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REVIEW

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Mind the gap- open communication protocols for vehicle grid integration

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Abstract

Mass adoption of battery electric vehicles (BEVs) and their associated charging requirements introduce new electricity demand, which needs to be managed to minimise electricity grid upgrades. Management of BEV charging requires coordination and communication between various mobility and energy entities. Communication protocols provide a set of rules and guidelines to facilitate the communication and data exchange between two or more entities to ensure successful charging demand management and electricity grid integration of BEVs. A key challenge is that companies are currently developing and implementing several proprietary protocols to manage BEV charging, which could risk losing or vastly under-utilising BEV charging demand flexibility, and consequently hindering proper grid integration. This work presents the status quo on communication protocols and standards for vehicle grid integration and it is targeted for industries and governments. The objectives of the work are to review current protocols, present some of the advantages of open protocols, identify challenges and additional efforts required to develop, implement, and standardise these protocols to ensure that charging infrastructure for electric vehicles is synergistic with the operation of the electricity system.

Keywords: Electric vehicle, Charging infrastructure, Vehicle grid integration, Smart charging, Open communication protocols, Standards, OCPP, ISO 15118, OpenADR, Third party operator

Background

Battery electric vehicles (BEVs)[1] can break our dependence on fossil fuels in both transport and electricity sectors.

BEV mass adoption and the associated battery charging requirements introduce new electricity demand, which needs to be managed to minimise electricity grid[2] upgrades (Fernandez et al. 2011; Calearo et al. 2019). Managing charging demand include shifting BEV charging from existing electricity demand peak, avoiding creating new local electricity demand peaks, and aligning BEV charging with renewable energy generation (e.g. daytime workplace charging using solar energy).

[1]Compared to a conventional liquid-fuel car, a BEV uses an electric motor and electricity stored in an on-board battery, instead of an internal combustion engine and fossil fuel to transport people and light goods around.
[2]Electricity grid; power grid; or electricity network is an interconnected network for delivering electricity from producers to consumers.

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There is an inherent flexibility in BEV charging demand that facilitates management strategies to reduce reinforcement needs and increase renewable energy integration into electricity systems. This flexibility is due to cars being typically parked for long periods of time and BEVs' battery capacity is in excess of most daily driving requirements (Neaimeh et al. 2015; Idaho National Lab 2016; Kempton 2016; Hardman et al. 2018; Quiros-Tortos et al. 2018).

Cars are routinely parked for most hours at home and the workplace, where the majority of battery charging demand could be met (Fig. 1). Therefore, home and the workplace are key locations at which charging management is required to ensure successful electricity grid integration of BEVs.

It must be noted that the parking time of BEVs can only be exploited under certain circumstances when charging equipment is present, the duration is sufficient for the charging process to be flexible and that the BEV is actually plugged in (which may require a user incentive).

Communication requirements for BEV charging management- data, protocols, entities

The focus in this work is on the integration of BEVs into electricity grids and the immediate communication links that need to be established to facilitate BEV charging management strategies. Protocols facilitating electric mobility roaming- allowing EV drivers to charge their vehicles at all non-private charging stations (Ferwerda et al. 2018) are not in scope of this work.

Management of BEV charging at residential and workplace locations requires increasing need for coordination and communication between various mobility and energy entities (Fig. 2, Table 1). Specifically, informational and control objects need to be exchanged between BEV chargers and entities to allow electricity system support, such as electricity demand peak reduction. Information such as car identification; battery state of charge (SoC); battery size; energy required for next trip would flow up across entities. Based on that information, and on information collected from the electricity system infrastructure (e.g. frequency, current, and voltage data)(Zhang et al. 2018), chargers' power set points are determined and sent down to control the charging process, ensuring proper integration of vehicles into the electricity grid. Such control should be dynamic so that a change in set points can be executed within seconds and ultimately as a sub-second response as required by some grid services (COTEVOS White Book 2016; Andersen et al. 2019).

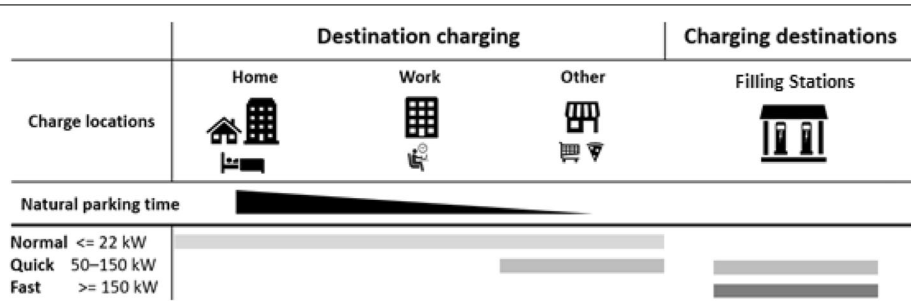

Fig. 1 Typical charging locations for private passenger BEVs. Home (i.e. residential) charging locations include private locations such as garages and off-street parking, and public locations such as on-street parking. When charging infrastructure at home and work (typically <= 22 kW) is neither available nor practical to meet charging demand, quick and fast chargers (50–150+ kW) located at "Other" locations such as supermarkets, and filling stations in urban areas and along long-distance travel corridors can be used to meet charging needs (Neaimeh et al. 2017; Nicholas and Hall 2018; Danish Electric Vehicle Alliance and DTU 2019)

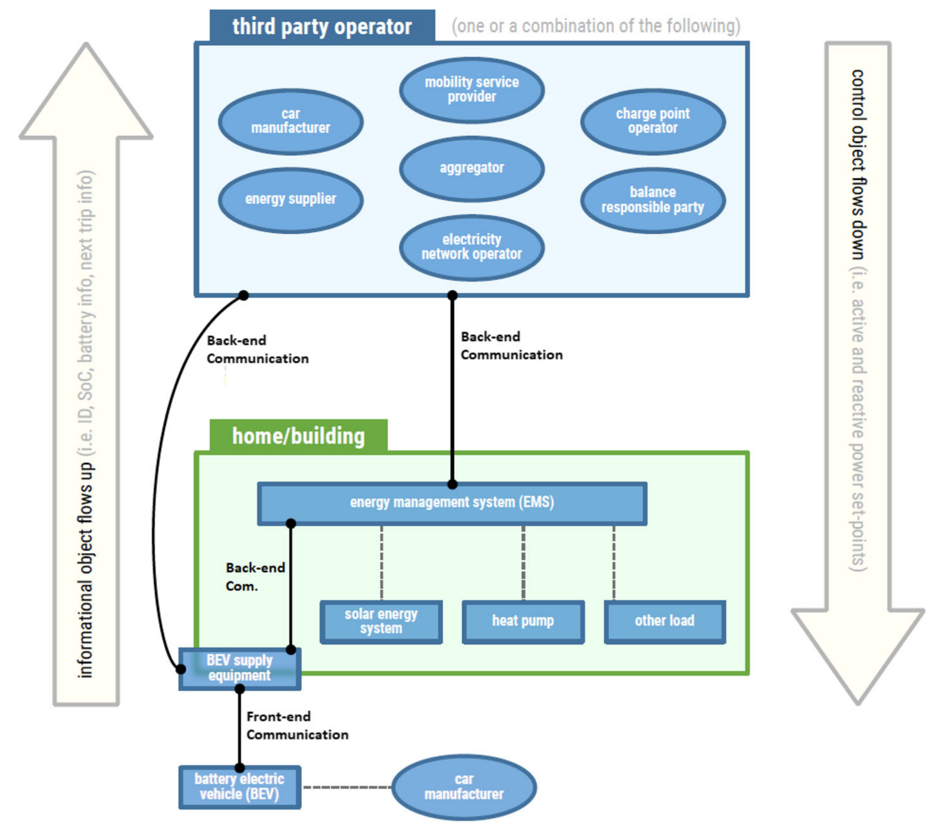

Fig. 2 Various EV ecosystem entities connected by communication protocols. Information and control objects must flow through entities to ensure proper grid integration. A direct communication link between a third party operator and charge points (referred here as BEV supply equipment) is specifically applicable for public charging infrastructure such as residential on-street chargers. For private charging infrastructure, we argue that communication to the charger would go through an EMS to optimise multiple resources co-located with BEVs (i.e. heat pumps, solar energy systems) at home or a workplace campus

Communication protocols provide a set of rules and guidelines to facilitate communication and data exchange between two or more entities. A protocol would define the interface between two or more interacting entities to ensure compatibility between these different systems (Krechmer 2008; Ferwerda et al. 2018).

Communication protocols linking various entities in the electric vehicles (EVs)' ecosystem can be divided into front-end and back-end protocols (Schmutzler et al. 2013). Front-end protocols define the link between car and charge point and specify requirements for plugs; charging topologies (on-board/off-board charging equipment; conductive/inductive charging); communication; safety and cyber-security. Back-end protocols, emphasising communication and cyber-security requirements, define the link between charge point and a third party operator.

Communication protocols can be proprietary- developed by private consortia; or they can be open- developed by public standard development organisations, or open alliances.

Table 1 Description of EV ecosystem entities as illustrated in Fig. 2

Entity	Description
Car manufacturer	Complying with electric mobility (e-mobility) protocols.
Battery Electric Vehicle (BEV)	Implementing various e-mobility protocols.
Electric Vehicle Supply Equipment (EVSE)	Enclosing charge controller (microcomputer) implementing e-mobility protocols. A charge point could contain one or more EVSEs.
Energy Management System (EMS)	Monitoring, controlling and optimising energy consumption and generation at a location such as home.
Third party operator	Container of various mobility and energy entities as illustrated in Fig. 2 and described in Advantages of open communication protocols.
Electric Mobility Service Provider (eMSP)	An entity which holds a contract with the BEV user for all services related to charging.
Charge Point Operator (CPO)	Central system entity which operates and manages charge points.
Energy Supplier	An entity selling electricity to consumers in compliance with regulations for electricity market organisation.
Balance Responsible Party	An entity which is financially responsible for the real-time net balance of electricity supply and demand.
Electricity (distribution and/or transmission) Network Operator	An entity operating, maintaining and investing in electricity networks, in compliance with regulations and standards on electricity supply quality and security.
Aggregator	An entity responsible for aggregating many distributed energy resources, including BEVs, to provide power system services to various third-party entities.

Review of communication protocols for vehicle grid integration

A review of communication protocols for vehicle grid integration is presented in Table 2. The protocols are briefly described and their location in the grid integration protocol structure is indicated. Specifically, a front-end protocol is a protocol covering the communication link between EV and EVSE and a back-end protocol is a protocol covering the communication link between EVSE and a third party operator (e.g. charge point operator). For back-end protocols, EV-domain specific protocol or a generic protocol covering distributed energy resources including EVs is indicated. Table 2 also includes some examples of protocol implementations and indicates some gaps in the protocols.

Moreover, the protocols are assessed using properties of openness, interoperability, maturity and market adoption. The specification of these properties and their assessment are mostly based on a previous protocol study, published by ElaadNL, where more detail can be found (Elaad 2016). Openness indicates if a protocol has been developed by an accredited standards organisation; whether it is subject to intellectual property (IP) rights; and if it is publicly accessible at no (or minimal) cost (Elaad 2016). Openness can also facilitate the possibility for different e-mobility entities to participate in protocol development process (Krechmer 2008).

Interoperability is the ability for multiple systems to work together without restriction (EPRI 2019). It can be captured by the amount of effort required when replacing one of the entities (e.g. charging station) in a communication link. This encompasses aspects such as technical interoperability (syntax and semantics); definition of the expected

Table 2 Protocols for vehicle grid integration (commonly used and under development) and their assessment on properties of openness, interoperability, maturity and market adoption

Description	Openness	Interoperability	Maturity	Market adoption	Gaps
IEC 61851 (*Front-end protocol*) Cross-cutting standard across charging topologies, safety and communication (Martinenas et al. 2017). The International Electrotechnical Commission (IEC) is an international standards organisation that prepares and publishes international standards for all Electrotechnology.	*High*	*High*	*High* Can be tested and certified at different test laboratories (Elaad 2016).	*High* Every EV in Europe supports the standard.	Advanced data exchange (e.g. meter readings, tariff information, etc.) necessary for advanced smart charging strategies is not possible.
ISO 15118 (*Front-end protocol*) Communication protocol allowing more advanced form of communication compared to IEC 61851 between EV and charging station. For example, ISO 15118 defines requirements for charging load management; metering and billing. ISO 15118 includes wired (AC and DC) and wireless charging applications. One main feature of ISO 15118 is using digital certificates to secure the communication. The protocol also allows automated authentication & authorization (ISO 2013; Elaad NL 2018; Mültin 2019a). ISO 15118 is part of the Combined Charging System (CCS), which is a set of hardware and software standards for charging systems. ISO, the International Organization for Standardisation, is an international standard-setting body composed of representatives from various national standards organisations.	*High*	*High*	*Medium* No official certification is available yet. Regular testing events (TS Testing Symposium 2019). Open source implementation (Mültin 2019b).	*Low* Research and development (R&D) implementations of smart charging and V2G functionality(Elaad 2019). Received support from several major automotive companies (CharIN e.V. 2017).	Upcoming edition (ISO 15118-20) is likely to be published end 2020 and will define use cases for bidirectional power transfer. First market implementations expected in 2023/2024 (Mültin 2019a). State of Charge information will remain optional but the car would communicate the energy amount necessary to fully charge (Mültin 2019a).

Table 2 Protocols for vehicle grid integration (commonly used and under development) and their assessment on properties of openness, interoperability, maturity and market adoption *(Continued)*

Description	Openness	Interoperability	Maturity	Market adoption	Gaps
CHAdeMO (*Front-end protocol*) Communication protocol maintained and developed by the CHAdeMO organisation. The protocol is used for DC charging and the v2.0 specification includes the possibility for bidirectional power transfer and the exchange of battery's state of charge (CHAdeMO 2019a). The protocol is available to paying members who can gain access to the source code needed to implement it but are not able to update/branch the code. The CHAdeMO protocol adheres to IEC 61851–23 (DC EV charging station) and IEC 61851–24 (Digital communication between a DC EV charging station and an EV for control of DC charging) (Martinenas et al. 2017). But these do not provide sufficient detail to fully implement the protocol. In 2019, CHAdeMO announced that it is co-developing the next generation ultra-fast EV charging standard called ChaoJi in collaboration with China Electricity Council (CEC) who is behind GB/T standard for EV charging in China (CHAdeMO 2019b)	*Medium*	*Medium*	*High*	*High* R&D and market implementation of CHAdeMO in V2G projects in Japan, UK, Denmark(Christensen 2018; UK Government 2018; Andersen et al. 2019; Octopus EV 2019; OVO Energy 2019).	CHAdeMO lacks secure communication features (Martinenas et al. 2017).
Open Charge Point Protocol (OCPP) *(back-end Protocol; EV-domain specific)* De-facto (as opposed to de-jure) standard for communications be-tween an EV charge point and a	*Medium/high* Medium because OCA is not accredited.	*High*	*High* Testing tool and certification of OCPP 1.6 is possible (Open Charge Alliance 2019b).	*High* Market implementations by many vendors in Europe and parts of the United States.	Lacks bidirectional power flow commands. On-going work to include it in upcoming versions of OCPP (de Leeuw 2019).

Table 2 Protocols for vehicle grid integration (commonly used and under development) and their assessment on properties of openness, interoperability, maturity and market adoption *(Continued)*

Description	Openness	Interoperability	Maturity	Market adoption	Gaps
central system operator (e.g. CPO). Some of the features of include support for external smart charging control signals. OCPP 2.0 implements enhanced security features. OCPP is available from and maintained by the Open Charge Alliance (OCA), which is not an accredited standards organisation (Open Charge Alliance 2019a; de Leeuw 2019).					
IEC 63110 *(back-end Protocol; EV-domain specific)* Protocol for management of EV Charging stations. It standardises the communication between charging station and a charging management system (IEC-TC69 2018; Bertrand 2020).	*High*	*High*	*Low*	*Low*	At an early stage of development. Might become the de-jure successor of OCPP.
Open ADR *(back-end protocol, generic)* Open Automated Demand Response (ADR) allows demand response service providers to communicate signals directly to existing customers using a common language and existing communications such as the Internet. For example, communication between a third party operator and an EMS. Open ADR allows manufacturer-independent and secure communication and it is available from and maintained by The Open ADR Alliance (Ghatikar and Bienert 2011; OpenADR Alliance 2019; Bienert 2019).	*High* The IEC approved the Open ADR 2.0b Specification as a full IEC standard, to be known as IEC 62746–10-1 ED1(IEC 2019).	*Medium* Generic description making it less interoperable	*High* The OpenADR Alliance has partnered with several international test houses required for certification.	*Medium/High* Increasingly being used on projects with EVs in R&D and market implementations. Open ADR mostly used in combination with OCPP (Ghatikar 2016; Hoekstra et al. 2016; Aylott 2019; Klein Koerkamp 2019).	Additional work required for alignment with complementary protocols (e.g. Open ADR- OCPP) Program Guides required for EV use cases (this links to the protocol being generic).

Table 2 Protocols for vehicle grid integration (commonly used and under development) and their assessment on properties of openness, interoperability, maturity and market adoption *(Continued)*

Description	Openness	Interoperability	Maturity	Market adoption	Gaps
IEEE 2030.5 (IEEE adoption of Smart Energy Profile SEP2) *(Front-end; Back-end protocol, generic)* IP-based protocol with documentation available describing how it can be applied to EV smart charging (Elaad 2016; IEEE Standards Association 2018; Lum 2020). Used for the communication between EV and EVSE (i.e. front-end) in some R&D projects in the US (Chhaya 2015). Allow manufacturer-independent, secure communication between a third party operator and customer installed equipment such as EMSs, solar systems and EV charge points (IEEE Standards Association 2018). The Institute of Electrical and Electronics Engineers (IEEE) is a professional association for electronic engineering and electrical engineering.	*High*	*Medium* Generic description making it less interoperable	*High* Test tools available and used in a conformance test program by nationally recognized testing laboratories in the US and Korea (Elaad 2016; International ZEV Alliance et al. 2019).	*Low* Limited use with EVs outside R&D implementations.	Program Guides required for EV use cases. If used as a front-end protocol, it lacks additional use cases such as automated authorisation &authentication.
EEBUS *(Back-end Protocol; generic)* Allow manufacturer-independent, secure communication between a third party operator (e.g. DSO) and customer installed equipment such as EMSs, solar systems and EV charge points (EEBUS Initiative e.V. 2019) EEBus is available and developed by the EEBus Initiative e.V.	*Medium/high* The EEBus Initiative e.V. is not an accredited organisation, but "the working groups ensure that only what is necessary is standardized."	Not able to assess.	*Low*	*Low* Limited use with EVs outside R&D implementations. E.g. Global Grid Integration Project (Bienert 2019).	Program Guides required for EV use cases.

Table 2 Protocols for vehicle grid integration (commonly used and under development) and their assessment on properties of openness, interoperability, maturity and market adoption *(Continued)*

Description	Openness	Interoperability	Maturity	Market adoption	Gaps
Several companies have developed their **proprietary back-end communication protocols** (for example, by extending on OCPP) (Christensen 2018; Astorg et al. 2019; Indra 2019; Octopus EV 2019; Nissan Energy 2019).	*Low*	*Low*	*Low*	*Low*	Diverse and proprietary protocols would lead to disjointed charging control strategies by managing different subsets of BEVs separately. This could risk losing or vastly under-utilising charging demand flexibility.

The protocol names are highlighted in boldface

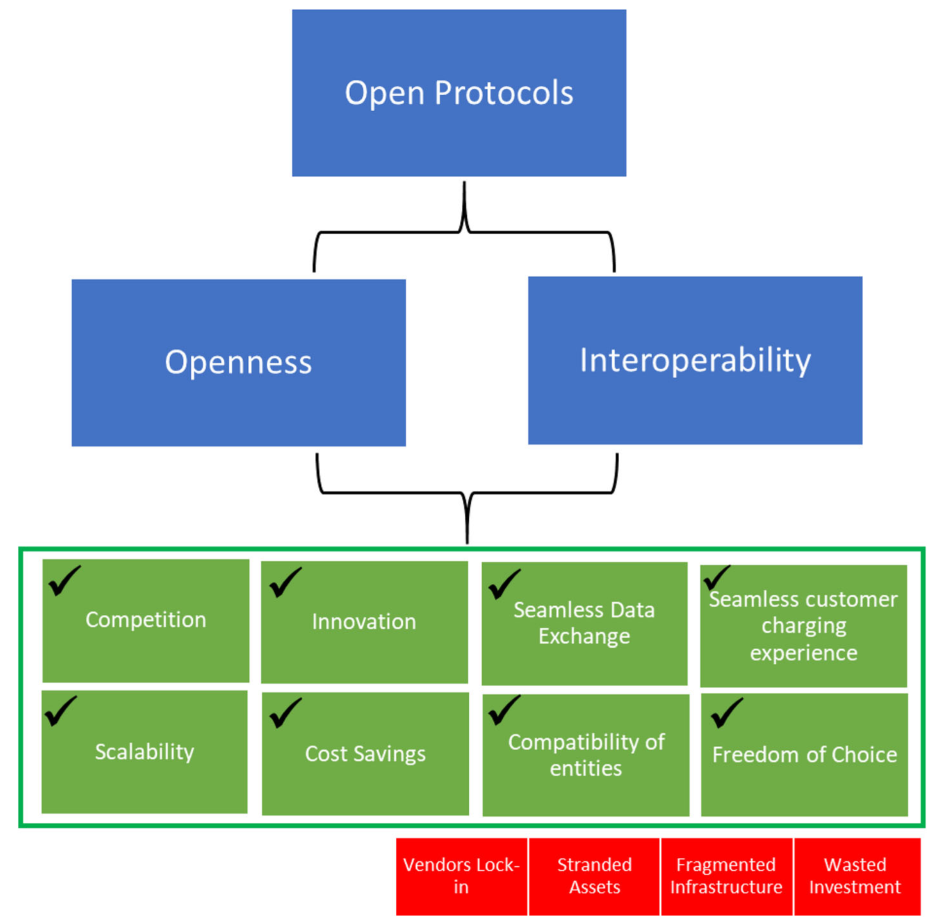

Fig. 3 Open protocols are a building block for a fit for purpose and future proof BEV charging infrastructure

behaviour of a protocol (e.g. detailed description vs generic description making it less interoperable); and clarity of specifications. Maturity indicates number of releases, time in use, certification possibility (at an official test laboratory); availability of a testing tool. Finally, market adoption is based on current numbers of users of the protocol.

Scoring different properties of the protocols is done using low/medium/high scale. Maturity and market adoption are considered within the context of EV market adoption, which is still low. Consequently, a high market adoption of an EV communication protocol can't be compared to the market adoption and maturity of other protocols such as WiFi. In addition, the emerging EV market means that extensive statistics on utilisation of protocols is not possible, especially that many of the protocols don't have yet an official certification in place (Elaad 2016).

Advantages of open communication protocols

While market share of electric vehicles is low and before they enter mass market (IEA 2019), there is a window of opportunity to shape charging infrastructure, norms and regulations so that BEVs can meet drivers' needs and support power system operation.

A building block for a fit for purpose and future proof charging infrastructure is the adoption of protocols that score high on interoperability and openness (characteristics defined in Review of communication protocols for vehicle grid integration).

Interoperability and openness facilitate an integrated infrastructure of compatible entities; seamless data exchange; freedom of choice; cost savings; better services; competition; innovation; and scalability (Fig. 3). These possible outcomes of interoperability and openness, described by some examples below, are intrinsic to properly defined and implemented open protocols and facilitate widespread BEV adoption and appropriate vehicle grid integration.

Interoperability of front-end and back-end entities warrants that the interface between these interacting entities is compatible and support an open path from third party operators down to the charger to ensure seamless flow of information and control commands facilitating grid integration strategies (Fig. 2).

Moreover, interoperability enables freedom of choice. For example, a fleet manager is not limited to purchasing certain types of charging stations because of the car brands in their fleet. Interoperability also enables freedom of switching products, companies or operators, while ensuring that a charging system/strategy would function as intended, without necessarily having to replace relevant equipment or undertake significant programming to re-establish the compatibility of the interface between interacting entities. This would avoid situations where controllability of charge points could be disabled if a third party operator implementing a proprietary protocol is changed. As such, interoperability would lead to cost savings and better services and charging experience by helping prevent vendors' lock-in, fragmented charging infrastructure; and minimise wasted investment in stranded assets (Ghatikar 2016).

Openness sets a level playing field for all EV ecosystem players and enable cost savings, competition, and quicker innovation.

Companies can save costs by collaborating to develop the bulk of grid integration protocols, removing competition for shared groundwork, then use their resources to customise their customer offerings and compete to provide better services to customers. An example of openness related to the car industry is the development and adoption of Automotive Grade Linux (AGL) by some of the largest car companies. AGL is a joint effort between automakers, their suppliers and technology companies to develop an open platform for infotainment and connected car systems. The aim of the open platform is to provide a bulk common groundwork for all participants and enable them to focus their resources on customizing their unique product (Linux Foundation 2019).

Openness allows for quicker innovation by opening up the market to new agile and disruptive entities (e.g. aggregators) and allowing existing energy and car companies to evolve and re-invent their roles to catch-up up and survive in a changing environment (Hughes 1987). Some examples of change include consumers producing and selling energy; and energy suppliers and network operators exploring greater controllability of what could be the new biggest source of electricity sales (i.e. electrification of road transport).

To consider new and evolving roles supporting innovation, a third party operator of a charge point is represented in Fig. 2 by a container of various mobility and energy entities. This is in contrast to considering current market players that could control chargers as separate entities. A third party operator could be one entity, which is assuming new roles of several different entities. Some examples include a UK energy supplier who is assuming additional novel roles of charge point operator and aggregator (OVO

Energy 2019); and network companies in California who are investing in BEV charging infrastructure programs made possible by recent regulation changes (California Public Utilities Commission (CPUC) 2018). Moreover, a third party operator could be constituted by one or a combination of several entities collaborating to optimise charging events (e.g. a collaboration between a car company and an energy supplier). Openness is key for quicker innovation by facilitating collaboration between entities and enabling new roles and responsibilities to adapt to the changes in the energy and transport sectors.

As opposed to proprietary protocols for BEV charging, open communication protocols- scoring high on openness and interoperability seem to be already the norm in the Netherlands. The Dutch experience can provide insights on the importance of open protocols from real world implementations. For example, open communication protocols were used to control 800 charge stations in the Netherland to minimise the impact on local electricity networks. Adopting open protocols facilitated the deployment of charge stations from several different suppliers, who implemented OCPP on their charge stations (Geerts et al. 2019). In addition, while the control signal came from the distribution network operator, the adoption of open communication protocols would allow different entities in the future to control the charging, such as an energy supplier (Geerts 2018; Elaad 2019; Geerts et al. 2019; Zweistra et al. 2020).

Challenges facing open communication protocols adoption for vehicle grid integration and recommendations for required efforts

Despite advantages of open communication protocols, overcoming challenges is required to ensure that market adoption of these protocols increases with the increase of BEV uptake. Some of the challenges and examples are presented below, followed by recommendations for required efforts.

Adopt open over proprietary communication protocols

A key challenge facing the adoption of open communication protocols for vehicle grid integration is that companies are currently developing and implementing their own proprietary communication protocols.

Central to widespread vehicle grid integration is to ensure that any BEV can communicate with any charge point and participate in advanced (e.g. dynamic) smart charging strategies (i.e. strategies going beyond stopping/starting the charger). Consequently, BEVs and charge points would need to speak a universal language as opposed to diverse vendor-specific communication protocols. Currently, front-end communication protocols allowing advanced charging management strategies are either semi-open (e.g. CHAdeMO, Table 2), or standards that are not yet implemented outside small scale trials (e.g. ISO 15118 in the Utrecht V2G trial (Elaad 2019)). In addition, most market implementations of back-end protocols to control charge points for smart charging strategies are proprietary (Christensen 2018; Astorg et al. 2019; Indra 2019; Octopus EV 2019; Nissan Energy 2019).

Adopting open front-end and back-end protocols is critical for coordinating BEV charging demand in local electricity grids where these cars are connected (e.g. residential and workplace electricity grids). Demand management strategies would need to integrate different car makes at a workplace location and/or integrate different charge point brands of different customers on one street to provide coordinated grid support to the local distribution network (grid) operator, whose responsibility is to ensure reliable and secure electricity supply. If every company is developing and deploying its own communication protocol as opposed to car and charge points speaking universal languages, then coordinating charging towards a common goal (e.g. avoid creating a new peak demand) would be difficult. It would be difficult for an entity coordinating BEV charging across an area, such as an aggregator, to control charge points from different manufacturers adopting various proprietary communication protocols. Consequently, diverse and proprietary protocols would lead to disjointed charging control strategies by managing different subsets of BEVs separately and could risk losing or vastly under-utilising charging demand flexibility.

To minimise or avoid disjointed charging management strategies, it is recommended that various EV ecosystem entities would need to implement standardised open protocols. An example relating to front-end protocols is that car companies and charge point manufacturers would both implement ISO 15118 and facilitate the exchange of required data to benefit from the provisions of the protocols.

Tackle protocol-specific and in-between protocols gaps

While some companies might not be aware of open protocol developments or choose not to adopt them to retain first mover market advantage, there are technical gaps in the open protocols that might justify why some innovative companies won't wait for a common technical-ready protocol to emerge to develop products. Some open protocols are at an early stage of development (e.g. IEC 63110), and other mature protocols include gaps preventing them from supporting innovative use cases. Furthermore, some gaps relate to how protocols link together. Examples of gaps followed by the recommendation are included below.

OCPP, a back-end protocol, doesn't yet define a use case for bidirectional power transfer and several companies are carrying out proprietary modification on OCPP to allow this innovative use case (Christensen 2018; Astorg et al. 2019). Instead of developing their own proprietary language, these companies could provide input to the Open Charge Alliance, which develops and maintains the protocol, on what is required to enable bidirectional charging in a future version of the publicly available OCPP.

Some additional work is required to align front-end and back-end protocols to facilitate implementing them together; for example, additional work is required to be able to combine ISO 15118 - OCPP and ISO 15118 - IEC 63110. In some instances, work is required to be able to combine two complementary back-end protocol such as OCPP, used between a charge point operator and chargers; and OpenADR used between a utility company (e.g. DSO or an energy supplier) and a charge point operator (de Leeuw 2019; Bienert 2019).

Some alignment work required include adding or configuring message exchange between the protocols to ensure that neither protocol act as a bottleneck from the necessary information and control needed for dynamic charging. Moreover, there are no definitions for gateways between protocols and these should be defined to ensure reliable performance of the BEV ecosystem. For example, certain power system services require real time communication and control; yet, communication latency for a message transfer between ISO 15118 and OCPP is not yet defined.

Collaborative effort is required to tackle gaps in some of the described protocols (Kirpes et al. 2019). Instead of developing proprietary protocols, companies could implement, test and support the development of these protocols and contribute to their improvement.

Harmonise and converge towards common standards

A third challenge is the development and adoption of several open protocols for same use cases and functions which, similarly to proprietary protocols, could lead to several disadvantages hindering vehicle grid integration such as a fragmented charging infrastructure (Elaad 2019; International ZEV Alliance et al. 2019; Crisostomo 2019).

For example, EEBus or IEC 63110 can be implemented for the same communication link between an energy management system and a charging station. Similarly, ISO 15118 or IEEE 2030.5 can be implemented for communication between a BEV and a charging station. While there is an argument for the possibility of adopting different protocols in different regions, global manufacturers can save costs by implementing the same protocol in their products worldwide.

Similarly, wasted investment and potentially stranded assets can be minimised while rolling out charging infrastructure if there is clarity on which protocol to adopt. As an example of early roll out of charging infrastructure, Norway provided funding to roll out public Type 1 chargers before the European Commission (EC) introduced legislation to ensure that charging stations are equipped with at least Type 2 plug for AC charging (EU 2014; Ferwerda et al. 2018; International ZEV Alliance et al. 2019). Consequently, additional investment in new charging infrastructure would have been required to comply with the EC directive.

To increase scores of openness (e.g. a protocol has been developed by an accredited standards organisation) and interoperability of open protocols, additional collaboration efforts are required to harmonise existing protocols (Andersen et al. 2019), where harmonisation is the process of minimising redundant or conflicting protocols which may have evolved independently. Early harmonisation efforts would decrease the complexity of the task which would be required later on to harmonise several existing protocols for future convergence towards a common standard, which may ultimately be universally applied (e.g. at least, a European-wide standard).

Set up a platform for collaboration on vehicle grid integration protocols

Standardisation experts can argue that standards don’t provide interoperability, but it is a good start. In practice, standards might not be properly implemented and if there is anything left for interpretation in the specification of the protocol, then this might create implementation/interoperability conflicts. This raises the importance of specifying the standards in sufficient clarity and detail to ensure correct implementation. Moreover, conformance testing and official certification of products can indicate if products properly implement the standards; however, with new market conditions, conformance testing and certification is not common. As such, an interoperability gap can result from unknown consequences of protocol implementation in these new market conditions, if the open protocol is not tested at scale and negotiated between different entities in the EV ecosystem (e.g. electricity network operators and car manufacturers).

In efforts to help overcome some of challenges described in the section including minimising a possible interoperability gap, it is recommended that a new platform for collaboration on vehicle grid integration protocols is set up. This platform, whether sponsored by governments or industrial associations, would bring together key mobility and energy entities, who typically have limited interaction, to advocate for the adoption of open communication protocols and facilitate development and implementation of standardised protocols.

Conclusion and future outlook

Appropriate grid integration is key for successful widespread adoption of electric vehicles, while minimising associated electricity grid reinforcement costs and facilitating integration of renewable energy sources.

Open communication protocols linking various entities in the EV ecosystem facilitate compatibility and communication between different entities and equipment, which are key to ensure universal support for grid integration. In addition, open protocols could improve customer charging experience, save costs and allow quicker innovation to achieve our decarbonisation targets.

While in the short term, adoption and collaboration across several entities to develop open, technically-suitable, standardised communication protocols could be more complicated than developing diverse and proprietary protocols; in the long term, such collaboration ensures the roll out of a fit for purpose charging infrastructure.

Governments are recognising the importance of open protocols for electric mobility and are encouraging their adoption. Open protocols are already the norm in the Netherlands and advantages from adoption are already being demonstrated. In California, the state led Vehicle-Grid Integration roadmap encourages the use of open protocols to integrate EV charging needs with the needs of the electrical grid (California Energy Commission 2018). In the UK, secondary legislation following the Automated and Electric Vehicles Act is being prepared and there is an on-going debate on mandating the use of open protocols to manage charge points (UK Parliament 2018).

It is yet to be seen if industry realises the significance of open protocols and if some influential companies would take a leadership approach to steer the market towards adopting and developing open protocols. Alternatively, additional government intervention might be required to achieve a vision of open and standardised protocols.

Developments in other sectors indicate that over time the requirement to coordinate efforts become rather obvious and protocols could converge towards one or few standards voluntarily (Wiegmann 2013; Ferwerda et al. 2018). Consequently, whether such coordination requires facilitation through government policy might be debatable. Yet, learnings from the process of converging towards the Type 2 connector in Europe can be used to argue that legislation might ensure that industry adopt vehicle grid integration standards more quickly to ensure that charging infrastructure for electric vehicles is adaptable to future needs, cost-effective, and synergistic with the operation of the electricity system.

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