In partnership with RICARDO

Deliverable 3.04: Network Guidance for V2G connections

(TransPower)

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Network guidance for V2G connections (TransPower)

Revision History

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Project Details

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Distribution & Sign Off

Stakeholder	Role	Input / validation
Harriet Walsh, LPN	Distribution planning	Distribution planning connection process UK Power Networks standards for network design
Chris Knightly	Distribution planning	Distribution planning connection process Final validation of report
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Thazi Edwards	TransPower project manager	Final validation of report
Ian Cameron	Head of Innovation	Final validation of report

Executive summary

This report is the first deliverable for Workstream 3 of the TransPower Vehicle to Grid (V2G) project. The TransPower project explores V2G as a smart technology to defer network reinforcement. The TransPower partner portfolio includes the V2G projects:

- Powerloop – residential V2G applications
- E4fFutures – V2G for fleets of EVs
- Bus2Grid – V2G for large commercial V2G
- V2Street – studying the market potential for V2G from public charge points

V2G enables excess charge in the battery of EVs to discharge and support the network during high demand and absorb power during low load or high local generation. This reduces the need for network reinforcement, as EVs can support peak load which tends to have a short duration.

This report focuses on different EV assets that can perform V2G operation, considering their different usage and charging profiles. The report considers how different EV assets can support different distribution network constraints, such as over voltage or under voltage, by importing or exporting power from the EV battery to maintain thermal and voltage limits on the distribution network. Alongside supporting the distribution network, EVs could support system operators through participating in the frequency response markets.

Conventional methods for connecting V2G assets follow existing planning standards, that may lead to network reinforcement where it is not necessarily needed. This report aims to address these issues, highlighting different planning approaches for connecting V2G to the network that will benefit the network whilst not disrupting the assets owner.

The primary aim of the V2G asset is to carry passengers or goods and it is likely that the operator of the V2G asset will wish to prioritise this function. Hence the V2G asset will only be available to export when it is not undertaking its primary function and if the export from the battery does not impact the primary function.

Whilst V2G assets have the ability to alleviate some network constraints by charging or discharging depending on the network requirements the constraints could be exacerbated if the V2G assets were to behave in a counterproductive way.

When following BAU connections procedures, V2G assets are required to follow the connection procedure for load and generation. At present these procedures are deterministic and involve a network study based on the worst case network conditions (peak demand for assessing new demand connections and peak generation for assessing new generation connections). The V2G asset may be offered a firm connection, where it is able to import or export at the agreed capacity at any time in the network, or it may be offered a timed connection where the V2G asset is able to only operate at the agreed capacity for fixed durations during the 24-hour period. There could be a conflict between using V2G assets to solve distribution network constraints and the existing BAU connections procedures which may require network reinforcement before allowing the V2G asset to connect.

It is expected that V2G assets behaviour will depend on many variables and a single V2G connection could have a random profile when considered over many days. The TransPower partner portfolio V2G projects aim to conduct trials to understand the different behaviours of V2G assets for residential vehicles, fleets of EVs and large commercial EV.

Continuing with a deterministic planning approach will require a significant effort on behalf of the DNO Planners. For example, assessing the suitability of V2G for assisting with network constraints, requires information about a number of variable factors such as the time when the V2G will be connected, the initial state of charge and the state of charge required by the EV asset owner to use the EV for its primary function.

The DNO also requires a minimum level of service and confidence that either single V2G or distributed V2G resources are able to provide the required services. For the DNO to maximum the opportunities V2G assets could provide, it is suggested that the network can no longer be planned entirely in a deterministic way. It is suggested probabilistic techniques could be used to understand how much V2G is required to provide the minimum level of service required by the DNO. The inputs to these probabilistic models and how the market influences the behaviour of V2G is expected to be an outcome of the TransPower trials.

Abbreviations and definitions

Term	Definition
ADMS	Advanced Distribution Management System
ANM	Active Network Management
BAU	Business as Usual
BMS	Building management system
CI	Customer Interruptions
CMI	Customer Minutes Lost
DNO	Distribution Network Operator
DSO	Distribution System Operator
DSR	Demand Side Response
ELS	Export limiting scheme
EMS	Energy management system
ER	Engineering Recommendation
EV	Electric Vehicle
Feeder	Mains cable connecting the loads to the substation bus bar
GB	Great Britain
GSoP	Guaranteed Standards of Performance
GW	Gigawatt
HV	High Voltage
LCT	Low Carbon Technology
LV	Low Voltage
PoC	Point of Connection
RMU	Ring Main Unit
SO	System Operator
TSO	Transmission System Operator
V2G	Vehicle to Grid

1 Table of Contents

2 Background and purpose

2.1 Introduction to the TransPower project

The TransPower project[1] explores vehicle-to-grid (V2G) as one of several smart technologies that benefits distribution networks; reducing network reinforcement costs with the increase in electric vehicles (EV). The TransPower portfolio consists of UK Power Networks activities contributing to several V2G Innovate UK competition projects. TransPower is funded by the Network Innovation Allowance (NIA).

UK Power Networks unique position in supporting and delivering several V2G Innovate UK projects allows UK Power Networks under TransPower to consolidate each project, evaluating the technical, commercial and customer proposition of V2G on distribution networks. The portfolio investigates the network impact and flexibility services for several different vehicle customer segments from domestic, to commercial and public charging through demonstrator trials and collaborate research and development.[2]

TransPower intends to encompass the necessary work to understand the value and further prepare the business for sources of network flexibility such as V2G. A greater understanding and use of mobile battery assets (vehicles) has the potential to defer network reinforcement and support network resilience, facilitating the connection of additional loads and low carbon technologies. It is estimated that the benefits of V2G could deliver in the order of £450 per vehicle (customer benefit) annually based on existing whole system flexibility markets. The project will carry out tests on existing and new flexibility services with the aim of being able to procure similar services as business as usual after the project.

This report is the first deliverable for Workstream 3, network modelling and data analysis. The purpose of Workstream 3 is to understand the impact and opportunities of V2G in the UK Power Networks licence area. This will be completed through network modelling and data analysis. The successful delivery of this workstream is to identify location specific opportunities to resolve network constraints.

2.2 Introduction to Innovate UK V2G projects

There are four Innovate UK projects that are part of the TransPower partner portfolio which include: Bus2Grid, e4Future, Powerloop and V2Street. Each of the four projects has a different project focus and objectives, with each project delivering a different outcome which contributes towards V2G becoming business as usual (BAU). The projects are outlined in the following sections of this chapter.

2.2.1 Powerloop

Powerloop uses V2G to allow users who have off-street parking to charge their EV intelligently at home, using the battery in their EV to power their home when electricity prices are high or chose to sell the spare power in their EV back to the grid. The flexibility and responsiveness of EVs allows greater use of variable generation like renewable energy across the power network, along with reducing EV ownership by rewarding owners who participate.

The project provides a critical insight into how effective EVs are as grid balancing mechanisms when located at a user's home and how users are likely to interact with their EV charging system and the technology used to make it possible. The data gathered from Powerloop will enable a smoother integration of V2G services, whilst validating domestic V2G at scale in regional clusters.[3]

2.2.2 e4Future

e4Future is a large scale V2G demonstrator which deploys groups of EVs with V2G capability which are controlled using an aggregator platform. The project supports a decrease in cost for EV ownership and provides a more efficient electricity system.

[1] TransPower on ENA portal: https://www.smarternetworks.org/project/nia_ukpn0033
[2] V2G Global Roadtrip: Around the world in 50 projects: https://www.smarternetworks.org/project/nia_ukpn0033/documents
[3] Powerloop: https://gtr.ukri.org/projects?ref=104226

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The project is composed of participants from typically disconnected sectors which includes private communal, commercial/delivery and public service vehicles. e4Future assesses the response time from commercial V2G offers for the distinct consumer groups, evaluating the acceptance of V2G operation and helping test and refine different business cases and reward mechanisms for providing V2G services.

The project aims to identify policy and regulatory framework barriers and cyber security issues for nationwide deployment of V2G across the GB electricity network. e4Future will be used to support the UK in increasing V2G through business models and optimizing EVs potential as a resource, improving flexibility across the electricity network.[4]

2.2.3 Bus2Grid

Bus2Grid is the UK's first electric bus to grid (Bus2Grid) project which is based in UK Power Network's licence area, with the aim to demonstrate at commercial scale the technology and advantages Bus2Grid can provide to TSOs, DNOs and bus operators.

Within the Bus2Grid project, there will be 22 new e-buses equipped with V2G and 11 e-buses retrofit with V2G capability, which allows for 2.64 MW of bi-directional charging at a London bus depot. This allows for 1-2 MW of V2G response that can be used to help support National Grid and UK Power Networks.

The project aims to deliver a clear V2G roll-out strategy within the e-bus market, using an aggregation platform integrated into the bus charging management system which interfaces with National Grid and UK Power Networks to offer V2G services. This includes creating new business models and market frameworks to identify the value V2G can offer to bus operators, TSOs and DNOs, with first-time bidding for frequency response from aggregated e-bus batteries. The project will also understand bus operators' attitudes towards V2G at different stages throughout the project, which will tailor V2G services that bus operators will provide.[5]

2.2.4 V2Street

V2Street addresses the issue of people who live in urban environments who don't have access to off-street parking and as a result may be less likely to buy an EV due to reduced EV charging stations near their home. Local councils may also be reluctant to build an EV charging infrastructure in urban areas if there is no noticeable increase in EVs within their council area. V2Street aims to break the deadlock by using the flexibility in V2G-enabled charging to provide Demand Side Response (DSR) services to the energy network, with the revenue stream created used to support fund an EV charging infrastructure.

The project aims to develop a range of consumer propositions and business models based on modelling of revenue that DSR flexibility can create. Consumer acceptance will be investigated, as well as the impact seen on the power network and urban infrastructure, which allows for the development of larger-scale trials in the future. V2Street aims to create a "virtuous circle" of infrastructure investment and EV uptake, whilst supporting the power network through V2G balancing and flexibility services.[6]

2.3 Purpose of this report

The increasing number of EVs on the roads and how best to charge and utilise the assets on the network whilst not disrupting the users experience is an important question that has not been fully addressed yet. The aggregated number of EVs on the network is expected to be significant, but the number of EVs plugged into a specific part of the network at any one time may have limited liquidity, restricting options for contributing within different markets, such as the fast frequency response (FFR) market. In contrast, there may be many EVs plugged into the network at times of high or low demand, depending on the EV assets deployment.

The aim of this report is to match distribution network constraints with V2G assets considering the connection of a range of EVs to commercial and residential networks which have different load profiles. It is expected that fleet vehicles will have the ability to support residential networks in the evening and weekends, where domestic vehicles will have the

[4] E4Future: https://gtr.ukri.org/projects?ref=104227
[5] Bus2Grid: https://gtr.ukri.org/projects?ref=104230
[6] V2Street: https://gtr.ukri.org/projects?ref=104224

ability to support commercial networks during the middle of the day by plugging their EVs in at work or at their residential home.

The report reviews the connection and planning requirements to enable site selection for the TransPower projects and identifies the challenges of enabling V2G to benefit the network.

2.4 Overview of the structure of this report

This report comprises the following sections:

- Section 3 considers V2G as a concept and summaries some key projects from around the world. A list of different V2G assets and charging locations that could support the network through V2G operation are outlined, highlighting the potential EVs and charging stations could bring to the power network.
- Section 4 discusses different network constraints that DNOs have on their network and considers how V2G operation could support the network through V2G operation.
- Section 5 considers the connection of V2G and site selection.
- Section 6 concludes the findings of the report.
- Appendix A reviews UK Power Networks Procedures for Connection V2G
- Appendix B contains connection examples for the Transpower project.

Section Summary

- TransPower investigates V2G as a smart technology to help reduce network reinforcement costs with the forecasted increase in EVs.
- TransPower portfolio consists of UK Power Networks activities contributing to several V2G Innovate UK competition projects including: Bus2Grid, e4Future, Powerloop and V2Street.
- This report considers the match of typical distribution network constraints with the capabilities of V2G assets.
- The structure of the report will evaluate different EV assets, different network constraints within the distribution network and how EV assets can support the network without disrupting the everyday routine of the EV assets.

3 Vehicle to Grid (V2G)

3.1 Introduction to V2G

Vehicle to Grid (V2G) is a concept that enables the batteries in plug-in electric vehicles (PEVs) to be used as energy storage for the grid. The batteries in electric cars can both be charged from the grid and discharged to the grid to provide grid services. Controlled charging (V1G) shifts and delays charging to help prevent peak demand being increased by the charging of EVs. V1G can also defer charging until electricity prices are lower which reduces the users cost, which tends to be at times of low load through the night. Using the battery within the EV as storage can reduce peak demand on the power network by discharging the battery (V2G) and as for V1G charging at times of low demand and when electricity prices are at their lowest.

V2G projects being trialled around the world are presented in "V2G Global RoadTrip: Around the world in 50 projects". The review highlights 50 V2G projects globally, of which 25 are in Europe, 18 in North America, and 7 in Asia which are delivering clear use cases. North America and Europe dominate in the number of projects currently being trialled. The literature review highlights a selection of key projects which includes the Parker project in Denmark. The Parker Project aims to validate how aggregated EVs can support the power grid by providing seamless support to the power grid both locally and system wide.[7] The project tested a range of EVs from different manufactures including Nissan Leaf, Nissan Evalia, Mitsubishi Outlander and Peugeot iOn as an example fleet using Enel V2G chargers controlled by a Nuvve Aggregator. The EVs participated in the Danish frequency response services. Another key project is City-Zen in the Netherlands which is trialling V2G chargers located at public locations throughout Amsterdam and at the offices of accounting firm PwC and at a large sports facility. The EVs can be either charged, provide DSO services or provide electricity directly to organisations where they are situated. .[8] In America, INVENT is a project in San Diego with 50 chargers which have V2G capability installed across campuses at the University of California San Diego, with part of the project using a solar forecasting technology developed at the university to inform the EV charging schedule. For example, if the forecast is for a cloudy morning and clear afternoon, charging will be delayed allowing the EVs to charge directly from solar energy directly.[9]

3.2 V2G assets and operation

There are several projects across the world looking at V2G and how different vehicles can support different aspects of the network. This section outlines different V2G assets that have different potentials to support the power network at different times of the day. Figure 1 presents the desirable characteristics for a V2G asset to support DSO and TSO services.

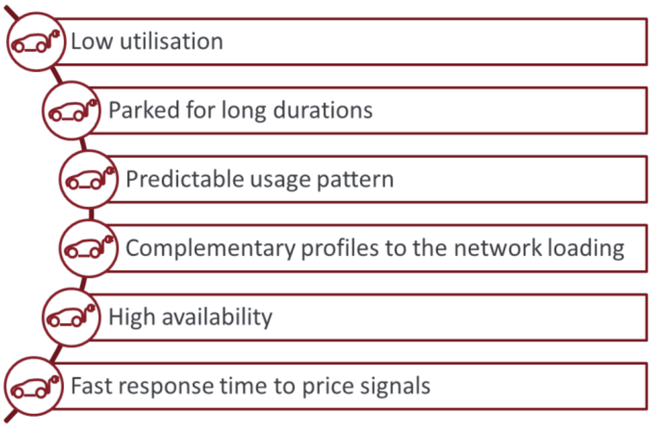

Figure 1: Desirable characteristics for a V2G asset

[7] Parker: http://parker-project.com/#about
[8] City-Zen: http://www.cityzen-smartcity.eu/
[9] INVENT: https://nuvve.com/2017/06/14/nuvve-and-uc-san-diego-to-demonstrate-vehicle-to-grid-technology-through-energy-commission-grant/

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It is assumed in all cases that when EVs are stationary at its normal place of rest, that the EV is plugged into a charging station with V2G available.

As of March 2019, the following CHADEMO vehicles are V2G compatible [10]:

- Nissan LEAF
- Mitsubishi Outlander PHEV
- Nissan E-NV200 van

3.2.1 Buses

There are two identified categories for electric buses which include public use buses which follow public bus routes, and the second identified category is private coach hire. Both categories have very different daily usage profiles and different expected daily distances. Public buses follow specific service routes and cover an expected daily distance of approximately 360 miles (depending on bus route) and will be in use for most of the working day. Private coach hire has a less predictable usage profile and can change daily depending on deployment and demand. The charging profile is also therefore unpredictable and could be plugged in at any time of day.

Public buses follow a predictable daily charging and usage profile but are in use a large proportion of the time, whereas private coach hire is unpredictable and could either be in full deployment for days or not in use. Seasonal events could also influence the deployment of private coach hire, with locational destinations also influenced depending on time of year and seasonal weather.

Both public buses and private coach hire could participate in the capacity market and contribute to frequency response services and reserve services for the distribution network. Using the battery to discharge power, it is possible to support the network to reduce thermal and voltage constraints across the distribution network, releasing capacity.

Private coach hire vehicles would be expected to have a larger battery due to longer distances that private coaches tend to perform, due to variability of the customers' requirements. In the UK there is a legal limit for any driver of passenger carrying vehicles to stop after 5.5 hours of driving for a 30-minute break. Providing there was suitable infrastructure, a coach could be charged during this 30 minute stop. The Department for Transport, part of the UK government, publish a report in July 2018 called "The Road to Zero"[11] highlighting the need to increase the electrical capacity at motorway service stations. This could provide the infrastructure to charge coaches.

V2G buses are being developed by the Bus2Grid project in partnership with BYD. Once this technology is developed, it could be deployed in electric coaches.

Multiple manufactures have electric bus and coach offerings including:

- Hyundai have unveiled a double decker bus which is 13 meters long with a battery capacity of 384 kWh and a single decker bus with a 256 kWh battery[12].
- Chinese automotive company BYD have manufactured over 50,000 electric buses since 2010. Their offering includes single decker buses, double decker buses and a 13-meter electric coach with a 200 km range[13].
- German manufacture Eurabus offer both electric buses and an electric coach with a 600 km range[14]

3.2.2 Domestic vehicles

There are two identified user profiles for residential V2G which include EVs that are used for commuting making regular and predictable journeys for multiple days of the week and EVs that remain parked at their registered address and making only random and infrequent journeys. The user groups that own these vehicles may use an EV as their second car, be

[10] https://www.drive-electric.co.uk/v2g/
[11] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/739460/road-to-zero.pdf
[12] http://trucknbus.hyundai.com/global/products/bus/elec-city
[13] http://www.bydeurope.com/vehicles/ebus/types/13.php
[14] https://www.eurabus.com/en/

retired, work from home or use public transport to travel to work. There are different driving and charging profiles for the two distinct groups, with EVs used for commuting having a higher battery utilisation than those that remain parked in residential networks during the day.

The average daily commuting distance in the UK by car driver is 10 miles[15]. The average distance travelled by cars in 2017 in the UK was 7134 miles[16] which is approximately 20 miles per day. Figure 2 shows the purpose of all car and van driver trips from the results of the National Travel Survey 2017 by the UK Department of Transport. The data shows that approximately 20 % of car / van trips were for commuting purposes.

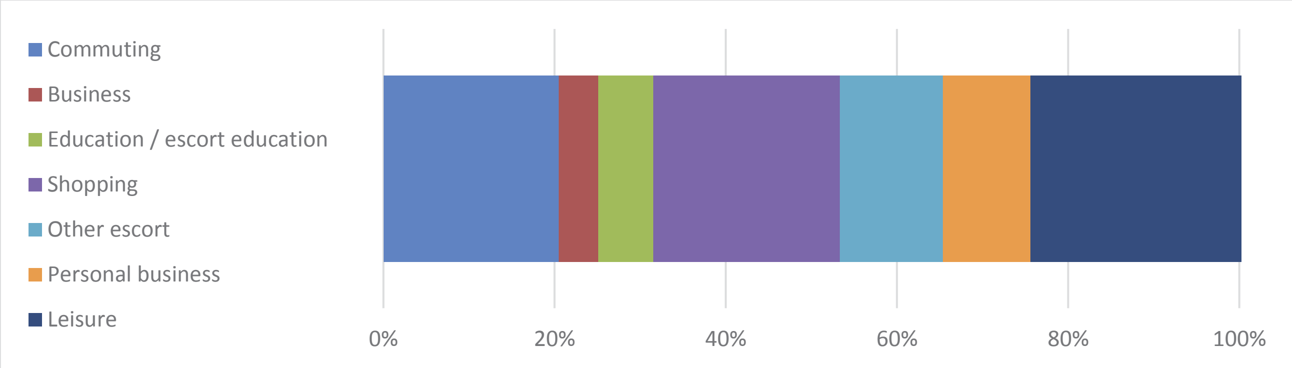

Figure 2: Purpose of all car/van trips (Department of Transport, National Travel Survey 2017)

Commuting vehicles are likely to have a predictable driving and charging profile through the working day, where non-commuting vehicles may not and could include a variety of charging in residential networks, charging on route and destination charging. Commuting vehicles are likely to be driven in the morning and evening peaks and parked in a commercial area during the working day. EVs used for commuting are likely to be plugged in to residential networks during the evening when the EV arrives home from work between 5pm and 9pm. They could be plugged in at the work place during the day. Non-commuting EVs tend to spread their charging more evenly throughout the afternoon. Half of commuter charge events begin between 5pm and 9pm compared with only a third for non-commuters[17]. Weekend driving patterns and charging tends to be more unpredictable. There is an opportunity to support commercial networks during the day if V2G charging stations are provided for those EVs which commute.

Both customer segments (commuters and non-commuters) can participate in the capacity market and contribute to frequency response services and reserve services for the distribution network through the working day, with non-commuting EVs having a greater potential to support the network at times of high demand as they are likely to have a higher charge in their battery. Demand side response services are also an option, controlling the charging of EVs to reduce the peak load through the working week. Weekend operation is less predictable for both clusters of assets, with the potential of weekend peaks on Sunday evening as EVs need charged for the following week.

3.2.3 Electric car-club vehicles

In larger cities, there are fewer vehicle owners due to good public transport, congestion on roads and the cost of maintaining a vehicle. As a result, car rental schemes are popular, allowing customers to travel out of the city on weekends, bank holidays or planned holiday leave. There are also car sharing schemes where consumers can use a car whenever they want if a vehicle available across the city, if they need to travel to a specific place twice a week for example.

Car club companies offering mobility as a service have many EVs in aggregation with an unpredictable driving and charging profile. Utilisation of the EVs in the electric car club will depended on their availability to offer services to the TSO and DSO. EVs which are highly utilised are unlikely to participate in the capacity market or contribute to frequency

[15] Figure 14, Commuting trends in England 1988 – 2015, Report by Department of Transport, November 2017 (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/657839/commuting-in-england-1988-2015.pdf)
[16] Anonymised MOT tests and results, https://data.gov.uk/dataset/e3939ef8-30c7-4ca8-9c7c-ad9475cc9b2f/anonymised-mot-tests-and-results.
[17] Charger Use Study Report by Recharge the Future - https://www.smarternetworks.org/project/nia_ukpn0028

response services because they will be required to charge ready for the next booked. EVs in the electric car club which have a lower utilisation could participate. They are generally parked close to the users in residential streets. Their unconventional duty cycles and utilisation could be complimentary to distribution network constraints. Analysis of the electric car club behaviour is required to assess the suitability of the electric car club in participating in TSO and DSO services.

3.2.4 Taxis

Different ownership models for taxis exist. Some companies will own a fleet of taxis and drivers will use a vehicle for their shift. These vehicles will have a random and unpredictable charging and driving profile, with a high utilisation through the day and evening. These taxis could cover a daily distance of up to 350 miles and require fast charging to ensure they have enough capacity to meet all requirements through the day and not loose time waiting for the vehicle to charge.

As a result of the high utilisation, it is unlikely that these taxies will be available to participate in the capacity market or contribute to frequency response services within the distribution network. There may be consideration to determine when and where EV taxis perform charging, especially if a fast charge is required at some point through the day.

The other ownership model involves the driver owning or leasing the taxi. These taxis will likely have defined shift patterns where the vehicle is available for up to 12 hours a day to participate in TSO or DNO services. The Black Cab Green[18] project identified the usage patterns in Figure 3.

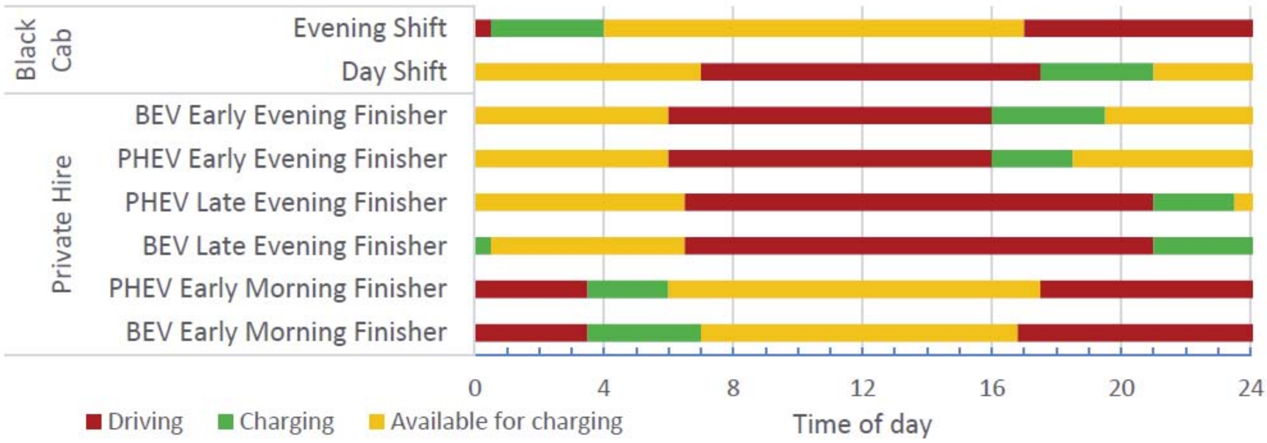

Figure 3: Usage profiles identified in Black Cab Green project

The owned or leased vehicles are likely to be parked at the driver's home in residential networks when not in use. The taxi could offer network services during the yellow periods shown in Figure 3. Taxis may also be able to provide grid services during charging by either exporting if there is sufficient state of charge in the battery or by shifting their charging to a time when there is available network capacity.

Existing V2G enabled vehicles (Nissan LEAF or Nissan E-NV 200) could be licensed as a mini-cab taxi to provide V2G services. Dynamo Motor Company have launched an electric taxi based on the Nissan E-NV 200[19]. The Nissan E-NV is a V2G compatible vehicle, therefore the Dynamo Taxi should be able to participate in V2G services[20].

3.2.5 Smaller commercial fleet vehicles

There are two identified categories for smaller fleet vehicles which include fleet vehicles that return to depot at the end of a shift, and those that return to residential homes at the end of a working day. Smaller fleet vehicles would include

[18] Black Cab Green: https://www.smarternetworks.org/project/nia_ukpn_0026

[19] Dynamo Taxi: https://www.dynamotaxi.com/

[20] European power files aim to harness electric car batteries, 21st January 2019, Reuters, (https://uk.reuters.com/article/uk-electric-vehicles-charging-grid-analy/european-power-firms-aim-to-harness-electric-car-batteries-idUKKCN1PF0HY)

last mile delivery vehicles and business call out vans, which have a larger battery storage capacity when compared to domestic vehicles but cover on average 50 – 90 miles a day, depending on operation and deployment.

Fleet vehicles are in operation for most of the working day and therefore have a high utilisation following a random driving profile. The charging profile is more predictable for fleet vehicles which return to the depot and charge through the evening and night. Fleet vehicles which return to residential homes have a longer driving profile and require charging through the night for longer than those in depots.

Fleet vehicles can participate in the capacity market and contribute to frequency response services and reserve services for the distribution network through the evening and on weekends, with fleet vehicles parked at the depot having a larger aggregated storage capability at the point of connection. Demand side response services are also an option for fleet vehicles which return to the depot typically at the time of residential peak demand. It may be possible to empty the remaining power from the fleet vehicles to support the grid at evening peak demand.

3.2.6 Larger commercial fleet vehicles (UK/EU Category C vehicles)

Larger commercial fleet vehicles are defined in this report as heavy good vehicles (HGV) performing depot to depot journeys. These are larger haulage vehicles delivering products around the country or across country borders to different depot locations. Examples include supermarket HGVs delivering goods from the distribution warehouse to the supermarkets or parcel couriers, for example DHL or Parcel Force, transporting between depots.

Compared to smaller fleet vehicles they would require a larger battery capacity and likely drive at least 200 miles a day on average. Larger fleet vehicles have a less predictable charging and driving profile but have the added stationary time when the fleet vehicle is being loaded and un-loaded.

Fleet vehicles are in high utilisation during large periods of time but are stationary for large periods also. Larger fleet vehicles can participate in the capacity market and contribute to frequency response services and reserve services for the distribution network but are less predictable to what time of day the EVs are available to support the distribution network, as it is dependent on location and deployment. If the depot is loading or unloading a vehicle for most of the working day, then there is potential to have a larger commercial fleet vehicle at a depot which will require charging but is therefore also capable of supporting the network using frequency response services.

It is not known if there are any existing V2G enabled electric larger commercial fleet vehicles and therefore these vehicles would not be able to participate in any V2G services. Electric larger commercial vehicles are arriving on the market. Arrival offer a 7.5 tonne electric goods vehicle and Tesla plan to produce a battery electric HGV in 2020. In future, a manufacture may develop a V2G compatible larger commercial vehicle.

3.2.7 Emergency response vehicles

The emergency services vehicles primarily include ambulances, fire-engines and police vehicles in this report. There driving profiles vary daily, with random deployment as they respond to incidents. Ambulances and police cars are always in near constant use throughout the day and may require fast charging on demand. Fire-engines on the other hand are not in constant use but must be ready to respond at a minute's notice when instructed. Fire engines also have a large battery capacity in comparison to other emergency response vehicles due to their need to pump water once they get to the fire.

Due to the unpredictability and high reliance on emergency response vehicles, it is not suitable for these EVs to contribute to frequency response services, with the note that fast charging may be required for many vehicles at the same time to meet the required incident response time.

3.2.8 Council owned vehicles

The council own a range of different vehicles, which include refuse collection, salt gritters, mini-buses and mobile library services. A lot of council owned vehicles have a planned schedule, such as waste collection, but also own a range of vehicles that are only in use at certain times of the year, such as salt gritters. Most council owned vehicles cover 50 miles a day on average during the working week.

Refuse collection vehicles would have a large battery capacity due to the need of compacting waste during collection. They begin their collection in the early hours to avoid traffic and are back at the depot by 2 pm where they are not in use again until 6 am the following day. Other council owned vehicles are in operation during the working day and return to the depot for charging in the evening.

Terberg RosRoca Group have developed a Dennis branded fully electric RCV called the eCollet which will enter production in 2019[21]. The waste management company Veolia are trialling a converter electric RCV in Sheffield and London[22]. If these trials have positive results, other waste management companies may consider converting or replacing their diesel fleet with electric RCVs. This could present an opportunity for RCVs to provide V2G services.

The variety of council owned vehicles allow for a range of different charging and exporting profiles to be developed, that allow council owned vehicles to participate in the capacity market and contribute to frequency response services and reserve services at different times of the day. Low use vehicles, such as salt gritters, can support the network for large periods of time, where scheduling their deployment in advance is possible. Salt gritters are in operation during the evening of winter months, allowing some council owned vehicles to charge and participate with frequency response services through the day and summer months when deployment of the asset is low.

Most council owned vehicles are not in use over the weekend, with smaller EVs such as park patrol vehicles, in use every day of the week. This gives the option for council owned EVs to support the charging of other council owned EVs if required to lower demand on the network.

3.2.9 Larger commercial boats

There are two identified categories for commercial boats which include social use and working use. Social use boats include cruise liners and ferry operators, whereas, working use boats include fishing vessels and cargo ships. Both categories are specific to coastal areas with deep water docks.

Ferry operators and cruise liners follow timetables and have a predictable sailing schedule. Ferry operators have a permanent dock where the vessel loads and un-loads cargo, whereas cruise liners travel around the world and dock at different locations throughout its trip. Due to the variability of cruise liners, it is not suitable for them to contribute to frequency response services, with the note that fast charging may be required when it is docked. Ferry operators, however, can support frequency response services when docked which is for a useful duration of time. Numbers of electric ferries are a growing with existing electric ferry services including:

- The Sognefjord crossing in Norway using a 1 MWh battery system.
- Services in Island from Landeyjahöfn on the mainland and the Westman Island.
- A small passenger service called Le Ferry Boat in Marseille.
- An electric powered shuttle ferry in Stockholm, Sweden.
- Niagara Falls' famous Maid of the Mist boat tour in the US.

For working use boats, commercial fishing vessels have a less predictable timetable but are expected to be operational through the day and docked at night. Cargo ships are at sea for long periods of the time but are docked for a few days while the cargo ships are loaded and un-loaded. Both can contribute to frequency response services and reserve services for the transmission network but are specific to when the vessels are docked.

Smaller electric boats are offered in the market place from over 100 manufactures. An IDTechEx report predicts that the market for hybrid and pure electric boats will rapidly increase[23]. This will be driven by a reduction in costs of electric boats and restrictions in emissions regulations for vessels to improve air quality around docks and ports[24].

There are no known V2G boats in operation but the market for electrified boats and ferries is increasing and can contain batteries with a MWh capacity. If the boat is docked for a significant duration and a V2G market is established, the owners of the boat may wish to participate in the V2G market as another revenue stream.

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[21] Dennis Eagle eCollect RCV, https://www.dennis-eagle.co.uk/en/products/ecollect/
[22] Veolia electric RCV trial, https://www.veolia.co.uk/press-releases/veolia-trial-electric-refuse-collection-vehicles
[23] Electric boats and ships 2017-2027: Large market emerging, IDTechEx 2017. https://www.idtechex.com/research/articles/electric-boats-and-ships-2017-2027-large-market-emerging-00010468.asp
[24] https://www.idtechex.com/en/research-report/electric-and-hybrid-boats-and-ships-2019-2029/648

3.3 V2G charging locations and operation

There are a variety of different methods and operations for charging EVs, which are dependent on location and time of use. The report Charger Use Study from the project Recharge the Future investigates EV charging behaviour through literature reviews and consultations[25]. The Charger Use Study identifies different charging profiles which could be used with assessing the impact of EVs connecting to the electricity network. This section summarises the different charging locations identified for the TransPower project and highlights the expected charging capacity.

3.3.1 Residential off-street charging

Residential off-street parking is applicable to consumers who have a driveway or an equivalent way of charging their EVs from a private residence. Residential properties in the UK generally have a single-phase connection and can accommodate a charging capacity of up to 7 kW. This enables residential connections to provide V2G services of up to 7 kW import and export.

Alternative residential off-street parking may include residential tower blocks with underground parking or equivalent. Blocks of flats are usually supplied with a three-phase connection to the building. A three phase connection provides the possibility of higher charging rates subject to the spare capacity available on the feeder to the block of flats. Building owners could install up to 50 kW charging facilities for residents enabling the possibility of V2G services up to 50 kW per vehicle. If the parking area contained many V2G enabled vehicles connected to the same feeder there would be a larger V2G service provision when compared to individuals using single property residential off-street parking. Large blocks of flats are likely to have a HV connection or have a dedicated substation to provide the LV services to the individual properties.

3.3.2 Residential On-street Charging

Residential on-street parking includes consumers who do not have the option of charging their EV from a private residence. There are several residential on-street charging options which are operated by different charge point operators. There are charging posts that are located across residential networks that have a maximum charging capacity of 22 kW. Most charging posts have a three-phase supply which enables 22 kW charging, with single-phase charging enabling up to 7 kW. In the future there may be higher rated chargers sparsely spread across residential networks that allow charging up to 50 kW. An alternative option is to connect EV charging infrastructure to the existing street light infrastructure by fixing an EV charging point to the existing pillar of the street light. This provides a method of installing on-street charging without increasing the amount of street furniture. Street lights may have up to a 24 A connection allowing for charging powers of up to 5.75 kW. Although in cases where the service cable is smaller, the allowed charge power would be reduced.

The TransPower partner project V2Street is investigating the flexibility in V2G-enabled charging to provide DSR services to the distribution network. If V2Street shows V2G is viable for residential on-street charging, V2G charging posts, such as those developed by Enel, would allow the market to offer residential on-street V2G products.

3.3.3 At Work Charging

In Great Britain 68% of commuters travel to work by car which results in a large number of cars parked at workplaces. Employers may decide to offer workplace charging to support the uptake of EVs or as a benefit for employees. Work place charging facilities will depend on the capacity of the network. As the EVs are likely to be parked for between 3.5 and 7 hours (depending on numbers of part-time and full-time employees), slower charging rates of 7 kW will be sufficient. Employers may install anywhere from few EV chargers to 10s of EV chargers depending on the number of employees working at the site. This provides the network with a potentially large V2G resource. The employer may also have PV installed and offer cheap electricity when there is excess generation and buy electricity from the EVs when wholesale prices are high.

[25] https://www.smarternetworks.org/project/nia_ukpn0028

Network guidance for V2G connections (TransPower)

Work place V2G could be considered by the DNO as a fleet connection where the fleet is connected during the operating hours of the company. The V2G chargers maybe the same as the chargers for residential off-street and residential on-street applications, hence both the V2G charger and EVs are already on the market.

3.3.4 Smaller Depot Charging

Smaller depot charging would charge EVs with a 22 kW three-phase supply or 7 kW single-phase supplies. Smaller depots such as depots for council owned vehicles and last mile delivery vehicles, may be in constrained areas of the network limiting the size of the chargers at the depot if reinforcement to the network is not performed.

There would be large numbers of EVs connected to the same feeder at certain times of the day, which will be able to support the network through V2G services.

Some smaller charging depots would not be able to accommodate V2G services and may require 50 kW chargers, such as depots for electric taxis which are in use for larger proportions of the day and may require rapid charging.

3.3.5 Larger Depot Charging

Larger depots charging EVs such as buses and depot to depot vehicles are likely to charge with a three-phase 22 kW or 50 kW charger and possibly at a higher power in the future. #These larger vehicles will have a larger battery capacity than smaller passenger vehicles. It is likely that the larger depots will have a greater aggregated battery capacity and a larger connection to the distribution network. These sites could provide more opportunities for V2G services and be able to offer more support to a distribution network. However, the asset owner may also have a requirement to have all vehicles fully charged by the start of the next service or shift. This could reduce the availability of the V2G vehicles to support distribution networks.

Larger charging depots require more parking spaces to store the vehicles and are likely to be in more commercial districts of cities where land is cheaper than in central city locations where land has a higher value. Depending on the customers connected in these districts, the load profiles are either likely to peak during the day when the companies are operating or be constant across the day and night if the company has a 24-hour shift pattern. Networks where the peak is during the day have spare capacity in the evening and night to charge the fleet vehicles but are unlikely to require local V2G services from these vehicles when the network has available capacity.

3.3.6 Car Parks

Car parks may have up to 1000 spaces and although cars may be entering and leaving the car park continuously, the car park may have a base load of spaces which they can guarantee are always occupied. Examples of car parks could be long- and short-term parking at airports, multi-story car parks in city centres, train stations and supermarkets or out of town shopping areas.

Car parks may have a selection of EV chargers which will depend on the length of time the vehicles are parking for, with short stay car parks likely to have higher power chargers and long stay having lower power chargers. It is expected that the lowest charging rate offered would be 7 kW.

However, the electrical infrastructure may not accommodate all the spaces being connected to a charger without reinforcement to the network. This could be prohibitive to the return on investment to the car park owner. If there was limited capacity from the network, the car park owner could incentivise the owners of cars that are parked in the long-stay section to discharge their battery to charge the cars parked in the short stay section that require fast charging. The cars in the long stay sections would then recharge after the cars in the short stay section had left the car park. This could be considered a Vehicle-2-Vehicle use case. The concept of Vehicle-2-Vehicle charging is offered as a function on the Sion car designed by the car company Sono Motors[26].

3.3.7 On route Charging

On route charging could include rapid chargers located at motorway service stations, forecourt type charging following the fuel station model and taxi ranks. These charging stations may have a mixture of 3-phase 22 kW to 150 kW chargers

[26] https://sonomotors.com/en/sion/

to accommodate charging rates supported by the different EVs. These are likely to be upgraded if a higher charging powers are adopted by a new model of EV. For example, the Ionity charging network is advertising charging powers of up to 350 kW and FastNed charging network offers up to 175 kW. EVs that charge on route do not stay for long periods of time and therefore, V2G services from EVs at service stations will be negligible.

3.3.8 Emergency Response Vehicles

Emergency response vehicles require priority charging via three-phase 22 kW or 50 kW chargers which are located at each respective emergency response location (e.g. hospital, fire station, etc). The high dependence on emergency response vehicles results in emergency response vehicles not being suited to participating in any V2G services.

Section Summary

- There is a large range of EV assets which could contribute to V2G services on the distribution network which include: buses, domestic vehicles, smaller commercial fleet vehicles, larger commercial fleet vehicles and council owned vehicles.
- There are a range of EV assets which are constrained by their deployment and are potentially unable to contribute to V2G services, which include: social domestic vehicles, taxis and emergency response vehicles.
- Fleet vehicles are not expected to be operational outside working hours with V2G potential for EVs on evenings and weekends.
- Charging locations across the network have different charging rates with a range from 3 kW to 50 kW.
- Depot charging for fleet vehicles are expected to have more chargers when compared to residential networks with up to 50 kW charging potential.
- Chargers on residential networks are typically up to 7 kW.

4 Distribution network constraints

4.1 Introduction to UK Power Networks distribution network

UK Power Networks owns and maintains electricity cables and lines across London, the south east and east of England, with the total area covering 29,000 square kilometres. They have three licence areas, Southern Power Network (SPN), Eastern Power Network (EPN) and London Power Network (LPN). Across the three licence areas, UK Power Networks distributes power to 8 million homes and businesses, which is approximately 27% of the UK's electricity distribution network. There are over 130,000 substations and 170,000 km of overhead lines and underground cables in the three UK Power Networks license area.

UK Power Networks invests more than £500 million in its electricity network every year with a team of 5,600 staff members. UK Power Networks is the country's biggest connections business, with 100,000 new connections to the network every year.

4.2 Typical distribution network constraints

All DNOs in the UK are required under Condition 21 of their licences to maintain a Distribution Code detailing the technical parameters and considerations relating to the connection to and the use of their electrical network.

Typically, distribution network constraints arise from thermal issues, voltage issues, security of supply issues, fault current and harmonics. Distribution network constraints are typically specific to a single geographical location, and support is best provided at the location of the constraint.

4.2.1 Thermal constraints

All equipment designed to carry electrical current has the property of resistance. The resistance of the equipment and the amount of current carried by the equipment determine the amount of energy dissipated. This energy is typically dissipated as heat. Thermal constraints arise when the power flow through equipment causes the temperature of the equipment to exceed the equipment's thermal rating. As such, all equipment designed to carry current is provided with a power or current rating. This rating is based on the power losses of the equipment and the amount of heat that the equipment can dissipate in a typical installation.

Typically, transformers will have a name-plate rating that is suitable for most installations and is usually based on the worse case installation. For example, the transformer may be designed to be positioned in direct sunlight with an ambient temperature of 30 degrees.

Cables are provided with a rating based on their installation which will have an impact on the amount of heat the cable is able is dissipate. Typically, cables which are directly installed in the ground have a better thermal performance than cables installed in ducts. Installing a cable directly in the ground will allow the cable to carry more current than the same cable installed in a duct.

Thermal constraints are usually a concern when the network is highly loaded as this is when the equipment is carrying the peak load.

4.2.2 Steady state voltage constraints

There are two considerations for voltage constraints, the first is when the steady state voltage goes above or below the statutory voltage limits and the second is the amount of voltage fluctuations caused by sudden changes in load or generation.

For Low Voltage (LV) networks, the allowed steady state voltage is between +10 % and - 6% of 230 V (216.2 V to 253.0 V). For High Voltage (HV) networks, the standard EN 50160 allows +- 10 % and the UK ESQCR permit +- 6 %. The GB DNOs are required to follow the ESQCR legislation.

Distribution networks are designed to support the peak load and prevent the voltage at the end of the feeder from being less than the statutory minimum. Typically, the voltage at the substation is set higher than nominal to allow headroom for the voltage drop along the feeders. Without any intervention or smart solutions adding distribution generation may require active management of the network voltage to prevent it exceeding the statuary limit.

4.2.3 Voltage fluctuations

Engineering Recommendation (ER) P28 "Planning Limits for Voltage Fluctuations Caused by Industrial, Commercial and Domestic Equipment in the United Kingdom" defines the requirements for voltage fluctuations. Typically, any load switching on or off must not cause the voltage to change by more than 3 % at the point of connection. Table 1 shows the recommended voltage fluctuations as per ER P28.

Table 1: Planning limits for voltage fluctuations

Maximum Number of Occurrences	Limit
More than one per 10 minutes	Less than 3 %
More than one per several months but less than one per 10 minutes	3 %
Less than one per several months	ER P28: DNO discretion

Voltage fluctuations are often noticed by flicking incandescent lighting since the light output is sensitive to the input voltage. LED or high frequency electronic ballast florescent lighting is often more resilient to changes in input voltage as the electronics inside these lighting devices is able to regulate the light output. Voltage fluctuations may also cause heating effects in induction motor loads and could result in premature failure of the motor. Extreme high voltage fluctuations may also cause cable insulation to fail resulting in a short circuit fault.

Rapidly changing large loads, fast acting generation assets or loads with a high in-rush current all have a high rate of change of current and are likely to cause voltage fluctuations on the network. The severity of the voltage fluctuation is a function of the rate of change of current and the impedance of the network. The larger the network impedance or the greater the rate of change of current, the greater the voltage fluctuation. Rural feeders which tend to be longer and therefore have a higher impedance are more susceptible to voltage fluctuations than an urban feeder which is short and has a low impedance.

4.2.4 Resilience constraints

In the event of a cable or transformer fault, networks are usually designed with spare capacity to allow for the load on one feeder to be transferred to other feeders. This spare capacity is installed to allow for networks to meet the requirements of ER P2/6 "Security of Supply" and is facilitated though interconnection to enable load transfers between feeders and transformers. ER P2/7 is in consultation and has the provision for demand side response to provide flexibility and replace the spare capacity required to maintain supplies after an outage.

For any new connection request impacting the HV network, a contingency study is completed to demonstrate compliance with P2/6. The study calculates if there is enough capacity for the load to be transferred to the adjacent feeders. If there is not enough capacity, reinforcement is recommended to install the capacity required to perform the load transfers after a circuit outage.

Contingency studies are only required if the group demand is over 1 MW. Many LV networks are supplied by a maximum transformer size of 1 MW where ER P2/6 does not require a minimum repair time or for any load to be met after an outage. Residential V2G and fleets which connect to LV networks with already available capacity are unlikely to require a contingency study. Any V2G connecting to a HV network will be likely to require a contingency study as the group demand of an HV network is typically greater than 1 MW.

A notable change from ER P2/6 to ER P2/7 is provision of demand side response (DSR) to support the group demand after reconfiguration. This may enable flexible assets, for example V2G, to not require to be supplied after reconfiguration of the network and they would not need to be included in any contingency study. DSR is the control of flexible loads, for example if the network reaches its maximum capacity, DSR enabled loads can be switched off to reduce the total load in the network, or if there is an abundance of generation in the network, DSR enabled loads could be switched on to increase the load in the network. V1G EVs can participate in DSR by using signals to control when they charge and when they stop charging but are not able to participate if their battery is at full capacity or the EV is disconnected from the network. V2G can further enhance DSR by allowing the EVs to export into the network to further reduce the demand in the network.

4.2.5 Fault current constraints

Equipment failures in the distribution network typically result in a short circuit, although circuits can also fail in an open circuit state. A short circuit is where the failure causes the phase conductor to become in contact with the earth or neutral conductor. A short circuit will cause a large current to flow, known as the fault current. Typically, protection systems are designed to detect the fault current and disconnect the relevant circuit from the supply. An example of a short circuit fault is when the insulation in a cable breakdown causing the phase conduction to contact the earth or neutral conductor.

An open circuit fault occurs when a break in the conductor happens without causing any of the conductors to become in contact with each other. Customers downstream of an open circuit will lose supply as they are no longer electrically connected to the substation, but the substation protection will not detect the fault as there is no fault current. The open circuit fault will appear as a loss of load to the substation. An example of an open circuit fault could be that the cable becomes disconnected from the LV bus bar causing a loss in electrical connectivity between the load and supply.

Equipment used on the distribution network is designed to allow a specific amount of fault current to pass for a specific period of time before protection trips to prevent causing damage to the equipment. If the fault current exceeds the manufacturer's rating, it is likely that permanent damage will be caused, and the equipment will need replacing. The DNO is also required by its license to manage the fault current and prevent the fault current from exceed equipment ratings.

Adding distributed generation to the network provides a new source of fault current and, depending on the network location, may cause the fault current to increase or decrease. Fault current may increase in the sections of network that are supplied from both the generator and DNO substation but may decrease in the sections of network that are only supplied form one source. Increasing the fault current may cause the fault current rating to be exceeded, potentially causing damage to the equipment. Whereas decreasing the fault current, especially when through the protection device, may increase the disconnection time or prevent the protection device from detecting the fault.

Different distribution generation technologies will have a different fault current contribution. Synchronous generators provide the highest fault current contribution which could be up to seven times nominal rating. Any large thermal generator is likely to use synchronous generators. Non-synchronous generators, for example DFIG wind generators, provide less fault current and inverter interfaced generation, for example PV, will only provide fault current up to the current rating of the converter.

4.2.6 Harmonics

Loads which draw a proportional current with respect to the supplied alternating voltage are known as linear loads and examples are resistive heaters and incandescent lamps. Loads which draw a current disproportionately to the voltage during each cycle are known as non-linear loads and can increase harmonic distortion. Any loads or generation with a power electronics interface are non-linear and these include battery chargers, electronic ballasts in lighting, variable frequency motor drives and PV generation. V2G chargers are likely to be a non-linear load and could increase the distortion in the distribution network.

Increasing the system harmonics may result in system resonances, reduce the lifetime of equipment or cause protection to mal-operate. Harmonic voltages applied to equipment can result in heating. If the equipment is already operating near the thermal limit, the harmonic voltage could cause the equipment to exceed its thermal rating potentially causing damage.

Therefore, network operators are required to maintain the harmonic voltages to within specified limits. These limits are specified within ER G5 "Planning levels for harmonic voltage distortion and the connection of non-linear equipment to transmission systems and distribution networks in the United Kingdom". ER G98 and ER G99 which are part of the Distribution Code and specify the requirements of generation connecting to the distribution network require inverters to comply with ER G5.

4.2.7 Imbalance power flow constraints

The LV network is designed and operated as a three phase and neutral system. Most residential customers are supplied at LV via a single phase and neutral connection. This connection arrangement creates the possibility for there to be differences in the currents and voltages of each of the three phases. The load on one phase could be at the thermal limit when the other two phases have available capacity. It is also possible for there to be more customers connected to one phase than on the other phases. The exact phase that most customers are connected on is generally not known by the DNO.

4.3 Use of V2G to solve distribution network constraints

V2G provides distribution network operators with a device behaving like a battery that may be charged from the network and discharged into the network. Unlike a static battery which is a fixed installation and is likely to be always available, a V2G asset is mobile and may not be connected when and where support is required. A V2G asset will have a greater energy consumption than other fixed battery installations since the primary use of the V2G asset is for transportation of people or goods. It is also noted that the user of the V2G asset may require that the battery in the V2G asset is charged to a high state of charge if they have a long journey for example. Understanding the state of charge of the V2G device and if the device is likely to be connected to the network is instrumental in understanding if the V2G asset can be used to solve the distribution network constraint.

The controllability of the V2G asset provides the required flexibility to manage distribution network constraints. However, the availability of the V2G asset will determine its suitability for solving a distribution network constraint.

4.3.1 Thermal constraints

Thermal constraints are caused by a large load connected to a transformer or feeder. V2G assets with available charge may provide support by exporting into the network in the correct location.

To support a transformer, the V2G asset or multiple assets must have an electrical connection to the secondary side of the transformer such that when the V2G asset exports into the network, the load on the transformer is reduced. For a distribution transformer (11 kV / 0.4 kV) the V2G asset must be connected to the low voltage network supplied by the transformer. To support a primary transformer (33 kV / 11 kV) or main substation (132 kV / 11 kV), the V2G asset could either be directly connected to the 11 kV network or the 0.4 kV network which is supplied by the primary or main substation.

If the thermal constraint is on the feeder, the V2G asset must be connected to the same feeder and preferably towards the end of the feeder to provide the maximum benefit without extensive measuring of the feeder. This is because the current from the V2G asset needs to travel in the opposite direction to the nominal current to reduce the load on the feeder. Without monitoring every section of the feeder, it may not be possible to determine which sections of cable are above the thermal limit. Connecting at the end of the cable will enable every section of cable to be supported. If the current flow along the cable is known, an optimisation calculation could determine exactly where in the cable the V2G asset should connect in order to minimise the losses in the cable. Connecting the V2G asset to a different feeder will not enable support of the feeder with the thermal constraint.

V2G assets may exacerbate the thermal constraints when charging the battery as this action will increase the load on the network. There could be conflicts between V2G services being offered to the system operator and the distribution network. For example, the system operator may require that V2G assets are charged for frequency response or when there is an excess of renewable generation. If these V2G assets are connected to a thermally constrained distribution network, the constraint may be exacerbated. Another example is if the user of the V2G asset requires that the EV is charged and does not allow for any flexibility in charging.

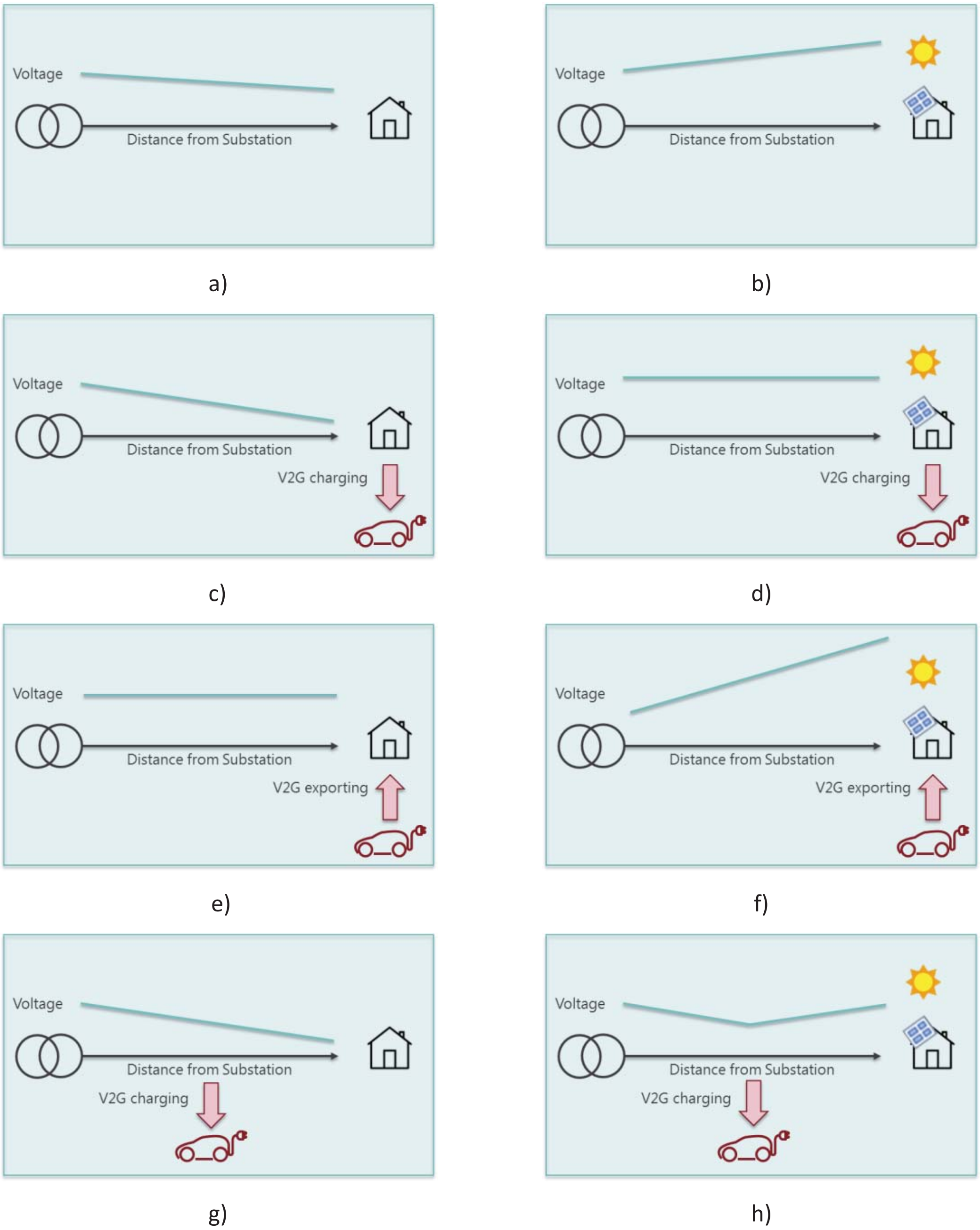
4.3.2 Steady-state voltage constraints

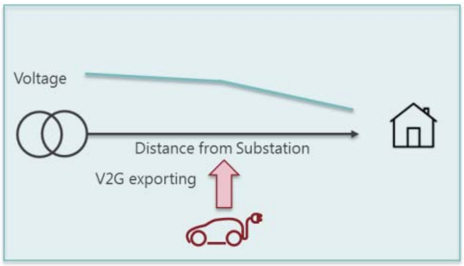
Uncontrolled generation is likely to cause a high voltage constraint as exporting power into the distribution network will cause the voltage to rise. A low voltage constraint is more probable in a highly loaded network as the load connected will cause a voltage drop along those feeders.

Using EVs to provide the opposite action will prevent the voltage from exceeding the limit. If there is excess generation on a feeder, charging any available EVs connected to the same feeder will, depending on the amount of load from the EVs, prevent the voltage from exceed the statutory maximum. Likewise, using V2G to export during peak loading will, depending on the export amount, prevent the voltage from going below the statutory minimum.

To provide maximum benefit when V2G is managing voltage constraints, the V2G asset should be connected towards the end of the feeder, or at the location in the feeder which is exceeding either the maximum voltage or minimum voltage. Maximum voltage typically occurs at the point of generation furthest from the substation and minimum voltage typically occurs at the end of the feeder. Connecting V2G assets near the substation is less likely to have any impact on the local voltage as the impedance of the network is lower and the voltage is less sensitive to changes in power. Connecting V2G at the end of a feeder with an existing high voltage constraint would likely require reinforcement if using a BAU connection procedure. The BAU connection procedure would investigate the impact the V2G asset could have on voltage and likely determine that the V2G asset would cause the voltage to further rise.

V2G assets may exacerbate voltage constraints by charging during the peak load causing a lower voltage and exporting during peak generation causing the voltage to rise further. The impact of V2G on voltage will depend on where the V2G asset is connected on the feeder, as shown in Figure 4 with examples of EVs importing and exporting power at different locations along the low voltage network. The further the V2G asset is connected from the substation, the greater the impact V2G asset will have on voltage. These factors are taken into consideration when the DNO connects V2G assets to the network and typically a worst case is considered, which could drive the requirement for reinforcement. This approach is contradictory to V2G being installed with the purpose of solving any voltage constraints.





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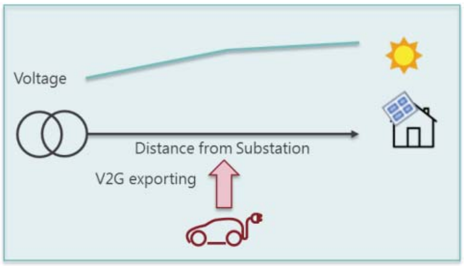

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Figure 4: Different voltage profiles along a feeder and how V2G influences the voltage profile under different conditions, a) feeder with load connected, b) feeder with PV generation, c) feeder with load and V2G charging, d) feeder with PV and V2G charging, e) feeder with load and V2G exporting, f) feeder with PV generation with V2G exporting, g) feeder with load and V2G charging in the middle of the feeder, h) feeder with PV generation and V2G charging in the middle of the feeder, i) feeder with load and V2G exporting in the middle, j) feeder with PV and V2G exporting in the middle.

4.3.3 Voltage fluctuations

Single residential V2G assets connected to the LV network and small fleets or commercial V2G connected to the HV network are unlikely to solve any voltage fluctuation constraints. The V2G assets are likely to only be 7 kW for residential applications and 50 kW for commercial applications. These charge rates are unlikely to have significant impact on the point voltage to which they are connected to solve any issues with large disturbing loads. A single 7 kW V2G asset connected 150 m from the substation on a 300 m feeder with 70 customers each consuming 1.5 kW would be expected to change the voltage by less than 1 %. A small fleet of 500 kW of V2G connected 2.5 km from the substation on a 5 km HV feeder with 10 substations distributed evenly and each consuming 500 kW would be expected to change the voltage by less than 0.25 %.

However, multiple residential V2G assets connected at LV or large fleets connected at HV on the same feeder could provide support for voltage fluctuations. A fast-acting control system would be required to operate locally with the V2G vehicle monitoring the voltage. For either a sudden voltage rise, or voltage fall near the 3 % limit, the V2G assets could operate to reduce the impact of the voltage fluctuation.

An example for an LV feeder is considered. Figure 5 shows the nominal voltage profile along an LV feeder which uses a 185 mm^2 aluminium cable. The feeder has 70 customers connected and assumed to be evenly distributed along the feeder. A disturbing load is connected half-way along the feeder, 150 meters from the substation, and causes a voltage dip as shown in the voltage profile in Figure 6. The disturbing load causes the voltage to change by more than 3% for the customers connected after the disturbing load as shown in Figure 7. This is outside the voltage fluctuation limits. If V2G EVs were connected, they could detect and operate before the voltage fluctuation reaches the 3% limit. Figure 8 shows the voltage profile along the when the V2G EVs are operating to prevent the voltage from exceeding the 3 % limit. Six V2G EVs (assumed to be evenly distributed) along the feeder export at 7 kW and keep the voltage change to less than +-1.5 % as shown in Figure 9.

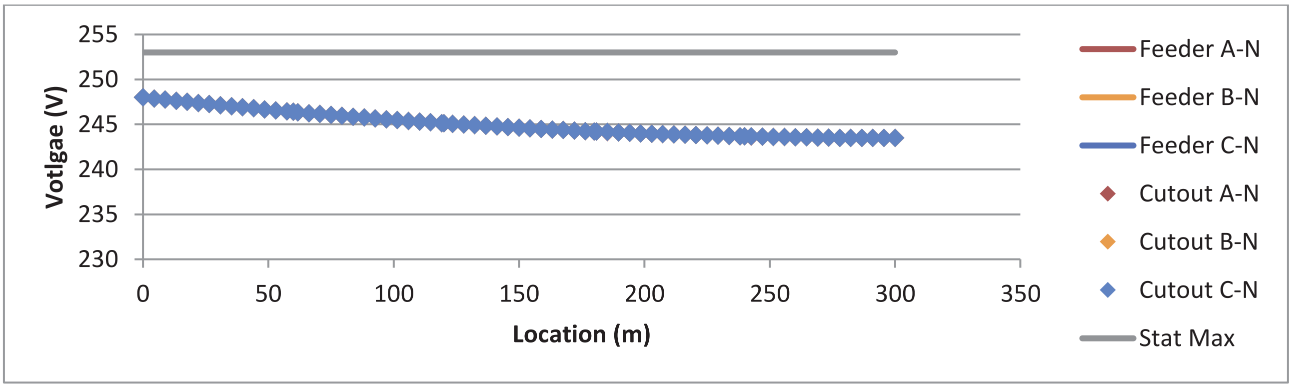

Figure 5: Voltage profile along an LV feeder of size 185 mm² with 70 customers connected each drawing an ADMD of 1.5 kW

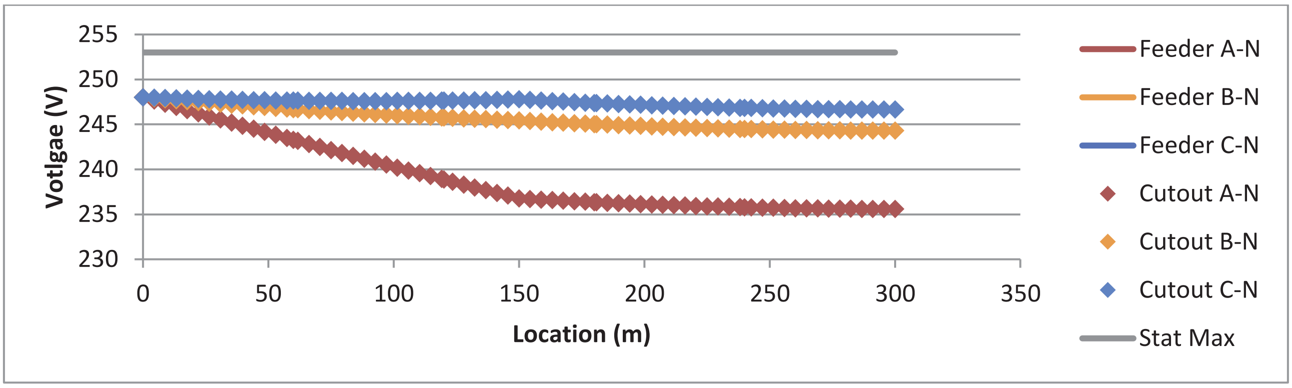

Figure 6: A disturbing load in the middle of the feeder causes a sudden voltage dip on one phase

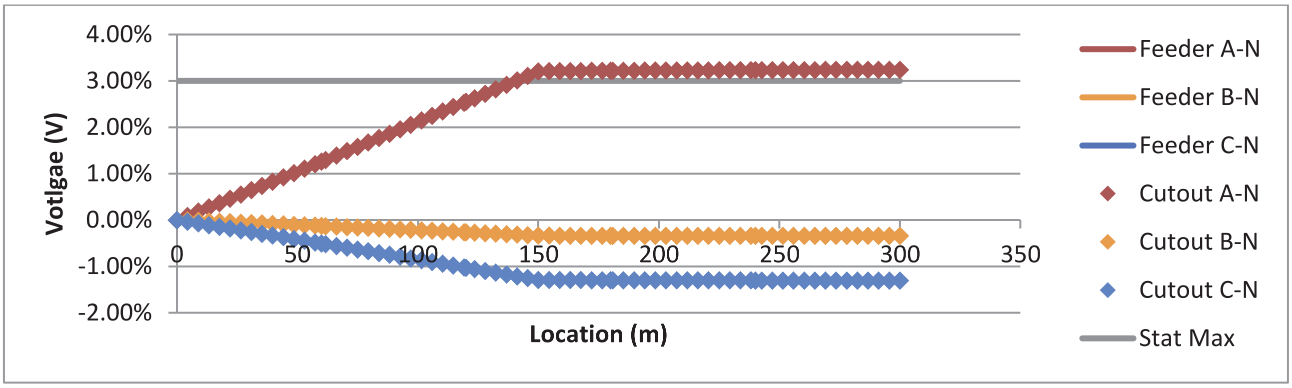

Figure 7: Voltage percentage change between the voltage caused by the disturbing load and the normal voltage profile

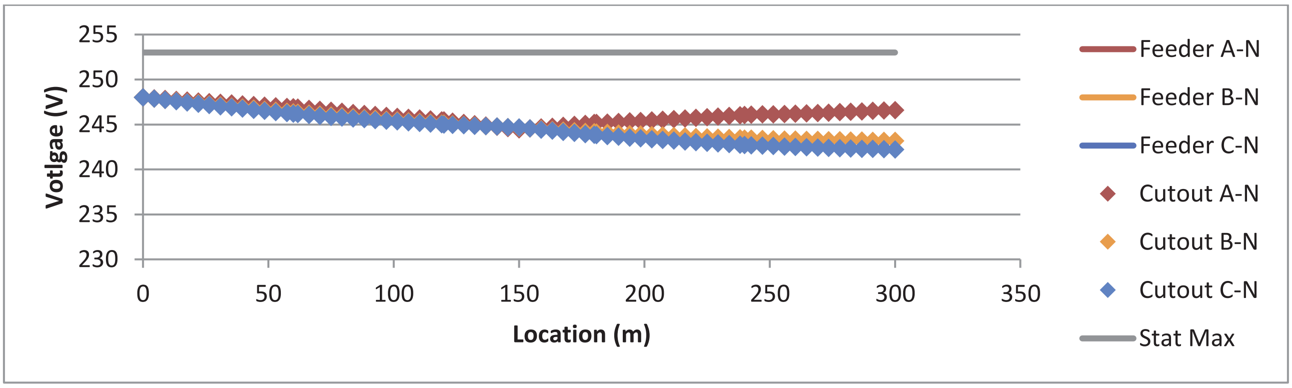

Figure 8: Voltage profile along the feeder after six 7 kW V2G operate to reduce the impact of the voltage fluctuation

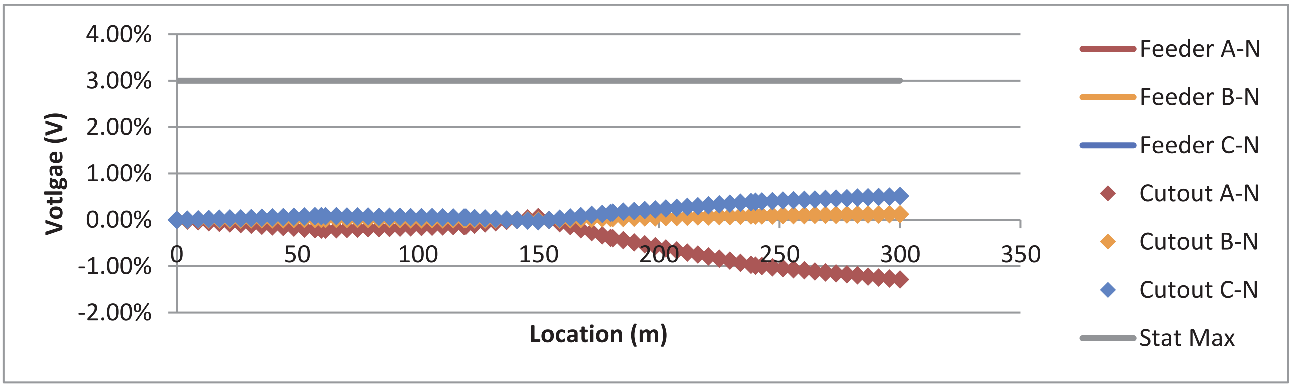

Figure 9: Voltage percentage change between the voltage after the V2G response and the normal voltage profile

4.3.4 Resilience constraints

After a fault has occurred and the protection has operated on the HV network, the HV network is reconfigured to restore supplies. HV networks are designed to continue to supply the demand after loss of a network asset and reconfiguration. If an active network management control system exists to control V1G and V2G assets, the charging of EVs could be managed and constrained to prevent any thermal or voltage violations following reconfiguration of the HV network. Owners of the EVs being constrained would need to be fully aware of the active network management scheme and its implications, for example, if the network is not fully reinstated within a short period of time, the constrained EVs may not be able to fully charge, although one solution would be to drive the EVs to a different changing location.

The EV owner or fleet manager would need to consider the cost and inconvenience of having charging limited for an extended period whilst the HV network is repaired, compared to the cost of reinforcement (where reinforcement would otherwise have been needed to facilitate their connection).

Section 4.3.1 discusses how V2G could be used to solve thermal constraints on the network by the V2G assets which are connected downstream of the thermal constraint, exporting into the network. After a HV fault the network is reconfigured to restore supplies to as many customers are possible. Some customers may not be restored because there is no alternative arrangement, for example, a fault on a rural teed HV connection. Some customers may not be restored because the alternative feeding arrangement reaches a thermal constraint, in this case downstream V2G assets could be used to provide support by exporting into the network.

4.3.5 Fault Current

The addition of EVs charging via power electronic converters do not increase the fault current levels due to the interface of the connection because power electronic converters by design do not have the provision to provide fault current. Harmonics

The impact V2G assets have on network harmonics will depend on the design and control of the power electronics used at the interface between the EV and the network. The V2G unit could be designed to provide harmonic compensation by using the converter as an active filter. If harmonic compensation was designed into the EV charger, the EV charger would need to be placed near to the source of the harmonic disturbance. It is assumed that the EV charger is itself not causing the harmonic disturbance.

4.3.6 Imbalance power flow

Any residential V2G will likely connect behind the residential customer's meter to a single-phase LV supply. This provides per phase control for the individual phases and the ability for different V2G assets to compensate each of the individual phases. If the residential street has many V2G assets connected which are near equally distributed across the different phases or connected to the phase which is constrained, some imbalance in the feeders could potentially be compensated by rebalancing the charging or discharging of the V2G assets where the charging time does not coincide with the non-EV load peak and where there is visibility of the demand on each phase (i.e. assuming full LV measurements at the upstream distribution substation).

Not every customer in a residential network may have a V2G asset or a V2G asset connected when support is required. There may be an associated randomness with which phases have V2G asset connected at any point in time. It is likely that the V2G assets will not be evenly distributed across all three phases. There is a risk that only the V2G assets connected to the same phase would be charging or discharging. This potentially creates large changes in power flow to only one of the three phases and therefore increases the amount of imbalance in the network.

V2G is only able to reduce the imbalance in the network if there is visibility of the phases that the V2G are connected to and the currents in the individual phases. Without measuring each phase of the LV conductor, it will not be possible to determine the imbalance.

Fleets that are connection at HV should design their network to charge equally across all phases. This will prevent any HV imbalance. It is expected that the HV network is balanced and not require rebalancing.

4.4 Distribution network constraints caused by V2G participating in system operator services

V2G assets could participate in System Operator (SO) services which includes the fast frequency response service. Frequency response services can be split into two markets which are dynamic frequency response and non-dynamic frequency response. Aggregators will most probably be required to meet the minimum 1 MW response and continuity of availability required by National Grid.

V2G could support network assets in both markets, with dynamic frequency response responding to second-by-second changes on the transmission system being more likely. Non-dynamic frequency response is triggered by an event and can be split into three categories; primary response, secondary response and high frequency response. Primary response provides response within 10 seconds and can be sustained for 20 seconds. Secondary response provides a response within 30 seconds and can be sustained for a further 30 minutes. High frequency response is provided within 10 seconds and can be sustained indefinitely.

EVs could export power onto the distribution network if there was a frequency drop and could charge in the event of a frequency rise. The effect on the distribution network would be minimal for primary response services due to the required length of operation being low. In contrast, secondary response may lead to increased distribution network constraints if monitoring and controlled charging of the feeder is not provided. The increase in generation on the feeder may lead to voltage change out of limits, or thermal constraints being breached along the feeder. Distribution network constraints which could be caused by EVs are discussed in Section 4.2. It is unlikely that EVs will participate in the high frequency response market due to each vehicle having a finite storage capacity.

V2G assets are controllable devices that can rapidly change from full import to full export and will have a similar response time as a fixed battery. This rapid change from load to generation has a risk of causing a voltage fluctuation on the network.

Fleet vehicles responding simultaneously to a price or network signals could rapidly transition from charging to discharging and cause a greater voltage fluctuation than residential V2G devices. It is unlikely that residential V2G devices will be completely synchronised as the different V2G chargers and EV batteries will have different response times. Fleet vehicles are more likely to be synchronised as they are likely to have identical V2G chargers and EVs will are likely to have very similar response times. Any such synchronisation (if it were to cause a voltage fluctuation on the network) could be managed by staggering the operation of the V2G or by controlling the V2G ramp rate.

Section Summary

- Typical distribution network constraints include: thermal, voltage, resilience, fault current, harmonics and imbalance power flow.
- Thermal constraints on the distribution network could potentially be reduced using V2G services by exporting power onto thermally constrained sections of the network if they are managed to charge and export at times best suited to minimise the daily load peaks. However, if V2G customers are not suitably managed (for example because the end customer opts out or they instead decide to take part in frequency response or other schemes), the V2G impact may worsen the situation and further constrain the network.
- Under voltage constraints on the distribution network could be improved by exporting power onto the network from EVs, with over voltage constraints improved by using the excess power on the distribution network to charge the battery in the EV.
- Resilience of the distribution network could be improved by controlling the charging of EVs (V1G) to reduce the EV charging impact on thermal overloading and voltage constraints. Further benefits could be obtained if the V2G customers participate in a scheme to generate after a fault. However, the success of this service will depend on the customers willingness to compromise on the level of EV charge and therefore the EV range, if the vehicle is required before the network fault is repaired.
- It is not expected that V2G services can support low fault current, but the addition of more EVs on the network is unlikely to make the situation worse due to the use of power electronic converters.
- Power electronic chargers are non-linear loads and the converter should be designed in accordance with ER G5. The V2G converter could be designed to compensate for existing system harmonics.
- Imbalanced power flows on different phases could be compensated for by exporting or charging on respective feeders to balance demand so long as there is sufficient visibility and control to manage the power flows in the different phases.
- EVs could participate in SO services however, the SO requirements may drive the opposite action to the minimisation of thermal intact constraints and resilience constraints. Hence network constraints should be monitored and maintained.

5 Site Selection Criteria

5.1 Prior art in connecting V2G

A selection of literature exists in research to explain the concept of V2G and identify the benefits for both the DNO and the SO. However, no literature considering how to connect V2G to the DNO network has been identified. A report by Idaho National Laboratory called Vehicle-to-Grid Power Flow Regulations and Building Codes Review by the AVTA[27] published in 2012 did not identify any V2G policies in 12 US regions reviewed by the report. An article by TNEI published by the IET identified that one of the challenges for V2G is that the "regulation and energy markets prohibit EVs participation in the provision of balancing services"[28].

In the simplest of terms, V2G may behave as a load and behave as a source of generation on the network. The conservative solution for connecting V2G is to follow the DNO connection procedures for connecting a load to the network and to follow procedures for connecting a generation source to the network. These two assessments would be required for the same point of connection. They would determine if the network at any time of day could support the load and if the network could support the generation at any time of day presented by the V2G asset. Any such connection would allow the operator of the V2G to charge at any time during the day or discharge at any time. If no network capacity existed to support the load and generation from the V2G asset, reinforcement would be required which could be costly and time consuming. A more probabilistic approach which assesses groups of V2G allowing for the likelihood of different charging, discharging and idle states is recommended.

5.2 Strategy for connecting V2G in UK Power Networks license areas

5.2.1 InnovateUK project strategy

The InnovateUK V2G projects being supported by the TransPower project will follow the standard BAU connection assessments for additional load and generation. The load study will follow the developed BAU procedures for connecting EV charging units and is recommended to first assess if the existing supply would likely be exceeded before suggesting any reinforcement. The generation study will follow the procedures for connecting under ER G99. Where the BAU assessment determines that reinforcement is required. The InnovateUK project or site owner must decide if they are willing to fund the reinforcement or if the trial should be undertaken at a different site.

The strategy for connecting the InnovateUK projects is to avoid reinforcement and identify sites with available capacity for both accepting any increase in load and the export of generation. Ensuring the network has capacity to charge and discharge the EVs through the V2G charger will ensure the trials are able to operate unimpeded. This will enable the connections teams to develop confidence and understand the opportunities V2G could provide to the distribution network.

For the trials, theoretically lower limits can be imposed on transformers and feeders below their thermal and voltage limits. This will enable the V2G services to be tested to determine if they are able to provide the desired benefits to the network. If the trials are not successful, the network will not be placed at risk as the transformers and feeders will be able to manage the maximum load and generation from the V2G assets.

5.2.2 Future connection strategy

The primary use case of the V2G asset is to be charged, appearing as a load on the network, and used for the transportation of people, goods or services. For accessing the impact on the network of V2G as a load, it is recommended that the profile of charging is understood. For example, will charging happen during the day which is likely for work-place EV charging, will charging happen during the evening which is likely for residential EV charging or will charging happen during the night which is likely for the charging of electric buses. If reinforcement is required in the network, a customer could be offered an anytime connection with the relevant network reinforcement costs. Or the customer could be offered

[27] https://www.energy.gov/sites/prod/files/2014/02/f8/v2g_power_flow_rpt.pdf, accessed March 2019.
[28] https://communities.theiet.org/groups/blogpost/view/55/223/5336, accessed March 2019.

a dynamic timed connection or TOU connection at a lower connection cost but with restrictions on when the V2G asset can charge.

A V2G asset would only likely export back into the network if there was a benefit to the owner of the V2G asset for exporting. This will only happen when the V2G assets is connected to the charger and either when there is a price signal from the market, flexibility procurement or in response to the measured frequency or the measured voltage at the point of connection of the V2G. When assessing the generation connection of the V2G asset, the market which the V2G asset would likely participate in and when the V2G asset is likely to be connected should be taken into consideration. There is also the possibility that a timed V2G export offer is made for when the network is able to export into the network. For example, if a residential feeder has a lot of existing solar PV generation and is not able to accommodate export from V2G at the same time as the solar PV generation, it may be able to accommodate export from V2G after the solar PV generation has reduced. Any V2G connection offer should include the times of the day when it is able to export and participate in V2G service markets. This could be different from the times of the day when V2G is able to import from the network.

Monitoring the demand at the secondary substations enables the DNO to understand the loadings and imbalance in the LV networks and can be used to identify which substations need support and when the support is required. Smart meter data or measurement sensors in the link-boxes could be used to measure the voltage along the feeder to identify which feeders required voltage support. Thermal support, voltage support and imbalance services for V2G could be offered as DSO products. The V2G asset owner, supplier or aggregator could, through an applications process, apply or bid to offer any of the required services. The V2G asset would be incentivised to import or export when the network required support, as requested by the DSO, a third party or the market provided a price signal. These services would be locational specific and the DNO, through the connections procedure, would need to identify which V2G assets were connected to the feeder or transformer which required support.

For a revised BAU process, it is likely that DNOs will need to understand the market that the V2G is likely to participate in as this will have an impact on the behaviour of the V2G asset. A new V2G connection could be offered the choice of three connection products:

1. A firm import and/or export connection with associated reinforcement costs or exposure to price signals reflecting the cost of network expansion.
2. A non-firm timed import and/or export connection. The offered times for import and export may be different from each other. The customer could also agree to have these times extended for a connection costs which is less than the reinforcement costs for the anytime connection. Also, the market that the V2G assets is wishing to participate in could also determine the time periods when the V2G is required to import and export.
3. A non-firm connection. When the network is reconfigured after an outage, the customer would be willing to either reduce charging, disconnect their V2G asset or export into the network to enable the network to meet its security of supply requirements as defined in P2/6 (soon to be P2/7). P2/7 has the provision to use DSR to meet security of supply requirements.

5.2.3 Matching future network constraints caused by demand and generation growth to V2G assets

Matching V2G assets to distribution network constraints caused by other demand and generation growth requires knowledge of:

1. The time in the 24 hour period (morning, mid-day, evening or night), magnitude and cause of the distribution network constraint
2. The availability for when V2G assets are likely to be connected to the network
3. A model of the behaviour of the V2G assets

It is unlikely that demand and generation growth caused by V2G assets can be solved by other V2G assets. However, a possible viable use case could be that a V2G asset charges from behind the meter generation and later sell this energy back to the network to solve a thermal or voltage constraint caused by other EVs charging.

Installing network monitoring before the connection of V1G and V2G will provide a baseline and allow the Planners to identify future distribution network constraints from the growth of generation and demand. For a network constraint, it is important to understand the 24 hour profile of the network. If the network has a residential load profile, peak load is likely to occur during the evening. For a commercial load profile, peak load is likely to occur during the middle of the day. If the constraint is caused by EV charging, controlling the EV charging (V1G) may be a more cost-effective solution than using EVs to export (V2G). If the constraint is caused by the addition of heat pumps or the growth of other loads, using V2G to provide extra capacity could be a suitable solution.

The time when V2G assets are likely to be connected to the network can be modelled by understanding the use of the V2G EVs and for residential V2G, the demographics of the population. For example, residential V2G EVs are likely to be connected to residential networks during the evening and night. They may also be connected during the day if the population is largely at home, predominately works evening or nights, or uses public transport to travel to work. Fleet delivery vehicles are likely to be back at their base during the evenings and night as the vehicles are dispatched during the day. The same use profile will also apply to electric buses and RCVs. Information on the usage of EVs will be an output of the InnovateUK trials.

A model of the behaviour of the V2G assets will determine the state of charge in the batteries when the vehicles return to their charge points. The V2G assets may require charging before their next use or their charging may be shifted to when the network has capacity for extra demand. This information will again be an output of the InnovateUK trials.

Table 2 matches distribution network constraints to V2G assets and describes the required action to solve the constraint. The V2G to network constraint matching does not consider the market implications and whether the services that could be offered by the V2G assets have a value in the market. The market value is considered in the TransPower report “CBA to assess the benefits of Smart Charging and V2G”, Baringa, TransPower workstream 2.

It is assumed that the V2G support can be obtained through the market place with the assistance of an ANM solution. For any of the services to be offered as a DSO product there needs to be both value to the customer in proving the V2G service and value to the DSO in managing their network.

Table 2: Matching network constraints to V2G assets

Network Type	Network Constraint	Likely time of Constraint	V2G Asset	V2G Action
Residential LV Network	High voltage Constraint	Mid-day	Residential V2G	Charge
Residential LV network	Thermal constraint or low voltage constraint	Evening	Residential V2G and fleets connected at LV	Discharge into the network
Residential LV Networks	Imbalance voltage caused by generation	Mid-day	Residential V2G	Charge depending on the phased connected.
Residential LV Networks	Imbalance voltage caused by load	Evening	Residential V2G and fleets connected at LV via single phase chargers	Charge or discharge into the network depending on the phased connected.
Commercial LV networks	Thermal constraint / low voltage constraint	Mid-day	Residential V2G connected at the workplace	Discharge into the network
HV networks with a mid-day peak	Thermal constraint / low voltage constraint	Mid-day	Residential V2G connected at the workplace	Discharge into the network

HV networks with an evening-peak	Thermal constraint / low voltage constraint	Evening	Residential, fleets and large V2G connected in the evening	Discharge into the network
HV networks with a direct connection of PV	High voltage constraint	Mid-day	Residential V2G	Charge
HV networks with a direct connection of wind generation	High voltage constraint	Night	Residential, fleets and large V2G connected in the evening	Charge
HV network security of supply constraint (P2/6)	Thermal constraint	Anytime	Any connected V2G	Limit charging or export into the network

5.3 Site selection criteria for TransPower

5.3.1 Residential V2G assets

Residential V2G assets connect behind the meter to a single-phase residential supply. A typical residential supply has a supply agreement between 30 A (7.2 kW) and 100 A (24 kW). However, it is unlikely that residential customers will draw at their rated supply continuously and any large load in the home, for example an electric hob or shower, is unlikely to be switched on for a long duration. There is a low probability that all the properties connected to the same feeder in a residential area connected will simultaneously draw a large current. This large diversity enables many residential customers to be connected to the same feeder without causing a thermal or voltage constraints. For an LV feeder supporting 50 properties, the average maximum demand per property may only be between 1.5 kW and 2 kW.

The maximum size of a residential V2G charger is likely to be 7 kW of import and export. The DNO is required to provide a residential service connection for up to 100 A of load. Protection at the consumer distribution board will prevent the V2G charger from exceeding the supply agreement of between 60 A and 100 A. Unless the customer requests to install more V2G charger or a larger V2G charger, the connections team should not need to access the impact of the V2G load on the network. However, the connections team will check service cable records for suitability for a V2G connection. A site visit may be required if the service records are missing and a service cable upgrade recommended if necessary. If the service cable is suitable for carrying 100 A but only a 60 A fuse has been installed in the service cut-out, the DNO may need to increase this fuse to 100 A to ensure there are no nuisance fuse operations when the V2G charger is drawing 7 kW from the network.

From the perspective of the network, only the impact of the generation needs to be considered. A 7 kW V2G charger may also be combined with an existing 3.6 kW of installed rooftop PV already connected under ER G83 or ER G98. For the connection engineer there is a risk that any PV generation could be exporting in parallel with the 7 kW V2G asset. ER G99 is the generation connection standards which must be followed for the connection of V2G. If there is existing generation connected under ER G83 consideration of the interface protection arrangements to cover both the solar PV and V2G will be required.

The distribution network was not designed to connect a high degree of unmanaged generation. Connecting a large amount of generation may cause the voltage to exceed the statutory maximum limit. Under ER G99 for LV connections, generation will not disconnect until the voltage is 14% above nominal for 1 second or 19% for 0.5 seconds. Both voltages are outside the statuary limits. Connecting a V2G charger to a feeder with a lot of existing generation may require network reinforcement or management of the generation.

The site selection criteria for the TransPower project includes identifying suitable networks where V2G could be connected without requiring network reinforcement. Figure 10 shows the connection process for residential V2G for the

Network guidance for V2G connections (TransPower)

PowerLoop InnovateUK project. Urban networks tend to have shorter feeders minimising any issues with regard to voltage drop or voltage rise and thus avoiding reinforcement. Selecting feeders without distributed generation further reduces the risk of there being any voltage issues during the trials. Rural networks may have long feeders that typically are lightly loaded and with smaller circuit ratings. Adding V2G assets in rural networks is more likely to require reinforcement. It is recommended that residential networks without overly high penetration of PV, preferably located in urban areas are selected for the TransPower trials.

Ideally the residential V2G projects would aim to create a cluster of V2G to understand their impact and how opportunities stack for solving distribution network constraints when the multiple V2G assets are connected on the same feeder. Also connecting V2G in networks with a high penetration of PV could explore the interactions between V2G and PV and identify the services which V2G could provide by charging when there is PV available and exporting during the evening peak.

However, using the BAU connection procedure, connecting multiple V2G assets on the same feeder, especially if there is existing PV connected, could result in a requirement for reinforcement as there is a risk that the multiple assets could export when there is already a lot of generation on the feeder from solar PV. To mitigate for this in the residential V2G trials being conducted as part of the Innovate UK projects by the TransPower project portfolio partners, there should only be one V2G connection per feeder unless monitoring is installed to check the feeder or transformer is not exceeding any voltage or thermal limits. A cluster on the same transformer is suitable and would create more options for thermal support as more V2G assets allows for a greater export. For example, a transformer with five feeders could connect five V2G assets (one per feeder) allowing for a likely export of 35 kW (7 kW per EV). A cluster could be created by creating a "virtual feeder" for the trial where several V2G customers are linked together as if they are on the same feeder. This would test if the service provider/network dispatch can manage them within predefined limits.

Once the technology is understood through the trials and shown to manage the export of the V2G assets, it would be expected that as BAU more devices can be connected per feeder.

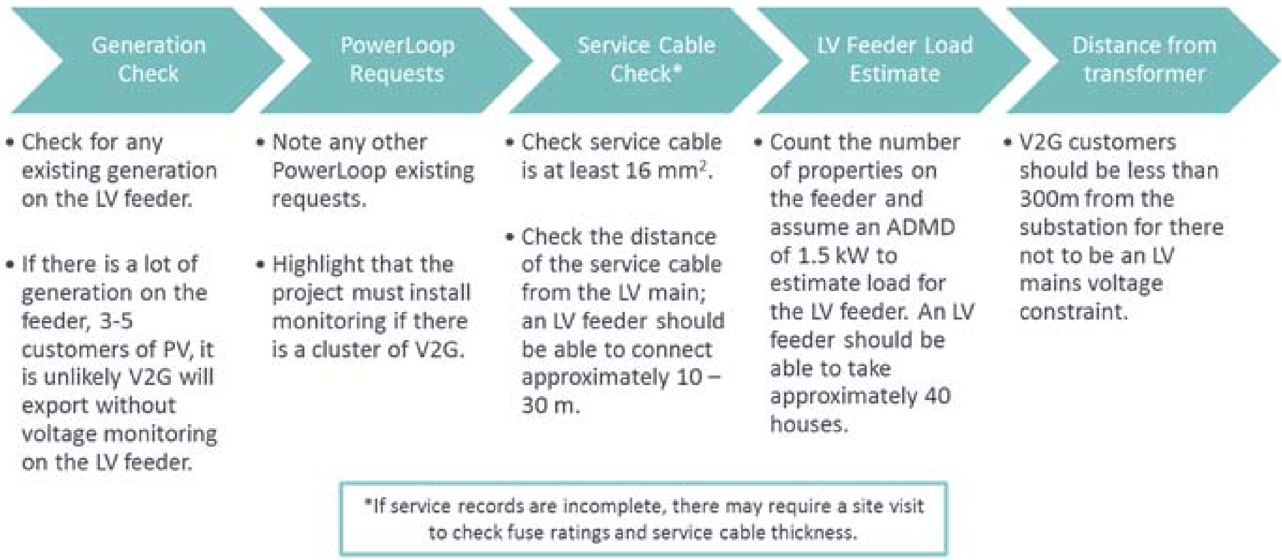

Figure 10: Residential V2G site selection criteria process for PowerLoop project

5.3.2 Fleet V2G assets

Fleet connections are likely to consist of multiple V2G on the same site connecting to the same point of connection. Depending on the total charging demand they may be either connected to the HV or LV networks. A V2G fleet demand greater than 250 kVA is likely to be connected directly to the HV network via an HV / LV transformer. Fleet vehicles are likely to charge at rates between 7 kW and 50 kW.

The existing site demand and existing generation need to be assessed before understanding the connection requirements. For example, a site has a connection agreement for 1 MVA of import and 0 MVA of export and required a 200 kVA V2G connection. If the sites maximum demand is only 600 kVA and export is 0 kVA only the generation request of 200 kW needs to be investigated as the 200 kW of load is accommodated within the 1 MVA connection agreement.

Network guidance for V2G connections (TransPower)

If the installed demand on site exceeds the connection agreement, one solution to manage the demand may be to allow a relay to open the site circuit breaker if the load at the PoC exceed the connection agreement. However, this may cause nuisance trips for the EV charging or for the other loads connected on the site supply and be detrimental to the broad measure of customer stratification for instance customer interruptions (CIs) and customer lost minutes (CLM) and is therefore not recommended. Alternatively, an inter-trip system could be used to remove the charging demand before tripping the remaining site demand. However, this will likely increase the cost of the electrical infrastructure on the site as a separate controllable switch or circuit breaker would be required to isolate the EV loads from the other building loads. Therefore, the smartest solution would be to use an energy management system (EMS) or building management system (BMS) to actively manage the site demand. The EV charging would be controlled to prevent the site supply from being exceeded. A relay set to the agreed export limit would be installed to provide the DNO with confidence, that if the EMS or BMS failed to manage the load, a relay would operate the site circuit breaker to prevent the site demand from exceeding the agreed capacity.

Installing more generation capacity on site than the agreed export limit requires the installation of an export limit scheme (ELS) as per the guidance in ER G100 "Technical Guidance for Customer Export Limiting Schemes". An ELS would measure the active power at the point of connection and use this information to restrict the V2G export in order to prevent the export to the network from exceeding the agreed export capacity. An ELS exceeding 3.68 kW per phase must be fail-safe and must ensure that the agreed export limit is not exceeded if any single component, including communication links between discrete units, fail or lose their power supply. A relay to operate a circuit breaker at the point of supply may be required to provide a back-up to the ELS.

If reinforcement is required to connect the V2G charger for either import or export. The cost of reinforcement should be compared to the cost of actively managing the load or generation over time. Actively managing the load or generation may limit the availably for charging the EVs or limit the revenue that could be generated from participating in either DNO or SO V2G services. The impact of actively managing the charging will depend on the site usage of the fleet and is expected to be site specific.

If the existing connection agreements do not require alteration, the DNO may require that monitoring at the PoC is installed. The exact monitoring arrangement will depend on how the site is connected to the network, but monitoring could be placed at the meter location or at the RMU.

After the customer reviews the site demand and the likely time when the EVs will require charging and submits the expected profile to the DSO, the DSO may decide it is more suitable to offer a timed connection or a time of use tariff. If the charging is likely to occur when the network loading is low reinforcement may not be required and for HV connections the network may have enough capacity for contingency as per ER P2/6. However, if the profile changes, the customer would need to renegotiate the connection agreement with the DNO.

After the customer reviews the site generation and the likely time when the EVs will be connected and able to provide V2G services, the export limit can be agreed between the customer and the DNO. The DNO should undertake the generation and voltage assessment for the time when the V2G will be connected and possibly exporting.

The recommended connection procedure for fleet vehicles is:

1. The fleet manager to assess the impact of the V2G on the site demand and generation. This analysis will be based on when the EVs will be connected to the V2G charger.
2. The fleet manager to decide if the site export agreement or site import agreement requires increasing. If the fleet manager decides that the existing connection agreement is suitable, the relevant relay should be installed to prevent the site from exceeding the export or import agreements. It is recommended that this control is incorporated into any existing Energy Management System (EMS) or Building Management System (BMS) to prevent nuisance tripping.
3. If the existing connection agreement does not need changing, the fleet manager should inform the DNO of the intention to install new V2G assets, comply with ER G99 and provide information of any relay operating a circuit breaker or control to prevent the V2G assets from exceeding the connection agreement. The DNO may witness any control system to satisfy themselves that the network is not placed at any risk and the existing connection agreements will be adhered to.
4. If the connection agreement requires an alteration to accommodate the V2G assets, then an application should be submitted to the DNO. The application should provide information the sites loads or maximum

generation on a half hour basis. This will allow the DNO to undertake a timed connection if this is more suitable.

5. The DNO should, using the half hourly data and possibly for each half hour period, undertake the following assessments to understand if network reinforcement is required.
    a. A load impact assessment.
    b. A contingency analysis if the site is connection to HV or if the LV network requires reinforcement to accommodate the addition load.
    c. A voltage impact assessment for the generation.
    d. A harmonics impact assessment undertaken by the customer with the DNO receiving the results of the study.
6. If the DSO offers a managed connection, the fleet manager may need to decide the proportion of vehicle loads that need to be maintained as a minimum and the times this minimum needs to occur. For example, the fleet manager may request a full charge between 7am and 8am and as a minimum a half charge or a quarter charge between 4pm and 8pm.

5.3.3 Large V2G assets

Large V2G assets are likely to include buses, last mile delivery trucks for carrying more than 3.5 tonnes or Refuse Collection Vehicles (RCVs). They are likely to have a battery greater than 300 kWh and be charged at minimum rate of 50 kW. Charging from 20% capacity to 80% capacity would take 3.6 hours at a continuous rate of 50 kW and provided a total energy of 180 kWh (60% of the battery capacity). These devices have a significant demand and could have a significant impact on the network.

Fleet sizes of large V2G assets are likely to contain many vehicles and require a connection greater than 1 MW. A 1 MW connection can charge a maximum of 20 V2G assets at 50 kW each. It may be advisable to leave a 20 % headroom on the connection to prevent any inrush current from causing a trip. Therefore, a connection of 1.2 MW would need to be applied for. Unlike for fleet V2G connections, where the demand from V2G is a smaller contribution of the total site demand, large V2G assets charging demand is likely to form most of, if not all the total demand at the point of connection.

Commercial vehicles that are on the road during the day and charged during the evening could be connected via a timed connection. The vehicles are unlikely to be at the depot during the day and therefore capacity does not need to be created for charging during the day. This capacity could be used by other customers in the network. Or the connection could utilise the capacity during the times of the day when it is not being used by other customers. If the depot is connected to a primary transformer supporting a majority of commercial loads, it is likely that the peak load will occur during the day when the vehicles are in operation. Capacity in the evening and during the night could be used to charge the V2G assets without requiring network reinforcement. If the commercial V2G assets are connected to a network with a residential profile, the charging of the assets should be delayed until after the residential peak. The V2G assets could be used to export into the network to support any constraints during the evening peak.

Connecting 1 MW of load to the network is likely to be at 11 kV. When connecting to the HV network a calculation is undertaken to ensure the HV feeder has the available capacity to support the charging at the required charging times. There is a requirement for there to be available capacity in the adjacent feeders to support the new and existing load if there were to be an outage on the HV circuit. ER P2/6 requires that for a feeder group over 12 MW, the group demand minus 1 MW is supported and restored within 3 hours.

A voltage impact assessment is required which includes calculating the impact of a step change from 100% import to 100% export. The voltage must not change by more than 3% as per ER P28.

It should be checked that exporting at the site will not prevent the protection at the primary substation from operating in the event of a HV fault at the end of the HV feeder. In some situations, export in the network may mask the fault and reduce the fault current observed by the protection at the Primary transformer.

Network guidance for V2G connections (TransPower)

The recommended approach for large V2G assets is:

1. The large V2G asset owner follows ER G99 and submits their maximum demand requirements, the times of day when the V2G assets are likely to be importing and exporting into the network and the maximum export and / or import for each time slot. The large V2G asset owner should also indicate if they are willing to either export into the network or not charge their assets to support the network at times when the network is recovering from an outage. This last option would only be available if there was an ANM scheme supporting the network to send price or other signals to the V2G asset.
2. The DNO uses this information to undertake a load impact assessment for an any-time connection or for a timed connection.
3. The DNO performs a contingency study for either a firm connection or a non-firm connection. The non-firm connection assumes that large V2G assets can either export into the network to provide extra capacity or reduce or stop their charging to free capacity for other customers who are on a firm connection.
4. The DNO undertakes a voltage impact assessment for the times when the V2G is likely to be exporting into the network. These time slots will be provided in the connection requests from the customer to the DNO. These times will be dependent on the markets which the large V2G is participating in.
5. The DNO undertakes a fault study to check that the protection at the primary will operate correctly if there was a fault at the end of the feeder when the V2G asset was exporting.
6. The large V2G asset owner undertakes a harmonic impact assessment in accordance with G5.

Section Summary

- V2G is a controllable load or generator which may charge using signals from the market and may export when instructed by the market.
- If using V2G to solve network constraints at the same voltage level, it is likely that the existing connections process will require the network constraint is solved through reinforcement before allowing the V2G to connection. Reinforcement will likely remove the network constraint that V2G was intended to solve.
- If the connections process in a constrained network allows for a timed generation and load connection at different times of the day, V2G assets could be used to solve network constraints.
- If the network constraint is caused by EV charging, managed charging may be a better solution than using V2G services.
- The usage profile of the V2G assets should be considered when connecting the V2G asset to the network and when determining the suitability of using the V2G asset to solve a network constraint. A probabilistic approach which assesses groups of V2G allowing for the likelihood of different charging, discharging and idle states is recommended.
- To solve thermal constraints, V2G assets should be connected downstream of the asset with the thermal constraint.
- To solve voltage and imbalance constraints V2G assets should be connected to the feeder experiencing the constraint.
- Low voltage and thermal constraints could be solved by using V2G to export into the network
- High voltage constraints could be solved by using V2G to import from the network.
- V2G assets connected at single phase LV could be used to solve unbalanced constraints.

6 Conclusions

V2G provides the DNO with the opportunity of discharging the battery of the EV into the network to provide network services. The primary aim of the V2G asset is to carry passengers or goods and it is likely that the operator of the V2G asset will wish to prioritise this function. The V2G asset will only be available to export when it is not undertaking its primary function and if the export from the battery does not impact the primary function.

When following BAU connections procedures, V2G assets are required to follow the connection procedure for load and generation. At present these procedures are deterministic and perform a network study based on the worst case network conditions (peak demand for assessing new demand connections and peak generation for assessing new generation connections). The V2G asset may be offered a firm connection, where it is able to import or export at the agreed capacity at any time in the network, or it may be offered a timed connection where the V2G asset is able to only operate at the agreed capacity for fixed durations during the 24-hour period.

Unlike a static battery which is always connected to the same point of connection and has a high availability, V2G assets may behave randomly or only be available at certain period of the day. The availability of the V2G asset to solve a distribution network constraint will likely be site specific and requires a probabilistic style study of the type and time of the constraint and the usage profile of the V2G asset.

It is expected that V2G assets behaviour will depend on many variables including the usage patterns of the EV, the signals from the market, ANM scheme or building management system. It is likely that the V2G asset will not require network capacity at all times of the day. The TransPower partner portfolio V2G projects aim to conduct trials to understand the different behaviours of V2G assets for residential vehicles, fleets of EVs and large commercial EV. The results from these trials will enable the TransPower project to understand the probabilistic behaviour of V2G assets.

V2G assets have the ability to help alleviate some of the distribution network constraints by exporting into the network during periods of peak demand, low voltage, or if the capacity of the network is reduced through an outage and if the V2G assets are available for export at the time of the outage. The effectiveness to the distribution network of the V2G provision will depend on the location of the constraint and the location of the V2G.

Network constraints could be exacerbated if the V2G assets were to charge at the wrong time during the period of constraint. High voltage constraints or excess DG generation in the network could potentially be managed by the V2G assets charging. These constraints could also be exacerbated if a system wide service required the V2G assets to export whilst a local network constraint required the V2G asset to charge. There could also be a conflict with the V2G user requirements in terms of the time they plan to use their EV and the time they require their EV to be fully charged and ready for use.

There is a conflict between using V2G assets to solve distribution network constraints and the existing BAU connections procedures. If the V2G asset is connecting to solve a distribution network constraint, the existing BAU connections procedure may require network reinforcement. Reinforcing the network will therefore solve the distribution network constraint that the V2G asset was being deployed to solve.

For V2G assets to assist local distribution network constraints, they will need to be allowed to be connected to constrained networks without the prerequisite of reinforcement and the provision of system wide services will need to be managed. Therefore, it is recommended that BAU connection procedures consider the service provisions that the V2G asset may be offering when assessing their impact on the network.

Continuing with a deterministic planning approach will require a significant effort on behalf of the DNO Planners. For example, assessing the suitability of V2G for assisting with network constraints, requires information about a number of variable factors, such as the time when the V2G will be connected, the initial state of charge and the state of charge required by the EV asset owner to use the EV for its primary function.

The DNO also requires a minimum level of service and confidence that either single V2G or distributed V2G resources are able to provide the required services. For the DNO to maximum the opportunities V2G assets could provide, it is suggested that the network can no longer be planned entirely in a deterministic way. It is suggested probabilistic techniques could be used to understand how much V2G is required to provide the minimum level of service required by the DNO. The inputs to these probabilistic models and how the market influences the behaviour of V2G is expected to be an outcome of the TransPower trials.