E.DSO technical paper on V2G charging mechanisms

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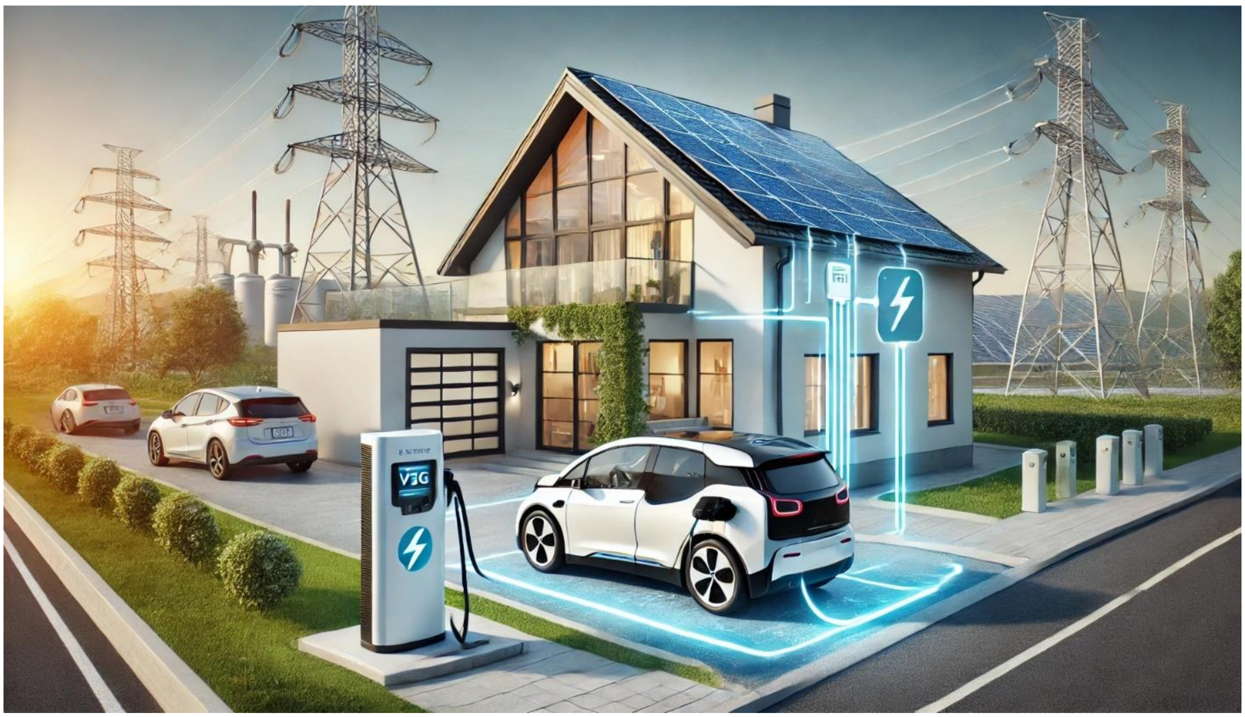

Acknowledgements

This technical paper focuses on the bi-directional charging of electric vehicles from the Distribution System Operator (DSO) point of view. The report itself gathers data and information from the members of Task Force 2 "E-mobility" of E.DSO and dedicated events such as the "V2X Symposium" organized by ElaadNL which took place May 29th, 2024. In particular, the report delves into the mechanisms of vehicle-to-grid (V2G) and vehicle-to-everything (V2X) charging, exploring how these technologies will be implemented with the new network codes and can be effectively implemented to enhance grid flexibility, reduce costs, and support the overarching goals of climate agreements.

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- Karima Boukir (Enedis)
- Dan Catanase (ESB Networks)
- Michal Fifowski (PGE Dystrybucja)
- Jan Kula (CEZ Distribuce)
- Ingmar Müller (Netze-BW)
- Roman Nowatschek (EVN)
- Miguel Pardo (Enel Grids)
- Markus Peyreder (E-Netze)
- Christian Simetzberger (Netz-noe)
- Bart Van Wulpen (Fluvius)
- Arjan Wargers (ElaadNL)
- Antoine Watelet (ORES)

For further information, please contact:

- Selene Liverani (E.DSO) selene.liverani@edsoforsmartgrids.eu

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Table of Acronyms

AC	Alternating Current
AFIR	Alternative Fuel Infrastructure Regulation
CPO	Charging Point Operator
DER	Distributed Energy Resource
DC	Direct Current
DSO	Distribution System Operators
EHV	Extra High Voltage
EU	Europe
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FRT	Fault Ride Through
HV	High Voltage
LFSM-O	Limited Frequency Sensitive Mode Over EV
LFSM-U	Limited Frequency Sensitive Mode Under EV
LV	Low Voltage
MV	Medium Voltage
NC DC	Network Code Demand Connection
NC DR	Network Code Demand Response
NC RfG	Network Code Requirements for Generators
OCPP	Open Charge Point Protocol
OEM	Original Equipment Manufacturer
RoCoF	Rate of Change of Frequency
SoC	State of Charge
TSO	Transmission System Operator
V1G	Vehicle-one-grid (unidirectional charging)
V2G	Vehicle-to-Grid
V2X	Vehicle-to-Everything

1 Introduction

The rapid electrification of passenger vehicles across the European Union (EU) presents both challenges and opportunities for distribution system operators (DSOs). With ambitious climate agreements and regulations driving the accelerated adoption of electric vehicles (EVs), DSOs must navigate the dual pressure of increased grid demand and the potential for leveraging EV batteries as sources of grid flexibility. That and more you can find in the report recently published by ElaadNL and PWC Seven barriers to optimal use of smart charging and V2G • ElaadNL[1].

At the European level, climate agreements have set stringent targets for CO_2 emission reductions. The European Council's March 2023 directive mandates a 55% reduction in CO_2 emissions for new cars from 2030 to 2034 compared to 2021 levels, escalating to a 100% reduction by 2035. These goals are expected to drive the large-scale electrification of passenger vehicles, with projections estimating approximately 35 million EVs across the EU by 2030.

While the transition to EVs will place additional demands on electricity grids, it also opens up new avenues for grid management through smart charging mechanisms. However, EVs can be viewed not just as a source of demand but also as a potential source of flexibility[2]. By adopting smart charging and vehicle-to-grid (V2G), EV batteries can help manage grid peaks and avoid substantial grid investment costs. "Smart charging" means that the charging or discharging operation is aligned with the grid needs, either through flexibility services, specific tariffs, etc.

Based on the PwC report, collectively termed "smart charging" strategies allow up to six times more stations to operate behind a transformer on the low voltage (LV) side at the same peak capacity. Smart charging, encompassing both controlled charging and V2G, could potentially avoid approximately €0.9 billion in DSO grid investments between 2025 and 2030 in the Netherlands while reducing peak demand by 10-15% by 2030. The PwC report also states that EV users engaging in smart charging can generate extra revenue, potentially offsetting 7-13% of their total charging costs.

The PwC report investigates the potential and barriers of smart charging for electric vehicles (EVs) in the Netherlands and the EU, aiming to alleviate grid congestion. Smart charging, can reduce peak demand, manage surplus renewable energy, and increase grid capacity. The findings of the report are summarized below.

Need for Smart Charging

Smart charging is one of the essential tools for managing grid stability and efficiently integrating higher volumes of renewable energy sources. In detail, this offers several benefits:

1. **Demand Reduction**: By flattening EV charging peaks, smart charging helps reduce charging demand during peak times.
2. **Excess Supply Management**: EVs can store energy when renewable production is high or when there is a curtailment risk (i.e. because demand is low).

[1] https://elaad.nl/en/pwc-report-seven-barriers-to-optimal-use-of-smart-charging-and-v2g/

[2] Regulatory Framework: According to EU Directive 2019/944, DSOs are required to procure flexibility services through market-based approaches. This helps them manage grid congestion and optimize grid capacity, Understanding European Flexibility Markets | Accenture

3. **Grid Capacity Enhancement**: By feeding stored energy back into the grid EVs help mitigate congestion and other operational needs.

Barriers to Unlocking Smart Charging

1. **Limitations in Network Tariffs**: The network tariff should be grid status-dependent and not just time-dependent, because in many cases it does not incentivise charging at low peak times. In some countries e.g. Spain or Czechia, there are tariffs specifically designed for EVs.
2. **Flexibility services are not deployed yet**: Flexibility services are still not widely deployed, thus preventing DSOs from compensating EV flexibility. In many countries, Art 32 of the Electricity Directive (EU) 2019/944 is still not fully transposed into national regulations.
3. **Unclear DSO Curtailment Authority**: There is still ambiguity over whether DSOs can curtail charging points, which is part of the implementation of the full DSO roles as defined in the Network Code on Demand Response (NC DR).
4. **Absence of Communication Standards**: Standard communication protocols between DSOs and charging point operators (CPOs)/aggregators are not still defined in regulations, hindering smart charging implementation, which is clearly related to the national implementation of the NC DR through the National Terms and Conditions.
5. **Interoperability Issues**: Differences in standards adopted by CPOs and original equipment manufacturers (OEMs) might create interoperability problems.

Solutions and Recommendations

1. **Regulatory Adjustments**: Assess and introduce updated distribution tariffs to incentivise efficient use of the network.
2. **Financial Mechanisms**: Consider tax reforms and specific subsidy mechanisms to incentivise V2G.
3. **Flexibility services**: Develop flexibility services at the distribution grid level, such as LV congestion markets, using learnings from platforms like SINTEG Enera and Piclo Marketplace.
4. **Communication Standards**: Establish a robust DSO-CPO communication and DSO-Customer interface standard through collaboration with industry and regulatory bodies.
5. **Interoperability Enhancements**: Ensure compliance with ISO 15118-20 for charge points and EVs to address interoperability issues.
6. **Incentivizing Digitalization**: Adjust DSO tariff regulations to incentivize proactive investments in smart grid infrastructure using forward-looking cost estimates.

2 Bi-directional charging definitions

Previous reports published by E.DSO on electric vehicles were focused on the availability of charging infrastructure in member states, smart charging and the implementation of the Alternative Fuel Infrastructure Regulation (AFIR). As the evolution of vehicle electrification moves forward, vehicle and charging station manufacturers are now focusing on non-conventional usage of cheap electricity. That switch brings us to bi-directional charging.

The updated version of the Network Code Requirements for Generators in preparation, so-called NC RfG 2.0, brings a new definition of vehicle-to-grid: *(69) 'V2G electric vehicle' means the vehicle that is powered, fully or in part, with electricity and is equipped with technology enabling the vehicle to inject electricity to the network over a V2G electric vehicle supply equipment. This definition takes into account all solutions, regardless of whether the V2G electric vehicle contains the inverter or not.* The last sentence is important because it includes both alternative (AC) and direct (DC) current charging.

Definition: *(70) 'V2G electric vehicle supply equipment' means the infrastructure necessary to conduct electrical energy safely from the electricity supply grid to the electric vehicle and from the electric vehicle to the electricity supply network with both generation and demand behaviour. Electrical wirings are not deemed part of an electric vehicle supply equipment. This definition takes into account all solutions, regardless of no matter whether the V2G electric vehicle supply equipment contains the inverter or not.*

(71) *'V2G electrical charging park' means the relevant installation that has a single connection point to the relevant network and where one or more V2G electric vehicles can be simultaneously connected.*

All the above-mentioned definitions for V2G and V2G electric vehicle supply equipment (EVSE) shall be considered as significant within the following vehicle categories: larger than or equal to 0.8kW and less than 2,4 kW as type EV1; larger than or equal to 2,4kW and less than 50kW as type EV2; larger than or equal to 50kW and less than 1MW as type EV3.

The proposal for the updated Network Code on Demand Connection Code (NC DC) 2.0 also brings a few new definitions: *(5) 'V1G electric vehicle' means the vehicle that is powered, fully or in part, with electricity and can only withdraw electricity from the network over a V1G electric vehicle supply equipment.*

(6) 'V1G electric vehicle supply equipment' means the infrastructure necessary to safely conduct electrical energy from the electricity supply network to the electric vehicle with demand-only behaviour. Electrical wirings are not deemed part of an electric vehicle supply equipment.

Existing regulatory frameworks (norms and standards) lacked clear definitions such as the ones described above. In order to deploy and scale new technologies like bi-directional charging, a common framework and vocabulary among technology ecosystems are necessary. This paper covers the part of Network Codes which are currently being developed and updated and should come into practice in 2025.

3 Regulation and legislation

As mentioned in the previous chapter, the NC RfG and NC DC are the network codes with the highest importance from the grid operators' point of view in relation to e-mobility. In article 13a of the NC RfG 2.0 one can find the requirements set for both type EV1 and EV2 such as:

- Frequency and voltage ranges.
- Rate of change of frequency (RoCoF) withstand capability.
- Data interface for charging infrastructure.

- Autonomous connection.
- Limited frequency sensitive mode – under (LFSM-U) EV and over (LFSM-O) EV.
- Voltage robustness and fault ride through (FRT).

In article 14a, additional requirements are set for EV3:

- Voltage ranges for medium (MV), high (HV) and extra high (EHV) voltage levels.
- System management.
- Reactive power capabilities.
- Post-fault active power recovery.
- Grid forming capabilities.

All the above-mentioned requirements were carefully selected in order to assimilate electric vehicles with generators such as photovoltaic inverters. Those functionalities are standardized and well described including specific technical parameters and attributes.

Regarding connection agreements between network operators and CPOs, the situation also differs according to the EV type and power. Type EV1, i.e. up to 2,4 kW, only requires equipment certification and connection agreements in accordance with national requirements. Type EV2 and EV3 are required to go through operational notification procedures to demonstrate their compliance.

NC DC 2.0 brings V1G and demand units like heat pumps or power-to-gas units with >0,8 kW in one group connected with frequency and voltage ranges, RoCoF withstand capability and LFSM requirements.

There are still several topics and issues for the EU DSO Entity Expert group on existing Network Codes to handle, such as possible modulation of reactive power, interface protection or anti-islanding protection. DSOs are working with stakeholders to determine how compliance and certification will work, such that EVs & EVSE can be awarded Equipment Certificates. For V2G the administration of certification and compliance needs to be simple, extremely low effort and automatic when EVSE is installed.

4 Communication Standardization

Communication protocols between electric vehicles and charging stations[3], mainly Open Charge Point Protocol (OCPP) and ISO 15118 are in the final stage regarding V2X functionalities and prepared to be scaled and rolled out. OCPP version 2.1 brings developers more than 30 message sets and 40 use cases including V2X, distributed energy resources (DER) control or battery swapping. Together with ISO 15118-20 compatibility, both standards provide strong benefits to charging stations and vehicle manufacturers and new product generations would communicate seamlessly with each other.

[3] More to be found on ESB Networks website: Advisory Council (esbnetworks.ie)

The message from Open Charge Alliance [4]is clear – “Do not use OCPP 1.6 for V2X, it will not fit!” OCPP 1.6 is fit for straightforward transactions and controlled charging, it is still very useful for many purposes, but it does date from 2015. For the advancing needs of today, you need a more advanced OCPP version.

It is now the turn of vehicle manufacturers to introduce compatible electric cars and charging stations for V2G. Renault announced a full V2G service including a V2G vehicle, a specific AC wallbox, energy contract and service activation. The whole ecosystem with one EV model works in France and should be followed in other markets. On the other hand, KIA, developed a whole palette of V2X-compatible vehicles and tried to partner up with different vendors and service providers. The benefit for the customer is still to be tested and proved but the market estimates direct savings provisions from electricity being delivered from the vehicle to the grid whenever the flexibility provider and grid operator need it for e.g. balancing or non-frequency services.

Although V2X has been discussed in technical industries for almost 15 years, until now no communication standards were set, or essential functions and capabilities were lacking. Now it seems that technologies have caught up with the vision of the whole system and it is necessary to properly implement V2X functionalities in cars, charging stations and back-end systems. The services that will be developed from this will then be able to offer benefits both for vehicle owners and infrastructure operators.

5 Grid Connection requirements and operational rules

DSOs must validate that new generators (or in this case vehicles and two-way charging stations) will not create unwanted effects on the network. This is mainly done through a so-called check of connectivity for voltage and current load of individual grid elements. From the DSO point of view, V2G should follow similar requirements as generators:

- Active power control.
- Compliance with NC RfG 2.0.
- Autonomous functions – mainly Q(U), P(U), P(F) and others such as Low Voltage Ride Through (LVRT), High Voltage Ride Through (HVRT).
- Possible verification of compliance with NC RfG or other national requirements.

In case of discharging, V2G installations will act as a generator parallelly connected to the distribution grid, and technical requirements will be almost equal to those for PV installations. The aim of DSOs is to secure reliable and cost-effective operation of the distribution grid. Below you can find an example from the process valid for future EV1, EV2 and EV3 foreseen in the Czech Republic and simplified into a few steps:

1. DSO set technical requirements (including requirements coming from NC RfG 2.0 regulation) which have to be fulfilled.
2. Customers apply for a connection request and for a connection contract and the DSO evaluates hosting capacity for V2G.

[4] More about Open Charge Alliance here: https://openchargealliance.org/

3. Based on the connection contract, the customer is allowed to discharge V2G (measured by the smart meter).
4. Without a connection contract and fulfilling technical requirements, the customer is at risk of high penalties set by national regulation (unauthorized supply of electricity which is evaluated by DSO's metering data).
5. Flexibility services provided by V2G must be registered in a Data Space (in the case of the Czech Republic, the so-called Energy Data Hub) and the activation cannot be done in case of DSO or transmission system operators (TSO) congestions according to 'grid prequalification' (in the Czech Republic, the so-called "traffic lights" mechanism).

Moreover, as included in the Directive (EU) 2024/1711: "In areas where electricity grids have limited or no network capacity, network users requesting grid connection should be able to benefit from establishing a non-firm, flexible connection agreement.", which means "a set of agreed conditions for connecting electrical capacity to the grid that includes conditions to limit and control the electricity injection to and withdrawal from the transmission network or distribution network". This might be explored in the future connection of new charging stations. However, this requires that national regulatory authorities develop their frameworks to coexist with future local services. Future NC DR will also set rules on this.

DSO tasks to be accomplished before the Market is ready to deploy V2G:

- Get planning and operational units aware of the cases foreseen.
- Provide guidelines, procedures (technical and IT for data collection) and training towards employees.
- Get the IT systems and connected V2G visibly flagged for the maintenance teams to be always aware of such assets behind the meter (similar to generator units).

Market Stakeholders to be provided with information, guidelines and procedures:

- Vehicle and Charging Stations (OEMs).
- CPOs.
- Energy Suppliers.
- End consumers.

DSOs are currently struggling with grid capacity for generators and long permission times for building stations and lines. The role of DSOs in the evolution of smart charging is essential, including in aspects such as direct control, traffic light concepts, non-frequency services and, finally, V2G. Smart functions and grid-friendly charging behavior is highly relevant, and testing and certification are crucial. Connection requirements will be updated with respect to NC RfG and new technological standards.

6 E.DSO considerations and recommendations

Standardization

With the development of V2X the EV becomes even more intertwined with the energy system as it is now. There are still things which still need to be developed to have V2G activated through the standardized protocols ISO 15118-20 and the latest version of OCPP must be implemented on the EV and EVSE side to facilitate V2X in an interoperable way. In relation to this, the initial State of Charge (SoC) of the EV, and preferably the final SoC desired by the EV driver, should also be communicated. Next to that, the autonomous functions for compliance with the NC RfG must also be developed. In line with the previous points, it can be considered whether to decide on a specific standard interface with which the NC RfG settings can be sent to the EVSE.

Flexibility

To tackle congestion, the flexibility potential of V2G needs to be unlocked accordingly. Today there is no price mechanism or regulation in place to activate V2G to solve congestion. On the other hand, there are already markets for balancing purposes where smart charging and V2G can play a role. However, the balancing need for flexibility is not aligned with the one to tackle congestion. Unlocking the flexibility of V2G for balancing with a high concentration of V2G-capable vehicles in one LV grid area could even worsen situations of congestion. Currently, there is no system in place to prevent local congestion when V2G is activated for balancing purposes. To manage this last aspect, DSO and TSO cooperation is needed for the further implementation of grid measurement and low voltage grid management systems. Based on the prepared Network Code Demand Response, activation of V2G will be made by a service provider not the DSO.

Certification

With regard to the requirements arising from the NC RfG, it is recommended to set up a certification process in a European context. In addition to certification for EVs and EVSEs with regard to the requirements from the NC RfG, a similar process shall be started for V1G EVs and EVSEs, heat pumps, PV inverters and home batteries. This certification must then at least contain the requirements from the NC DC, for which a new version is also in development. EN 50549 should be one of the normative the certification scheme should be based on. Notification obligation for charging stations and also include in this whether these charging stations are suitable to facilitate V2X. EV certification (similar to PV inverters) and reporting obligations throughout Europe (also for V1G charging stations) should be considered.

Power Control

E.DSO recommends considering a European harmonized solution for Active power control. For this a standard DSO – CPO protocol can be chosen (not developed since there are existing solutions) through which capacity boundaries can be communicated. Moreover, further investigation of the potential of Autonomous functions for power control is needed. A standard interface able to communicate additional or changing NC RfG settings should be considered, similar to a standard to communicate a limited capacity profile in case of congestion challenges.

Impacts on the grids

V2X can also have a large impact on the electricity grids. A recent study from Fraunhofer[5] and another simulation studies of Enexis and ElaadNL show that five V2X capable cars can provide the same amount of flexibility as twenty smart charging-capable cars to tackle local congestion. An important aspect regarding grid impact is that V2G can be both a great solution and a major problem for grid

[5] https://www.transportenvironment.org/uploads/files/2024_10_Study_V2G_EU-Potential_Final.pdf

operators; based on the imbalance market(s), V2G can / will be deployed at times and locations that can worsen local congestion. To prevent such situations tools are being developed. One of them is the so-called "grid prequalification" described in Article 31 of the NC DR. How the implementation will be effective will depend on the market conditions and effects of regulations (and underlying systems to operationalize these regulations). Last but not least, it is important to consider that when an EV battery is used as temporary energy storage, it leads to an increase in technical losses across the entire energy system.

7 V2G use-cases and examples

See the list of collected use cases and references for V2G projects or activities:

- Example from iLumen, an installer who uses bidirectional invertor to connect an EV - www.ilumen.solar/ilucharge2.
- EV chargers have to be declared at Fluvius and V2G chargers specifically follow the same processes as productions and storage devices (Bidirectionele laadpalen | Fluvius). V2G chargers have to comply with the same connection requirements set for other inverters (Meldingsplicht private laadpaal elektrische wagen | Fluvius). The different steps to take are explained here: Stappenplan aanmelden bidirectionele laadpaal | Fluvius. On the other hand, the list of inverters/V2G chargers (DC) allowed on the Belgian market are listed here: certified production devices.
- Enedis network has connected first V2G EVs from Renault into the grid using Linky Meter for the settlement - Recharge bidirectionnelle pour véhicule électrique - Mobilize Power).
- Enel Group, Areti, Acea Energia and E.DSO are partners in the EU-funded project FLOW which aims to develop and validate innovative smart charging and V2X business models fostering the optimal integration of EV charging infrastructure into distribution grids. In the Spanish island of Menorca, FLOW is investigating the potential of EV charging flexibility in enhancing the reliability of power supply and relieving network congestion through the monitoring and control of smart charging and V2G-ready chargers. At the same time, as part of the Italian Demo, FLOW partners are researching the use of non-firm connection agreements as a temporary solution to reduce connection costs and waiting times for charging stations to be installed in areas affected by local congestion issues. More information on the project can be found here: https://theflowproject.eu/.
- Enel installed 10 vehicle-to-grid (V2G) units at the headquarters of Danish utility Frederiksberg Forsyning, 10 Nissan e-NV200s V2G hub will help stabilise the national electric grid in Denmark, by providing power capacity services to grid operator Energinet.dk: https://www.enel.com/media/explore/search-press-releases
- WDS, mywheels and Renault partnership installed bidirectional chargers and compatible vehicles under the SCALE project. https://scale-horizon.eu/