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Vehicle as a source and its grid integration aspects

Eraldo Preci[1], Fabio Monachesi[1], Joe Bablo[1], Ken Boyce[1]
[1]*UL Solutions, Eraldo.Preci @UL.com*

Executive summary

The rise of CO_2 levels has led to global policies to reduce them, emphasizing the transition to renewable energy and e-mobility. Regulations like EU Regulation (EU) 2019/631, the U.S. Corporate Average Fuel Economy (CAFE) standards, and the Chinese Ministry of Industry and Information Technology (MIIT) directives set CO_2 emission limits for cars. Electric vehicle sales have grown from 0% to 10% of global sales from 2010 to 2020, with projections to exceed 30% by 2030. Innovations in charging systems and electric vehicles, such as vehicle-to-everything (V2X) technologies, have facilitated their spread and integration with the electric grid, promoting self-consumption and grid stability with vehicle-to-building (V2B), vehicle-to-home (V2H), vehicle-to-load (V2L) and vehicle-to-grid (V2G) solutions. Thanks to these, charging sessions become a cost and profit center for electric vehicle users. Manufacturers of charging infrastructures and bidirectional electric vehicles must comply with safety standards and grid code compatibility. In December 2023, the Agency for the Cooperation of Energy Regulators (ACER) proposed to the EU an update to the European network code "Requirements for Generators" to include requirements for charging stations and bidirectional electric vehicles.

1. Introduction

The escalation of CO_2 levels in the atmosphere has triggered a global response aimed at reducing harmful emissions, emphasizing the transition to renewable energy sources and e-mobility. Influential regulations, such as European Union (EU) Regulation 2019/631, the U.S. Corporate Average Fuel Economy (CAFE) standards and directives from China's Ministry of Industry and Information Technology (MIIT), have imposed strict limits on vehicle CO_2 emissions, pushing the automotive industry toward a radical change.

The electric vehicle (EV) market has experienced exponential growth from 0% to 10% of global car sales in the decade from 2010 to 2020, with projections indicating a share exceeding 30% by 2030, as shown in Figure 1. This increase has been supported by innovations in charging systems and the development of EVs, particularly through the adoption of vehicle-to-everything (V2X) technologies. These technologies have not only facilitated the spread of EVs but have also allowed for their more effective integration with the electric grid, promoting self-consumption and contributing to the stability of the electric system through innovative solutions such as vehicle-to-building (V2B), vehicle-to-home (V2H) and vehicle-to-grid (V2G) technologies.

With the implementation of these technologies, charging sessions have transformed from a mere expense to a potential profit center for EV users. Indeed, the ability to sell excess energy back to the grid or use the EV as a home storage system during peak hours enables EV owners to actively participate in the energy market, turning their vehicles into strategic assets for a more flexible and resilient energy system.

To maintain the safety and efficiency of these interactions, manufacturers of charging infrastructure and bidirectional EVs must comply with strict standards governing grid code compatibility. In this context, in December 2023, the Agency for the Cooperation of Energy Regulators (ACER) proposed to the EU an update to the European network code "Requirements for Generators" (RfG), including specific requirements for charging stations and bidirectional powertrains.

This step represents a significant evolution in regulation, reflecting the growing importance of EVs as both consumers and suppliers of energy. The regulatory update aims to establish a clear and harmonized framework that facilitates the integration of EVs into the energy system, promoting innovation and supporting operational safety.

The transition to e-mobility and the adoption of advanced charging technologies are key elements in achieving environmental sustainability goals. Collaboration between regulators, industry and energy providers is essential to creating a safe, efficient and beneficial electric mobility ecosystem for all stakeholders, thereby contributing to a cleaner and more sustainable future.

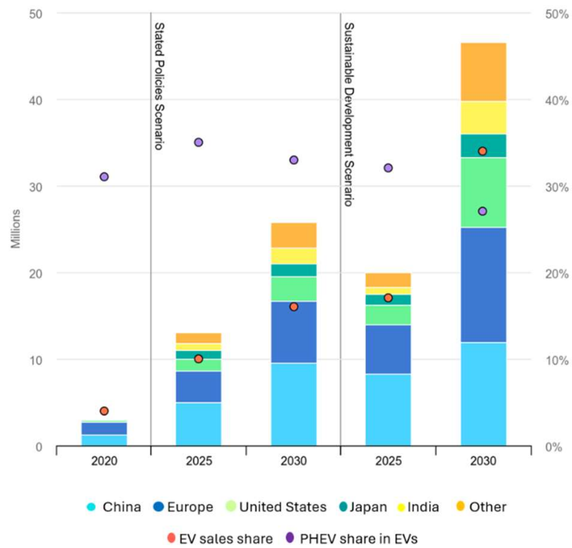

Fig. 1: International Energy Agency (IEA) (2021), Global EV sales by scenario, 2020-2030, IEA, License: CC BY 4.0

2. Smart and bidirectional charging of powertrains: Definitions and use cases

In the era of sustainable mobility, smart charging of EVs represents a milestone toward a greener future. This article explores the fundamental definitions, use cases and standardization requirements, with a particular focus on Europe and North America, as well as access to the global market.

2.1. Main definitions

Unidirectional smart charging, known as "vehicle one grid" or "V1G," is a system that allows EVs to be charged in a "smart" manner. The charging process, which includes time, speed and energy flow, can be managed and optimized based on various factors such as grid demand, electricity prices and user needs. Unlike V2X, which involves a bidirectional energy flow, V1G only allows energy to flow from the grid to the vehicle.

Here are some key aspects of V1G smart charging:

- **Optimization of time of use** – V1G systems can schedule charging during off-peak hours, when electricity demand and costs are lower. This saves money and balances the load on the electric grid.
- **Demand response** – V1G can respond to signals from the grid operator to temporarily reduce or delay charging during periods of high demand, helping to prevent overloads and potential blackouts.
- **Integration of renewable energy** – Smart charging can be synchronized with periods of high renewable energy generation to maximize the use of clean energy.
- **User preferences** – V1G systems can consider the user's schedule and mobility needs to ensure that the vehicle is charged and ready for use when required.
- **Remote control and monitoring** – EV owners can often control and monitor the charging process remotely via smartphone apps, offering greater convenience and flexibility.

V2X refers to a model of interaction where the EV interacts with any entity that can influence or be influenced by the vehicle's charging process.

In the context of EV charging, V2X is an export or discharging action that includes several specific interaction scenarios:

- **V2G or V2H multimode** – EVs can interact with the electric grid to sell excess energy or manage charging times based on grid load. V2H is interconnected with the home/building such that local consumption can occur, and excess power is exported to the utility.
- **V2H or V2B backup-only/islanded** – EVs can supply energy to a home or building, serving as an alternative or backup power source.
- **V2L (vehicle-to-load)** – Vehicles supply energy to external devices in case of power outages or applications without access to the electrical grid.
- **V2V (vehicle-to-vehicle)** – EVs can share energy: One EV serves as a donor (source) EV and the other acts as a receiving (load) EV. No other sources or loads are present in a V2V application.

V2X technology for EV power export involves a combination of hardware and software that enables secure and efficient communication between the vehicle and various entities. It is an important part of initiatives related to microgrids, smart grids and smart cities, which aim to improve energy efficiency, reduce costs, and increase the overall sustainability of transport and energy systems.

Fig. 2

3. Examples of key use cases

3.1. Load management with V1G

Dynamic load management (DLM) is a system that actively manages the energy consumption of EV charging stations, typically in response to power availability or to optimize costs, efficiency and grid stability. Smart charging systems can adjust the charging speed of each vehicle in real time based on various factors, such as the maximum available power and charging capacity, so all vehicles charge efficiently.

3.2. Self-consumption with V2H/V2B

Self-consumption is utilizing locally produced energy onsite within the building or home and/or storing it. In a home or building with solar installations, consuming the energy produced by the solar system is generally more cost-effective than buying it from the grid. Further, an entity with the ability to store energy, such as one with a bidirectional EV charging system, could take advantage of self-consumption and charge EVs during solar hours and then release it back to the house or building during other times, minimizing or even eliminating consumption from the grid.

3.3. Flexibility services with V2G

Flexibility services enable the energy transition with greater adoption of renewables. In the United Kingdom, demand-side response (DSR) in residential areas and industrial and commercial processes supports system flexibility. EVs utilizing the V2G functionality have the potential to reduce demand by 32 GW by 2050, the largest among the applications for flexible energy consumption.

4. Safety standards, network code compliance and interoperability for V1G

In North America, there are several standards to promote the safety of EV charging stations and equipment. These standards are used to certify the safety of these devices, covering risks such as fire, electric shock, and injuries from the predictable use and misuse of the product.

4.1. AC Charging stations

The standards for AC charging stations in North America are harmonized via UL 2594, the Standard for Electric Vehicle Supply Equipment. This Standard covers portable, mobile and fixed charging applications for residential and public access. Internationally, the leading standard for these products is IEC 61851-1, Electric Vehicle Conductive Charging System – Part 1: General Requirements, which establishes general requirements for portable, mobile and fixed charging stations focusing on AC charging.

4.2. DC charging stations

For North America, the leading DC charging standard is UL 2202, the Standard for DC Charging Equipment for Electric Vehicles. This Standard covers all DC output charging stations, such as wallboxes and fast-charging stations.

Internationally, IEC 61851-23, Electric Vehicle Conductive Charging System – Part 23: DC Electric Vehicle Supply Equipment, addresses DC charging stations and is used with IEC 618511. Additionally, IEC 61851-24, Electric Vehicle Conductive Charging System – Part 24: Digital Communication Between a DC EV Supply Equipment and an Electric Vehicle for Control of DC Charging, defines use cases and digital communications between the charging station and the vehicle for charging control. Although these standards are continually under review, they have already been published, with the latest edition of IEC 61851-23 issued in December 2023.

5. The vehicle as a distributed energy resource — V2X

A developing application aims to use vehicles as distributed energy resources. It is necessary to carefully design the technology to support operational safety. It is also necessary to understand how it will affect devices connected to the vehicle and how the EV acting as a source will affect devices connected to the local or area grid network. The requirements may vary based on the specific use of the system, which can include various use cases such as V2G, V2H, V2B, V2L and V2V. In each scenario, the inverter that facilitates bidirectionality of energy flows with the powertrain can be located either in the external charging stations or onboard the vehicle, influencing the applicable standards. In some V2G split topologies, the grid export functionality can also be located outside the EV, e.g., within the EV supply equipment (EVSE), and separate from the power conversion circuitry (inverter).

In V2G applications, the vehicle is connected to the grid to allow the EV to export power to support the grid during peak demand. This also allows the owner to sell energy to the grid. This raises safety concerns for grid networks. For example, the quality of the energy must meet grid stability requirements. Additionally, export from the EV to the utility must be coordinated for stability of the overall grid network, avoiding over-generation conditions and supporting the grid in times of overconsumption or other abnormal grid conditions. V2H/V2B backup-only applications allow vehicles to act as generators during emergencies. In contrast, V2L and V2V applications enable the vehicle to supply power to external devices that are not connected to the grid.

The development of these technologies requires specific standards and safety considerations. In North America, UL Solutions has developed UL 9741, the Standard for Electric Vehicle Power Export Equipment (EVPE), for offboard equipment affording bidirectional charging of EVs where an EV power export function is included. UL 9741 is also a binational Standard with Canada under CSA 348. For connection to electric grids, compliance with Supplements SA and SB of UL 1741, the Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources, is required via reference within UL 9741, which refers to the IEEE 1547 (2018) and IEEE 1547.1 (2020) grid codes.

The International Electrotechnical Commission (IEC) community also discusses how to include these technologies in future standards. The regulation governing the RfG EU 2016/631 network codes is under revision in Europe. The next edition, expected during 2025, will be developed based on the ACER amendment. It will require that the bidirectional charging system, defined as either the vehicle and charging station or the parking lot itself, connected to the electric grid, must have a Certificate of Conformity (CoC) for national network codes. This certificate must be issued by an accredited certification body that operates according to the ISO/IEC 17065 standard. The main standards adopted in Europe are EN 50549 harmonized at the European level, VDE-AR-N 41xx in Germany, CEI 0-21/0-16 in Italy, NTS 631 in Spain and G99 in the United Kingdom, where V2G is already considered. The introduction timelines for these requirements are expected within the next five years, as shown in Fig. 4.

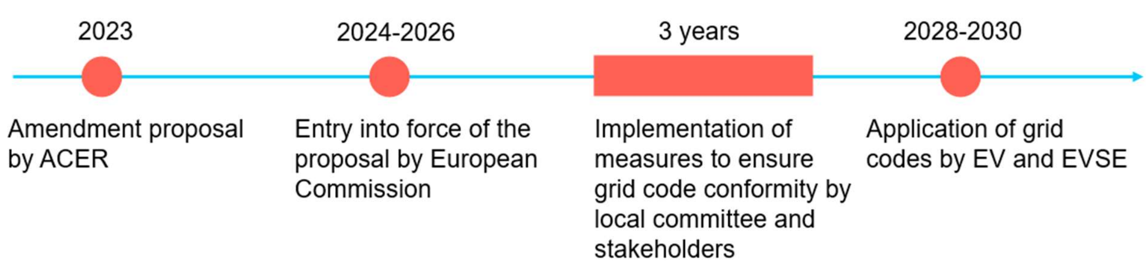

Fig. 3: Estimated timeline for the new European grid code requirements

6. Interoperability and global challenges

Interoperability between vehicles, charging stations and electric grids is crucial for a functioning electric mobility ecosystem. International standards such as ISO 15118, Road Vehicles – Vehicle to Grid Communication Interface, and SAE J1772, Electric Vehicle and Plug In Hybrid Electric Vehicle Conductive Charge Coupler/SAE J3068, Electric Vehicle Power Transfer System Using a Three-Phase Capable Coupler, are essential steps toward harmonization. Still, challenges persist due to the diversity of vehicles and charging infrastructure and the continuous need for software updates.

Collaboration among various industry stakeholders is essential to overcome these technical and regulatory barriers. Manufacturers of EVs and their charging stations must adhere to specific international standards to achieve compatibility for their products. These standards also include regulations that govern the configuration and communication methods of the equipment.

Regarding bidirectional charging, ISO 15118-20 is undergoing improvements that are expected to include functional parameters for the network code. The various stakeholders need to agree on where to place the interface for data exchange and the communication protocol. Additionally, in cases where the stability of the electric grid is at risk, the European regulation EU 2016/631 allows grid operators to intervene to regulate the power produced by electricity-generating units. Consequently, grid operators must review their information technology infrastructures and digitalization strategies to determine whether updates are needed, such as implementing coordinated control and monitoring systems to manage the energy fed into the grid by EVs and charging stations.

7. New services for access to the global market

UL Solutions leverages decades of experience to offer comprehensive testing and certification services for both external and onboard EV charging infrastructure and electric charging parking stations to support compliance with standards and the global adoption of V1G and V2X. Among the various services, the most relevant are the following:

- Testing for charging system safety standards and their certification based on UL and IEC standards
- Performance testing of charging stations and their certification per network codes

- Evaluation of charging device interoperability according to International Organization for Standardization (ISO) standards and proprietary protocols
- Validation of software models for bidirectional charging systems, simulations and network studies for compliance with local network code standards

Collaborating with UL Solutions as a comprehensive provider of testing, inspection and certification (TIC) services helps EV manufacturers and charging station providers reduce the time and effort needed for local network code compliance activities. UL Solutions also helps EV charging station owners identify local compliance requirements for installing bidirectional systems.

8. UL Solutions’ network code compliance services for bidirectional charging systems

With decades of experience in TIC services for charging systems and accreditations as a testing and certification body for over 60 network codes worldwide, UL Solutions is ready to support customers by providing testing, informative reports and certification services for bidirectional charging systems in its laboratories — such as the one in Madrid, Spain, with a capacity of up to 500 kW — or at the customer's site. Network code accreditations for ISO/IEC 17025 and ISO/IEC 17065 are issued by various entities such as the German accreditation body DAkkS (D-ZE-11326-01-00 and D-PL-11095-01-00) Spain's National Accreditation Entity (ENAC, 147/C-PR335 and 1376/LE2560) and the American Association for Laboratory Accreditation (A2LA, 5314.01&5314.02)

Additionally, UL Solutions provides a digital service called Global Compliance Management (GCM), a comprehensive and intuitive software platform for managing compliance requirements from all regulatory aspects. It facilitates access to various global markets, including network codes.

9. Reducing barriers for more sustainable electric mobility

In conclusion, smart charging of EVs is a rapidly evolving sector that plays a crucial role in integrating EVs into modern energy grids. V1G and V2X applications not only improve energy efficiency and reduce operational costs of electric mobility but also contribute to greater penetration of renewable energy and increased electric grid resilience.

Standardization initiatives, particularly in Europe and North America, are working to harmonize technical requirements and testing procedures, thus facilitating global market access for EV manufacturers and charging infrastructure. This harmonization process is essential to achieve compatibility and interoperability between vehicles, charging stations and electric grids in different countries and regions.

Companies like UL Solutions play a fundamental role in providing TIC services that support various technology providers in achieving product compliance with current regulations. This helps reduce barriers to entry and accelerates the adoption of smart and bidirectional charging technology globally.

With the increase in demand for EVs and the growing need for efficient and sustainable charging solutions, the market is poised to experience significant expansion in the coming years. Smart, innovative charging technologies, such as V1G and V2X, will be at the forefront of this change, offering consumers and electric grids new opportunities for a cleaner and smarter energy future.

Ultimately, as the world moves toward a low-carbon future, smart charging of EVs is essential in achieving sustainability goals and promoting continuous innovation in the automotive and energy sectors.

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Presenter biographies

Eraldo Preci is a senior knowledge specialist at UL Solutions, specializing in grid code regulations and compliance. Eraldo earned his Bachelor of Science and Master of Science (with honors) degrees in electrical engineering from the University of Pisa, Italy, in 2010 and 2013, respectively. Between 2014 and 2017, he worked as a consultant for General Electric Turbomachinery at Intertek Italia. From 2018 to 2021, he pursued an exchange Ph.D. with the Power Electronics, Machines and Control (PEMC) group at the University of Nottingham, splitting his time between the campuses in Nottingham, U.K., and Ningbo, China. His research primarily focuses on the modeling, analysis and multiphysics optimization of electrical machines and drives, collaborating with the industries operating in the automotive and aerospace sectors. From 2021 to 2022, he served as a project engineer for the e-motor team at Silk-Faw Automotive. Subsequently, from 2022 to 2024, he worked as a research and development engineer at ABB, where he was involved in designing, testing and prototyping electromechanical devices.

Fabio Monachesi is a product manager at UL Solutions, where he oversees the company's global business strategy for EVSE, distributed energy resources and microgrids, with an extensive background in the energy industry. Fabio has accumulated significant experience in product portfolio management, project management, business development and strategic marketing through various roles in international corporate settings such as ABB and the Italian Electrical and Technical Experimentation Center (CESI). He has led innovative hardware and software offerings and has been instrumental in developing their go-to-market plans and extending the service business in other areas, particularly for grid code compliance.

Fabio holds a master's degree in electrical engineering from the University of Pisa and an executive master's in business administration from the Business School of the Polytechnic of Milan, both with honors. He also co-founded alumni clubs there. His educational background has provided a strong foundation for his professional endeavors in the energy sector.

As a member of the Italian Electrotechnical Committee (CEI) for grid code certification, Fabio contributes to developing industry standards. He also represents UL Solutions at the CharIN association, focusing on grid integration and bidirectional charging issues.

 Joe Bablo, a Distinguished Member of Technical Staff in the William Henry Merrill Society at UL Solutions, plays a pivotal role in advancing safety innovations in EV charging technologies. His contributions to technical standards development for EV charging — including EVSE, EV chargers and EV couplers — demonstrate his commitment to our mission of working for a safer world. Through his dedication and leadership, he has become a recognized authority in standards development, product certification and EV charging safety awareness, helping drive global advancements in safety and innovation throughout this fast-paced industry.

 Ken Boyce is a Corporate Fellow in the William Henry Merrill Society at UL Solutions — a distinction reserved for the highest level of technical achievement, external recognition and contributions to UL Solutions' safety mission. He influences global trends in energy, safety, risk management, sustainability and technology through his engagements as a researcher, technical expert, speaker, lecturer and author at symposia, government events and universities.