December 2023

Enabling two-way communication: Principles for bidirectional charging of electric vehicles

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Introduction

Electric vehicles (EVs), from passenger cars to large heavy-duty trucks and buses, have a primary purpose, which is transport and mobility. With electrification, new uses for these vehicles are emerging. These batteries-on-wheels can play an important role in making better use of renewable energy generation and the electricity grid, thus contributing to lower prices for vehicle operators — through smart charging savings[1] — and reducing overall costs for energy system users.

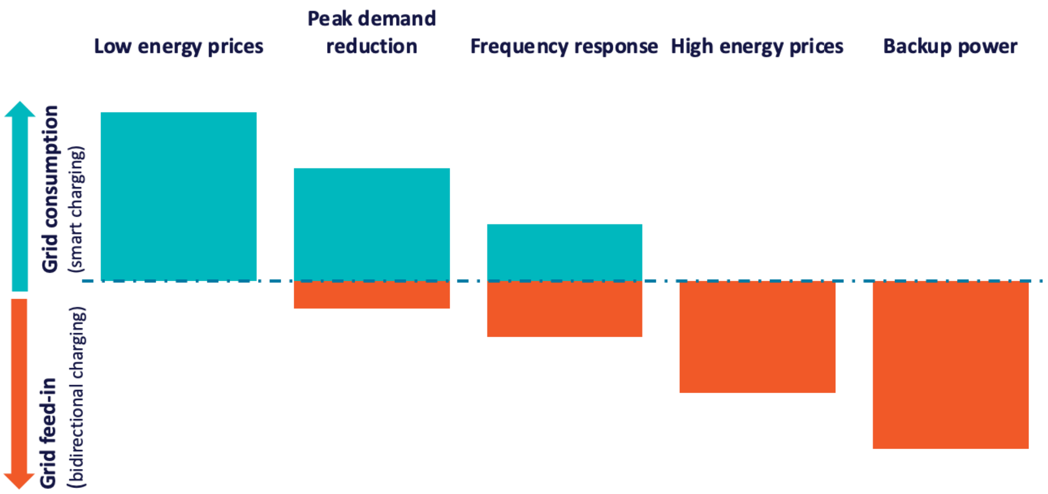
When these EV batteries are charged matters: if charged at times of high renewables production and low electricity demand, the charging contributes to a more efficient energy system. Conversely, by not matching charging to available supply or capacity, it creates additional demand for expensive peak capacity expansion.

By smart charging, or using the best moments to load electricity into the battery, vehicle users turn a necessity (charging energy for propulsion) into an advantage. Compared to uncontrolled charging, smart charging reduces costs for consumers and can make it easier for the energy system to integrate more renewable generation and supply additional electric consumers, such as even more electric vehicles.

[1] More on smart charging benefits in Burger, J., Hildermeier, J., Jahn, A. & Rosenow, J. (2022) *The time is now: smart charging of electric vehicles*. Regulatory Assistance Project (RAP). https://www.raponline.org/knowledge-center/time-is-now-smart-charging-electric-vehicles/ and Hildermeier, J., Kolokathis, C., Rosenow, J., Hogan, M., Wiese, C. & Jahn, A. (2019) *Start with smart: Promising practices for integrating electric vehicles into the grid*. RAP. https://www.raponline.org/knowledge-center/start-with-smart-promising-practices-integrating-electric-vehicles-grid/

Bidirectional charging technology takes all the use cases and benefits of smart charging, as shown in Figure 1, and goes one step further. It allows electricity to flow both into and out from a battery, enabling electric vehicles to act as power sources to a building or to the grid (hence the name vehicle-to-grid, or V2G).[2] Making better use of these existing batteries creates a new role for electric vehicles, contributes to resource efficiency and avoids the need for additional energy system investments. Conservative estimates indicate that with the growth of EV batteries and the deployment of V2G technology, short-term storage needs in the EU power system can be met.[3] For bidirectional charging to be useful and valuable for EV users and the energy system, however, it is important to have a framework which takes into account the mobile, decentralised and connected nature of this technology.

Figure 1. Grid power flows with smart and bidirectional charging



This paper[4] is intended to help policymakers and other stakeholders better understand bidirectional charging and some of the barriers to its implementation as V2G. The principles aim to overcome these obstacles, ensuring that the regulatory framework enables the benefits of bidirectional charging for EV drivers and all those who use the electricity system.

Different use cases of bidirectional EV charging

The energy stored in a vehicle's battery can be used to power individual appliances in the absence of a grid connection; provide electricity system services; and feed into a building, including in the event of a power outage, or back into the grid. The latter category of battery

[2] Applications of bidirectional charging are commonly referred to as vehicle-to-load (V2L), vehicle-to-building (V2B) and vehicle-to-grid (V2G). They differ in whether they operate in synchronisation with the public electricity grid or in isolated, or island, mode. This brief focuses on the grid-synchronised use cases of bidirectional charging.

[3] Xu, C., Behrens, P., Gasper, P., Smith, K., Hu, M., Tukker, A. & Steubing, B. Electric vehicle batteries alone could satisfy short-term grid storage demand by as early as 2030. *Nat Commun* 14, 119 (2023). https://doi.org/10.1038/s41467-022-35393-0

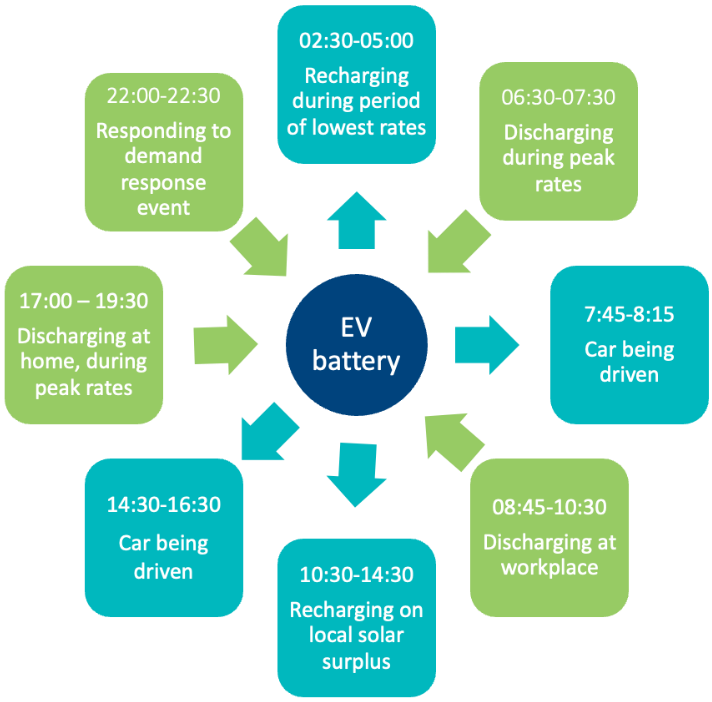
[4] The author would like to acknowledge and express his appreciation to the following people who provided helpful insights into early drafts of this briefing: Brieuc Giard and Marion Malafosse, smartEn; Simon Köppl and Jakob Zahler, Forschungsstelle für Energiewirtschaft; and Bram Claeys, Julia Hildermeier and Andreas Jahn of RAP. Responsibility for the information and views set out in this paper lies entirely with the author.

use, V2G, offers great potential for users and the energy system. It allows low-cost, renewable electricity to be stored (avoiding further curtailment) and reinjected into the grid for later use or resale at expensive times, reducing both energy bills and the carbon intensity of the electricity system. V2G can support grids through precise, local adjustments in the direction of charging, helping to reduce grid congestion.

For users, it means better use of their own generated electricity (either individually or collectively in a renewable energy community), bypassing expensive peak periods and providing additional resilience to supply disruptions. Bidirectional charging can also enable fleet operators to charge their fleet even when grid capacity is limited, allowing, for example, energy to be redistributed to the vehicles that need a boost. The economic benefits of providing services to the grid and optimising 'behind the meter' can offset some vehicle costs by reducing energy expenditures. This, in turn, makes it easier for more consumers and businesses to switch to electric vehicles, whether they be cars, vans or heavy trucks.

Some bidirectional charging opportunities are only of interest to small groups, such as the ability to power appliances while on the move, or provide back-up power for a home. However, all these use cases rely on the same underlying technology. That's why it's so important to have standards for vehicles and charging infrastructure that cover a wide range of applications, a market framework that facilitates these different use cases and technology that enables a seamless user experience. Figure 2 illustrates possible uses.

Figure 2. Battery power flows with smart and bidirectional charging



From V2G on the horizon to V2G capabilities on the road

To realise the potential of bidirectional charging — and especially V2G — it is important to overcome the technical, market and regulatory barriers that prevent vehicle batteries from supporting the electricity grid. Other types of distributed energy resources, such as heat pumps, rooftop solar, home batteries and smart charging share many of these barriers.

The combination of being both a consumer and a producer of electricity, as well as a mobile storage solution, means, however, that vehicles capable of bidirectional charging bring into focus the existing differences in regulatory and fiscal treatment across technologies, segments, markets and Member States. Barriers to V2G should not be addressed in a technology-specific way by adding more exemptions, but by promoting a level playing field for all technologies and capacities.

Vehicle electrification is progressing, as is the development of charging technology — including bidirectional charging. Due to the early stage of standards and market access, however, the number of vehicles and chargers supporting this functionality remains limited, with high costs for manufacturers. Consumers are therefore not yet benefiting from economies of scale that will drive down the cost of bidirectional charging technology.

Supportive policies can help European and national policymakers ensure that bidirectional charging can realise its potential to benefit the electricity system and consumers. Rapid European electricity legislation implementation at national level would allow demand-side flexibility access to the electricity markets.[5] Uniform grid codes[6] are needed so that products and services work seamlessly across the European Union without major adjustments (or blockages) on a country-by-country basis. Inaccessible or incompatible markets and a lack of user trust and benefits could risk that bidirectional charging is developed at the international level without grid interaction and system benefits.

We offer three policy principles that could provide a path to realising the potential of bidirectional charging in the EU. With a clear framework, including energy regulation and grid codes, and a market for bidirectional chargers and services in Europe, the ongoing electrification of the vehicle fleet can be made smart and beneficial — and not burdensome — for the energy system; the benefits would not remain with the individual, but extend to

[5] There is still a lack of implementation of the 2019 European provisions designed to advance demand-side flexibility in national legislation, and the rollout of smart meters has been very slow in some European countries such as Germany. smartEn (2022) The implementation of the Electricity Market Design to drive demand-side flexibility. *SmartEn Monitoring Report.* https://smarten.eu/report-the-implementation-of-the-electricity-market-design-2022-smarten-monitoring-report/

At the time of writing, a reform of the electricity market design in Europe was debated. For more information on this see Claeys, B., Pató, Z., Scott, D., Jahn, A. & Hogan, M. (2023) *Better, faster, stronger: A look into further electricity market reforms*. RAP. https://www.raponline.org/knowledge-center/better-faster-stronger-look-into-further-electricity-market-reforms/

[6] For bidirectional charging, both the network code on demand connection and the network code for requirements for grid connection of generators apply. Also, a new network code for demand response is under development. See European Union Agency for the Cooperation of Energy Regulators (n.d.) *Connection Codes.* https://www.acer.europa.eu/electricity/connection-codes

society as a whole. Renewable electricity can be better integrated faster, and grids can be operated more efficiently and resiliently, leading to lower costs for all energy system users.[7]

Principle: Build trust and establish common standards

Trust is a prerequisite for the meaningful use of electric car batteries in the energy system. It enables different actors to work together. Without trust, an EV user will not allow their vehicle battery to be used or controlled by another party, such as an intelligent charging service. System operators and energy market players should be able to trust the contribution that EV batteries and other distributed energy resources can make to a more efficient energy system.

A key requirement to utilise a vehicle battery for purposes other than mobility is owner or user confidence that their core battery needs can be met. That means a user must have control over what happens, be informed and have decision-making power. Users do not need to constantly interact with or check their devices; automation will work in the background, ensuring that user requirements — such as a full battery at the desired departure time — are met. A user must trust the automated service to charge and discharge in line with their needs; to be assured that their vehicle is charged and ready to drive when they need it.

Part of that trust for the user is confidence that making the vehicle battery available for energy services will not lead to faster obsolescence or void the warranty. Policymakers and vehicle manufacturers will also have to deliver on the promise of bidirectional charging with a warranty that includes, not limits, this use.[8]

The EN ISO 15118-20 standard for communication between EVs and charging points should also be swiftly implemented in charge point and vehicle regulations, ensuring full and unrestricted compatibility between cars and devices of different manufacturers. Policymakers and industry could jointly work on making this standard the default, and where necessary, add the required technical details to avoid different national or manufacturer-specific implementations. Users investing in V2G chargers should be assured that compatibility with future generations of EVs will be maintained through upgradeability.[9]

Reliability for the power system also hinges on trust. This means that relevant stakeholders in V2G flexibility, such as retailers, aggregators, and grid operators, can count on power being made available from participating batteries in accordance with the technical requirements that ensure grid stability. Vehicles and services must also reliably meet set requirements and be able to cope with disruption. Trust would allow system operators to rely on the contribution of demand-side flexibility as an alternative to grid reinforcement (whether temporary or otherwise), to provide system services, and as a balancing resource.

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[7] Yule-Bennet, S. & Sunderland, L. (2022) *The joy of flex: Embracing household demand-side flexibility as a power system resource for Europe*. RAP. https://www.raponline.org/knowledge-center/joy-flex-embracing-household-demand-side-flexibility-power-system-resource-europe/

[8] United Nations Economic Commission for Europe. (2022). *United Nations Global Technical Regulation on In-vehicle Battery Durability for Electrified Vehicles*. https://unece.org/transport/documents/2022/04/standards/un-gtr-no22-vehicle-battery-durability-electrified-vehicles

[9] Ensuring upgrade capabilities is important. Currently, not all vehicles on the market support the newly finalised international ISO 15118-20 standard. Additional information on the ISO/IEC 15118-20 standard and future proofing charging infrastructure can be found in ECOS/RAP. (2022). *Standards for EV smart charging. A guide for local authorities*. https://www.raponline.org/knowledge-center/standards-for-ev-smart-charging-a-guide-for-local-authorities/

Likewise, market players should be able to rely on harmonised requirements across the European Union, such as grid codes, market rules or technical standards, so that a single market for V2G products and services is effectively created. This is important to achieve and exploit economies of scale in hardware production, leading to significant price reductions. This, in turn, will make bidirectional charging, including V2G, an attractive option for even more users and increase the number of participating vehicles in Europe.

Lastly, we should not forget that hundreds of thousands of vehicles suitable for bidirectional charging have already entered the European market in the past decade. Many of these vehicles, equipped with the CHAdeMO[10] standard, are still driving around, albeit with a second or third owner, often a private individual. For this group, too, being able to use that car for energy services is attractive, and the size of this fleet would make it a welcome asset for the energy system (see principle 2). It is therefore important to consider these older vehicles when setting requirements for bidirectional charging infrastructure.

Trust and standards can ensure that bidirectional charging technology can be used uniformly across Europe and that EV drivers are willing and able to use their vehicles for V2G services. Adequate remuneration is an important prerequisite for this.

Principle: Get the prices right to guide charging and discharging

Where, when and how an electric car battery is used for charging or discharging can be most efficiently determined by prices that reflect its value or cost. A bidirectional charging system uses power system price signals to help consumers optimise the process, e.g., to start charging on local solar or instead to feed energy back to the grid.

Prices should reflect system conditions. When they do, user response can align benefits, through lower prices, with system needs. With a battery, consumers can react more easily to price signals, as the European Commission acknowledges in its 2023 storage recommendations.[11]

Prices from wholesale energy markets and system services should be complemented by time- and location-varying prices for grid use. Wit deliberate design, dynamic grid tariffs can contribute to a grid-friendly deployment of bidirectional charging technology and other distributed energy resources. These dynamic network tariffs could themselves be bidirectional, with values applying to consumption or supply, signalling system needs and constraints. Automated smart charging services can easily process these highly granular, dynamic prices for energy import and export on behalf of the user.[12] This grid-friendliness

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[10] CHAdeMO is an EV direct-current charging standard developed in Japan. One of the functions it supports is bi-directional power transfer. It is standardised as IEC 61851-23 for the charging system, IEC 61851-24 for communication, and IEC 62196-3 *configuration AA*.

[11] European Union Directorate-General for Energy. (2023). *Staff working document on the energy storage – underpinning a decarbonised and secure EU energy system*. https://energy.ec.europa.eu/publications/staff-working-document-energy-storage-underpinning-decarbonised-and-secure-eu-energy-system_en

[12] California Public Utilities Commission. (2022). *Advanced Strategies for Demand Flexibility Management and Customer DER Compensation*. https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-costs/demand-response-dr/demand-response-workshops/advanced-der-and-demand-flexibility-management-workshop

means that the charging and discharging is aligned with (local) grid needs, such as by storing solar energy generated in the neighbourhood, or by discharging during high local demand.

For price signals to be effective, it is important that taxes and charges do not get in the way. This is particularly the case for household consumers, who in many Member States are subject to higher taxes and charges than larger entities. V2G charging would typically involve two charging sessions (for which taxes and charges would be paid in addition to the electricity and network prices), and one discharging session in between, with remuneration according to the system contribution. Member States should therefore provide for taxes and charges only to apply to final – net of discharge – consumption, so that bidirectional charging does not lead to double costs.

Not all of the earnings or savings from bidirectional charging will come from price signals that are sent directly to the user. Some of these earnings could be payments for availability or delivery of flexible capacity, such as for system services and balancing. V2G charging services can also have varying pricing models to cater to different user preferences. One user might want a rate that closely follows wholesale energy market prices and may also be willing to take on more risk; another will prefer to see the savings and revenues of V2G result in a discounted monthly fee for their leased electric vehicle, for example, without having to deal with price fluctuations. In addition to dynamic energy tariffs, other models that are highly responsive to system needs are emerging.[13]

It's also important that the flexibility in charging and discharging can be used for various purposes at the same time, such as optimising on-site energy flows, supporting the local grid and allowing activity on wholesale markets. This requires good transparency and interoperability across actors and devices.

Principle: Ensure equal access and treatment

In order to maximise the value of bidirectional charging for the energy system, it is important that distributed resources can participate in all energy markets to which large resources have access, such as wholesale energy and balancing and system services.

Accurate measurement of reactions to demand response events and of energy consumption and delivery is important in the chain of trust, as outlined in the first principle. However, some existing requirements, designed for large, stand-alone power plants, do not fit well with the small-scale, distributed — yet highly standardised — nature of EV chargers and other smart energy devices. There is a need to look at how access and measurement requirements can be simplified while ensuring the same reliability at system level.[14]

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[13] One such example is The Mobility House's eyond tariff, which offers consumers a fixed energy price and additional savings bonuses according to the flexibility offered, such as longer connection times to the charger and the user's input of the desired departure time. https://eyond.mobilityhouse.com

[14] Such as through device-level metering in the proposed Electricity Market Reform. European Union Directorate-General for Energy (2023) *Electricity Market Design revision: Proposal to amend the Electricity Market Design rules.* https://energy.ec.europa.eu/publications/electricity-market-reform-consumers-and-annex_en . In the UK, a Power Responsive working group is looking at updating metering requirements to better suit distributed energy resources. National Grid ESO (2023) *Invite to Trial. Smaller scale aggregated assets entering the BM.* https://www.nationalgrideso.com/industry-information/balancing-services/power-responsive#Working-groups

Equal access for distributed energy resources can make the sum of many small things into a powerful tool for the European electricity system.[15] Together, millions of electric vehicles connected to charging points in Europe can make a significant contribution to stabilising the energy system through small adjustments to charging behaviour.[16] Bidirectional charging could further enhance this EV power.

It is important to take a broad view of the added value of such flexible, distributed energy resources. All forms of residential or distributed flexibility, such as smart charging (uni-directional), heat pumps, home batteries, solar inverters and similar devices that are capable of shaping their electricity profiles can deliver system benefits.[17] It's crucial for policy to ensure that these small resources have similar access to power markets as traditional generation resources.

Conclusions

The continuing electrification of the vehicle fleet offers unprecedented opportunities to deploy these batteries-on-wheels not only for transport and mobility, but also to provide energy services. This would reduce the need for expensive peak power solutions and could help integrate additional, and cheaper, renewable energy while providing financial benefits to consumers.

There is a good reason for policymakers to ensure the regulatory framework enables distributed energy resources to participate fairly and fully in all power markets. The benefits of bidirectional charging extend beyond the individual with V2G services. By deploying the flexibility in charging and discharging in such a way as to support the power system, there are broader societal benefits: lower costs for the electricity grid and better integration of cheaper renewable energy. This makes it easier to achieve energy transition goals, cost-effectively.

We have proposed three principles to realise these benefits for users and the energy system. By building trust, guaranteeing that price signals reflect system needs, and ensuring that distributed resources are on a level playing field with traditional power system resources, barriers can be effectively removed so that EV batteries can play a significant role in the European power system. Smart charging already provides systemic benefits, but bidirectional charging and V2G services will maximise them for users (through savings and rewards) and all stakeholders active in the energy system.

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[15] Yule-Bennet, S. & Sunderland, L. (2022) *The joy of flex: Embracing household demand-side flexibility as a power system resource for Europe*. RAP. https://www.raponline.org/knowledge-center/joy-flex-embracing-household-demand-side-flexibility-power-system-resource-europe/

[16] European Environmental Agency / European Union Agency for the Cooperation of Energy Regulators (2023) *Flexibility solutions to support a decarbonized and secure EU electricity system.* https://www.acer.europa.eu/news-and-events/news/rapid-growth-renewables-calls-greater-cooperation-among-member-states-double-flexibility-eu-power-system

[17] A deeper dive into policies for distributed energy resource integration is provided in Thomas, S. & Pató, Z. (2023). *Integrate to zero: Policies for on-site, on-road, on-grid distributed energy resource integration*. RAP. https://www.raponline.org/knowledge-center/integrate-to-zero-policies-onsite-onroad-ongrid-distributed-energy-resource-integration/

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