives related to this deliverable have been achieved in full and as scheduled. Based on the unanimity among all task partners, dissemination level of D2.2 has been changed from ‘confidential’ to ‘public’.

Revised version has been submitted taken into account suggestions and remarks of the project officer.

# Partners' Contribution

| Company | Sections | Description of the partner contribution |
|---|---|---|
| IBERDROLA | All | First release of the document contributing to all chapters. |
| ENGIE-LAB | All | Second version of the document |
| ENEXIS | All | Grid expansion, identification and payment. |
| VUB | All | Power quality and measurements. |
| SCHOLT | All | Recommendations and requirements from bus operators |
| IDIADA | All | View of automotive industry |
| FEV | All | Recommendations and requirements from bus operators |
| WP Leaders | All | Review and comments |
| Coordinator | All | Review and comments |
| All partners | All | All partners have contributed punctually completing and correcting all chapters. |

# 1. Introduction

## 1.1 OBJECTIVE OF THIS DOCUMENT

The objective of this document is to collect and organise a set of requirements from grid side for the charging points that must be designed in this project. In the “State of the art” chapter it will be shown that most of experience accumulated during the last years refers to low power charging points (below 50 kW) and passenger cars.

ASSURED project focuses on electric heavy duty vehicles (e-HDV) (trucks and buses). The energy needs of this type of vehicles are higher due to their size and weight as well as to the particular uses required for them. A bus attending an urban route needs to stop only for a short time to avoid delays on the schedule. The best opportunities to stop are at bus stops while passengers are going up and down (this means a time not over one minute) or at the end of a route (for a few minutes, when possible).

The power demand required for each e-HDV-charging point from the grid is very high (150-450kW), and the proliferation of them would impact the grid design further than was expected in the past. Furthermore, charging stations are often combined at one location, further increasing the required capacity. All these issues are reason to develop a solution taking into account grid needs and requirements.

## 1.2 ORGANISATION OF THE DOCUMENT

The justification of this document as well as the organisation of the information inside it is explained in the first chapter.

In the second chapter authors established what is already known about requirements, barriers and needs related to the grid connection of Electric Vehicles (EV). This should be a good starting point to prepare the requirements list.

The main sources of information used are:

- Requirements extracted from real experiences in places where EV has started to operate.
- Information extracted from EV Roadmaps[1] of (HDV, LDV, EV, etc.) but focusing on aspects related to grid connection.
- Requirements and difficulties related to grid appeared on technical journals.
- Requirements extracted from other EV European Research Projects.

In chapter three, the points of view of main stakeholders involved in transport electrification express what is needed to foster this market:

- View of DSOs

- View of energy/ energy services providers
- View of automotive industry
- View of bus operators

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[1] European Roadmap Electrification of Road Transport, http://www.ertrac.org/uploads/documentsearch/id31/electrification_roadmap_june2012_62.pdf

Chapter four deals about the grid requirements. They have been organised as follows:

- Grid operation needs: Traditional problems on the grid in the daily operation can grow due to the electrification of the transport, particularly in the case of opportunity charging of e-HDV. These aspects will be reviewed here.
- Grid expansion needs: the increase of demand is habitually considered in grid planning. Now EV and specially e-HDV must also be considered.
- Installation, safety and security needs

Chapter five provides the conclusions of this study that will be used in the next steps of the project.

# 2. State of the art on grid connection of EV

## 2.1 EXPERIENCES WITH EV

Battery-electric bus is not yet a really mature technology and experiences are led in several cities with different types of buses and charging technologies. Results from these experiences will be used for wider implementation of e-buses.

There are experiences on other types of EVs (vans, trucks, etc.) and charging technologies (wireless charging, super-fast charging, etc.).

A distinction is made between experiences in and out of Europe and experiences about e-buses and other EVs.

### 2.1.1 Europe

E-buses

The following list of e-bus projects is not exhaustive. It aims to be representative of the experiences with e-buses that have been performed so far in the different European countries, with different technologies and charging strategies.

| Country | Description |
|---|---|
| Austria (Graz)<br>[1] | - 2 buses with supercapacitors (32kWh) and 2 buses with supercapacitors (24kWh) + batteries (25kWh)<br>- Pantograph charging at terminal and selected bus stops |
| Belgium (Namur & Charleroi)<br>[2] | - Total order: 90 hybrid buses (11 operational now)<br>- Total order: 12 charging stations<br>- Run on electricity 70% of route<br>- Pantograph opportunity charging takes 3-4 minutes |
| Czech Republic (Plzen)<br>[3] | - 2 battery e-buses and 16 hybrid trolleybuses<br>- E-buses: pantograph charging (7 min) and overnight charging (5h) |
| Denmark (Copenhagen)<br>[3] | - The city wants all new buses to be electric by 2019 and have 100% e-buses by 2031<br>- Demo: 2 long-range e-buses (324 kWh) and 2 short-range e-buses (55kWh)<br>- Pantograph opportunity charging for short-range e-buses (total power 700kW, 1.5-3min)<br>- Overnight charging for short-range (30 min) and long-range (5h) e-buses |
| Bulgaria (Sofia)<br>[3] [4] | - 1 operational e-bus and plans to have in total 30 e-buses (21kWh-32kWh) with 12 charging stations<br>- Two operational pantograph charging stations at terminal (each 150kW, 5-6 min)and depot charging (5-6 min) |
| Finland (Helsinki)<br>[3] | - 6 e-buses in operation (55 kWh), charged via roof-mounted pantograph (5 min), 6 more e-bus to come in early 2018<br>- Helsinki plans to increase e-bus fleet to 30% of the total of roughly 1400 by 2025 |
| France (Grenoble)<br>[3] | - Grenoble is experimenting 4 e-buses (of different constructors), all charged overnight at depot (5-6h) with capacities in the range 199–376kWh<br>- The city aims to have no more diesel buses by 2021. |
| France (Paris)<br>[3] | - A fleet of 23 e-bus is being tested in Paris (240 kWh), charged overnight at depot (5h)<br>- Paris bus operator (RATP) plans to renew its entire fleet, by having 80% of e-bus and 20% of biogas bus by 2025. |

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|---|---|
| France (Nantes)<br>[5] | - A line will be electrified by 2018 with 20 e-buses (24m) and flash-charging technology<br>- The buses will be charged in 20 seconds at 600kW boost at selected stops. A further 1 to 5 minutes charge at the terminus at the end of the line enables a full recharge of the batteries.<br>- It takes less than one second to connect the bus to the charging point, making it the world's fastest flash-charging connection technology |
| Germany (Berlin)<br>[3] [6] | - In 2015, Berlin introduced the world's first wirelessly charged e-buses (90 kWh) in its fleet in the capital city. It is charged at depot, terminal and selected bus stops (6-8 min)<br>- The Berlin public transport company BVG intends to order 30 electric-powered buses due for delivery in 2018 or 2019. |
| Germany (Cologne)<br>[7] | - In December 2016, the first full electric bus line was in operation in Cologne. The line is operated with 8 e-bus (123 kWh), charged with pantograph (250kW, 5-10 min) at terminal and selected bus stops as well as overnight |
| Hungary (Budapest)<br>[3] | - Budapest is running 20 e-buses (141 kWh), charged at depot (2.5-3h) |
| Italy (Turin)<br>[3] [8] | - Turin transport operator (GTT) has purchased 20 e-buses (324 kWh), charged overnight at depot (5h). GTT serves an area of 2 million people with a fleet of 1100 buses |
| Netherlands (Amsterdam Airport)<br>[3] [9] | - Amsterdam Airport Schiphol (3rd largest European airport in terms of passengers) is incrementally electrifying transportation on the site. Since 2015, a fleet of 35 e-buses (216 kWh, charged overnight 3.5h) and 167 taxi EVs is operating. They replaced the previous fleet of 20-40 diesel buses. |
| Netherlands (Eindhoven) [10] | - 43 operational e-buses, with pantograph based opportunity charging and depot charging. Installed charging power 4MW. |
| Poland (Gdynia)<br>[3] [11] | - The city of Gdynia has 38 battery trolleybuses (27/69 kWh) running. They are charged with overhead wires, plug at depot and selected bus stops (1.5-3h). Thanks to the batteries, unwired parts of the cities can now be served by the trolleybuses<br>- In 2018-2020, the city plans to further develop the battery trolleybus fleet and purchase an additional 30 vehicles. |
| Romania (Bucharest)<br>[3] [12] | - In 2015, the city of Bucharest tested 3 e-buses (172/324 kWh), charged at depot (6-7h)<br>- The city announced in 2017 that they plan to purchase 100 additional e-buses |
| Slovakia (Košice)<br>[3] | - Since 2016, Košice has 14 operational e-bus (120 kWh), charged overnight (11h) |
| Spain (Barcelona)<br>[13] | - In September 2016, Barcelona added two new articulated (18m, 125kWh) to its fleet as well as a pantograph fast-charging station (6-8min, 400kW). The city has 6 e-buses in total now. |
| Sweden (Stockholm)<br>[3] [14] | - In 2016, Stockholm was testing one plug-in hybrid bus (56 kWh) that can be charged on a wireless inductive station located under the road surface (7 min)<br>- The city also tested 8 plug-in hybrid buses (19kWh) charged via pantograph (6 min) and at depot (2h). These hybrid buses use biodiesel as fuel.<br>- The city reached 87% of its bus fleet running without fossil fuel (electric, biodiesel, ethanol, etc.) |
| Switzerland (Geneva)<br>[3] [15] | - Since 2014, Geneva is equipped with 33 electric trolleybuses (28 kWh).<br>- The city tested an e-bus (40 kWh) using flash-charging at selected bus stops (20s, 600kW) and terminal (5min, 400kW), as well as overnight charging (30-40 min). In 2018, 12 of these buses, 13 flash-charging, 3 terminal and 4 depots stations should be in operation. Stationary storage near charging stations is used, reducing the required current from the grid by up to 10 times. |

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|---|---|
| UK (London)<br>[3] [16] [17] | - There are 71 pure electric buses and 8 hydrogen buses operating in London, out of a total bus fleet of 9,590. 51 of the e-buses are overnight charged buses (6h, 324 kWh).<br>- The city plans to bring the e-bus fleet to 170 units by 2019 and plans to make all buses zero emission by 2037. |

Figure 1 E-buses experiences in Europe [3]

Figure 1 shows the geographical repartition of the e-buses experiences (within or outside of ZeEUS) as well as the upcoming projects.

Table 1 Number of e-buses per European country. Countries not mentioned have no reported e-bus. Based on [18], last updated on 12/02/17, new e-buses have probably been added to the European fleet since then.

| | | | |
|---|---|---|---|
| Austria | **15** (15 BEV) | Latvia | **2** (2 BEV) |
| Belgium | **145** (3 BEV + 11 FCEV + 131 PHEV) | Luxembourg | **37** (4 BEV + 33 PHEV) |
| Bulgaria | **1** (1 BEV) | Netherlands | **143** (133 BEV + 5 FCEV + 5 PHEV) |
| Czech Republic | **4** (4 BEV) | Norway | **23** (18 BEV + 5 FCEV) |

| | | | |
|---|---|---|---|
| Denmark | **2** (2 BEV) | Poland | **74** (74 BEV) |
| Estonia | **24** (24 BEV) | Portugal | **2** (2 BEV) |
| Finland | **16** (16 BEV) | Romania | **3** (3 BEV) |
| France | **31** (30 BEV + 1 PHEV) | Slovakia | **9** (9 BEV) |
| Germany | **167** (65 BEV + 16 FCEV + 86 PHEV) | Spain | **47** (29 BEV + 18 PHEV) |
| Hungary | **33** (33 BEV) | Switzerland | **6** (1 BEV + 5 FCEV) |
| Iceland | **1** (1 BEV) | United Kingdom | **213** (190 BEV + 20 FCEV + 3 PHEV) |
| Italy | **19** (6 BEV, 13 FCEV) | | |
| Total | **1017** (665 BEV, 75 FCEV, 277 PHEV) | | |

Table 1 gives the number of e-buses European countries had in February 2017, with specific numbers for each type:

- BEV = Battery Electric Vehicle; These buses have an electric motor and a battery/supercapacitor.
- FCEV = Fuel Cell Electric Vehicle; These buses use a fuel cell instead of or in combination with a battery/supercapacitor.
- PHEV = Plug-in Hybrid Electric Vehicle; These buses have an ICE (usually run with diesel), an electric motor and a battery that can be recharged via plug-in.

To give a point of comparison, there is an estimated urban bus fleet of about 200,000 units in Europe [19].

### Other EVs

| **Country** | **Description** |
|---|---|
| France, Italy, Sweden [20] | - Fabric project (2014-2017): the goal is to test the feasibility of on-road wireless charging solutions. There are 3 test sites: in France, Italy and Sweden.<br>- For instance, the testing site in France will be equipped with at least 100m of tracks with induction technology. Various power levels will be tested, with a target of least 20kW at maximum speed.<br>- FABRIC targets various types of vehicles, including passenger cars, light-weight duty vehicles, heavy vehicles and buses. |
| Netherlands,<br>Portugal,<br>UK,<br>Spain,<br>Italy,<br>Norway,<br>Netherlands,<br>Sweden [21] | - FREVUE (Freight Electric Vehicles in Urban Europe) exposes 80 Electric Freight Vehicles (EFVs) to the day to day rigours of the urban logistics environment.<br>- FREVUE aims to prove that electric vans and trucks could offer a viable alternative to diesel vehicles, particularly when combined with state of the art urban logistics applications, innovative logistics management software, and with well-designed (local) policy.<br>- The vehicles have payloads that go from 1.5t (van) to 20t (truck). |

| | |
|---|---|
| Germany [22] | - Mercedes-Benz and courier service Hermes will partner to electrify the logistic provider's fleet by adding 1,500 battery-electric vans for last-mile delivery. The plan is to deploy the entire fleet of electric delivery vans in urban areas across Germany by the end of 2020<br>- Hermes will incorporate the emission-free Mercedes-Benz Sprinter and Vito vans with electric drive into its daily operations in early 2018 as part of a pilot program in Hamburg and Stuttgart, Germany. |
| UK [23] | - Ford prepares 20 plug-in hybrid electric vans for a 12-month trial in London, starting in late 2017.<br>- The London fleet trial project is supported by Transport for London, and features a cross-section of city-based businesses, including Metropolitan Police, that will integrate the vans into their day-to-day operations. |

### 2.1.2 Global

At the moment, China, USA and Canada are the main other regions where e-buses are being experienced.

| Country | Description |
|---|---|
| China [24] | - At the moment, China is clearly leading the way in e-buses with more than 98.3% of the global total. For instance, the city of Shenzhen already has (November 2017) 14000 units of e-buses which is basically the entire bus fleet of the city. According to some reports, SBG (Shenzhen main bus company) rents 82 charging stations and 1341 charging points for their e-buses. |
| USA [3] | - The estimated e-bus stock in the USA accounted for 200 units in 2016, with the greatest number currently operated by Foothill Transit in Los Angeles region. |
| Canada [3] | - The operator « Société de Transport de Montréal » purchased three full-electric buses and installed two fast-charging stations and four slow-charging stations, in order to test the technology in a real life operating context between 2016- 2019.<br>- This project is part of a wider strategy to promote 'green' energy in the province of Quebec, which has abundant hydroelectricity. |
| Chile [25] [26] | - The first two e-buses came into operation (November 2017) in Santiago<br>- The city plans to have 90 more e-buses in 2018, making them pioneers of electrified public transport in Latin America<br>- The system's 6000 buses could be eletctric in 2030 |
| Argentina [27] | - Province of la Rioja (north west of Argentina) will have 50 electric buses |

### 2.1.3 Consumption profiles for regular EV

An average household connection follows the profile as shown in Figure 2.

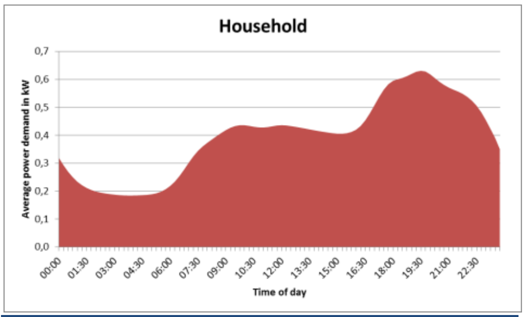


Figure 2 Profile of an average household connection in the Netherlands (no EV connection) [28]

In general, EV chargers give different profiles considering the area they are installed. See in Figure 3 the profiles of two different areas.

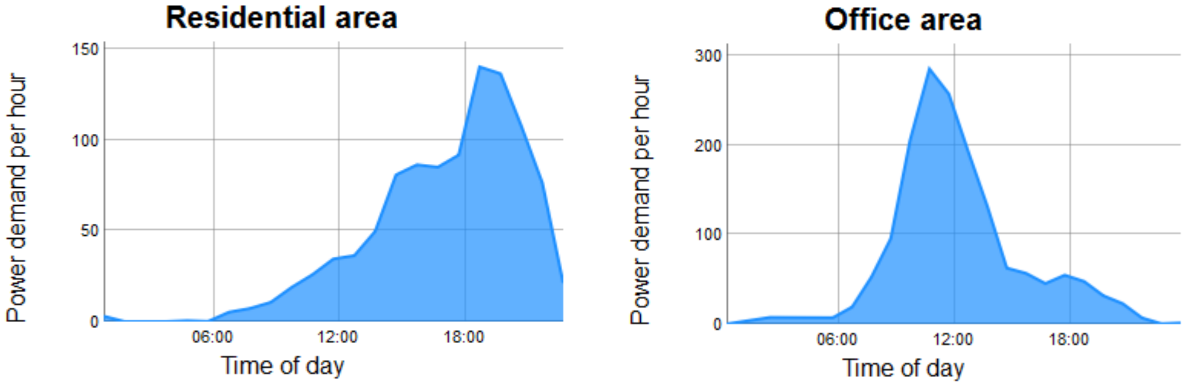


Figure 3 Different profiles considering the area the EV car-chargers are installed in the Netherlands [29]

In an extreme case an AC charging (and connected EV) in a residential area could cause the following profile on the demand of the household connection (every household an EV and all simultaneously charging (simultaneity factor = 1)).

See figure

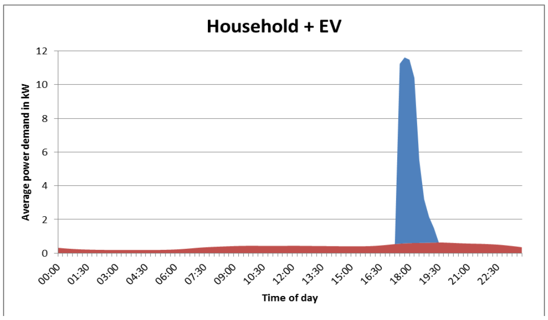


Figure 4-A An AC charger (and connected EV) in a residential area in the Netherlands

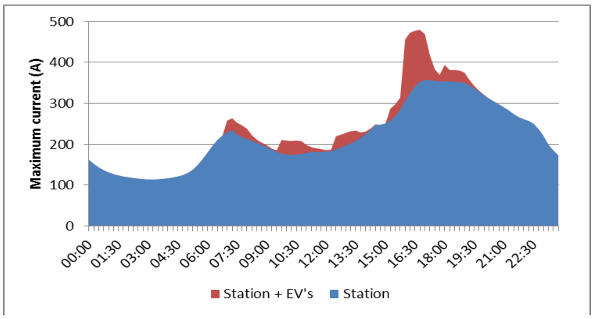


Figure 4-B An average household profile and real in the Netherlands

As previously exposed, this is an extreme case, because this is an average household profile and a real direct EV profile of one EV (charge with 11kW). Looking at real data we see slowly the following profiles (Low voltage level of a transformer station), at more and more dense ‘EV areas’. See Figure 4-B.

So, in short, capacity and congestion caused by (the evening) peak demand in especially residential areas is going to be a challenge for the DSOs. Considering that DSOs try to deploy their grids in the most economical way, and consequently they try to search for possibilities to spread the peak demand instead of investing in grid extensions because of this peak demand. This congestion risk and possibilities are present at the Low Voltage Level.

### 2.1.4 Consumption profiles for HDV

The consumption profile of a fleet e-HDVs is different from consumer EVs as they are likely to have more operating hours and often charged multiple times per day. In Figure 4-C the average consumption profile of a fleet e-HDVs is given over the weekdays of August to November on 15 minute intervals. The bounds are defined as the average plus or minus two standard deviations. The y-axis is normalized and a value of 1 indicates the theoretical maximum energy consumption, defined as the combined rated power of the chargers installed.

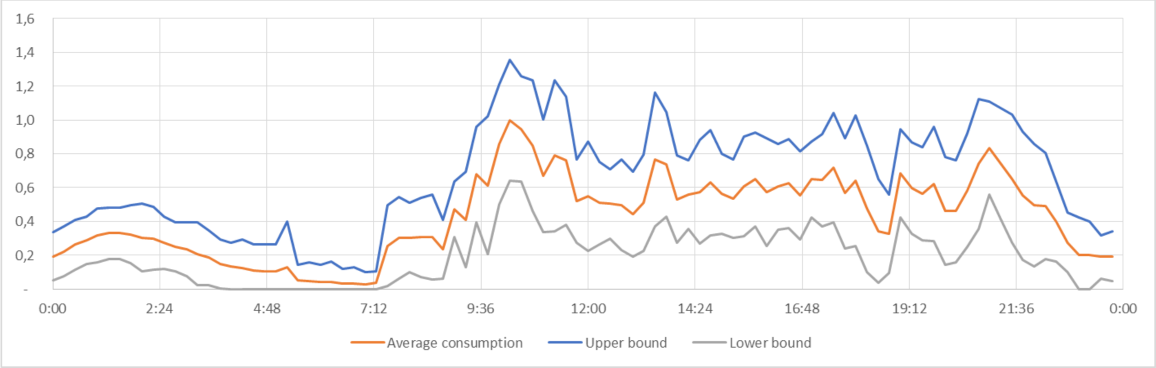


Figure 4-C Average consumption profile of a fleet of e-buses [30].

The figure indicates that there is a significant amount of energy consumption between 9AM and 10PM with peak consumption around 10AM after morning rush hour. The space between the bounds indicates that there are significant differences in the energy consumption when comparing multiple days making it more difficult to accurately forecast the energy consumption on a given day. It follows that there is significant room to increase the full load hours of the installation.

## 2.2 EXISTING ROADMAPS

### 2.2.1 Europe

E-buses

A few cities are taking initiatives to reduce the emission of urban buses. For instance, the mayor of 12 cities (among which 5 European cities: London, Paris, Copenhagen, Barcelona, Milan) pledged to procure only zero-emission from 2025 and ensure that a major area of their city is zero-emission by 2030 [30].

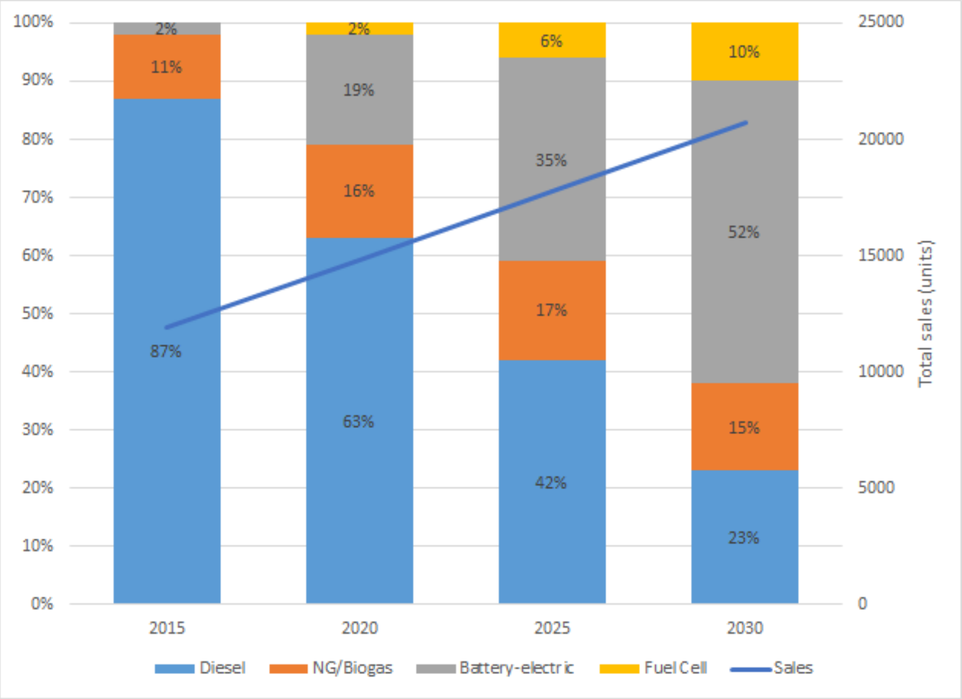


Figure 5 European urban bus market evolution

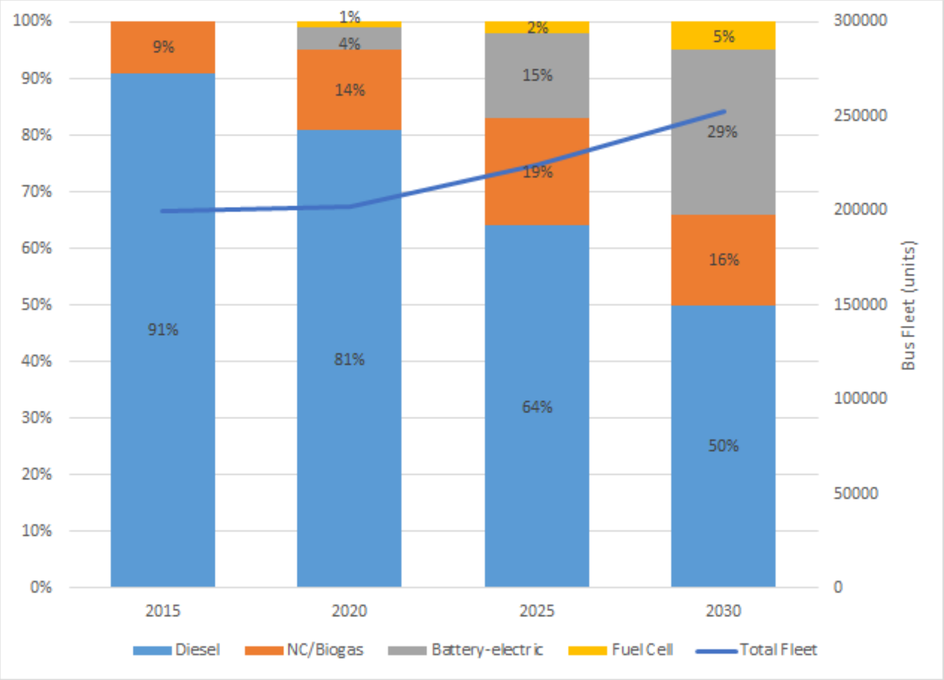


Figure 6 European urban bus fleet evolution

Battery-electric buses are expected to be the main technology that will replace diesel buses. Figure 5 shows the expected evolution of the European urban bus market. The market share of battery-electric buses (grouping pure electric, plug-in hybrid and fuel cell + battery combination) is expected to reach 52% by 2030. Figure 6 shows the predicted evolution of the European urban bus fleet. It should be noted that "diesel" also includes non-rechargeable hybrid diesel-electric buses. The sales for this kind of bus are expected to stay at about 10% from 2020 to 2030 [3].

The calculations used to obtain Figure 5 and Figure 6 are based on the following data and hypothesis:

- ZeEUS prediction (October 2017) for urban market bus evolution [3]. These data were obtained together by ZeEUS and UITP (Union Internationale des Transports Publics) VEI (Vehicles and Equipment Industry), based, among other things, on surveys given to bus operators.
- Evolution of alternative fuel bus fleet during the last years [31]
- The total European urban bus fleet is estimated to be about 200,000 by 2017 [19].
- The estimated lifetime of both diesel and NG buses is about 14 years. The hypothesis is that, each year, 1/14 of diesel buses go out of service. The same applies to NG buses but only from 2025 since most of them were introduced later. Buses with other technologies will not go out of service before 2030 since they are introduced later and e-buses can have a lifetime that goes up to 30 years [32].
- The annual bus sales in Europe are expected to increase from 11,900 by 2015 to 16,000 sales per year by 2022, due to several factors such as growth of European urban population. It is supposed for the calculation that this evolution is linear and goes on beyond 2022 [33].

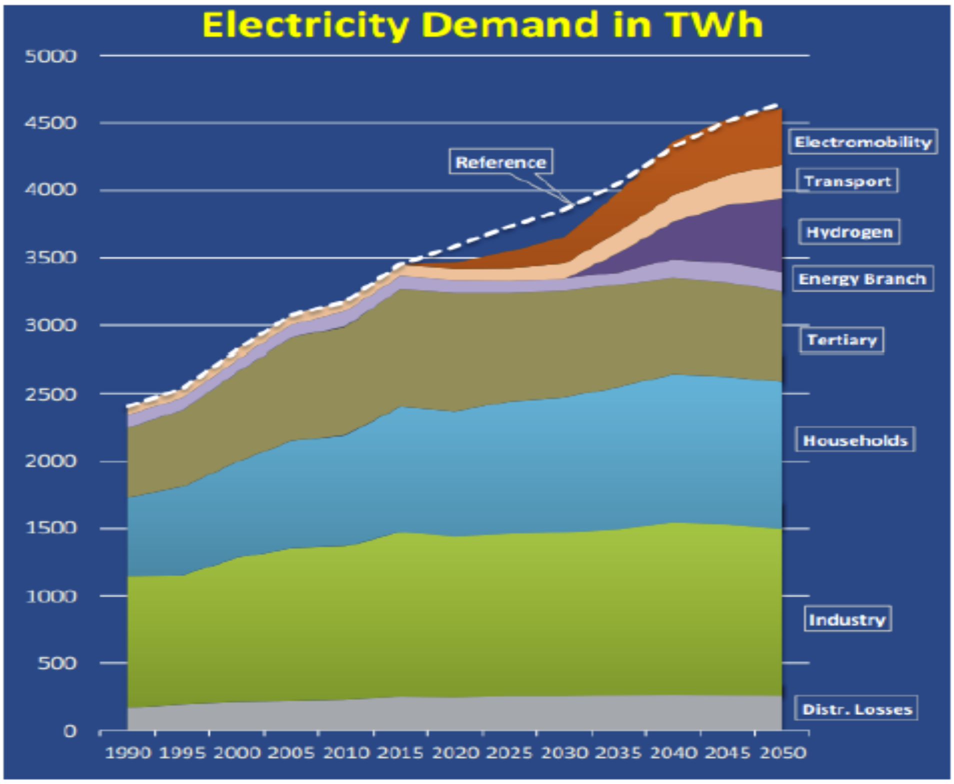


Figure 7 Prediction of EU annual energy consumption (Source: Eurelectric 2014)

Based on the expected size of the e-bus fleet in EU, its energy and power consumption can be estimated. To do this, the following hypotheses are made:

- E-buses are supposed to do 150km/day in average and have an average consumption of 200kWh/100km [3]. The average energy consumption is thus 300kWh/day.

- The relative consumption is based on the annual European consumption, which is expected to increase as depicted in Figure 7.
- For the required power capacity estimation, all buses are supposed to be fully charged overnight during 8 hours with equal repartition. This does not correspond to the reality as many e-buses use opportunity charging but this aims to simply give an order of magnitude.
- The relative power capacity is based on the total European capacity of 982 GW in 2015 and is supposed to keep increasing at an average rate of 20GW/year as it did between 2010 and 2015 [34].

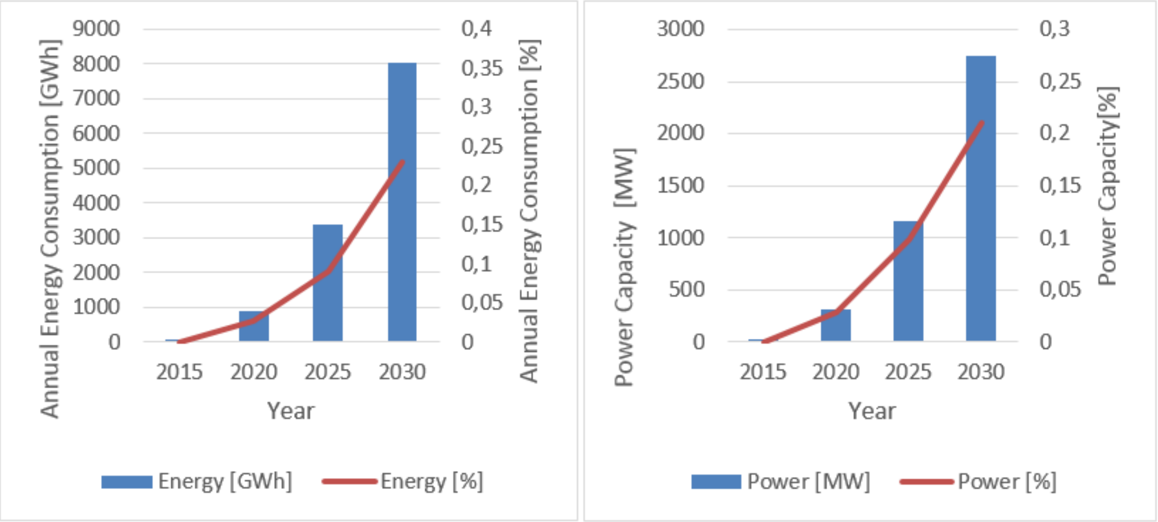


**Figure 8 Increase of energy consumption and required power capacity (supposing overnight charging) for the expected e-bus fleet, taking as starting point the energy and power consumed in 2015.**

Seeing Figure 8, the global impact of bus electrification in terms of consumption and power capacity seems relatively low. The required power capacity might however not be exact, as considering only overnight charging is a strong assumption. This approach also does not take the local effect on the grid into account.

### Other EVs

In order to reach their objectives in reduction of greenhouse gas (GHG) emission and urban pollution, EU countries are expected to support the electrification of the transport sector. A few countries have already taken initiatives to supporting EVs with incentives or by putting in place future bans of diesel and petrol cars, which should boost EVs sales.

Table 2 groups the initiatives and forecasts for a few European countries.

**Table 2 Initiatives and forecasts for some European countries**

| | |
|---|---|
| France | - Ban sales of petrol and diesel cars by 2040 [35]<br>- Forecast: EVs could represent 60% of sales in 2035 (38% PHEV + 22% BEV) and 68% in 2050 (38% PHEV + 30% BEV, rest would be NG) [36] |
| Germany | - Could ban sales of petrol and diesel cars by 2030 (not decided yet) [35] |
| Ireland | - Objective: All new passenger cars and vans sales by 2030 will be zero emission [37] |
| Netherlands | - Plans to ban sales of petrol and diesel cars by 2030 [38] |

| | |
|---|---|
| | - Objective: 200,000 EVs by 2020 and 1 million EVs by 2025 (respectively about 2.5% and 12.5% of total fleet) [39] |
| Norway | - Objective: 100% BEV or PHEV sales by 2025 (no ban on petrol and diesel) [40] |
| UK | - Ban sales of petrol and diesel cars by 2040 [35]<br>- Forecast: Average scenario predicts 6 million EVs in UK by 2030 (about 17% of total fleet) [41]<br>- Forecast: By 2040, 80% of car sales could be electric in UK (Bloomberg [42]) |

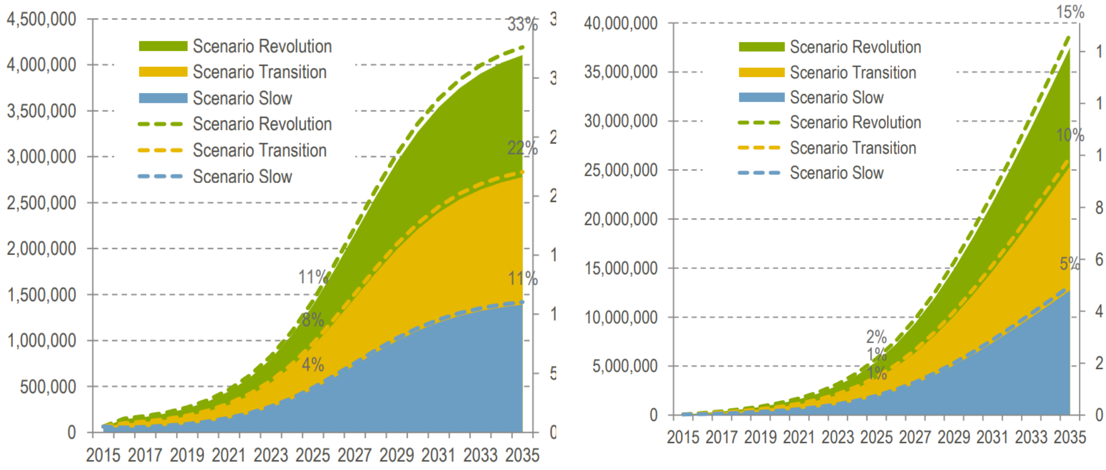
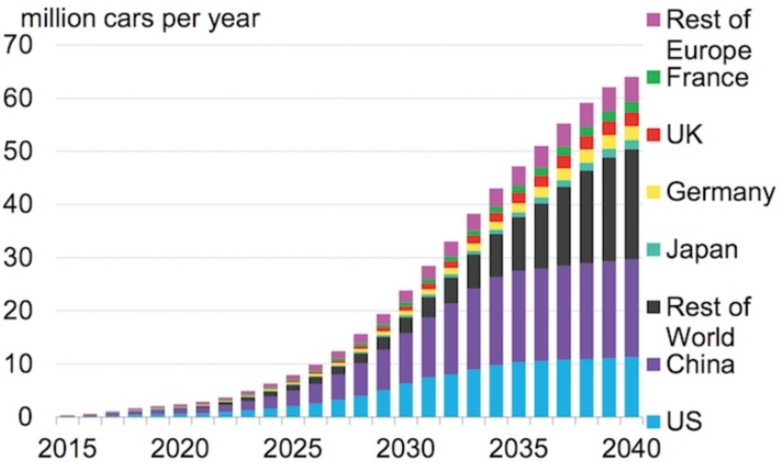


Figure 9 – A. Annual market share (%) and sales (millions). 9 - B. Accumulated market share (%) and sales

Eurelectric report [43] gives predictions of the evolution of EV market for different scenarios (Figure 9). As for Eurelectric, most predictions for EV sales are depicted with an S-shaped curve. Figure 9 predicts a significant increase in sales starting around 2023. It should be noted that this report was published in 2015 and that recent announcements of new and bans on fossil-fuel cars from some major European countries may accelerate the EV deployment.



*A new forecast for electric cars shows explosive growth in new sales, particularly in China.*
*Credit: Bloomberg NEF*

**Figure 10 EV sales prediction for different countries/regions**

There will most likely be significant disparities between European countries. For instance, Norway already has a 32% share of EV sales in 2017, which puts it far ahead of other countries [44]. This results from the fact that Norway has been incentivizing EVs since the 1990s. These include exempting EVs from value added taxes (VAT), thus making conventional automobiles significantly more expensive in the country, low annual road tax, and no purchase and import taxes [45]. In total number of sales, Germany, France and UK are expected to represent together the majority of European sales (see Figure 10).

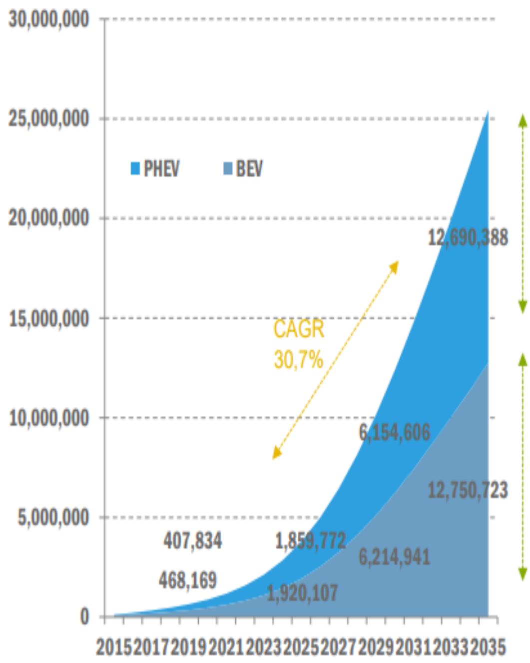


**Figure 11 Share of accumulated PHEVs & BEVs by 2035 in a transition scenario (% and million) (Source: [43])**

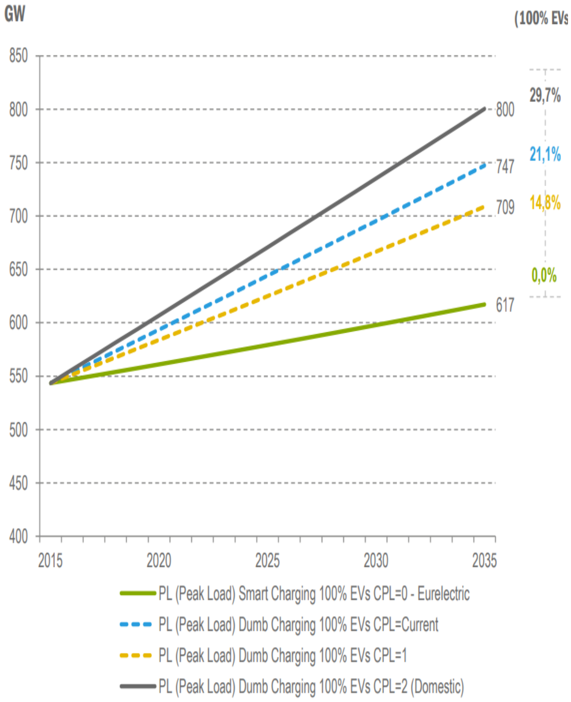


**Figure 12 European peak load in case of 100% EVs by 2035 and potential of smart charging (Source: [43])**

According to the estimates, a simultaneous development with an equal share of both plug-in hybrids (PHEVs) and fully battery electric vehicles (BEVs) could take place by 2035 (Figure 11**)**. PHEVs and BEVs may have different impacts on the grid depending on the country, use case or the availability of the charging infrastructure.

Eurelectric report also gives an estimation of the required additional capacity in case of the total electrification of transport (100% EV) by 2035 for different cases of load repartition (Figure 12). The Current Peak Load (CPL) corresponds to the ratio between peak load and average load. More specifically on (Figure 12):

- CPL=0 corresponds to the case in which Smart Charging (SC) is used so that, EVs are not charged during peak load and thus do not contribute to raise the peak load.
- CPL= Current. This corresponds to the case where EVs are charged in such a way that the current CPL is the same
- CPL=1 corresponds to an EV charging that is constant with time (peak load=average load)
- CPL=2 corresponds to an EV charging that typically coincides with the usual peak load, thus contributes to strongly raise it

This figure shows how the EV load repartition strongly affects the peak load and consequently the required capacity.

Other sources consider different levels of electrification, and energy consumption for EVs and e-buses.

Table 3 Energy consumption estimations for 2030 and 100% EVs

| | | | |
|---|---|---|---|
| **Total elec, e-cars, EU 2030** | **30.1** | **TWh/year** | 6% EV |
| **Total elec, e-buses, EU 2030** | **8** | **TWh/year** | 30% of buses |
| **Total elec, EU 2030** | **3500** | **TWh/year** | |

| | | |
|---|---|---|
| **% elec for cars, 2030** | **0.86%** | |
| **% elec for buses, 2030** | **0.23%** | |
| | | |
| **If 100% elec cars (2050)** | **501.7** | **TWh/year** |
| **If 100% elec buses (2050)** | **26.7** | **TWh/year** |
| **Total elec, EU 2050** | **4500** | **TWh/year** |
| | | |
| **% elec for cars if 100% elec cars** | **11.1%** | |
| **% elec for buses if 100% elec buses** | **0.59%** | |

**Source : EURELECTRIC, ENGIE Laborelec**

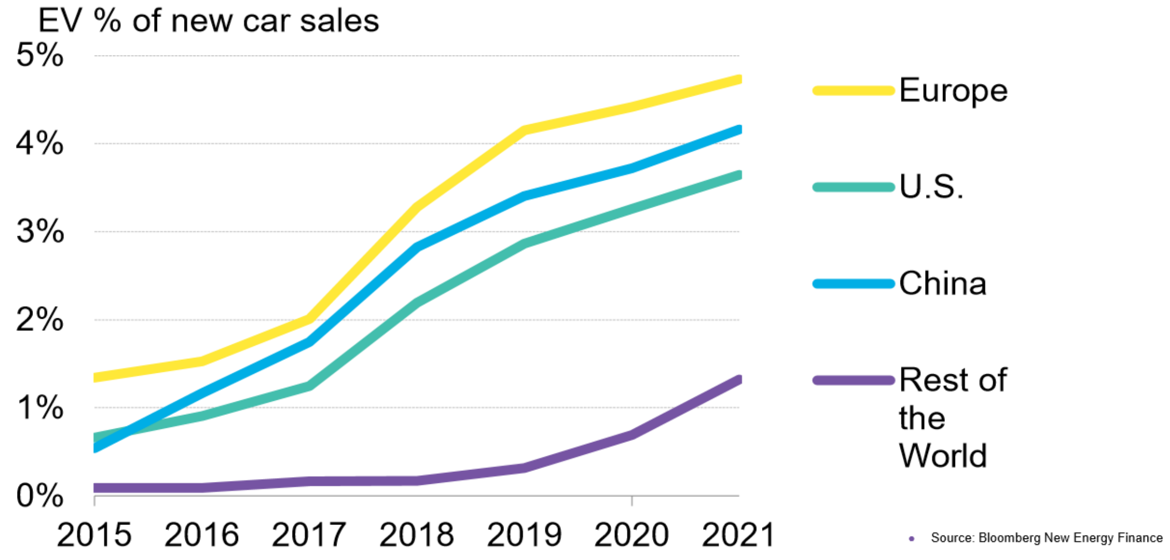
Energy consumption for EVs can be estimated in 2030 and for 100% EVs **(Table 3)** considering the following hypothesis:

- Average mileage is 13000 km/year in Europe for passenger cars [46] and EV consumption is about 20 kWh/100 km [47]
- 50% of e-cars are plug-in hybrid and 50% are pure electric (Figure 11)
- 55% of PHEV annual mileage is driven on electricity [47]
- For e-buses, same hypothesis as used to obtain **Figure 8**

It should be noted that by 2030, there could be more car sharing, meaning more km driven per year per car. But at the same time, the efficiency will increase, meaning less energy needed per distance.

### 2.2.2 Global

In the short term, Europe, U.S. and China are expected to lead the way in EVs (Figure 13). It can be noticed that this prediction for Europe is a bit optimistic than the one given in Figure 9.



Source: Bloomberg New Energy Finance

Figure 13 Short term prediction of EV sales

In the long term, EVs and PHEVs sales are expected to grow all over the world. Specific data is not given for some regions (Africa, South America) that are gathered in “All other” (Figure 14).

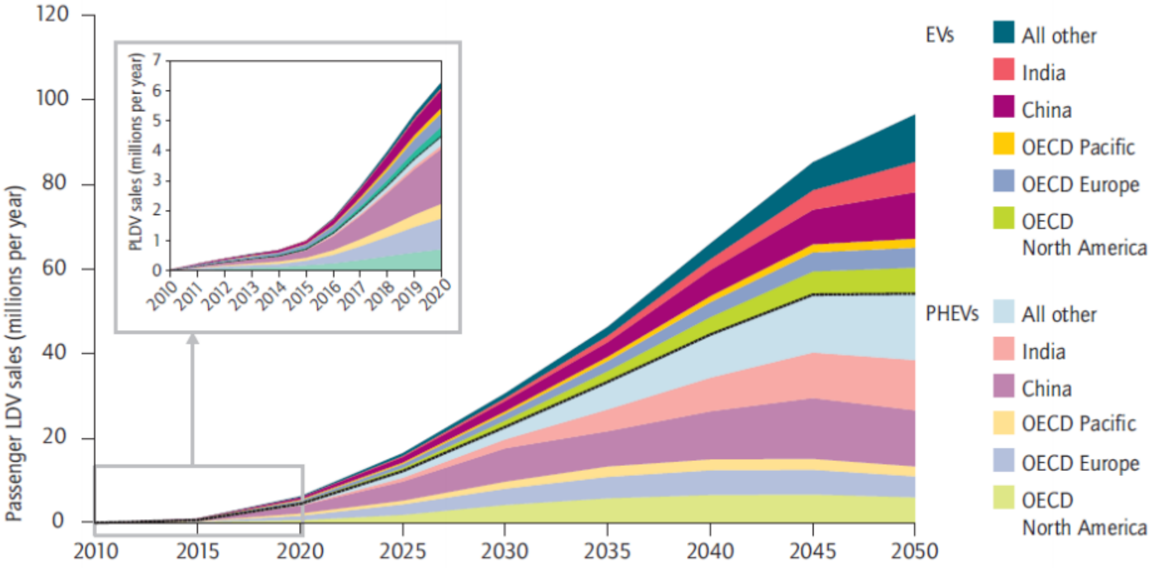


Figure 14 Predictions of EVs and PHEVs sales for different regions (Source: [48])

### 2.2.3 Messages extracted from EV EGVIA roadmaps

Analysing existing roadmaps of EV, the following messages can be found.

- “The success and the rate of market penetration of EVs will strongly depend on the degree of usage and perceived suitability for usage of these vehicles in urban areas” [49].

- "Charging infrastructure is a crucial topic for the success of electrification and is most often neglected" [49].
- "…the added dimension of refilling comfort. Daily e-charging would mean that drivers never have to stop at filling stations in the future; charging would be done daily at home or at work or at public or commercial parking areas (shops, motorway rest areas, etc.)" [49].
- "Regulatory efforts for the re-charging of xEV's have already been initiated. The EU has made steps towards the creation of EV re-charging infrastructure with Directive EU 2014/94/EU5. This provides an obligation on member state governments to expand the network of charging points" [49].
- "Public education initiatives should be considered to raise awareness through a variety of media channels. It has been observed that acceptance of electrified mobility increases dramatically after initial usage of the electric vehicles. Vehicle sharing could be an icebreaker in this respect" [49].
- "Increasing range capability of electric vehicles remains a high priority, as previously mentioned, in order to increase the user acceptance"…"increasing driving range supplied by the electro-chemical energy stored in the battery can only be achieved directly by increasing the size of the battery" [49].
- To take advantage of the full potential of an EV, a bi-directional smart charging V2G capability may be aimed at in the longer term [50].

## 2.3 RECOMMENDATIONS OR ISSUES RAISED IN TECHNICAL PRESS

### 2.3.1 E-Buses

| Issues | Conclusion & Recommendations | Ref. |
|---|---|---|
| - With overnight charging, more buses are required to operate the transit in the chosen study case (13 vs 11). It should be noted that the study case does not consider a possible redesign of the lines.<br>- With flash/opportunity charging, the impact on the grid is higher (substation transformer and feeder overload, under voltage)<br>• In this case, the transformer capacity must be 5-6 times higher than with opportunity/flash charging. | Operational feasibility and grid impacts generate contradictory recommendations for selection of BEB (Battery Electric Bus) configuration<br>➔ Both aspects must be considered for each case study | [51] |
| With fast charging of 300kW and buses with capacity of 220kWh, 50% of service trips in Muenster (Germany) can be electrified. With 500kW fast charger, this increases to 80%. However, the resulting power profile has high dynamic with sporadic peak demands. | - The load can be equalized with buffer batteries<br>- Decreasing the demanded passenger capacity allows to increase the battery capacity, thus reducing the required charging power | [52] |
| Fast charging of e-buses can overload existing MV/LV transformers | - Use of an ESS to make fast charging more cost effective since it can decrease and even out power demand<br>- Connection of the system to 10kV grid and have the fast charging station use its own MV/LV transformer | [53] |

| | | |
|---|---|---|
| | Case study of 6 bus lines of average length of about 8.6 km length (Ohio state university campus). The full bus transit can be electrified with 22 buses (55kWh each) and either 2 x 250 kW or 1 x 500 kW charging station(s) | [54] |

### 2.3.2 Light-duty EVs

| **Issues** | **Conclusion & Recommendations** | **Ref.** |
|---|---|---|
| A massive deployment of EV connections into the electricity distribution grid may bring some grid operation problems such as branch congestions or large voltage drops (transformer overloading not considered), especially if EVs follow a free charging policy. In the chosen example of a semi-urban MV grid, 5% voltage deviation was reached with 10% EV penetration and “dumb charging”. | Smart charging can be used to increase the maximum EV penetration without grid reinforcement. This is done with a centralized control that shifts the EVs charging to ensure there is no voltage or congestion problem. In the case study, the maximum EV penetration is 52%. | [55] |
| The EV additional load on the distribution networks, and EVs charging at peak periods could significantly stress the distribution networks requiring major infrastructure investments. This research demonstrates that the distribution networks are highly sensitive to the EVs uptake and charging strategy. | This research also shows that if the suitable EV charging strategy is used, the existing grid will support a significant number of EVs avoiding network reinforcements. Charging capability from solar panels at work will have a beneficial effect in the reduction of the peak demand. | [56] |
| Previous studies concluded that, with high uptakes of EVs, existing distribution networks will frequently exceed their limits. Reinforcement can be used to strengthen the existing networks; however, a widespread adoption of infrastructure upgrades would be very expensive. For example, it has been concluded that the required grid reinforcement may reach up to 15% of the grid cost from a case without EV integrations. | In this paper, the proposed control algorithm reallocates EV charging loads in advance based on the short-term load forecasting. It is assumed that the proposed control algorithm receives the short-term load forecasting from DNOs. However, the performance of the proposed control algorithm is tested with the real daily profiles of EV charging loads acquired from the smart meters during trials of the Customer-Led Network Revolution (CLNR) project. These profiles were used to synthesize stochastic charging durations for each EV with one-minute time resolution considering unbalanced EV charging loads across the three phases. | [57] |
| Many works on EV grid impacts do not take the randomness of the power demand into account, leading to underestimation/overestimation of the grid perturbations | This paper has presented a probabilistic impact assessment of realistic EV charging on nine UK LV networks that are part of the ‘My Electric Avenue’ project. The paper evaluates the effect of increasing EV penetration and compares the probabilistic approach with a deterministic approach:<br>- Deterministic approach concluded that transformer congestion would start occurring with EV penetration higher than 70%. Most notably, no problem was found at feeder level (congestion/voltage drop)<br>- Probabilistic approach concluded that feeder congestion and significant voltage drop can occur if EV penetration is higher than 70% | [58] |

| | | |
|---|---|---|
| | The comparison highlights that deterministic approach may fail to quantify some of the EV impacts in LV network. | |

In summary, it is important to look at the possible grid perturbations, both with e-buses and light-duty EVs.

E-buses can cause local grid perturbations because of the high power they require, especially with fast-charging. Operational feasibility and grid impacts can typically generate contradictory requirements: a higher charging power allows for a higher transport electrification but induces more grid perturbations. However, there are ways to mitigate grid impacts: use of local energy storage system, connection to MV grid, etc. Choice between overnight and opportunity has to be analysed case-by-case, depending on the parameters of the bus line and of the distribution grid. In the case of e-buses, the operation can be planned based on the bus lines schedule. A deterministic approach can thus be used to evaluate the impact on the grid.

Light-duty EVs can also cause local grid perturbations in case of high penetration and simultaneity. Residential charging is the main mean of charging for e-cars and most people start charging in the evening. Smart charging is thus important to prevent EVs from increasing the existing evening peak and thus reducing necessary grid reinforcements. A factor of randomness has to be taken into account for e-vehicles as the charging schedule is not totally predictable.

## 2.4 RECOMMENDATIONS FROM EUROPEAN PROJECTS

The list of EV research projects is large (PlanGridEV, Green eMotion, EDISON, e-gomotion, E-Light, E-VECTOORC, EAGLE, EASYBAT, eCAIMAN, eCo-FEV, ECOCHAMPS, ECOGEM, ECOSHELL, eDAS, EFUTURE, eLCAr, ELECTRIFIC, etc.), but the number of projects dealing with grid requirements is much shorter. The main recommendations that can be extracted from existing public documents are shown below:

| Issues | Recommendations & Messages | Ref. |
|---|---|---|
| This report focuses on the issues of power supply when connecting fast-charging stations to the distribution grids. As a case study, two fast-charging stations were placed on nearby positions. Then, the stations load was estimated based on traffic data and grid connection studies were performed to evaluate necessary the grid reinforcements. | - To know precisely what the necessary grid reinforcements are, load flows have to be performed in the area where the fast-charging station is to be installed, in normal and contingency situation, depending on what the contingency requirements are.<br>- To precisely evaluate the expected demand profile of a charging station, it can be interesting to know the traffic data of the road next to which the station has to be installed. | [59]<br>EDISON |
| Large EV penetration will induce problems in the distribution grid if not properly managed. | The report recommends, inter alia, an overview of G2V (Grid to vehicle) management features for the DSO and EVSE operators to prevent issues such as congestions:<br>- **DSO predefines peaks**: forecasting peaks to define the upper bounds of peak absorption in a load area and communicate to EVSE operators<br>- **Load management:** EVSE operators process the inputs from DSO end EVSP to define how to distribute constraints over its EVSEs. | [60]<br>Green eMotion |

| | | |
|---|---|---|
| | - **Congestion management:** used in case of critical congestion event, DSO is allowed to send congestion signals to a particular EVSE operator to interrupt or reduce charging.<br>- **Current EV charge:** Feature that an EVSP can deliver to benefit customers and other business actors, e.g. DSO and TSO to provide an overview of energy availability at the LV/MMV grid<br>- **History of EVSE use** | |
| The grid extension needed to provide the energy for EVs is actually rather small, the power need, especially for fast charging, is substantial. Challenges arising from this are line/transformer loading issues and voltage drops. | - Introduction of ICT and LV and MV grids can help dynamically balance supply and demand on all voltage levels<br>- The report proposes a new planning approach for distribution grids (implemented via a prototype tool): Instead of simply considering the estimated peak load of the grid, as with traditional distribution grid planning, the PlanGridEV approach additionally considers the controllability of the loads in conjunction with the estimated generation from renewable sources | [61]<br>PlanGridEV |
| The project "**e-DASH**" (**Electricity Demand and Supply Harmonization for EVs**) coordinated by Volkswagen aims at the design, development and validation of an innovative charging solution for fleets of Fully Electric Vehicles (FEVs) enabling sustainable FEV grid integration in the context of sometimes contradicting requirements like individual driver requests, availability of renewable energies, energy demand as well as low-voltage grid capacity. | - Distributed energy resources strategies to minimize the grid impact<br>- Flexible control of charging/discharging process<br>- V2G communication for forecasting and load levelling | [62]<br>e-DASH |
| The objective of the project is to develop an analytical framework for the planning of technological developments in the grid infrastructure and the definition of related ICT and policy requirements in order to cope with the mass introduction of EV and PHEV. | - A clear relation between the different countries and the capability to integrate EVs cannot be observed. The diversity of grids in every country is too large.<br>- Actions to improve the integration of vehicles should not be carried out country by country, but in joint effort by all European countries and in common with automotive industry<br>- Control strategies which allow the steering of the specific load of EV charging avoid grid re-enforcement | [63]<br>G4V |
| ELECTRIFIC will revolutionise how electric vehicles are integrated into power grid and user's life. The fundamental premise on which the project will work that significant improvements to electro mobility can be unlocked by | - Electric vehicle theoretically can be run entirely by renewable energy resources if travel plans and charging schedules are coordinated among multiple users and aligned with power supply and grid equipment<br>- Sustainable electro mobility trough smart vehicle-grid interaction. | [64]<br>ELECTRIFIC |

| | | |
|---|---|---|
| increasing coordination of all the actors in the electro mobility ecosystem. | | |
| Electric power systems are facing a major new challenge (and hence opportunity): future massive integration in the electric grid of electric plug-in vehicles (EV). Distribution and transmission grids and power system architectures still follow planning rules and procedures defined for the traditional operational paradigm. | - A set of new management and control concepts that will facilitate the safe integration of EV into electrical grids, using as much as possible renewable energy for battery charging;<br>- An evaluation suite of simulation tools capable of analysing the impacts and the adequacy of the different EV integration control strategies in the electric power system considering different EV deployment levels; by using this simulation suite will be possible to identify the necessary related policy and regulations, as well as to plan the technical evolution of the required generation and network infrastructures. | [65]<br>MERGE |

## 2.5 BUS OPERATORS

When choosing a charging strategy for a particular bus or set of buses the operator can typically choose between three strategies or a combination of them [66]:

- Slow charging (overnight charging)
- Opportunity charging at central points
- Opportunity charging along the routes

Comparing these strategies it is found that slow charging is typically associated with a lower cost charging infrastructure and larger battery packs whereas opportunity charging requires a more expensive charging infrastructure but smaller battery packs. The installation of chargers along the routes then typically depends on the existing infrastructure and associated complexity of placing an extra charger in terms of land ownership, permits and grid connection.

A combination of overnight charging and opportunity charging is also possible given the availability of the large infrastructure. This setup can be used to allow buses to begin their operation fully charged making them able to operate continuously during morning rush hours. In some situations the overnight chargers are over dimensioned creating the possibility to delay the charging of some buses to smoothen the charging profile for the entire fleet.

# 3. Identification of requirements and limitations for transport electrification

This section gathers the points of view of the different stakeholders taking part in the electrification of heavy-duty vehicles. By confronting the different views, the requirements and limitations for transport electrification can be more clearly identified.

## 3.1 VIEW OF DSO'S

The association of European Electricity Distribution System Operators (EDSO4SG) has been consulted regarding regular EV and the main messages received are summarised below:

- Charging infrastructure must be deployed considering flexibility.
- About 80% of EV charging is expected to take place at homes and offices when the car is mostly in idle position. From a DSO's perspective, AC charging has more benefits than DC fast charging as it opens the way for charging management processes at lower costs for customers. Combining home charging with high power DC charging connected to medium voltage grids will help maximize customers' satisfaction and meet DSOs' flexibility needs.
- Power is the challenge, but not the delivery of energy
- The additional demand arising from EV use can be handled with the existing grid capacity (kWh). However, the impact on peak demand (kW) is more critical.
- Suitable standards to reduce the power quality issues are needed
- Further research is needed to analyse the potential disturbances due to the charging effects on harmonics, voltage drops and overloads. Standardization bodies and regulators should address these aspects in close cooperation with DSOs.
- Create value with smart charging for EV grid integration
- Smart charging (organising efficiently the charging process to maintain grid reliability) is a necessary precondition for electro-mobility. Using appropriate charging-management strategies, it is possible to reduce the expensive grid reinforcements and supply side efforts while integrating high shares of EVs. The interface between smart charging infrastructure and DSO's dispatching centres must be developed as well as metering, sensors and means to reach visibility of congestions in LV grids. The potential of smart charging must be assessed.
- Regulation should allow DSOs to incentivize (to adapt users' behaviour) charging where it is more convenient for an optimized use of the network.
- DSO must be actively involved in smart charging and e-mobility
- DSOs will play a key role in facilitating the integration of electro-mobility and managing smart charging processes. They must have visibility about charging station site location and capacity requirements from EVs. DSOs' grids need to be equipped with devices able to detect grid constraints at relevant locations. Charging stations and their management systems shall also be equipped with communication devices able to communicate with DSOs' systems.
- Smart regulation and tariffs to activate smart charging

- It is important that all relevant charging infrastructures should be able to charge EVs in a more intelligent way. Regulation should therefore incentivize smart charging infrastructure, operated by DSOs or by commercial parties, to reduce the network costs. Smarter distribution contracts and tariffs can activate a more intelligent use of the network and customers'
- European Interoperability is necessary
- There should be a common system to use the public charging infrastructure, not only at a single country level, but overall Europe. This system should include payment alternatives, as well as information systems to know location, availability, state of the charging station, maximum power, price, etc.
- The public charging places will raise, given that, EV penetration will increase and part of the population will not have a private charging facility at home.
- The ownership and operation of public charging stations is not carried out by DSOs but by third parties in many countries. The massive deployment of EV depends on the charging points' deployment that is evolving at different speed depending on the countries.
- DSOs should take the role of deploying the charging infrastructure as normal distribution assets, providing the metering service. The commercial operation of this service would be a retail activity in an open competitive market.

## 3.2 VIEW OF ENERGY AND ENERGY SERVICE PROVIDERS

This subchapter summarizes the feedbacks received from experts on electric mobility, coming from different energy providers and energy service provider consulted.

Three development axes in e-mobility should be considered:

- Charging infrastructure (installation, operation, maintenance)
- Energy provider (with renewable sources for instance)
- Energy management → propose solutions to successfully integrate charging stations to the grid

Development of EV represents an opportunity for energy providers because it is a source of flexibility. Consequently, it helps reducing the imbalance (mismatch between production and consumption of energy). This is particularly interesting as renewable energy sources will increase.

Three aspects have to be considered when dealing the limitations and needs for electrification of transport: technical, environmental and economic.

Technical limitations:

- Lack of charging infrastructure and standardization.
- E-buses batteries are very heavy, reducing the number of passengers that can be transported.
- Need for bus-warehouses with higher electrical capacity.
- Fuel cells could be interesting for heavy vehicles (because of their high density, when gases are compressed) but they are at an early stage of development at the moment.

Environmental limitations:

- The environmental interest of developing EVs depends very much on the energy production mix of the country, and should be followed by a progressive transition to zero emissions electricity generation.

- There is a lack of global European regulation regarding emissions in cities. Several cities take local initiatives but global policies would be more effective.
- Hydrogen fuel cells could be environmentally interesting for heavy vehicles in a later stage, when their efficiency, infrastructure and renewable energy production increase.

Economical limitations:

- There is still too little offer of EVs at the moment.
- Total Cost of Ownership (TCO) is still higher for EVs (due to the battery cost) but it is expected to decrease in the following years. In frequent stop-and-go operation, EVs have shown less wear and need for maintenance than ICE-powered vehicles resulting in better availability and less maintenance cost to a vast benefit of the operator [67].
- Tenders should not only be sent to e-buses manufacturers but also to charging stations installers. In this way, the management of the e-bus fleet and charging points could be better optimized.

The increase of battery capacity might lead to more overnight charging than opportunity charging because most buses would be able to run the entire day without having to charge, thus reducing the need in high power charging points.

The role of the DSO needs to be established, given that several alternative solutions can be implemented. For example, in a liberal market, the role of the DSO could be to formalize his needs in terms of products. The market players (e.g. aggregators) would then propose their services to fulfil the needs of the DSO. The DSO should however keep some direct control over the charging infrastructure for the grid operation needs, and particularly for emergency issues in the distribution system. Another possibility could be considering the charging infrastructure as grid assets (connection points). Then the control over these assets would be optimal for the grid operation, and the service would be provided by an open market of retailers. The advantages of this alternative would be double: optimal grid operation, and fast deployment of charging infrastructures.

Many cities are taking local initiatives by restricting the access to city centres to low-emission vehicles. This could foster the development of EVs, but these initiatives are not coordinated: these restrictions are different in each city and will not come into operation at the same time (they depend on the environmental case of each city). In many cases, the information do not arrive to drivers with time enough to plan their movements. There is a need for a set of clear rules of common application in the cities that need to take measures. It is the role of the EU to provide us with the global and clear guidelines.

In a scenario of slow growing of EV, new stations will naturally be installed as the number of EVs keep increasing (as their TCO keeps decreasing). To accelerate the transition to a clean environment in the cities a basic charging infrastructure must be deployed before the EV needs.

## 3.3 VIEW OF AUTOMOTIVE INDUSTRY

This part of the document focuses on the view of automotive industry for increasing electrification on transport sector. It will be presented some requirements and limitations/opportunities giving prominence to manufacturing process and vehicle operation, especially for e-heavy duty type and for city transport application.

- Mandatory partnership engaged strategies for cost reduction and technology compatibility

Due to the application sector of this type of vehicles it's very important to have joint strategies to minimize TCO, standardize the technology as much as possible and to create partner synergies on the whole engineering and production process.

It has been a very clear bad example the light electric vehicle market, where coexisting several charging technologies and different charging interfaces impede a higher penetration on the market due to the lack of customer's confidence.

The bus operating companies and also the European cities government would not accept different charging standards for each bus manufacturer or a complete technological difference between similar application vehicles. Also in charging technology needs to be equal power levels and charging methods.

The implementation of this type of strategy will not only allow a higher introduction of electric urban transport vehicles in city environments, also will shunt in better competitiveness levels and higher commercial margins for bus and truck manufacturing companies.

- Interoperable charging standards development for quicker and comfortable technology implementation on the cities

It is expectable that a big amount of European cities will welcome the possibility of electrifying their public transport fleets so a big amount of charging systems will be installed. This type of infrastructure is expensive, and it also has huge operational costs depending on the country, for this reason all kind and all manufacturer of heavy duty public transport vehicle must be able to charge its batteries in different provider fast charging solutions. There must be hardware and software interoperability.

- Technology development, testing and validation to ensure high safety, reliability and high durability levels of EV transport vehicles

The relatively new electric powertrain technology must be as safe as the traditional ICE vehicles. This is a critical aspect, as many people uses this kind of transport solution and it cannot exist any risk or damage to any user in any possible context. On the other hand, the transport operators will never invest in a not reliable technology, which do not guarantees a good performance over the years. A higher durability and reliability level must be achieved for electric heavy duty transport vehicles.

Complementary, test, homologation and certification protocols must be in constant revision and development because of the quick technology renovation cycle in EV sector. Also in charging capabilities, a critical issue, the technology is constantly improving to get faster procedures for a better customer acceptance. As a result, testing and validating charging solutions is a key factor for EV development.

- High cost of EV components due to the actual medium-low production levels.

Actually, a same specification EV in comparison with a traditional ICE vehicle represents a higher acquisition costs. Then, when the vehicle is on work, the operational cost is reduced due to the electric powertrain technology. No fuel consumption, less maintenance costs… But, ultimately, it takes around 8 years to start profiting the initial investment (Figure 15). They are not bad investment results but it can be much improved through the increase of the production levels (according on the demand) and technological improvements of the EVs.

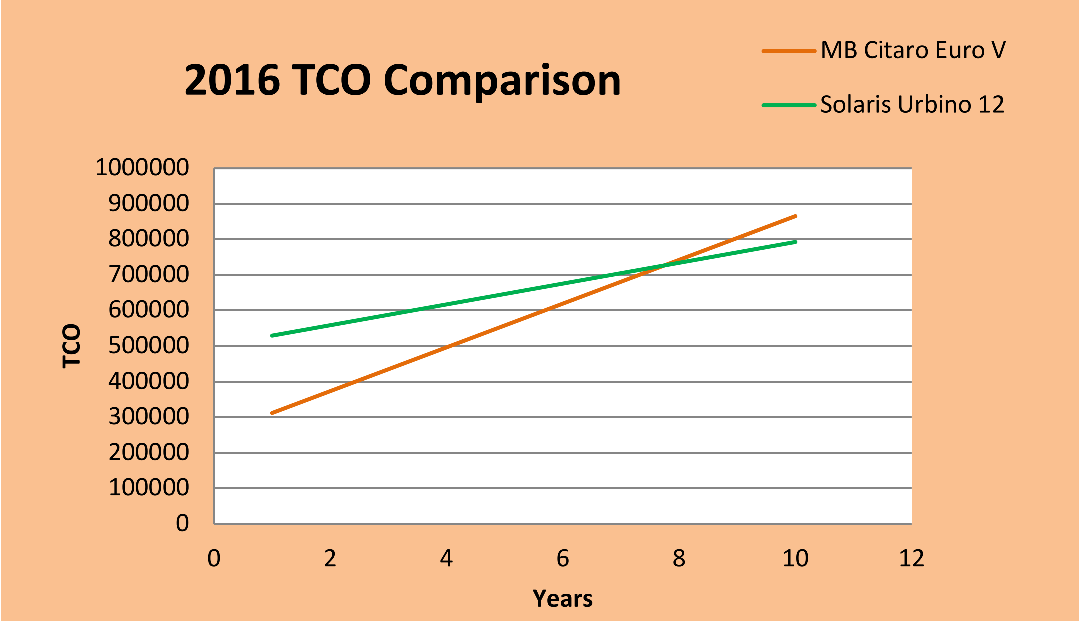


Figure 15 TCO comparison between Electric and Internal Combustion Buses

Taking into account the next cost parameters to perform a TCO evaluation:

| Year | MB Citaro euro V (€/year) | Solaris Urbino 12 (€/year) |
|---|---|---|
| 1 | 311548 | 529272 |
| 2 | 373096 | 558544 |
| 3 | 434644 | 587817 |
| 4 | 496192 | 617090 |
| 5 | 557740 | 646363 |
| 6 | 619288 | 675636 |
| 7 | 680836 | 704908 |
| 8 | 742384 | 734181 |
| 9 | 803932 | 763454 |
| 10 | 865480 | 792727 |

Table 4 Cost per Year (€)

- Fuel costs (1,20€/L) vs electricity cost (0,12€/kWh or similar. It depends on the country).
- Standard distance and working days (200km/day-322days/year).
- Acquisition costs
    - 250.000€ (MB Citaro)
    - 500.000€ (Solaris Urbino)
- Fixed costs like insurance, depot costs, bus driver and other workers, administration costs, cleaning and miscellaneous. These aspects are considered the same for both models.
- Maintenance and tyre changing costs. Electric bus maintenance is considered as a third part of the conventional vehicle maintenance costs.

- Public Transport vehicle operational and charging characteristics

Electrification in public transport vehicle is such a great idea because daily operation of this kind of vehicles allows exploiting all the advantages of electric powertrain technologies:

- Low speed operation:

  As electric vehicle, low speed and continuous stop and go actions means high powertrain efficiency and, as a result, low energy consumption. High speed conditions represent a very hostile environment for BEV in terms of power consumption.

- High torque levels as principal need:

  For city operation is usual to perform slope climbing, taking into account the vehicle weight added to the payload it results in a very high torque needs at low speed that fits perfectly with electric motor characteristics.

- Opportunity charging ability in programmed stops:

  As a transport vehicle with a programmed routine it has the possibility of opportunity charging during stops without any implication for passengers.

- Better bus design configuration possibilities due to axle motors and roof battery installation:
  New powertrain technologies allow rethinking the overall configuration of the vehicle. The ICE transport vehicles has very restricted configuration possibilities, but with electric technology it can be achieved a more optimised vehicle with higher comfort levels and passenger capacity.

- Reduced noise and vibration level

  This is a very obvious statement but it has many implications on improving comfort and passenger’s mood.

- Cities greenhouse gases emission reduction
  Of course this is a zero emission technology but it has associated manufacturing and energy generation emissions, the last one is depending on the country energetic production mix.

- Operational requirements:
    - 100-200km each day and 14 - 16 hours journey
    - Average speed of 15-30km/h

- Two charging possibilities:

  - Depot charging (3-8 hours) at medium power level 50-150kW. Mandatory for battery balancing and aging effect minimization. There is also the possibility of pantograph charging on depot.
  - Stop and go (opportunity) pantograph charging (2-5 minutes) at high power level 300-600kW.

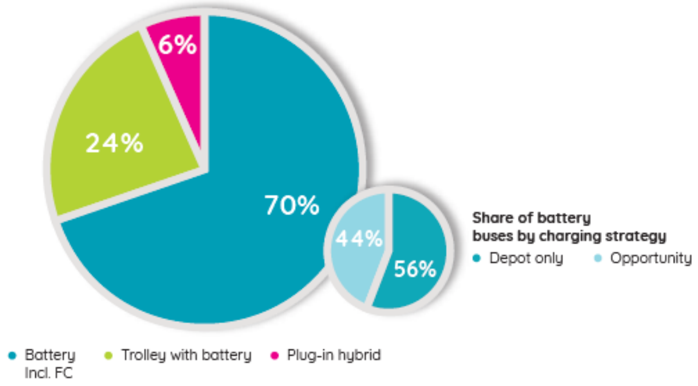


**Figure 16 Electric bus technology in Europe 2017. Source: Alexander Dennis Limited**

- Charging infrastructure expansion rate and related costs

These two charging possibilities for e-buses represent a different impact:

For depot charging is used a medium power charging based on actual DC charging interfaces (CSS, CHAdeMO, GB/T). It can achieve similar power levels as EV cars, but charging process on buses will spend much more time due to the larger battery capacity (10:1). As depot charging is performed during nights the impacts on the grid and economics are reduced.

Stop and go (on route) charging is an opportunity charging method conceived for suppling an usable amount of energy in a reduced time during bus stops. This type of charging process requires a dedicated infrastructure and also requires a fast charging system receptor included on the bus.

For this public transport application, the manufacturers, the city authorities, the bus operators and the electricity companies are responsible for electric buses charging infrastructure so the expansion rate would depend on the introduction of public transport electrification in each city.

In terms of cost, a depot DC charging equipment (device and installation) could be around 20-40k€, on the other hand, super-fast DC charging systems (pantograph based) is surely a more expensive system. But this kind of charging, after infrastructure generalization in cities, will allow reducing the battery capacity due to the possibility of continuous opportunity charging during the route, this can mean lower battery capacity, and therefore, lower cost for electric buses.

- Possible lack of raw materials and price fluctuations in supply chain.

In front of the big future demand of some specific materials, mainly for battery and power converters manufacturing, like Lithium, Cobalt, … is possible to have supply problems or big price fluctuations due the dependency of consolidated monopolies on minerals extraction and commercialization process.

This is a very big weakness with important implications on EV market. For a sustainable market growth and through many years of investigation this issue has to be solved by replacing these materials for less expensive and more abundant ones.

- Environmental effects relating to EV production and operation

In summary, an electric bus during its operation, in front of an ICE bus, displaces the associated polluting, mainly $CO_2$, emissions out of the cities (where electricity is generated) and has a much reduced heat and sound emission.

Despite this, an electric bus is not an emission free vehicle because it has associated emissions due to electricity generation and manufacturing process. This is the proof that transport electrification is not just a powertrain technology change; it's about commitment for reducing to maximum levels the emission footprint of the whole operation and manufacturing process of the transport industry.

## 3.4 VIEW OF BUS OPERATORS

In the context of "dieselgate", also diesel-powered bus fleets have come into the focus of air quality improvement measures [68]. Urban buses are not the main source of emissions in the city, but, in order to guarantee seamless continuation of service, bus fleet operators will need to replace their old buses with poor emission levels at high priority by clean diesels or electric vehicles. Public Transport Authorities and Operators have understood the interest of this "cleaning"-process and have enormous interest on it. Numerous local authorities have already introduced environmental areas banning diesel vehicles of outdated emission standards from these zones. And discussions have started about banning diesel and maybe even any internal combustion engines totally from certain metropolitan areas, which will likely involve also diesel-powered buses [30]. Clean air legislation may actually urge municipal authorities to prohibit using certain or all internal combustion engines in areas suffering from smog – at least temporarily for the time of acute health threatening air quality. In particular then, cities are in need of a reliable public transport system to avoid a collapse of urban transport and business. This indeed motivates to favour buses with electric powertrain over clean diesels, when bus operators renew their vehicle fleet.

Despite a future shift to multimodal transportation, buses as a mode of people transport are in permanent competition about their share in transportation with other modes like personal vehicles (cars, motorbikes, bicycles, pedelecs), shared mobility services, or walking. Therefore, fleet operators have to maintain or improve the customer acceptance by providing their service with appropriate comfort at an attractive pricing. Therefore, cost plays an important role, when bus fleet operators place their orders.

One scenario to consider the integration of electric buses is associated with replacing diesel-fuelled buses at the start of a new concession. Since the transportation demand is likely to only show minor changes in a concession, the operator attempts to merge the new e-buses with its existing fleet. Moreover, a complete redesign of a city's public transport network is often a complicated option due to the lack of possibilities to move existing infrastructure such as bus stops and bus terminals. However, a joint optimisation can possibly happen, resulting in a redesign of the bus network to make it easier to integrate e-buses.

Bus operators choosing for e-buses have multiple options with respect to their vehicle and charger type. When investing in e-buses operators wish to maximize passenger capacity and vehicle operating hours while minimizing the total investment cost. Depending on the operation profile, this often requires operators to opt for large battery packs, high power charging or frequent charging with chargers placed along the route. Opportunity charging can be used to compensate for a smaller battery pack, which has the added benefit of allowing more passengers on a bus. That smaller battery, however, will require more frequent opportunity charging and, therefore, more charging stations along the bus line routes. And the electric grid has to be able to provide the necessary power with the appropriate dynamics at these spots.

When investing in new vehicles, bus fleet operators have to consider:

- The total cost of ownership. As highlighted before, this depends of the investment cost of the vehicles, charging equipment and the maintenance of both, as well as of the commercial conditions for energy supply by the grid operator.
- The expectations and satisfaction of customers in order to guarantee a similar or better revenue from the investment.

The cost for charging infrastructure and for vehicle poses a trade-off. A small battery with its cost and weight advantage may require higher cost for setting up multiple charging stations for intraday opportunity charging. Frequent ultrafast charging at high power may also cause premature aging of the battery and require a costly replacement. On the other hand, electric vehicles show much less wear, and thus much less maintenance cost, than conventional ICE-powered vehicles in operation scenarios, in which they undergo frequent stop-and-go [67].

Due to the charging stops, passengers' travel time should not increase in a way that they notice. Also rerouting bus lines in the attempt to use charging stations with multiple bus lines may be detrimental to passenger acceptance and motivate them to change transport modes. Ideally, the bus line network will allow allocating opportunity charging, if any needed, to end stations in central hubs. When combining opportunity (fast-) charging with slow overnight charging, a battery charge strategy can be applied that only partly replenishes the battery charge at each stop. When the bus reaches the depot with its battery much depleted by the end of the day, it can be recharged gently by slow charging in the depot. Likewise, legal boundary conditions like mandatory driving pauses can have an impact on the choice of the battery capacity and charging devices.

In any case, the requirements of operators will depend on their particular use cases. Criteria include the energy consumption caused by the payload, route length and topographic profile, grid capacity and future grid extension plans as well as by climate boundary conditions requiring heating and/or air-conditioning.

The impact of the operator requirements on the grid depends on the distribution, type and power-level of fast-charging stations in that area as well as on the size of the depot and the number and type of charging stations therein will be operated for how long and how any busses will be recharged at a time.

# 4. Identification of grid requirements

This section explains the requirements that the DSO and TSO have to take into account to ensure that EVs are successfully integrated into the grid.

## 4.1 TSO'S REQUIREMENTS

The stability of the frequency is responsibility of the TSO. When the demand is higher than the supply the frequency goes down. The simultaneous connection of a number of EVs, or HDV could require fast power ramps of generators that may exceed current capabilities. Response times vary depending on whether a primary level, secondary level or third level frequency regulation is executed.

In general, it is important to organise and coordinate the massive charging process of the EVs, and the large peaks produced by e-HDV connecting simultaneously in the city requesting high power during short periods of time. This could be done using Smart Charging systems at DSO level, which will avoid problems at TSO level.

Smart charging would be applicable to secondary level / third level frequency regulation, by aggregating enough EVs within a geographically constrained group of primary HV/MV substations, controlling their charging process though a controlling load curve designed in order to have an impact on the frequency regulation, with a range of 10 seconds – 5 minutes response time and an estimated maximum depth of process of 2 hours. TSOs decide on the minimum lot size required to participate to frequency regulation. For instance, in Germany, the minimum size to be part of the secondary and tertiary reserves is 5 MW [69]. Expected market exploitation for cars is to be set beyond 2025 [70].

Regarding buses, if a depot was to be completely electrified, the power required to charge all the buses overnight would be in the order of 6-7 MW with the following hypothesis:

- An average of 175 buses/depot, based on the data from STIB (Brussels public transport operator) [71]. The number is similar for Transport in London [72].
- Average consumption of 200kWh/100km and mileage of 150km/day
- All the buses are charged overnight during 8 hours with equal load repartition

This is thus the same order of magnitude as the minimum power required to be part of the frequency regulation. However, e-buses could only participate either when they are at a fast-charging station or when they are charging overnight. Moreover, a reserve has to be available throughout the day to participate to frequency regulation. E-bus depot and fast-charging stations could thus be aggregated with other loads in a certain group of HV/MV substations to form a lot that can participate to frequency regulation. Considering the high power of e-bus charging stations, their market exploitation as frequency reserve could come earlier than e-cars.

## 4.2 DSO'S REQUIREMENTS

This section develops the different aspects that the DSO should consider in order to deal with the connection of EVs to the distribution grid:

- Expansion (planning)
- Installation
- Operation (day-to-day)

The expectations of EDSO4SG for 2030 is an increase of 1% to 10% in energy, which would not be a problem and an increase of up to 20% in peak load, which should be taken into account.

### 4.2.1 Grid expansion needs

The normal expansion of grids follows a process that considers a population growth expectation, information provided by municipalities, industrial requests of power increase, and simulations. This should be analysed, talking with planning departments of utilities to know their requirements for an easy and fast transport electrification process.

The current presence of EV in Europe is not a problem for the grids, but in a near future, the progress of EV will force DSOs to prepare the grids to assume the peaks produced by this new market. Particularly, considering that the expected level of simultaneity will be high.

In general, the EV is now mostly connected to Low Voltage grids, which are in general not supervised at all. A massive deployment of EV could require LV grid reinforcement or larger LV grid connection(s), for example charging islands. Another solution is “smartening the LV grid” which could be an alternative way to increase the capacity of the grids to manage the new scenario, avoiding the costs of generalized reinforcements. This could be done by introducing of ICT (Information Communication Technology) to dynamically balance the power and supply in LV grid, thus avoiding risks of overloads and under voltages.

The limiting factors at LV level will be cables and transformers’ capacity and maintaining the voltage levels. A direct, short-term congestion challenge is not expected with AC-chargers for cars. The issue could be a capacity and power quality challenge.

The plans of charging stations, city bus-lines, taxi-stops, etc. should be done in coordination with DSOs to optimise the future reinforcements. The relatively limited number of buses compared to commercial, provides the opportunity to coordinate the planning and installation of chargers for buses following a project-based approach and also taking into account the grid situation. The use of appropriate tools to assess different locations, using well-established guidelines will lead to the decision of the right kind of grid connections, for the right kind of chargers.

The grid connections for buses are providing an opportunity to be used for multiple purposes. Next to bus chargers, the connections can also be used for normal charging of the commercial EVs and there is a wish and possibility to connect local sustainable energy sources to storage facilities. These storage facilities could also positively impact the needed capacity for a grid connection for bus charging.

To assess these possibilities, the costs of the different kinds of connections are of importance. MV-T or MV-D connection options are given in a scheme in Figure 17. MV-T stations have mostly a redundant (N-1) connection to an HV/MV-station and/or other MS-T stations. The MV-T station feeds the MV-distribution grids and/or directly larger MV customers.

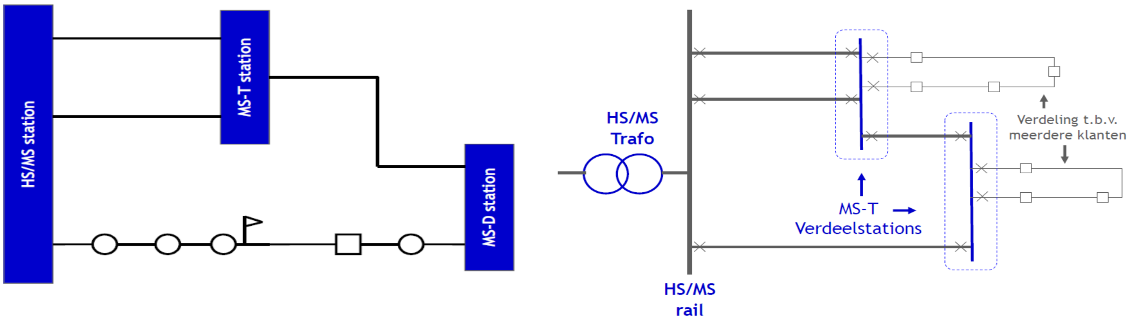


Figure 17 MV-T or MV-D connection options

Connections to a HV/MV station are more expensive than connections from an MS-T station, due to the heavier design guidelines.  Therefore, it is sometimes cheaper to build a new MV-T station behind an existing MV-T station. For example, this is the case when the distance is shorter than the distance to the HV/MV station, and because of saving in cables at the HV/MV-station. In this case, it is possible to build a new station fully ‘behind’ an existing MV-T station, or partly.

A few possible extension possibilities are proposed below. The first solution (Figure 18) is preferred considering the vulnerability of the second solution. For the first solution there is an redundant N-1 situation. When MV-T station A goes down, MV-T station B is still working. The second solution shows that when MV-T station A goes down also MV-T station B will go down.

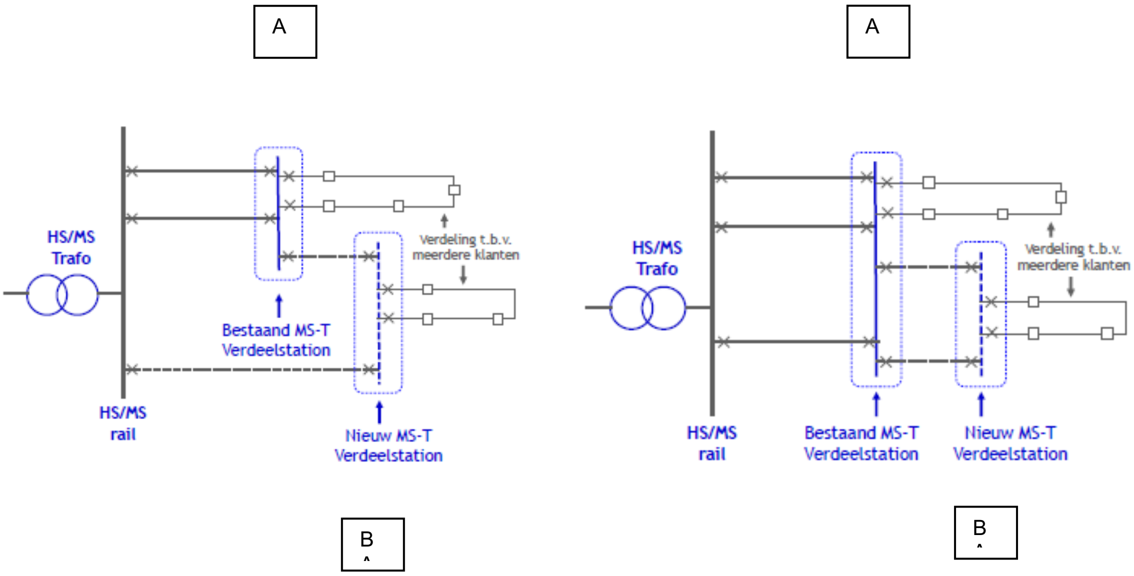


Figure 18 Alternative deployments

In practice, multiple constellations exist because of historic growth. When extensions are needed, the total existing configuration needs to be taken into account. It is important to prevent having too much MV-T stations ‘behind’ or ‘next’ to each other. There is danger of lack of clarity and it is harder to protect these complex constellations. Because of the N-1 character of this grid, the down-time in these grids is low but when there are faults with, for example a selective switch, the impact is often big because of the large number of the customers and the quite long time to repair. The impact on the most common grid constellations and extensions must be assessed.

The most common grid-connections in the Netherlands are on MV-T, MV-D (Distribution), MV/LV (a cable from a substation only for one connection) (Figure 19 and Figure 20).

| Connection category | Grid plane | Rated connection voltage |
|---|---|---|
| 3 x 160 A | MV/LV | 0.4kV |
| 3 x 250 A | MV/LV | 0.4kV |
| up to 630 kVA | MV-D | 10/20kV |
| more than 630kVA up to 1750kVA | MV-D | 10/20kV |
| more than 1750kVA up to 6000kVA | MV-T | 10/20kV |

Figure 19 Possible MV level connections

| Connection value | Accounting capacity (kW) | Maximum capacity (kW) |
|---|---|---|
| 1 x 6 A | 0,05 | 1.4 |
| 3 x 25 A | 4 | 17.3 |
| 3 x 35 A | 20 | 24.2 |
| 3 x 50 A | 30 | 34.6 |
| 3 x 63 A | 40 | 43.6 |
| 3 x 80 A | 50 | 55.4 |

Figure 20 Possible LV level connections (1x6A, 3x25A, etc. up to 3x80A)

### 4.2.2 Installation needs

Connection

In most of the European countries, when a consumer request a connection point at Low Voltage (LV), to the electricity distribution company, the DSO provides one of this two alternative solutions:

- A LV connection when the power is below a certain limit (for example, 150kW in Spain, 50kW in Netherlands,…).
- A MV connection when the power requested is over this limit. In this case, the consumer has to install a Secondary Substation (SS) to transform from MV to LV.

For HDV charging points of 600 kW as foreseen in ASSURED project, the connection should be at MV. In this way the impact on the grid is lower and the short circuit power is higher.

On the other hand, it is completely unusual, especially in the cities, to have a Secondary Substation with available capacity for such high power loads. Consequently, a private Secondary Substation must be built at the connection point. In the cities, these SS are usually underground installations. Normally, it is easy to find the MV cables near the installation point, but it is necessary to find available space to install the SS for the charging point.

For all these reasons, it would be convenient to design the high power charging point equipped with a transformer inside the enclosure, to avoid the difficulties of the additional civil works to build a Secondary Substation at the installation place.

Measurement (voltage and current of grid)

Furthermore, measurement system should be installed in the charging station. In general, these measurement systems are divided into two parts: the DC measurement system and the AC measurement system. The AC and DC measurement devices are placed at connection point between the grid and the charging station and between the charging station and the vehicles, respectively. This paragraph is focused on the AC grid measurement system only. The 3-phase AC measurement device must therefore be connected to the secondary of the transformer, which connects the high voltage grid to the charging station. This equipment is used to measure the currents and voltages of the three phases. These measurements should be able to provide:

- The AC currents (A) of the secondary of the transformer
- The AC voltages (V) of the secondary of the transformer

- The Total Harmonic Distortion (THD) (%) of the 3-phase currents and voltages systems
- The active power (kW), reactive power (kVAR), and power factor
- The energy (kWh)

The data derived from the above-mentioned measurements should be compared to IEC 6100 standard to assess the conformity of the ASSURED solutions.

In most countries, an independent and certified AC measurement is required following certain regulations. The installation must be conducted by the DSO or measurement companies, dependent on the country. While the measurement may be used by the end-customer, the measurement device typically does not contain power quality measurements. This may lead to a second meter being required.

### Power Quality

This part aims to identify the requirements and limitations related to the power quality of the grid that must be ensured in ASSURED project. Considering the aspect of grid extension due to the increase in the transport electrification in urban areas, an important parameter that must be considered is the power quality of the grid. The power quality requirement must ensure the compatibility between the grid and the load (i.e. charging stations). The European Standard EN 50160 has been adopted by the European Committee for Electrotechnical Standardization (CENELEC). Power quality has several indicators and parameters such as continuity of service and voltage wave quality **(**Figure 21 and Figure 22**).** Regarding the voltage magnitude and according to the proposal, ASSURED solutions should not cause more than 5% ripple on the voltage amplitude of the grid. Nevertheless, other disturbances may occur due to the ASSURED solutions or other consumers on the grid. The main standardized disturbances are summarized in Table 5. The reduction of these disturbances improves the power quality, the lifetime of the equipment, and the service quality.

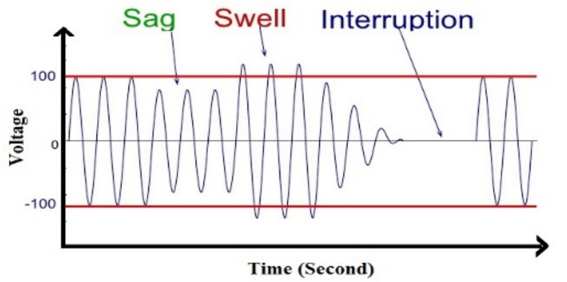


Figure 21 Waveform of voltage sag and voltage swell

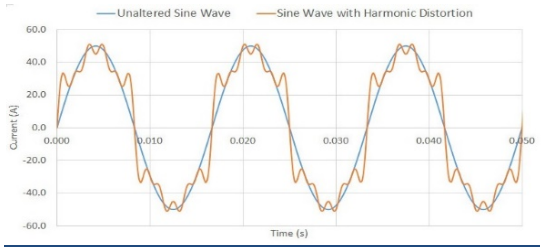


Figure 22 Waveform showing the effects of harmonic distortion

Table 5 Main standardised disturbances in electric power grid

| Disturbances | Definition | Standards values |
|---|---|---|
| *Voltage Sag* | Decrease of the voltage below the prescribed effective voltage ($V_{rms}$) for a short period. | Duration: 10ms to 60s<br>Magnitude: 1 to 90% |

| | | |
|---|---|---|
| *Voltage swell* | Increase of the voltage above the prescribed effective voltage ($V_{rms}$) for a short period. | Duration: 10ms to 60s<br>Magnitude: 110 to 180% |
| *Over voltage* | Increase of the voltage above the prescribed effective voltage ($V_{rms}$) for a long period. | Duration: Greater than 60s<br>Magnitude: Greater than 110% |
| *Under voltage* | Decrease of the voltage above the prescribed effective voltage ($V_{rms}$) for a long period. | Duration: Greater than 60s<br>Magnitude: Lower than 90% |
| *DC offset* | DC current or voltage offset in an AC system. | Duration: Steady state<br>Magnitude: 0 to 0.1% |
| *Flicker* | Oscillation of the voltage amplitude modulated by a signal with frequency of 0 to 30 Hz. | Duration: Intermittent<br>Magnitude: $P_{st} \leq 1$ |
| *Frequency variation* | Deviation of the fundamental frequency from its nominal value (50 or 60 Hz) | Duration: Lower than 10s<br>Magnitude: > or < than 1% |
| *Voltage unbalance* | Voltage variation in a 3-phase system in which the three voltage magnitudes are not equal. | Duration: Steady state<br>Magnitude: Up to 2% |
| *Voltage interruption* | Reduction of the effective voltage ($V_{rms}$) to zero or close to zero. | Magnitude: lower than 1%. |
| *Harmonics* | Sinusoidal voltages or currents with frequencies that are multiples of the fundamental frequency | Magnitude: THD ≤ 8% |
| *Inter-harmonics* | Waveforms with frequencies which are not multiples of the fundamental frequency | Magnitude: 0 to 0.2% |

The grid operators guarantee a certain level of power quality and continuity of service to the customer. Standardized guarantees are given in standard EN 50 160 (Table 6 and Table 7).

**Table 6 Standard EN 50 160 regarding the power quality**

| **Perturbations** | **Standards values** |
|---|---|
| *Short interruption (up to 3 minutes)* | Few tens to few hundreds per year (70% of them < 1s) |
| *Long interruption (longer than 3 minutes)* | Up to 10-50 per year |
| *Voltage magnitude variations* | ± 10% during 95% of week |
| *Rapid voltage changes* | Medium Voltage: 4% normal (6% infrequently)<br>Low Voltage: 5% normal (10% infrequently) |
| *Supply voltage unbalance* | Up to 2% (3% in some locations) |
| *Over voltage* | Up to 1.7 $V_{rms}$ (solid or impedance earth)<br>Up to 2.0 $V_{rms}$ (unearthed or resonant earth) |
| *Power frequency* | ± 1% during 99.5 % of week<br>+4% and – 6% during 100 % of week |

**Table 7 Value of individual harmonic voltages at the supply terminals given in % of Vrms (EN 50 160)**

| **Odd harmonics** | | | | **Even harmonics** | |
|---|---|---|---|---|---|
| *Not multiples of 3* | | *Multiples of 3* | | | |
| Order *h* | Relative volt. (%) | Order *h* | Relative volt. (%) | Order *h* | Relative volt. (%) |
| 5 | 6 | 3 | 5 | 2 | 2 |
| 7 | 5 | 9 | 1.5 | 4 | 1 |
| 11 | 3.5 | 15 | 0.5 | 6 …. 24 | 0.5 |
| 13 | 3 | 21 | 0.5 | | |
| 17 | 2 | | | | |
| 19 | 1.5 | | | | |
| 23 | 1.5 | | | | |
| 25 | 1.5 | | | | |

### 4.2.3 Grid operation needs

Traditional problems on the grid raise as grid overloads, grid voltage drops at the end of the lines, high peaks of consumption, power not granted in case of failure of one component (N-1 operation), etc. All these kinds of problems should be analysed, in a scenario of high EV penetration, and transformed into requirements to be considered in the high-power charging systems design.

At LV level, the grid is usually developed under demand, but the EV presence will change the consumption profile and the way to develop new grid. As it has been previously explained, the power will be the real issue, and network overloads will reduce the expectancy of life of grid assets, and will produce voltage fluctuations. When the voltage goes out of the margins, consumers' devices stop working.

In general, the grid requirements depend on the following parameters:

- Local grid configuration (e.g. rural vs urban)
- EV penetration
- Number and power of charging stations
- Charging strategy (smart vs dumb charging, opportunity vs overnight charging for e-buses)

Using conventional charging, a large deployment of EVs will have impacts on the distribution system: problems of load forecast, lines or transformer overloading, important voltage drops, increased losses. The rural areas would be mostly affected [61].

Local congestions could occur in the case of fast charging, ultra-fast charging or heavy-duty vehicles chargers, as the punctual power requested is higher.

Low Voltage (LV) networks of the different DSOs present similar characteristics in their construction and used topologies. The LV structure in rural zones is typically aerial using bundled cables and fed by pole-mounted transformers. In most cases, in urban areas underground cables are used, fed by ground-mounted transformers, but some aerial bundled cable structures can also be found [61].

High loads can cause high perturbations. Connecting them through a transformer to MV grid, the impact is much lower. A Secondary Substation is frequently equipped with a transformer of 250, 400, or 630 kVA. Consequently, it makes sense to dedicate a transformer for a high-power charging point. When we avoid sharing the equipment with residential customers, there will be no other users affected by the voltage variations, and the impact on the other side of the transformer will be limited due to the high capacity of the MV grid.

Typically, Medium Voltage (MV) networks of the different DSOs also present similar characteristics, particularly in the voltage levels used, their construction and the topologies used. Similar approaches are used by the DSOs in MV network topologies, where two types of topologies are present, closely related by the nature of the load: the radial topology, typically aerial and associated with rural zones, and the mesh topology, typically underground and associated to urban areas. Generally, for all the DSOs, the MV radial topology is composed by a main feeder, leaving from an MV bus bar of an HV/MV main substation, which supplies branch clusters of MV/LV secondary substations.

In the case of several high-power charging points close to each other, and connected to the same MV feeder, even if they are equipped with their own transformers, an impact on the grid can appear, and reinforcement at MV level (transformers or lines) can be needed.

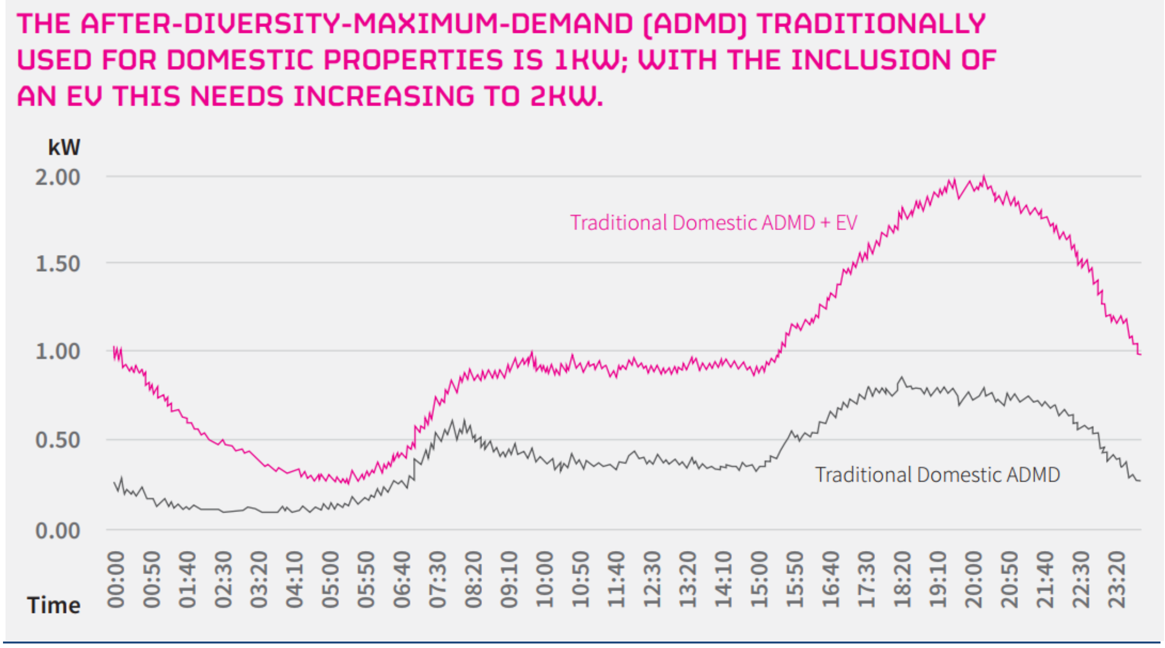


Figure 23 Daily consumption of an English household without and with an EV

The English project "My Electric Avenue" [73] gives the daily mean consumption of a UK household without or with an EV, charged with a power of 3.3kW. From there, the ADMD (After-Diversity Maximum Demand) can be deduced, which corresponds to the average peak demand of households. It can be seen that the ADMD of a household without EV is about 0.8 kW, whereas it raises to about 2kW for a household with an EV (see Figure 23).

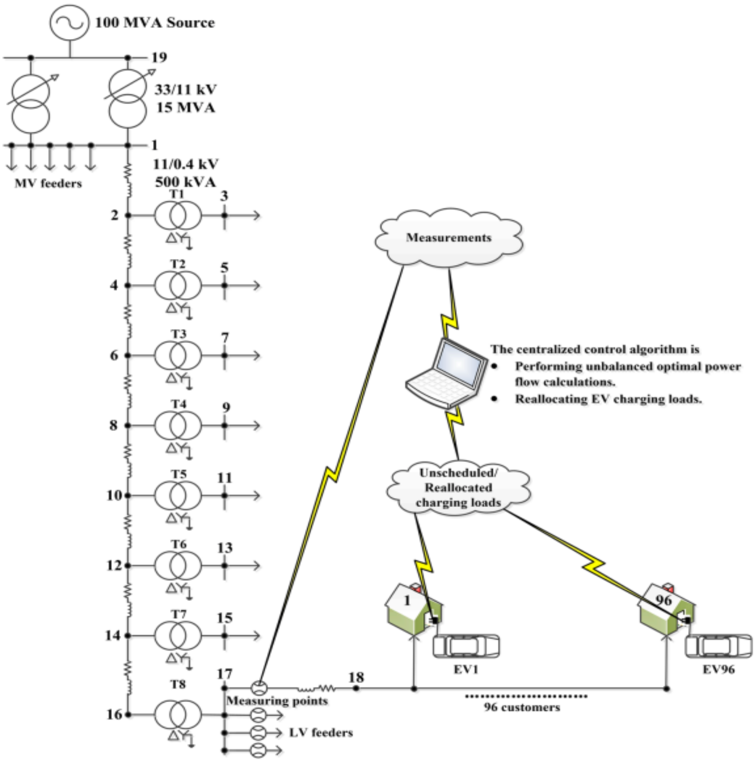


Figure 24 UK Generic Distribution Network

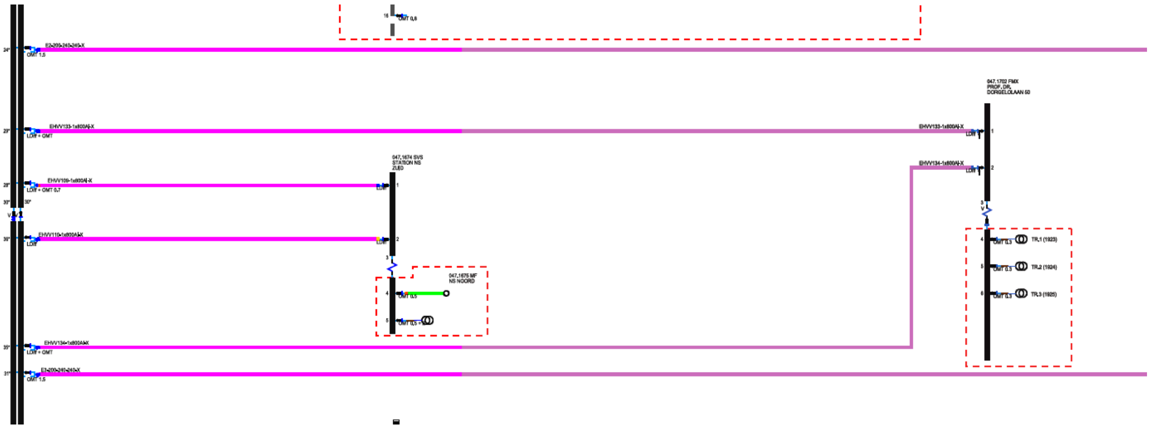
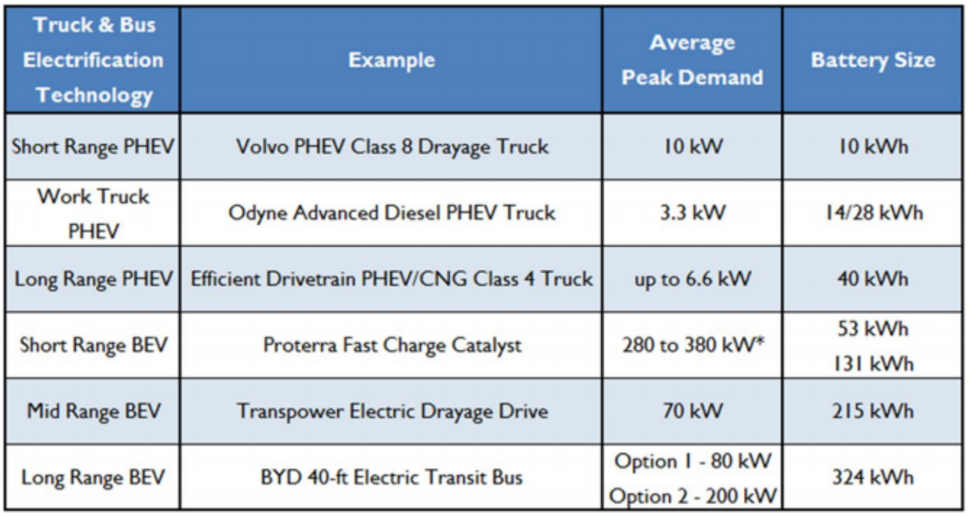


Figure 25 Structure of distribution grid of Enexis in Eindhoven, Netherlands. It gives another type of structure as the UK Generic Distribution Network

In order to estimate the effect of EVs on a typical urban distribution grid, Paper [74] uses the *UK Generic Distribution Network* (UKGND) (Figure 24). Six radial feeders are emanating from the medium voltage (MV) side of the two parallel on-line tap changing transformers. The capacity of each transformer is 15 MVA 33/11 kV. The MV feeders serve 18,432 customers with 3,072 customers for each feeder. Each MV feeder is divided into 8 segments, serving 8 ground-mounted distribution transformers. Each one (i.e., 500 kVA 11 kV/0.4 kV ground-mounted distribution transformer) serves 384 customers distributed across 4 LV feeders. Ninety-six customers were distributed along each LV feeder.

Table 8 Typical charging powers for heavy-duty EVs (Source: [75])



| Truck & Bus Electrification Technology | Example | Average Peak Demand | Battery Size |
|---|---|---|---|
| Short Range PHEV | Volvo PHEV Class 8 Drayage Truck | 10 kW | 10 kWh |
| Work Truck PHEV | Odyne Advanced Diesel PHEV Truck | 3.3 kW | 14/28 kWh |
| Long Range PHEV | Efficient Drivetrain PHEV/CNG Class 4 Truck | up to 6.6 kW | 40 kWh |
| Short Range BEV | Proterra Fast Charge Catalyst | 280 to 380 kW* | 53 kWh<br>131 kWh |
| Mid Range BEV | Transpower Electric Drayage Drive | 70 kW | 215 kWh |
| Long Range BEV | BYD 40-ft Electric Transit Bus | Option 1 - 80 kW<br>Option 2 - 200 kW | 324 kWh |

Grid requirements will be different for e-buses than typical EVs because:

- Charging powers of e-buses are higher than typical EVs (see Table 8). The local stress on the grid might thus be higher with e-buses.
- Power demand is more unpredictable with typical EVs while bus transits and charging schedules are planned and more regular.

Smart charging is considered as an effective way of mitigating the effect of charging stations on the grid. It is particularly the case for overnight charging where the load is more likely to be flexible and could thus be reallocated. Power consumption coming from fast charging points will most likely be less flexible.

This would be a totally different strategy than the traditional “fit and forget” which consists in adapting the distribution network to the peak load. To include customers in the grid management, the DSOs will have to formalize their needs in terms of products. Other actors such as aggregators would then offer solutions to the DSOs.

When connecting charging stations to the distribution grid, a few aspects should be considered:

- Grid overloads: The power demand of the charging station added to the other loads connected to the same substation, might cause an overload of the transformer.
- Grid voltage drops: High power demands can cause unacceptable voltage drops across on the feeder to which the charge is connected. Usually the voltage at the end of a LV feeder is not the same than in the customers connected at the beginning of the line. The DSO has to make sure that the voltage stays in the limits given by the standards.
- Consumption peaks: If several loads in a specific area are connected simultaneously, there can be local congestions.
- N-1 needs: The DSO must guarantee a certain level of resilience, for instance if a power line is disconnected.
- Reactive power: The connection between the battery of an EV and the grid needs an AC/DC converter. In general, it is assumed that cos phi should be over 0.95 to avoid unnecessary reactive power flows, but it is well known that a controlled amount of reactive power is necessary. So, reactive power must be under control at any moment.

- Harmonics: The conversion of energy from AC to DC produces harmonic currents of frequency higher than 50 Hz. As the frequency increase, energy and heat produced also do it, affecting the lifespan of infrastructures. The voltage is also influenced.
- In-rush current: Requiring high amounts of current for a few milliseconds at the start of the charging process may produce voltage issues. Controlling these first moments of the starting process, to avoid high peak current demands is important.
- Voltage unbalance: The single-phase connections should be equally distributed to limit the voltage unbalance.

The following subsections take a closer look at the 3 first concerns in the list above.

### Grid overloads

Overloads can either occur on substation transformers or power lines. This subsection covers transformer (global) overloads whereas the consumption peaks subsection covers the problem of local congestion in power lines.

Transformer loading is typically the limiting factor in LV urban grids, while feeder loading can be problematic in MV rural/urban grids [61].

The used HV/MV transformers have a nominal power rating range of between 10 MVA and 63 MVA and are equipped with remote load tap changer in operation. In the MV/LV rural substations, the typical range for the pole-mounted MV/LV transformers' nominal power rating is 50 kVA to 250 kVA. In urban areas, substations with pad-mounted transformers are used, where the range is between 250 kVA to 630 kVA [61].

In the case of UKGDN, the peak consumption occurs at about 6-7 p.m., both for customers without EV (0.8 kW) and customers with an EV (2 kW), in the case where no load management is performed. Considering no EV, the peak consumption of the LV transformer is about 308 kW, leaving a margin of 192 kW. As a result, the LV transformer could take 160 EVs in charge (without load management), which corresponds to 42% of customers owning an EV. The order of magnitude is compliant with the results obtained in the English project “My Electric Avenue” [73], which claim that 32% of English LV feeders will require reinforcement when 40-70% of customers have EVs with 3.3 kW charging power.

The total consumption would be 14.8 MVA at peak, leaving a margin of 15.2MVA at the HV/MV transformers. In this case, these transformers would be overloaded with about 12700 EVs, corresponding to 69% of customers owning an EV.

The installer has to provide the demand profile of the charging station to see with the DSO it the total load might overload the transformer. If the LV transformer capacity is not high enough, the fast-charging stations and bus warehouses can be connected to the MV grid as the capacity of HV/MV transformers are higher.

Fast charging stations can thus be either connected in LV or MV [76] (the battery is typically connected at 450-750V DC [76]). If charging station is connected to the MV, it will require its own transformer(s). In this case, charging station operators will buy, install and manage the transformer(s) themselves.

Solutions for preventing overloads:

- Involve energy utilities from the beginning in the charging infrastructure projects in order to use their expertise to find solutions.
- Use smart charging to reallocate EV loads (more difficult for fast charging).
- Increase transformer capacity.
- Use storage systems connected to the same transformer to smoothen power consumption and reduce consumption peaks.

- Use local energy production (e.g. PVs).
- Charge in MV.

### Grid Voltage drops

Voltage drop is typically the limiting factor in LV rural grid because the total feeder lengths are longer, thus the impedances are higher [61].

Fast-charging points and warehouses of overnight charging e-buses may also cause large voltage drop because of their high power demand.

Fast charging of some e-buses can last only a few minutes. As a result, it may be considered as rapid voltage change, which has different requirements.

The DSO has to guarantee that the power quality is fulfilled at all point of the distribution system. In order to achieve this, Synergrid, the federation of Belgian DSO's, specifies that the voltage drop across the connection of all user connected to the LV grid cannot exceed 1% [77].

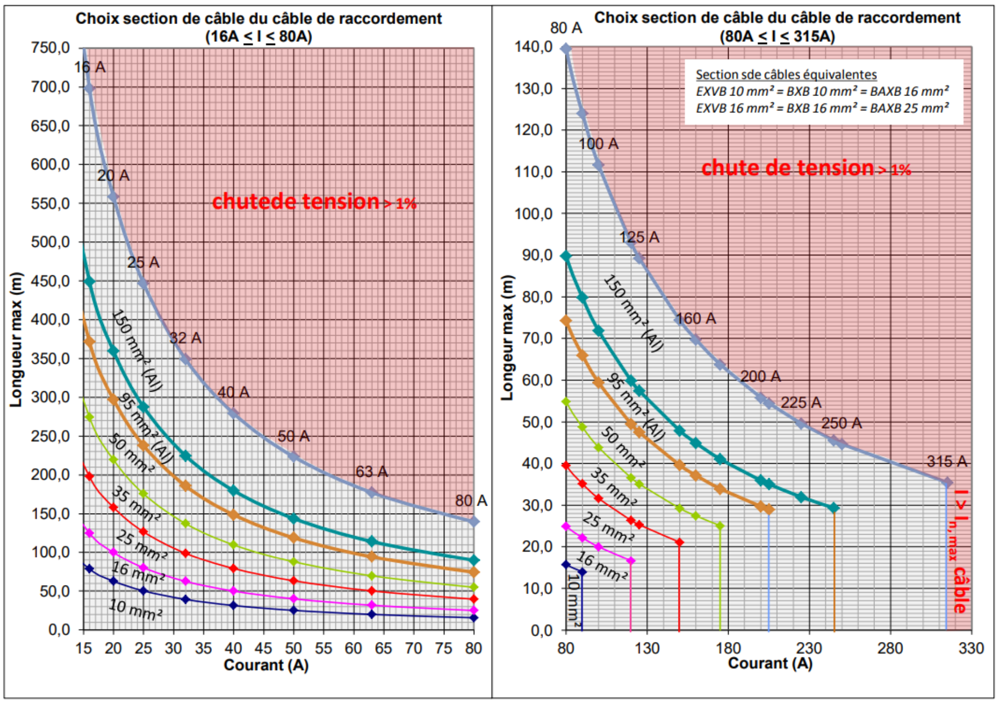


Figure 26 Type of cable required in LV as a function of connection length and maximum current (Source: [77])

As a result, the DSO requires customers to use specific types of cables depending on the maximum current and the connection length (see Figure 26)

In case of connection in MV, the requirements are determined case by case between the DSO and the customer (here charging station operator) [78]. More specifically, it will depend on:

- The demand profile of the MV load
- The short-circuit impedance at the PCC (Point of Common Coupling) and the impedance connecting the load to the PCC

Based on this, the voltage drop at the PCC can be estimated. If it is not compliant after a first estimation, further analysis can be performed. If the perturbation is too high, the charging station may have to be connected closer to/at the HV/MV substation where the short-circuit impedance is smaller.

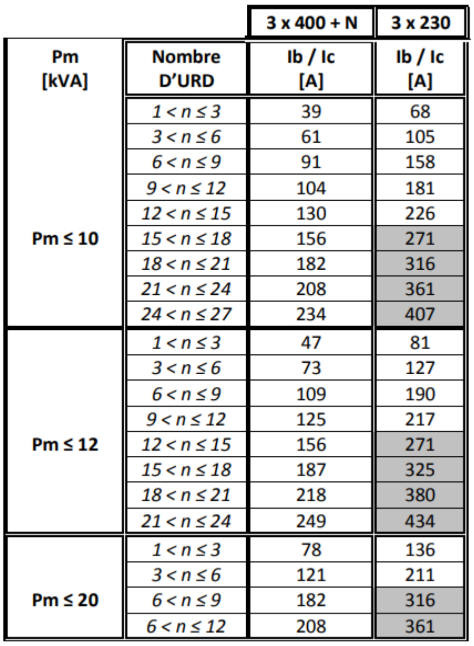
Solutions for preventing large voltage drops:

- Involve energy utilities from the beginning in the charging infrastructure projects to use their expertise to find solutions
- In case of LV connection, connect the load closer to MV/LV substation. In case of MV connection, connect the load closer to/at the HV/MV substation → decrease short-circuit impedance at PCC.
- Use local storage to smoothen power consumption and reduce peak
- Use local energy production (e.g. PVs)
- Use On-Load Tap-Change transformers (OLTC)
- Use voltage control with reactive power injection (especially in MV)
- Use smart charging to reallocate EV loads.

### Consumption peaks

In order to avoid local congestion, the installer is limited by the DSO in the maximum power they can take from their connection. Synergrid specifies the limits for users who are connected to the LV network (Table 9**).** For instance, if one charging point is to be connected to a LV feeder, the maximum power would be 54kVA (assuming Pm ≤ 20kVA). This is not enough for most e-bus fast-charging systems.

**Table 9 Maximum charge current (Ib/Ic) of the connection depending on the mean power (Pm)**



| | | 3 x 400 + N | 3 x 230 |
|---|---|---|---|
| Pm [kVA] | Nombre D'URD | Ib / Ic [A] | Ib / Ic [A] |
| Pm ≤ 10 | 1 < n ≤ 3 | 39 | 68 |
| | 3 < n ≤ 6 | 61 | 105 |
| | 6 < n ≤ 9 | 91 | 158 |
| | 9 < n ≤ 12 | 104 | 181 |
| | 12 < n ≤ 15 | 130 | 226 |
| | 15 < n ≤ 18 | 156 | 271 |
| | 18 < n ≤ 21 | 182 | 316 |
| | 21 < n ≤ 24 | 208 | 361 |
| | 24 < n ≤ 27 | 234 | 407 |
| Pm ≤ 12 | 1 < n ≤ 3 | 47 | 81 |
| | 3 < n ≤ 6 | 73 | 127 |
| | 6 < n ≤ 9 | 109 | 190 |
| | 9 < n ≤ 12 | 125 | 217 |
| | 12 < n ≤ 15 | 156 | 271 |
| | 15 < n ≤ 18 | 187 | 325 |
| | 18 < n ≤ 21 | 218 | 380 |
| | 21 < n ≤ 24 | 249 | 434 |
| Pm ≤ 20 | 1 < n ≤ 3 | 78 | 136 |
| | 3 < n ≤ 6 | 121 | 211 |
| | 6 < n ≤ 9 | 182 | 316 |
| | 6 < n ≤ 12 | 208 | 361 |

In case of connection to MV, the requirements are determined case by case between the DSO and the customer (here charging station operator) [78]. This would be based on the demand profile of the MV load that is to be connected as well as the demand profiles of the surrounding loads, to prevent local congestions.

Solutions to prevent local congestions due to consumptions peaks:

- Involve energy utilities from the beginning in the charging infrastructure projects to use their expertise to find solutions
- Use local storage to smoothen power consumption and reduce peak
- Use local energy production (e.g. PVs)

- Use smart charging to reallocate EV loads.

### 4.2.4 Safety and security needs

High power installations placed in the cities where citizens walk around need appropriate safety and security measures to avoid any kind of accident. Several levels have been considered:

1. Normal Operation conditions: the system (composed of charging point and vehicle) connected to a grid must be designed to be safe, in normal operation conditions. All electric and metallic parts (bus and charging infrastructure) must be protected employing the normal isolation and grounding solutions for this type of installations. Climate phenomena should also be taken into account (rain, wind,…) in the design. The infrastructures must be solid enough to resist without damages in conditions of high wind or rain. IP protection must also be studied.
2. Accidental electric contact or arc: The bus users will be going up and down from the vehicle at the bus-station, while the charging process is active, unless bus-operators decide the contrary. Consequently, any contact with electric or metallic parts, even in case of isolation failure, must be granted. Potential risks associated to the presence of users must be detected to avoid an accident during the charging process. A contact or electric arc hazards from the installations to the umbrella of a passenger should not be possible at all. Probably, the most critical point is the contact between the bus and the pantograph. The structure of the bus and charging system must grant the safety distances to avoid any electric arc. Table 10 gives the safe distances when working near powered elements for different voltage levels.

Table 10 Safe electric distances for working near powered elements

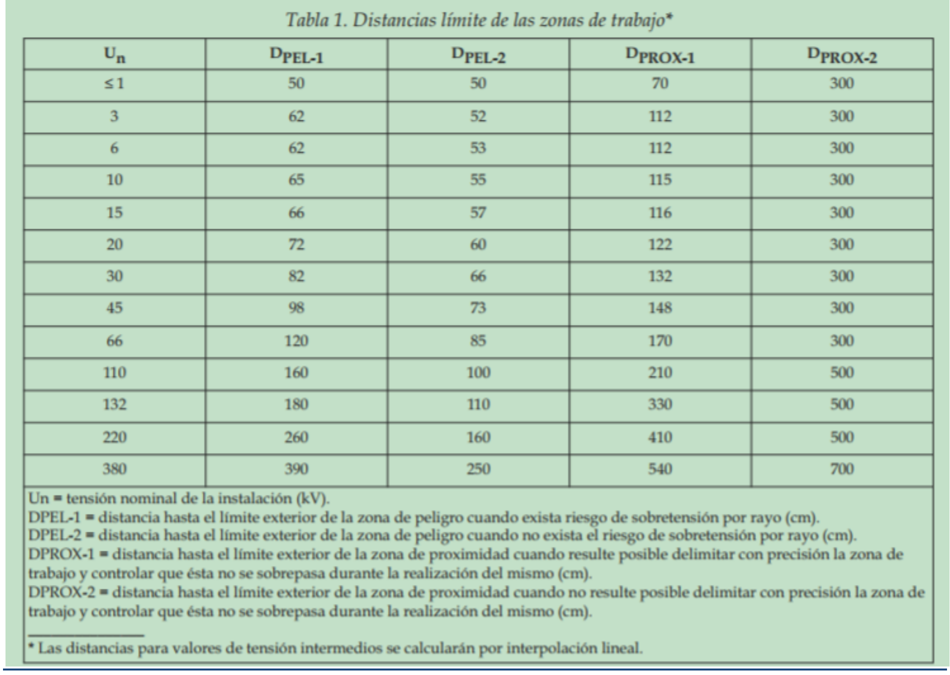


*Tabla 1. Distancias límite de las zonas de trabajo**

| $U_n$ | $D_{PEL-1}$ | $D_{PEL-2}$ | $D_{PROX-1}$ | $D_{PROX-2}$ |
|---|---|---|---|---|
| ≤1 | 50 | 50 | 70 | 300 |
| 3 | 62 | 52 | 112 | 300 |
| 6 | 62 | 53 | 112 | 300 |
| 10 | 65 | 55 | 115 | 300 |
| 15 | 66 | 57 | 116 | 300 |
| 20 | 72 | 60 | 122 | 300 |
| 30 | 82 | 66 | 132 | 300 |
| 45 | 98 | 73 | 148 | 300 |
| 66 | 120 | 85 | 170 | 300 |
| 110 | 160 | 100 | 210 | 500 |
| 132 | 180 | 110 | 330 | 500 |
| 220 | 260 | 160 | 410 | 500 |
| 380 | 390 | 250 | 540 | 700 |

Un = tensión nominal de la instalación (kV).
DPEL-1 = distancia hasta el límite exterior de la zona de peligro cuando exista riesgo de sobretensión por rayo (cm).
DPEL-2 = distancia hasta el límite exterior de la zona de peligro cuando no exista el riesgo de sobretensión por rayo (cm).
DPROX-1 = distancia hasta el límite exterior de la zona de proximidad cuando resulte posible delimitar con precisión la zona de trabajo y controlar que ésta no se sobrepasa durante la realización del mismo (cm).
DPROX-2 = distancia hasta el límite exterior de la zona de proximidad cuando no resulte posible delimitar con precisión la zona de trabajo y controlar que ésta no se sobrepasa durante la realización del mismo (cm).

* Las distancias para valores de tensión intermedios se calcularán por interpolación lineal.

3. Physical security and Vandalism: The previous paragraphs explained the normal safety conditions that an electric installation should consider as well as the aspects imposed by the presence of users, without specialized education on electricity. Here, we deal with the risks associated to an improper use of infrastructures and the way to protect them. To avoid damages to the grid, charging point or vehicle, but

particularly for persons involved or not in the incident. Violent attacks to infrastructures may be caused by the intention to steal materials, as well as the intention to obtain illegal connection points to obtain electricity for free or by simple vandalism with no economic interests, among other causes. When the intention is to steal materials, the actors usually have certain knowledge about how the electrical protection systems work.

  a. A typical action at MV is producing a short circuit among phases to ensure that protections will open the circuit letting the robbers to work safe. In our case, this could be produced throwing a metallic chain on the pantograph if it is not protected against this action. The solutions could be doors to hide the pantograph, switching off the power while the bus is not connected and safe, etc.
  b. Sensors, detecting certain events (opened door, presence of bus, presence of power, short circuit,…), could also be an alternative, but costs of the alternatives should be considered in the design of the solution.

4. Cyber security:
   a. Impact of a compromised charging station on the electrical grid environment:
   b. Smart Grids should operate resiliently to cyber-attacks due to their criticality. The cyber security of its components is often very low or non-existent by design. However, many components are connected to each other and air-gapping/one-way communications are generally either not considered or not correctly designed. Sophisticated attacks can cross-domains and zones, impacting more services as the attack propagates (Figure 27).

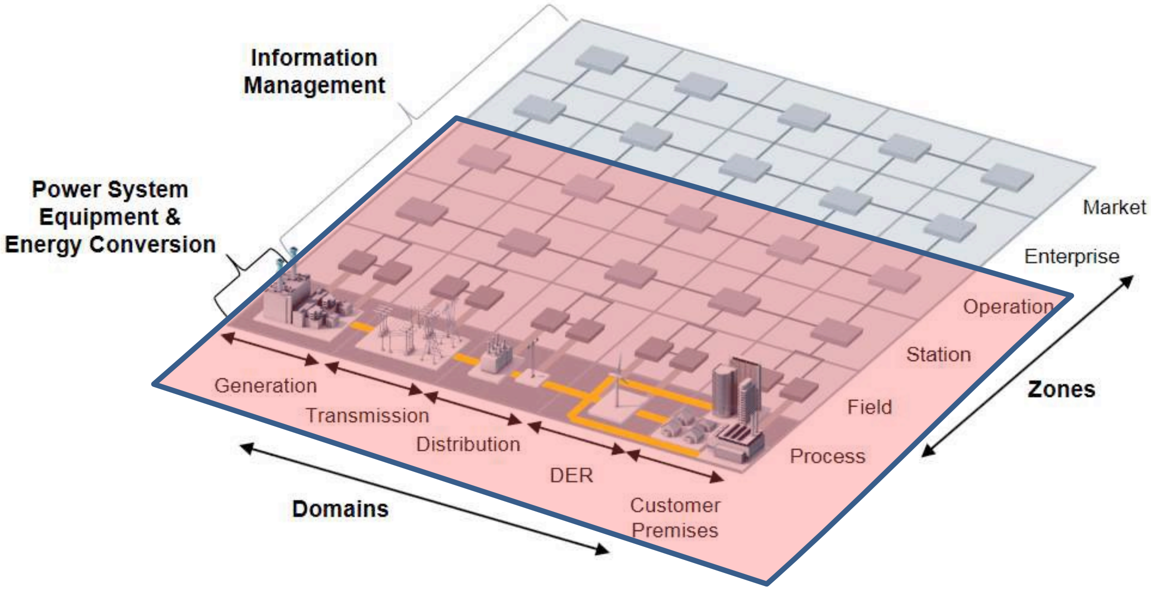


Figure 27 CEN-CENELEC Smart Grid architecture model. In red: power grid potential impact

   c. Possible risks associated
      i. Denial of Service: preventing EV charge can paralyze the public transport system. Impacting upper domains could lead to power disruption (e.g. triggering transformer circuit breakers from an overload, Aurora Generator Test-like attack [79]).

    ii. Illegitimate use: granting unauthorized access to charging stations for personal profit.
    iii. Physical damage: Damaging EV batteries through incorrect charge parameters could damage the batteries, the vehicle or even its passengers. Overloading or misusing the DER network could also damage it.

d. Underlying electrical grid problems due to compromise of EV/charging station:

If the EV charging system is designed in a way that it does not support the full charging power of all its stations at the same time, and a such scenario is made possible by taking the full control over the charging stations, this could cause potentially unsupported:

    i. Grid overloads
    ii. Grid voltage drops
    iii. Consumptions peaks
    iv. N-1 needs failure
    v. Transport-level perturbations (probably not significant ones w.r.t. the current and projected power requirements for electric buses)

These issues are described in Subsection 4.2.3. Some of these problems can although be avoided without cyber security measures if electromechanical security mechanisms are put in place.

e. Cyber security high-level requirements for charging stations and its environment (among others)

Security of data at rest and in transit must be enforced by applying availability, integrity and confidentiality security controls. Communications between the charging infrastructure and its environment, including the smart grid components as well as the EV, must be authenticated and encrypted. Cyber security requirements for EV charging systems have been recently elaborated by the European Network for Cyber Security (ENCS) and ElaadNL for a generic car-charging infrastructure [80]. These can be safely used to secure the charging point itself and its communications with the distribution system. Detailed cyber security considerations are handled in task 3.4 of the ASSURED project.

### 4.2.5 Requirements for Future Services to the Grid

A large penetration of EV could open the door to new services:

1. Flexibility offered by the EV batteries to the grid.
2. New ways of using the electricity (Vehicle to home, trading,…)
3. New services to the EV users using the infrastructures (providing information to the EV user or EV controller about special tariffs, new charging points in the area, answering requests about travel: charging points on the route,…)

The presence of EV in general on the city offers the possibility to the EV users of having incomes in exchange for flexibility services.

It is clear that buses will not be the best candidates for this use while they operate in an urban route, but it is also clear that the use made by the charging points by buses is claiming for additional uses. For example, the charging point could be shared with other electric vehicles. Particularly, if the bus-stop with charging point is placed close to the parking of a Shopping Centre, or other public or private parking areas.

In these cases, the charging infrastructure could be used for grid purposes using private vehicles parked there, given that previous agreements exist.

This possibility introduces new requirements to be considered:

- Non-expensive telecommunications solutions, protocols adapted to this uses, etc.
- Bi-directionality of inverters in this particular charging places (shopping centres, near parking areas,…).
- Designing adaptable or modular charging points where new uses can be added easily. Bus charging points should allow adding modular private EV charging connections for several vehicles. The solution should include a priority management algorithm to transfer all available capacity to the bus when it is present, stopping the charging process of the rest of the vehicles during 30 seconds.
- DSOs should be involved in the process of the selection of the best places to install new charging points (especially for HDV). Looking carefully for city areas with other potential uses. Shopping centres, parking areas, taxi-stops, train station’s parking, etc.

### 4.2.6 Identification, Payment and Roaming

Charging points of a bus route probably do not need economic transactions. In the probable case that these charging points would be shared among buses and other vehicles, the payment of the service must be solved for private users.

Many alternatives have been studied to face this aspect, and most of them imply identification of the vehicles. For buses, the payment will be probably done at the end of the month by the transport company to the utility. In the ASSURED case in which high power-short time charging points will be developed, it is probable that Utilities need to share this charging station with other vehicles (trucks, taxis, EV in general) for grid operational constraints. In this case, the identification of the vehicles, the possibility of direct or indirect payment, and the capacity to transfer the bill to certain retailer need to be considered.

# 5. Conclusions and Recommendation

The success and the rate of market penetration of EVs will strongly depend on the degree of usage and perceived suitability for usage of these vehicles in urban areas. Charging is a crucial topic for the success of electrification as well as the refilling comfort. Daily charging at home, at work or at public or commercial parking areas (shops, motorway rest areas, etc.) could reduce the need of charging stations, accelerating the EV deployment.

The high power charging systems and the use for short times impose the need of optimise the use of associated grid infrastructures sharing the installation with other uses (charging other type of vehicle, etc.) and implementing “smart charging” solutions at DSO level that flattens the consumption profile of these points.

These charging elements should be connected directly to MV grid instead of to LV grid to ensure a lower impact on the system and a higher control of assets operation. This means that a compact solution to integrate a transformer in the charging point must be found and even a switcher with remote control capacity. Avoiding the installation of a new Secondary Substation for the charger will make easier and faster the implementation of new points.

The DSOs should be involved in the deployment of infrastructures and should have visibility and a certain control of the assets for grid reliability purposes, while the service can be provided by third parties.

Regulatory efforts for the charging of xEV’s have already been initiated. The EU has boosted the creation of EV charging infrastructure with Directive EU 2014/94/EU5, which obliges member states to expand the network of charging points.

Several initiatives are necessary to increase the acceptance of electrified mobility. Public education, vehicle sharing and increasing range capability of electric vehicles are important drivers. Incentives to consumers and industry are what has produced results in the past.

Bi-directional smart charging for V2G uses is desirable at longer term.

A massive deployment of EV will require LV grid reinforcement or at least larger LV grid connection(s) in charging areas. The degree of supervision and control of the LV grid will have to be increased in the short and medium terms.

The limiting factors at LV level will be cables and transformers’ capacity and maintaining the voltage levels. A direct, short-term congestion challenge is not expected with AC-chargers for cars. The issue could be a capacity and power quality challenge, especially with electric HDV in urban areas.

The measurements at the charging point should be able to provide the information listed below and should be compared to IEC 6100 standard to assess the conformity of the ASSURED solutions:

- The AC currents (A) of the secondary of the transformer
- The AC voltages (V) of the secondary of the transformer
- The Total Harmonic Distortion (THD) (%) of the 3-phase currents and voltages systems
- The active power (kW), reactive power (kVAR), and power factor
- The energy (kWh)

Power Quality should also be assured, respecting the European Standard EN 50160. ASSURED solutions should not cause more than 5% ripple on the voltage amplitude of the grid. Other perturbations should respect the margins indicated on tables 5 to 7.

When connecting charging stations to the distribution grid, a few aspects should be considered (Grid overloads, grid voltage drops, consumption peaks, N-1 needs, reactive power, harmonics, in-rush current and voltage unbalance), but congestion, voltage drops and consumption peaks are the most typical problems. In fact, transformer loading is typically the limiting factor in LV urban grids, while feeder loading can be problematic in MV rural/urban grids. Voltage drop is typically the limiting factor in LV rural grid because the total feeder lengths are longer.

High power installations placed in the cities where citizens walk around need appropriate safety and security measures to avoid any kind of accident at four levels: normal operation, accidental contact or arc, physical security or vandalism, and cyber security. Appropriate means must be established in and around the charging point design to avoid incidences during the operation.

The presence of EV in general in the city offers the possibility to the EV users of having incomes in exchange for flexibility services. Bus charging infrastructure could be used for grid purposes using private vehicles parked in the area if bus-stops are placed near Shopping Centres or other kind of parking areas. Additionally, new ways of using the electricity (Vehicle to home, trading,…), and new services to the EV users can be implemented. ASSURED solutions should be designed taking that into account all these possibilities. This implies the possibility of bi-directionality in chargers, modularity for expansion of new services, and not expensive communication solutions.

For high power - short time - charging points, it is probable that Utilities need to share this charging station with other vehicles (trucks, taxis, EV in general), in order to avoid any kind of grid constraints. This will imply the necessity of identifying vehicles, the possibility of direct or indirect payment, and the capacity to transfer the bill to certain retailer. These aspects should at least be considered to make possible an easy and modular expansion of the functionalities of the charging point.

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