Integration of electromobility with the electric power systems: The key challenges

By **Yannick PEREZ** and **Wale AROWOLO**
Armand Peugeot Chair, Laboratoire de génie industriel,
Équipe Développement durable, CentraleSupélec

Introduction

As a result of the ongoing energy transition propelled by deep transforming trends, such as liberalization, decarbonization, and digitalization, the traditional electric utilities are undergoing unprecedented transformation of their mode of operation. To decarbonize, the IPCC (Intergovernmental Panel on Climate Change) identified many possible pathways to reach carbon neutrality by the end of the century. These include acting on decarbonizing the production of electricity, undertaking massive electrification (to increase reliance on clean electricity), switching to cleaner fuels, improving efficiency, and reducing waste in all sectors [14]. For the electric utilities, decarbonization impacts power generation, for instance, a change from fossil fuels, such as coal, oil, and gas plants to renewable energies.

Digitalization is the growing application of Information and Communications Technologies (ICT) in the energy systems [15]. The electricity sector is now impacted by this transformation, where digitalization is blurring the distinction between generation and consumption, and enabling four interrelated opportunities – smart demand response, integration of variable renewables, facilitating the development of distributed energy resources, and electromobility smart charging technologies [15]. At the heart of electromobility is the Electric Vehicle (EV) that interacts with the electric grid and utilities. According to the International Energy Agency (IEA), there are over 10 million electric cars, 290 million 2 and 3 wheelers, 378,000 light commercial vehicles, 600,000 buses, 31,000 trucks, and 230 million micromobility e-scooters, e-bikes, electric mopeds globally in the year 2020 [10 ; 13]. Moreover, forecasting for the coming years is positive for end-users' electromobility acquisition due to battery costs decline, mass production of the battery cells, and the energy density increase.

If energized with decarbonized electricity and smart (digitized) charging, electric vehicle (EV) smart charging can help to shift charging to the periods when electricity demand is low, and supply is abundant. According to the IEA, this would provide further flexibility to the grid while saving between USD 100 billion and USD 280 billion in avoided investment in new electricity infrastructure between 2016 and 2040 [15]. Furthermore, electromobility will provide a partial solution to protecting collective public goods like local public health (*via* reduced urban air pollution). It is also helping to reduce NOx and CO_2 emissions, thus helping to stabilize the climate, and reducing domestic consumption of transport fuel, thus increasing energy security and independence [5]. Nevertheless, large fractions of EVs could also impact the load profile of utilities by overloading the electric generation capacity (regionally) or the electric distribution systems (locally) [5]. In some cases, EVs will also require extending and reinforcing the existing electricity grids when electrifying urban areas or highways for fast charging.

Therefore, market design rules, regulations, and government policies should proactively address the new challenges of the EVs (*i.e.,* V1G – that can charge power from the grid, and V2G – that can charge and discharge power to the grid) interaction with the electric utilities.

This paper analyzes the opportunities and challenges those electric utilities are facing with the increased uptake of electromobility (V1G and V2G) in section 1. Section 2 is the discussion of the transformation of the electric utilities and electromobility. Section 3 is the discussion of the challenges, and it also presents a descriptive framework for the market design and regulatory challenges.

Electric utilities and electromobility

Electric utilities decarbonization entails reducing or eliminating carbon emissions by phasing out fossil fuels from the generation of electricity. This involves shifting the generation to carbon-neutral electricity sources. For example, by replacing coal and gas plants with intermittent renewable sources of energy, such as wind and solar power. The intermittent sources of energy bring new challenges to the utilities, such as ensuring system reliability and the security of supply to instantly balance supply and demand of power generation. In addition, it brings new market actors and increases the need for coordination and management of the grid. Moreover, complexity increases with increasing renewable energy shares while in parallel phasing out fossil fuels. In terms of demand planning, future energy demand forecasts rely on models that contain uncertainties about forthcoming needs of the installed capacity [17]. The model results vary broadly depending on the institution and the considered scenarios. While improvements in efficiency would decrease the final energy demand, the electrification of other sectors (for example transport *via* electromobility), however, will increase the electricity demand and, therefore, the total energy demand [17].

Decarbonization also brings to the utilities the risk of stranded assets. Changes in the market structure could lead to a situation in which technical units are unable to earn money before the end of their lifetime and, thus, become stranded assets. Besides, stranded assets can also occur with renewable energy when, for instance, support schemes expire [17]. Moreover, since renewable technologies have zero marginal cost, they reduce the average electricity prices. Thus, renewables can amplify market design flaws, leading to negatively priced periods at times. In addition, the concern about making (the right) investments in the energy sector during an uncertain period can result in a reduction of electricity generation capacity and incapability to meet the demand [17].

Digitalization holds the potential to build new architectures of interconnected energy systems, including breaking down traditional boundaries between demand and supply [15]. Digitalized energy systems in the future may be able to identify who needs energy, and deliver it at the right time, in the right place and at the lowest cost. The greatest transformational potential for digitalization is its ability to break down boundaries between energy sectors, increasing flexibility, and enabling integration across entire systems. Aggregated and anonymized individual energy use data can improve the understanding of energy systems, such as the load profiles, and help lower costs for consumers [15]. While digitalization can bring many positive benefits, it can also make energy systems more vulnerable to cyberattacks and create consumer privacy issues.

Linked with the electric utilities' transformation is electromobility. Electromobility is a part of a wide and intertwined ecosystem, that involves both transport (car, battery, charging infrastructure manufacturers etc.) and electric systems (utilities, regulatory authorities, market traders, service providers etc.), as well as urban planners, researchers etc. The increasing number of EVs that will interact with the power grid in the coming years will certainly require special attention from the grid operators and regulators. EVs will both represent an additional load and a distributed flexible resource for the grid services. Only through an optimal management of the charging process will it be possible to solve the potential system challenges and take advantage of the potential opportunities [12]. As EVs become a significant fraction of the fleet (and if they are implemented along with intelligent V1G and V2G systems) would lead the whole electricity system to undergo an important paradigm change [5]. The need to match generation and load becomes more challenging as the variable generation increases to represent a larger fraction of the generation mix. However, large-scale EV introduction, along with the possibility of charging and discharging these vehicles in an intelligent way, will facilitate the real-time management and greatly reduce the short term need to precisely balance generation with load [5]. Electromobility represents a crucial opportunity for more sustainable transport, and its optimal charging management could generate relevant benefits for the energy sector as well [12].

Electromobility challenges for utilities - The technical issue

The most compelling technical challenge of V1G and V2G systems is the battery degradation as a result of wear from increased use [2]. Battery degradation can cause loss of capacity over time which impacts an EV's range capability. The fear of battery degradation may make EV owners unwilling to participate in rendering V2G services to the utilities and prevent the utilities from accessing the valuable flexibility services the batteries can provide. According to some V2G expert working on some EV battery pilot project in Denmark, the batteries are reported to have degraded between 7-12% (after 4 years of use). It is reported that 1-2% of the degradation is due to V2G while the rest is due to battery aging, driving, and fast charging [11].

The second key technical challenge is the overall efficiency of V2G sending energy to and from the grid, particularly from the electric vehicle supply equipment (EVSE) [2]. The aggregators face two central challenges, the first is with implementing algorithms that can handle the growing complexity of the V2G systems, and the second is with the communication system [2]. In addition to the challenges of aggregation, algorithms, and scaling of a V2G system, a related challenge is the communication standard that is used in the V2G system to transmit messages to and from the EVs/EVSEs and the electric utilities. Across the various existing V2G projects, no single standard has taken hold, with projects around the world using different communication protocols [2]. Other technical issues are the cybersecurity risks, managing data privacy concerns, and metering accuracy and reconciliation among different actors. With respect to metering, a key challenge is to clearly define who is metering what and how to manage/prevent a metering dispute.

Apart from the large fractions of V1G that could impact the load profile of the electric utilities by overloading the electric generation capacity or the electric distribution systems [5], the current market rules in several wholesale markets are insufficient and need to be modified to better accommodate aggregators offering the V2G services [4]. Other challenges include defining and clarifying the regulatory complexities of V2G and energy storage, and the market entry barriers for the storage-based actors. As the V2G capacity grows, it has the potential to participate in several markets at once, providing "stacked" services, but the current market design rules inhibit simultaneous bidding into multiple markets [2]. In a nutshell, there are a variety of regulations within current and emerging ancillary services markets that need to be resolved, both in the short and in the long run, to increase the value of V2G and decrease the barriers to entry [2].

Besides, there are also other market design elements that reduce the economic viability of a V2G system. These elements include double taxation and the curtailment requirements of renewable energy. With respect to double taxation, the aggregators of V2G services are required to pay fees and taxes when they charge and discharge electricity. This can have substantial economic implications for V2G when providing services like frequency regulation, where electricity frequently flows in and out of the battery. The curtailment requirements stipulate the maximum amount of renewable energy supply allowed into the grid to manage the intermittency without jeopardizing the security of supply [2].

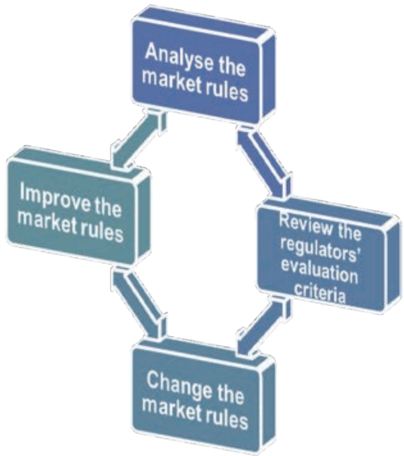
Ways to overcome the challenges

Minimizing battery degradation, optimizing charger efficiency, and implementing effective algorithms to aggregate resources pose significant challenges, but the V1G and V2G systems need to do all of the above while also scaling up in the near future [2]. There is also a need to regulate the privacy and security aspects of the data streams. Privacy and security of data collection during V1G and V2G operations may become an increasingly pressing challenge, that requires further regulation [2]. Also, common standards should be developed and adopted to guarantee the interoperability of charging networks [12]. Moreover, EV-charging control systems should be designed in such a manner that data failure or manipulation does not lead to a substantial change in the system balance (cyber-resilience), and emergency situations are properly managed (such as the restoration after blackouts) [12].

To unlock the full flexibility potential of electric vehicles through V1G and V2G services, reap the synergies with variable renewable generation, and reduce electricity generation capacity needs, would require the adaptation of the market and regulatory frameworks. Currently, flexible EV integration is not on track for power systems to accommodate the distributed loads of the EV batteries in a coordinated way, and on a large scale. The aggregators and the business models require updated regulatory frameworks to reward EV owners for providing flexibility services. This will ensure EV batteries can contribute to the power system's stability on a significant scale [16].

We will discuss four potential solutions in an attempt to address the market design and regulatory challenges as follows: analyzing the market rules ; improving the market rules ; reviewing the regulators' evaluation criteria, and changing the market rules.

- Analyzing the existing rules in the V2G frequency regulation markets to (i.) identify the barriers to entry for the aggregators and to (ii.) identify some options to overcome the barriers, and identifying a combination of rules that could facilitate reserve provision by the EVs in the frequency regulation market [8].
- The TSO market rules could be improved by (i.) creating a legal framework and a formal status for distributed storage units in the TSO rules, and by (ii.) easing the rules to encourage the building of coalitions of small, distributed units [9]. Such aggregation would have a single-entry point from the TSO perspective, which would enable them to dispatch the power flows among the distributed units, thus maximizing the aggregators' ability to bid in the electricity market [9]. Increasing the granularity restriction would make it possible to offer more reserve, thus increasing the potential revenues and allowing business cases to be more viable [7].
- The EV industry is a complex system within which firms choose among competing organizational architectures, and regulatory institutions emerge from the interaction between firms' choices and rule-makers' beliefs. The main drivers to change regulatory institutions are the 'evaluation criteria' applied to outcomes. Evaluation criteria are the rule-makers' simplified models against what outcomes are evaluated. The emergence of a dominant organizational design may be crucially affected by those criteria, and the organizational design affects the path of technological evolution. Consequently, the rule-makers' beliefs might determine the technological path chosen by the EV industry [6]. Therefore, it is critical to review the evaluation criteria of the regulators.
- Using EVs as TSO reserve-providing units have been demonstrated as a feasible and a profitable solution. Nevertheless, the TSO market rules have potentially a great impact on the EV's expected revenues [9]. Since the subsisting rules are made for existing actors in the electric power industry, introducing the EVs to the market requires changing some of the subsisting rules to facilitate money (revenue) flow from the grid operator (TSO or ISO) to the aggregators, and from the aggregators to the EV owners [9].



Description of the VtoG challenges (© All rights reserved)

Based on the foregoing arguments, we provide a descriptive framework to address the market and regulatory challenges in Figure 1 below. Figure 1 would help to provide insight and guide decision-making to address the market and regulatory challenges of the V1G and V2G interaction with the electric utilities in a methodical manner.

It should be useful for the regulators and the other stakeholders to understand the market rules and to facilitate informed decision-making on the market design. It is noteworthy that this framework is iterative and not necessarily a step after the other. Its application will depend on the state of the market design at any point in time. For example, a review of the regulator's evaluation criteria may require a need to improve the market rules that may subsequently require a change of some market rules. In this case, it may be logical to start with the review of the regulator's evaluation criteria.

Conclusion

This paper discusses the energy transition challenges of decarbonization and digitalization facing the electric utilities and the increasing interaction with electromobility. First, it discusses decarbonization that brings new market actors, and increases the need for coordination and management of the grid, but can also cause stranded asset problems. Second, it discusses the impact of digitalization, such as breaking down boundaries between energy sectors, increasing flexibility, and enabling integration across entire systems, which can also raise security and privacy concerns. Third, it discusses the technical, market design, and regulatory challenges of the interaction of electric utilities and electromobility. Finally, it attempts to provide an iterative analytical framework that entails (i.) analysis of the market rules; (ii.) improvement of the market rules; (iii.) a review of the regulators' evaluation criteria, and (iv.) the need for a change of the market rules to address the market design and regulatory challenges.

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