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Mitigating the impact of high power charging of electric buses: Perspective of European distribution grid operators

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Summary

High power charging of electric buses (150-600 kW per charging point) during short breaks (typically 3-10 min) is popular in Europe (60% of the e-buses ordered in 2017). The European H2020 project ASSURED has highlighted the need for consolidated data on DSOs (Distribution System Operators) view of potential risks for the distribution grids broth by super fast charging. This article reviews first the landscape of DSOs in the European Union and the evolution in the electricity market with the recently approved directive on electricity market (EU 2019/944) that introduces many new incentives and requirements for demand response, for the DSO cooperation with bus operators and for grid planning taking into account the electric mobility projections, etc. The view of the DSOs, collected in a one-day workshop with grid operators and several DSO organizations from nine European countries, is presented. Congestion followed by the power quality were seen as the two main concerns. To reduce congestion, different strategies were proposed (changes of the charging strategy, grid upgrades, mitigation of power needs and improvement of predictability). The workshop was focussed on DSO perspectives. This work will be integrated in the ASSURED project for aspects regarding the charging process and the impact of fast charging on the grid (low voltage and medium voltage). The view of other stakeholders such as bus operators and bus manufacturers and cities will also be taken into account in ASSURED.

Keywords: BEV, bus, harmonics, public transport, ultra- fast charging

1 Introduction

In 2018, 2.250 electric buses are estimated on European roads. Bloomberg expects this figure to raise quickly: 12.000 in 2025 and 52.000 electric buses in 2030 [1]. High power charging of buses (150-600 kW per charging point) during short breaks (typically 3-10 min) is popular in Europe, representing the preferred solution for 60% of the electric buses ordered in 2017 [2]. When charged at high power, the vehicles can have smaller (lighter and cheaper) batteries. However, high power charging may impact the local grid by overloading the local transformers & cables and causing power quality issues (e.g. voltage drops).

The level of bus fleet electrification is uneven across European cities. Some cities have already over one hundred electric buses while others are just considering pilots. Moreover, bus operators have different preferred charging strategies (i.e. eco-charging and pre-conditioning strategy), which result in different impacts on the local grid. The European H2020 project ASSURED has highlighted the need for a consolidated feedback of the DSOs (Distribution System Operator) concerning the potential risks for the distribution grids after integrating utra-fast charging systems as well as large scale depot charging systems. This has led ENGIE Laborelec, as part of the ASSURED consortium, to organize a workshop in order to have feedback from European DSOs on the risks and grid mitigation measures for the distribution grid impacts when introducing high power charging of electric buses, electric trucks and electric vans.

This paper is organized as follows. After a general presentation of the ASSURED project, the results of simulations of grid issues are given. Then, the landscape of European DSOs and the 2019 directive on electricity market in the European Union (EU) are described. Next, the feedback of European DSOs regarding their concerns with opportunity charging of increasing number of electric buses and their view on mitigation measures is presented. Finally, we discuss the findings in a broader context (bus technologies, bus operators) and give our conclusions.

2 The ASSURED project

ASSURED is a project co-funded by the European Commission with 39 partners (including DSOs, OEMs, academia, research centers) tasked with overcoming the main barriers to large-scale deployment of electric buses in European cities through developing, testing and verifying high power charging infrastructures in real operational environments in European cities [3]. One of the tasks in the project is to design multi-objectives energy management and charging strategies for electric buses taking into account the point of view of different stakeholders (e.g. bus operators, OEMs).

3 Simulations of grid issues

In the ASSURED project, simulations were performed using a network developed within the EU project DECAS along with data from the city of Vienna regarding the average distance between bus stops and the average travel speed of busses, to assess the grid impact [4]. Four scenarios were simulated (charging at each stop, at every other stop, at end stations only, and depot charging) with charging points of 300 and 600 kW. Additional scenarios were carried out to assess the impacts of photovoltaics on grid congestion.. Although grid congestion was limited when chargers were connected to medium voltage levels and above transformers, they present significant risk of congestion when connected to low voltage transformers. Simulations performed within the ASSURED project suggested that to ensure voltage stability, it is advisable to connect high power chargers to medium voltage transformers instead of low voltage transformers. Additionally, it was recommended to enable the grid operators to curtail the charging points in case of emergency regarding grid stability. Additional planning of the infrastructure location and power limit (e.g. via smart charging) are other possible mitigation measures. In the future, electric buses could have larger batteries which would reduce the proportion of opportunity charging and increase the proportion of depot charging, shifting the impacts.

However, the work carried in the ASSURED project showed that there are gaps in the establishment of mitigation measures for the negative impacts of high power charging:

- there is no consolidated assessment by European DSOs of the possible negative impacts of high power charging of electric buses on the power distribution grid;
- there is no consolidated view from European DSOs on mitigation measures (including market and technical oriented approaches).

4 DSOs view on challenges and mitigation measures for opportunity charging

4.1 Landscape of DSOs in the EU

In the EU (European Union), there are approximately 2.400 DSOs with 90% serving less than 100.000 customers but only 191 DSOs are serving more than 100.000 customers [5]. The number of DSOs per country can be large (over 100 in Austria, France, Sweden and even more than 800 in Germany), low (only one DSO in Cyprus, Ireland and Lithuania) or in-between.

There are large differences in the number of customers served, in the topology of grids (e.g. urban vs rural), type of loads (e.g. industrial, commercial, residential), load profiles (e.g. electric heating vs air conditioning), penetration of distributed renewable energy and energy mix, level of connection to the transmission grid (think of islands vs mainland), structure of electricity tariff, level of exchange of information with transmission operators, etc. Metrics such as number of consumers per km², LV (low voltage) circuit length per LV consumer, number of LV consumers per MV/LV (medium voltage/low voltage) substation are based on 99 of the 191 large EU DSOs are given in [5].

The roles of the DSOs are defined in the new *Directive on common rules for the internal market for electricity* (EU 2019/944) and *Regulation of the European Parliament and the Council on the internal market for electricity* (EU 2019/943), both published in June 2019 [7]. The directive introduces important articles facilitating smart charging and demand response:

- *Direct lines* (art. 7);
- *Entitlement to dynamic electricity contracts* (art. 11);
- *Aggregation* (art. 13);
- *Active customer* (art. 15);
- *Citizen energy community* (art. 16);
- *Demand response through aggregation* (art. 17).

The directive could have an impact on demand response in general and as a result also on the bearing of the opportunity charging on the grid. The consequences have not yet been quantitatively assessed since it depends on practical implementation of the directive by each EU member states (the directive gives general guidelines and leave room to member states to define the practical conditions) and how the market and stakeholders will react.

The role of the DSO is specifically defined in art. 31 of EU 2019/944 : "*The distribution system operator shall be responsible for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity, for operating, maintaining and developing under economic conditions a secure, reliable and efficient electricity distribution system in its area with due regard for the environment and energy efficiency*" [8]. Additional articles in the directive detail the rights and obligations of DSOs:

- *Incentive for the use of flexibility in distribution networks* (art. 32). The member states should give incentives for DSOs to acquire flexibility services (including congestion management) from distributed generation, demand response or energy storage when it is cost effective, efficient and secure. The DSO should publish at least every two years a network development plan with planned investment for 5-10 years. This should include flexibility services needed and required infrastructure for connecting new distribution generation and charging points for electric vehicles.
- *Integration of electromobility into the electricity* network (art. 33). The DSOs should cooperate with actors that own, develop and operate charging points.
- *Unbundling of DSOs* (art. 35). DSO should at least be separated at organization level from commercial activities (generation, retail). Member states may not apply unbundling to DSOs with less than 100.000 customer or serving small isolated networks.

More recently, in December 2019, the EU published *The Green Deal* that defines EU strategy and strategy in different areas including to smart and sustainable mobility [9] [10]. From 2020-2021, new actions will be taken by EU such as funding for charging infrastructure or the review of the *Alternative Fuels Infrastructure Directive and the Trans European Network – Transport Regulation*.

5 Qualitative view of European DSOs

5.1 Methodology

Given the very wide differences among EU DSOs, and the discussions with stakeholders that showed that there are many unknowns regarding DSOs' fears on potential grid problems and on mitigation measures, it appeared that there was a need for a better understanding. Given this framework, ENGIE Laborelec as part of the ASSURED consortium conducted interactive discussions with DSOs in order to have the perspective of European DSOs on:

- 1/ possible negative impacts of high power charging of electric buses on the power distribution grid
- 2/ recommendations proposed by European DSOs (both technical and economical) to mitigate the negative impacts of high power charging of electric buses.

In practice, these interactive discussions were carried in three ways: two interviews with Belgian DSOs, an interview with Western Power Distribution (WPD) from the UK and a one-day workshop with European DSOs.

The workshop *Mitigating the risks to the power grid: DSO perspective* was organized at ENGIE Laborelec on February 6 (see Figure 1**Error! Reference source not found.**) [6].

Twelve DSOs and local DSO organizations from nine European countries (Belgium, Denmark, France, Greece, Poland, Portugal, Italy, Spain, Sweden) participated in the workshop. Other stakeholders were also present, including power grid and electric vehicle experts from ENGIE Laborelec, work package leaders from ASSURED, a representative from DG (Directorate-General) Energy from the European Commission, a bus operator from Barcelona, but also the public transport sector associations UITP[1] and the energy sector association Eurelectric[2].

Figure 1 Invitation for the workshop

Participants were divided into four groups. Each group consisted of DSOs, a moderator (typically a non-DSO EV or power grid expert) and optionally of non-DSOs. Although non-DSOs participated in the discussions, this article is focussed only on DSOs' perspective. The same groups participated sequentially to two round tables: one dedicated to the risks and one to the mitigation measures.

The DSOs views on grid concerns were collected in four round tables in three steps:

- The DSOs had to rank five potential problems (congestion, power quality, grid reliability, V2G, protection devices, with possibility to add new categories) according the level (high, medium or low) of perceived concern
- Through interactive discussions with the DSOs around the table, the moderator built a summary. The goal was to find the similarities and differences among the DSOs and to understand the reasons

[1]UITP - International organization for public transport authorities and operators, http://www.uitp.org/
[2] Eurelectric - The Union of the Electricity Industry, https://www.eurelectric.org/

behind this. For this reason, in the summary, the level of concern is sometimes a range (e.g. from medium to high) instead of a single value.
- The four moderators (grid or electric vehicle experts) presented the findings of their respective table to the whole audience.

A similar approach was used for DSO views on mitigation measures:

- Each DSO representative alone ranked and listed mitigation measures for the main concern of the table.
- The moderator of the table built a summary with focus on three criteria (technical maturity, cost effectiveness and market/regulatory readiness).
- The four moderators presented the findings of their respective table to the whole audience.

The view from individual DSOs and from the summary at the round tables made by the moderators were collected. These views are consolidated and described in the following sections.

5.2 Main concerns

This section describes the main concerns of the DSOs expressed during the discussion in four round tables (A, B, C, D). Table 1 presents the similarities and divergences among DSOs **Error! Reference source not found.**. In general, congestion was seen as the highest threat followed by power quality. Grid reliability is linked to the previous two threats. V2G was considered as not yet mature and also a potential solution. Finally, the risk to protection devices was rated as low but further studies .

Table 1: Ranking of DSO's concerns at the round tables

	Table A	Table B	Table C	Table D
Congestion	High	Low-High	Low-Medium	Low-medium
Power quality	Medium	Medium	Medium-high	Low
Grid reliability	Medium	NA	Low-high	Low
V2G	Low	Low	Low	Low
Protection devices	Low	NA	Low?	Low

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5.2.1 Congestion

At the round tables, there was a large divergence in opinion regarding the importance of congestion (from low to high). The discussions showed that some divergences are linked to the local context, circumstances and practices:

- Congestion when the charging points are connected to the grid vs congestion when the charging stations are already in operation;
- Only one charging station connected to the grid vs several charging stations connected simultaneously;
- Connection to the low voltage vs to medium voltage grid.

When congestion happens, the negative consequences are:

- High current and voltage drop that may lead to local outages or power quality issues;
- Costly and long grid upgrade. One to three years may be needed for grid upgrade depending on local situation. Cost is highly dependent on the local situation;
- Low predictability of electric bus charging load but also of other "new" loads such electric cars and heating and risk of simultaneous loads from these sources.

These risks will be higher in case of connection to a low voltage grid (instead of medium voltage) and to a transformer with low spare capacity. The rated capacity of low voltage transformers tends to be relatively small (e.g. 200 kVA, 400 kVA or 630 kVA in Flanders, Belgium), while a single opportunity charger has a large nominal power (150-600 kW). Similarly, simultaneous connection of several loads (electric buses and other "new" electric loads such as electric cars and electric heating) also increases the probability of congestion.

5.2.2 Power quality

Power quality problems depend also on the local context (e.g. customers with sensitive loads located near the bus charger, presence of PV, etc). The impact might be higher with old assets (cables, transformers, …) that were historically submitted to low loads. Some of the power quality problems are consequences of congestion (e.g. voltage drop). Other power quality risks were mentioned:

- Harmonics;
- Voltage drops due to rapid load step (transient);
- Reactive power (also linked to voltage issues);
- Rower quality issues due to the combination of several charging stations, even if taking separately, each charging station respected the grid code;
- Potential impacts on communication infrastructure.

A need was expressed for further studies on power quality risks. This includes better understanding of transients on voltage drops and checking whether the local grid codes are adapted for ultra-fast high power charging, especially when charging with up to 600kW.

5.2.3 Grid reliability

Low grid reliability causes interruption of power supply. Grid reliability was seen as a problem linked to congestion and power quality. The ageing of old assets (see above) could also cause grid reliability problems. There is a trade-off between high uptime and low grid tariff, both expected by the customers.

5.2.4 Vehicle to Grid (V2G)

V2G was seen as a technology not yet widely available on the market and as a possible solution. However, application of V2G needs to be coordinated with DSOs in order to avoid congestion by over-feeding the grid and also to avoid potential power quality problems. Doubts were expressed regarding the economic interest of V2G with high power charging.

5.2.5 Protection devices

It was not clear if fuses with short, high power and repetitive charging will still behave appropriately for AC/DC safety (including isolation). Another potential problem is unselective tripping. Two other risks were also mentioned: uncertainties regarding cost of protection devices and risks of vandalism. These topics indicated that further studies were needed to understand better the behaviour of protection devices with opportunity charging.

5.2.6 Other concerns

Other concerns were expressed during the round tables:

- Deployment speed and cost of charging infrastructure. There might be pressures from bus operators and local authorities for fast and cheap grid connection;
- Uncertainty in growth of power demand. It is hard to predict the power required in the future (total peak power) by electric vehicles due to uncertainties on number of electric buses, charging schedule, power profile, location of the chargers, and combination of other new loads on the grids (electric cars and electric heating). This leads to uncertainty in the planning of grid upgrade;
- Operation of the grid might be more complicated (e.g. grid reconfiguration).

5.3 View on mitigation measures

The section describes the mitigation measures for the two main concerns during the round tables: congestion and power quality.

5.3.1 Congestion

Congestion was seen as the main problem at the round tables. Several strategies were proposed:

- Change of the charging strategy;
- Grid upgrades;
- Mitigation of power needs;
- Improvement of predictability of load profiles.

5.3.1.1 Change of the charging strategy

Changing the charging strategy was seen as the most attractive approach by most DSOs, with the following practical approaches:

- Connecting only to medium/high voltage to avoid issues related to limited spare capacity at low/medium voltage transformer;
- Using depot charging instead of opportunity charging;
- Discussing with the bus operator one to three years in advance in order to plan the best charging strategy and best location for both the DSO and the bus operator;
- Evaluating other alternatives such as hydrogen buses or electric buses with a fuel cell as a option of range extender;
- Publishing a capacity map. As an example, Western Power Distribution has published a map that shows three levels of spare capacity (extensive capacity available, capacity available, some capacity available) at street level [12]. This helps to choose a location for a charger that does not require new grid upgrade. This map was designed primarily for electric cars, but could be extended for electric buses.

5.3.1.2 Grid upgrade

Besides the inherent cost and time, grid upgrade may lead to oversizing the grid (peak power used only for few minutes/hours per day). In densely populated areas, finding space to install a new substation may be complicated. Underground cabins require special protections against flooding and special health and increased safety measures when technicians have to visit the substations. This is because, in many places, they can be considered as a “confined spaces”, which among others makes a colleague technician staying on the surface mandatory [11].

5.3.1.3 Mitigation of power needs

The power needs can be mitigated by:

- Providing in the first phase only a fraction of the requested power and later the total power requested by the bus operators;
- Installing stationary storage. Although it is a mature technology, the general feeling of the spanel was that currently stationary storage is still expensive. This can change in the future (reduced battery price and arrival of second life batteries);
- Designing new tariffs and demand-response schemes. This can incentivize peak shaving, however, the operational requirements of bus operators do not give them much power flexibility. For these schemes, stationary storage can also be used. During the workshop, uncertainty was expressed on whether the economic incentives will be enough to change charging behaviour. Non-economical incentives such as contributing to more sustainable and ecologically friendly society could be an additional push. Market design (e.g. congestion market) can also be a solution, but it looked complicated for most of the DSOs.

5.3.1.4 Improvement of predictability

To improve the predictability of the grid load, the following approaches were proposed:

- Discussing with bus operators before the decision to deploy the charging infrastructure;

- Getting the location of new loads (e.g. in the UK, the department of Transport informs the grid operators of all new electric car purchases by indicating the street of the customer in an anonymous way);
- Developing simulation tools to assess grid impacts. However, this task requires to simulate many different scenarios which can be time-consuming and require knowledge of the charging strategy (bus schedule taking into account traffic jams, remaining battery capacity, maximum charging power, battery charging curve, battery ageing, etc);
- Launching measurement campaigns on the grid.

5.3.2 Power quality

Mitigation of power quality issues was also discussed to a smaller extent. The suggested measures:

- Reducing the risk of congestion (see above);
- Installing power quality filters. This technology is available but depending on the location, new grid codes may be needed (this process often takes years). There was a pilot on wireless charging (using 6 pulse AC-DC converters at approximately 20 kHz) on Western Power Grid network which lead to writing requirements for filters (passive filters of low order odd harmonics);
- Creating a database of power quality profiles of chargers (e.g. there is a database shared among UK DSOs).

6 Discussion

The main concerns for European DSOs are congestion followed by power quality. One of the preferred solutions is to discuss with bus operators before the decision on the charging strategy and the location of the chargers. This is well in line with art. 32 and art. 33 of the new European directive on internal market of electricity (2019/944) that requires planning of electric mobility penetration and cooperation with other stakeholders. This requires effort on both sides, since the usual timeframes are different for DSOs that are used to install transformers for 40-50+ years, and bus operators that typically proceed to a large tender every 2-3 years. As a result, there is typically an order of magnitude difference in implementation times for the planning of grid upgrade by DSOs vs bus tenders by bus operators (typically a few years vs a few months).

Favouring only overnight charging at depot makes it simpler for the DSOs since this will require a standard installation (business as usual for industrial customer): 100 electric buses would need approximately 5-10 MVA. However, the technology readiness should be checked: the bus battery should be able to drive without charging during the day (typically for up to 200-300 km or even more per day). These buses require bigger, heavier and more expensive batteries. Currently some routes cannot be operated by electric buses with the same service as conventional buses without opportunity charging. There is however a trend for buses with bigger batteries. For example, in October 2019, at the European Bus World[3] (one of the largest bus fair in Europe), MAN and Scania (both member of VW group) announced 12m and 18m buses with 480 kWh and 640 kWh in the short term (2021-2022). These buses would make possible respectively ~ 240 km and ~220 km range in adverse conditions (excluding the effect of battery ageing) [14]. Other manufacturers indicated increase in battery size of articulated buses (18m): Volvo Bus (up to 396 kWh), Daimler (441 kWh) and Solaris (553 kWh). The trend for even larger buses (e.g. 24 m) would probably require opportunity charging, at least in the first stages.

When opportunity charging is used, the use of larger batteries (e.g. Volvo Buses with 150-250 kWh battery) enables to make several round trips without charging. Here again coordination of charging strategy (location, schedule, power) between DSOs and bus operators can reduce congestion risks.

The announcement by Heliox (a charging station manufacturer) of SprintCharge, which is a battery storage solution specially dedicated for fast charging, may also mitigate grid congestion. This solution was announced in October 2019 and claims to be the first one on the market. It draws 150 kW from the grid but enables to charge at 450 kW.

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[3] https://www.busworldeurope.org/

Congestion markets (such as the project GOPACS in the Netherlands) are emerging [13]. They could contribute to deferring grid upgrades.

This article was focussed on electric buses, but similar concerns and mitigation measures can be used with other types of vehicles such as electric cars. However, electric cars have different characteristics (battery size, charging power, less predictable routes, multiple charging strategies, etc) which may lead to different level of the concerns and attractiveness for the mitigation measures (e.g. in urban areas, 50% or more of car drivers do not have their private driveway for overnight charging).

7 Conclusions

Large differences among DSOs in Europe are observed (e.g. number of customers, type of loads, etc). In addition, the recently (June 2019) approved EC directive on internal market of electricity is introducing many changes: incentives for demand response, for cooperation between DSOs and bus operators, for planning, etc. This development will help to cope better with congestion, the largest concern for European DSOs. Cooperation between DSOs and bus operators was seen as one of the main mitigation measures. Further studies are also needed to understand better the behavior of power quality and protection devices when introducing high power charging. The authors are open to receive feedback from other grid operators in and outside Europe. The workshop was focussed on DSO perspectives. This work will be integrated in the ASSURED project for aspects regarding the charging process and the impact of fast charging on the grid (low voltage and medium voltage). The view of other stakeholders such as bus operators and bus manufacturers and cities will also be taken into account in ASSURED.

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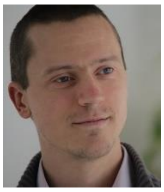

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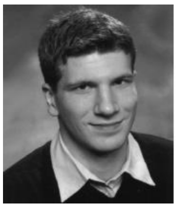

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