ELECTRIC VEHICLES AS FLEXIBILITY PROVIDERS FOR DISTRIBUTION SYSTEMS. A TECHNO-ECONOMIC REVIEW

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ABSTRACT

Electric vehicle massive integration into power systems will pose significant challenges, in particular to distribution grids. However, they can be a source of flexibility for the power grid operation and planning. In this work, we systematically identified the key technical and economic aspects for the proactive integration of EVs into electricity grids as providers of flexibility services. Technical aspects have been addressed in literature, analysing EV impacts and smart charging strategies at various levels of the power systems. Main barriers come from economic and institutional aspects, such as the absence of frameworks for local flexibility trading, uncertain viable business models and the evolution of roles and responsibilities of DSOs as well as their interactions with other stakeholders. However, there have been significant advances in recent years, with demonstrator projects proposing new technical solutions and testing business models, increasing interest in exploiting flexibility at the distribution level from EU regulators, and the development of local flexibility mechanisms by DSOs.

INTRODUCTION

Distribution system operators (DSO) face a challenging environment, coming from the integration of distributed renewable energy sources (DRES), novel schemes to empower prosumers and the uptake of other distributed energy resources (DER), such as demand response programs, batteries and electric vehicles (EVs) [1]. In particular, EV market is rapidly growing, with worldwide sales increasing by 57% in 2017, a trend that is expected to continue [2]. The massive integration of EVs into electricity networks will pose serious challenges, in particular to distribution grids where they are connected. However, EVs can present benefits to the power systems, as they can provide flexibility services by controlling the charging process (smart charge), and even act as distributed storage systems by using the Vehicle-to-Grid technology (V2G), and more generally V2X technology

This works seeks to analyse the key aspects to consider regarding the provision of flexibility services to distribution grids by EVs. By adapting a methodological analysis framework, we were able to identify the associated main technical and economic barriers, as well as emerging opportunities that consider the latest developments on the exploitation of flexibility at the local level.

The remainder of the work presents the motivation for using EV flexibility at the local level, followed by the methodological analysis framework. Then, we present the detailed analysis of the technical, economic and social elements. Finally, we conclude by summarizing the key barriers to exploit EV flexibility at the local level and recent developments in Europe.

ANALITICAL FRAMEWORK

The integration of EVs is one of many challenges that electricity systems are facing, and they could affect them both at the local (distribution systems) and global (system-wide) level.

At the local level, EVs will affect the operation and planning of distribution networks. Their impacts can be categorized in load and voltage issues. Additional load by EVs increases active power losses and can create congestion in the distribution grid [3]. Overloading of transformers and can cause equipment degradation and failure and lifespan reduction. On the other hand, voltage issues refer to the quality of service delivered to final users. EV charging can create voltage drops and phase-unbalances outside the grid requirements. These impacts depend on several factors including EV penetration rate, grid topology, user behaviour and tariff schemes [4]. To deal with these issues, DSOs would need to invest in infrastructure reinforcements, upgrading transformers or lines to alleviate congestion or to keep the voltage between the required boundaries.

Even though EVs can present impacts to the distribution grids, they present great flexibility potential. In fact, EVs are idle over 80% of the time, and the average daily consumption can be charged in 2.5 hours with a standard 3.7 kVA home charger [5]. This leaves margins for controlling the charging process of the vehicle (smart charge) and even use it as a storage system, being able to give back power to the grid (V2G). In the case of distribution grids, EV flexibility can be exploited to defer or avoid costly reinforcements. The project My Electric Avenue estimated that by 2050 one third of low voltage grids in the UK would need reinforcements (with an EV diffusion between 40-70%), but a simple coordination system could generate up to £2.2 billion in investment savings [6].

In the present work we adapted an analysis framework presented in [7] to systematically identify the aspects to be addressed for a proactive integration of EVs into distribution systems. For this, we reviewed the scientific literature and the results and recommendations of main European demonstrator projects in the subject of smart grids and on electric vehicle grid integration (VGI). The proposed framework allowed us to identify the main technical, economic and social aspects to take into account to exploit EV flexibility, which is shown in Figure 1.

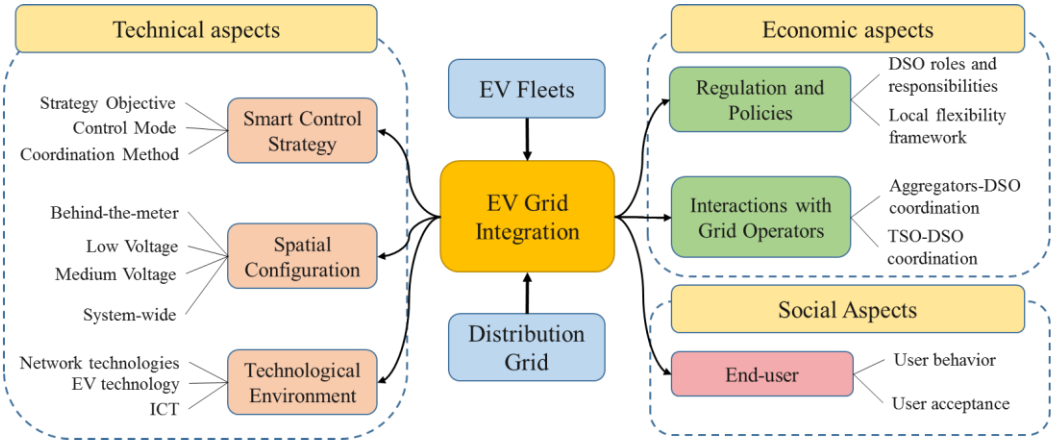

Figure 1: Analytical framework

TECHNICAL ASPECTS

They are related to the technological environment necessary to make use of electric vehicle flexibility. Its main aspect refers to the charging control strategy. Several EV smart control strategies have been proposed in the literature with different objectives and coordination methods. These strategies are applied in a given spatial configuration of the electrical grid, from a low voltage district network to a regional (medium voltage) or national level (transmission level, wholesale markets), within a given technological environment, that can include DRES (PV, wind), EV technology (fast charging, V2G, reactive power provision) and information and communication technology (ICT) standards and requirements.

EV flexibility services can be proposed at various levels of the electricity system, as shown in Table 1. On one end, EV flexibility can be used to benefit directly the end-user in a behind-the-meter fashion, with the objective of reducing its energy bill or providing security of supply (vehicle-to-home and vehicle-to building). On the other end, EV fleets can provide system-wide services such as frequency regulation and energy portfolio management. In between, EV fleets can provide flexibility at the distribution level to solve local constraints (congestion or voltage issues), as well as other services such as phase balancing (in low voltage grids) and peak-shaving or valley filling services. These services have been studied in various demonstrator projects in Europe.

Table 1: EV flexibility services by level.

Level	**User**	**Service**
Behind-the-meter	End-user	Electricity bill optimization
Local	**DSO**	**Local congestion management**
		Voltage Regulation
		Phase balancing
		Peak-shaving / Valley Filling
System-wide	TSO	Frequency regulation
	BRP	Portfolio optimization

In particular, the technical flexibility potential of EV fleets has been proven for highly complex services such as frequency regulation. Most notably, in the Parker project an EV fleet provided frequency containment regulation in the Danish market, using commercially available EVs and V2G technology [8].

However, there still exist technical barriers that need to be overcome, which come from the lack of both (i) real-time monitoring of distribution grids and the communication standards, and (ii) requirements of EV capabilities. In the latter case, many studies have proposed the use of bidirectional chargers, even with reactive power compensation capabilities. However, these chargers are still not a mature technology and they still need improvements for the reduction of costs and losses [9].

Also, battery degradation can represent a major impediment for V2G-based services, as V2G-induced additional battery cycling can reduce the battery's expected life. Battery degradation is a complex process, ruled principally by two behaviors: calendar aging, and cycling aging [10]. Though calendar aging is seen as the major factor in battery aging, V2G might significantly reduce battery life if not used properly [11]. The effects of distribution flexibility services in battery aging still need to be studied, as frequency services are more related to power reserve, while distribution services will involve energy provision.

Finally, the development of grid services require advanced metering, control and transactional communication that involve several agents: EVs, charging stations, aggregators, DSOs, Transmission system operators (TSO), and other market players. Increased observability in the distribution grids and widely accepted communication protocols and standards that support the necessary information exchanges (such as V2G support) are required to enable the provision of flexibility. Smart meter rollout in most of European countries [3] and new communication protocols, such as future ISO 15118 for EV-EVSE communication, will help overcome these barriers.

ECONOMIC ASPECTS

Understanding economic and regulatory aspects is crucial for a successful EV integration and the development of robust business models on flexibility services. These are related to the evolution of policy and regulation that will allow and encourage flexibility provision at the local level, not only from EVs but from other types of DERs as well, and the interactions between stakeholders, namely DSO with aggregators as service providers and with TSO.

DSO evolving roles and responsibilities

Historically, the DSOs operated radial grids with unidirectional power flows, from the transmission grid to end-users, where main concerns, congestion and voltage issues, were addressed by investing in grid reinforcements, through a “fit-and-forget” approach. A regulatory framework that remunerates DSOs based on their total costs, inciting them to invest in costly infrastructure to solve grid issues, reinforces this [3].

However, the surge of DERS and digitalization, are making DSO's roles and responsibilities to evolve towards an active management of distribution system operation [12]. With this approach flexibility management at the local level can avoid costly reinforcements and have a more efficient use of existing assets. Regulatory frameworks for DSOs need to evolve to incite cost efficiency, quality of service and innovation [13], enabling smart and flexible solutions.

In recent years, European regulators have had increasing interest in the use of flexibility at the distribution level. A major step forward was the EC Clean Energy Package that explicitly stated the need for DSOs to procure flexibility [14].

Flexibility Frameworks

Currently EV flexibility is exploited in existing markets for system-wide ancillary services. Existing commercial applications can be found for energy portfolio management [15] and system balancing [8] [16]. However, currently there are no frameworks for accessing flexibility at the distribution level.

In particular, the frameworks for flexibility procurement by DSOs can be divided in the following categories [17]:

Rule-based

This approach uses rules and grid codes to impose flexibility requirements. Reactive power compensation by charging infrastructure has been proposed as a grid requirement in [18] to provide voltage support. However, this measure may pose an unfair requirement on electricity vehicles against other resources.

Network Tariffs

This mechanism provides an indirect value for flexibility, as it provides incentives to encourage end-users to adapt their consumption. These tariffs can reflect the costs of distribution system, giving incentives for the development of different forms of demand side response mechanisms.

The most common studied tariffs are Time-of-Use or Peak/Off-Peak tariffs. Though these tariffs provide the incentives to shift EV load from peak to off-peak hours, they can create local congestion or voltage issues due to synchronisation of the EV charging process during the beginning of the off-peak period.

More complex tariff structures have been analysed in the literature, such as dynamic day-ahead tariffs [19] or Distribution Locational Marginal Prices (DLMP) [20], having positive results in simulations but may have difficult practical implementation. Complex tariffs may present issues on transparency and stability of end-user tariffs [21], and in the case of DLMP, they may go against the equalization principle that exist in some European countries (*principe de péréquation* in France).

Connection Agreements

In this case, DSO and customer may reach an agreement for the provision of flexibility. They may take the form of variable capacity contracts, where customers have interruptible or reduced connections during certain periods of the day or according to events such as local congestions. These contracts can benefit customers with lower connection costs and delays but may preclude their access to local or system-wide flexibility markets.

This type of contract was tested in the FlexPower project in Amsterdam, where public charging points have a reduced capacity during peak hours but benefit from an increased one the rest of the day. This leads to a better utilisation of grid assets and faster EV charging for customers during off-peak hours [22].

Market-based

In this approach, DSOs explicitly procure flexibility services from a market, either by long-term bilateral contracts or via a short-term market platform. This approach is preferred by regulators [17].

Bilateral contracts can enable the procurement of flexibility for medium to long-term horizon. In this case, DSOs identify flexibility requirements that will enable to defer or avoid costly reinforcements and procure flexibility, rewarding the availability and activation of it. This type of contract can be signed between DSOs and flexibility providers after a tender process or through over-the-counter contracts, if there are no sufficient conditions for the formation of a liquid market.

This approach has been taken by UKPN, the London area DSO, who adopted a "flexibility first" policy towards all new investments in medium and high voltage (over 10 kV). They have identified grid sections where the use of flexibility during certain critical periods (in winter, during peak load) could help defer reinforcements, and have subsequently organized a tender process to procure flexibility from DERs. Currently, the 2018/2019 tender process will seek to procure up to 206 MW of flexibility to be used during the winter season of 2019-2020 (6 month ahead tender) and 2020-2021 (18 month ahead tender), and their Flexibility Roadmap [23] establishes the contracting of short-term flexibility during 2019. French DSO Enedis is following a similar approach, launching a consultation to develop their own local flexibility auction process [24].

Table 2: Frameworks enabling DSOs the access of flexibility

Framework	Value	Examples	Benefits	Risks
Rule-based	No value	Reactive power compensation	Useful where no market solutions	Technology bias Inefficiency
Network Tariffs	Indirect	Peak/Off-Peak Dynamic Pricing, DLMP	Incentives for all users	Don’t solve local issues Equalization principle
Connection Agreements	Direct	Variable Capacity Connections	Expedite connection process Lower connection costs	May preclude access to flexibility markets
Market based		Bilateral Contracts Local flexibility platforms Local Energy Markets	Preferred by regulators Competitive and transparent Foster innovation	Reduced size of local markets

Mechanisms to trade flexibility within a short time frame (day-ahead or intraday) have been proposed in the literature and various demonstrator projects (IDE4L [25], INVADE [26] and Interflex [27]), in particular in the form of flexibility market platforms. In these projects different flexibility sources can participate to provide services to various stakeholders, such as DSOs, TSOs or Balancing Responsible Parties (BRP).

Having a market-based approach arises the issue of product definition and procurement. For this, flexibility products should be defined, in particular the power (active or reactive), duration and location requirements. It should enable the participation of different flexibility sources, not only EV, but all DER.

Also, market-based approaches might not be suited for all distribution-level services, as small size markets may lack sufficient competition and can suffer from high transactional costs, for example at the low voltage scale.

Table 2 resumes the four frameworks for flexibility procurement, with their main benefits and risks.

Interactions between stakeholders

This aspect relates to how the different stakeholders interact along the flexibility value chain. On one side, there is the interaction between providers of flexibility and customers of flexibility, in this case EV users and DSOs respectively, and whether there is direct interaction or through an aggregator of flexibility. On the other hand, there is the interaction between two possible customers of flexibility, in this case DSOs and TSOs, and how their level of coordination and cooperation affect the use of local flexibility.

The SmartNet project studied DSO-TSO coordination, analyzing five possible coordination schemes. Different schemes appeared according to the cooperation level of both entities, their role and responsibility definition and the level of integration of markets (centralized or decentralized). In particular, higher coordination schemes are necessary for the participation of DER, such as EV fleets, to both global and local flexibility markets [28].

SOCIAL ASPECTS

Social aspects of EV as flexibility sources for electricity grids are often overlooked or misrepresented in academic studies and demonstration projects, but are key for the success of its deployment [9].

On one hand, to evaluate impacts and flexibility potential of EVs it is necessary to have good knowledge on user behavior. This refers mainly to how EVs are used (driving patterns) and how much and where they are charged (charging patterns). On the other hand, mobility is and will continue to be the primary purpose of electric vehicles. Flexibility services should be designed to meet driving requirements and work should be done to increase end-user awareness, to ensure user acceptance. Demonstrator projects of great utility, as they provide insight inot real end-user data [4] and raise awareness of flexibility solutions [29].

CONCLUSIONS

The massive integration of EV into electricity grids will pose serious challenges, in particular to distribution grids. However, they present a great opportunity for active management of the grid, by using smart charging and V2G. EV flexibility has value for distribution grids as it can defer or avoid costly reinforcements and provide a more efficient use of existing assets.

EV flexibility has been proven technically, and technology is rapidly advancing to overcome technical barriers on EV technology, ICT protocols and observability.

For this reason, main barriers for the provision of distribution flexibility services by EV fleets are economic and institutional. These barriers are the need for DSOs roles and responsibilities to evolve from a “fit-and-forget” towards an active management approach, and the lack of frameworks to valorize flexibility at the distribution level. However, significant advances have been made in recent years. There has been an increasing interest of regulators on the local management of flexibilities by DSOs, the development of local energy communities and increased DSO-TSO coordination. Mechanisms that enable DSO to access flexibility are emerging, most notably with the local flexibility auctions in the UK. Also, technical and economic aspects have been addressed by several European demonstrator projects in the last five years, demonstrating new technical solutions for distributed flexibility, including EVs, while analyzing and proposing new frameworks for flexibility procurement.

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