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Integration of Vehicle-to-Grid in Local Energy Systems: Concepts and Specific Requirements

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Summary

Electric vehicles have great potential to improve local air quality and reduce greenhouse gas emissions especially in combination with green electricity production. Vehicle-to-grid technology presents an opportunity to increase penetration rates of renewable energy sources by balancing their intermittent nature. Local energy systems, or microgrids, provide a clear use case for early adoption of vehicle-to-grid by executing energy balancing locally. This work focuses on how well the current standards and interoperable EV charging market fit the requirements of the specific case of vehicle-to-grid in local energy systems. The paper identifies and presents the possible configurations to integrate vehicle-to-grid into a local energy system. The paper presents further specific requirements of these configurations with regards to communication and compares them to the current standards for communicatiom in the European context.

Keywords: electric vehicles, charging infrastructure, vehicle-to-grid, local energy system, microgrid

1 Introduction

Electric vehicles have great potential to improve local air quality and reduce greenhouse gas emissions [1], especially in combination with green electricity production [2], [3]. With electric vehicle market slowly expanding, question arises whether current electricity grids will be able to accommodate largescale penetration of electric vehicles and if this will lead to increased electricity demands. Studies have shown that various ways of smart charging can reduce the load on the grid and would limit peak demands [4]. Furthermore, vehicle-to-grid (V2G) technology presents an opportunity to increase penetration rates of renewable energy sources by using electric vehicles' batteries for load balancing of the grid and deal with the intermittent nature of renewables [5]. Transition of the energy system towards a more distributed system where local energy systems (or microgrids), with local energy production and consumption, can increase the efficiency of the system, allow further integration of renewables, and reduce the interaction with the main electricity grid by local energy balancing. V2G technology can play an important role in this local energy balancing in local energy systems (LES), in case energy demand and mobility needs of the LES are of considerable size, could provide other ancillary services for the main grid. The following services have been identified for vehicle-to-grid: frequency regulation (active power control), voltage regulation (reactive power control), peak shaving and valley filling (demand side balancing), renewable energy system support (supply side balancing) [5]. Literature on this topic mostly focuses on control or scheduling algorithms and their potential economic benefits or associated cost and battery degradation without taking into account the current state of the market and technology, and their associated constraints and specific needs. However, they are subject to the specific local system set-up, the current technological developments of chargers and EVs, the communication standards, as well as the actors in the charging infrastructure market and regulatory aspects. This paper focuses on the specific constellation of the integration of V2G in a local energy system of considerable size and frames it within the context of the current market of interoperable charging infrastructure [6].

2 V2G concept in a LES

We consider a local energy system has one (or multiple redundant) connections to the distribution or transmission grid and manages electricty supply and demand locally with his own generation units and loads. Introducing storage in such a LES can increase the flexibility of the system to cope with local demand-supply imbalances. Introducing EV smart-charging and V2G technology adds to that flexibility under the form of additional fixed load, flexible load, or storage capacity depending on the driver requirements for charging. However, interoperable EV charging is usually currently organized in Europe with Charge Point Operators (CPO) controlling the charge process and charge points (CP) or electric vehicle supply equipment (EVSE), mobility service providers (MSP) governing contracts with drivers, and interoperability platforms, or HUBs, connecting different MSPs and CPOs [6]. The integration of EV charging into the local energy system optimization will have to take this into account in order to be able to get all the right information and control down to the level of the driver and vehicle. The central research question of this paper focuses on the technical and communication requirements to organise V2G in local energy systems and evaluates these requirements in the current implementation of the standards and organization of the EV charging market. Figure 1 illustrates the systems and central research question.

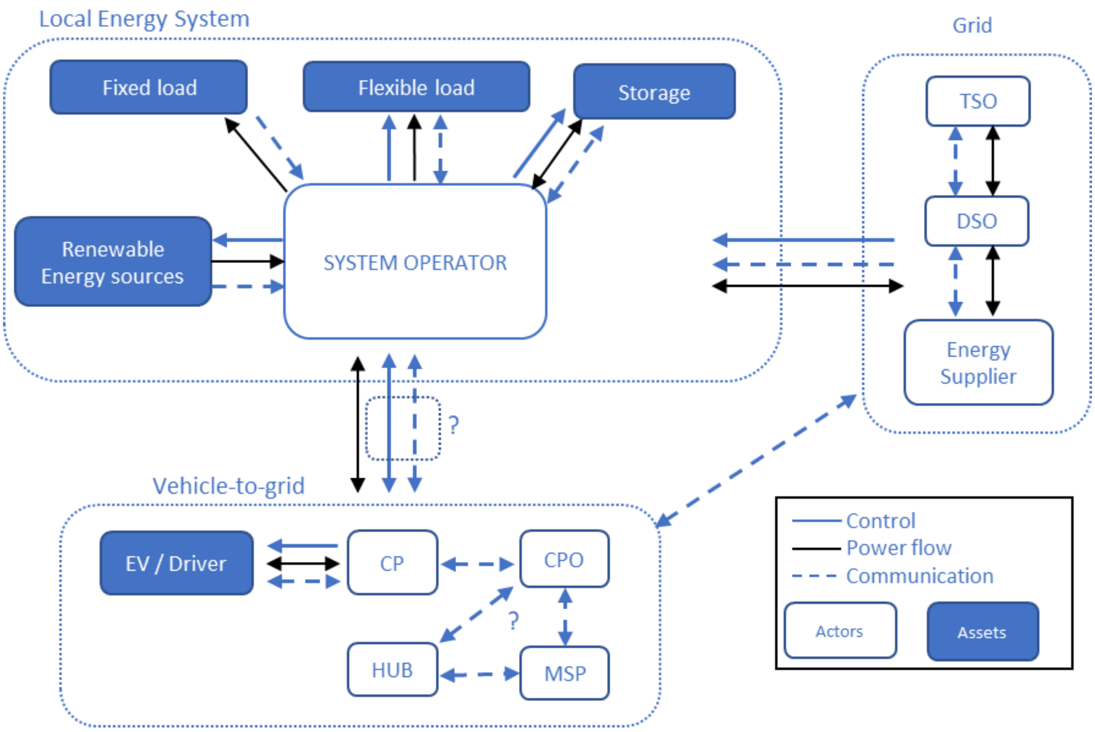

Figure 1: Illustration of the problem statement for the research conducted in this paper.

2.1 LES configurations for V2G application

The unique constitution presented in Figure 1 needs some further breakdown to fully understand the different ways V2G can be integrated into a LES. In this thought experiment (setup) we consider that the assets (such as renewables, generation units, and flexible consumers) in the local energy system are controlled by a system operator. We have indentified multiple configurations to organize V2G in a LES depending on the nature of the considered service for V2G, the relation the LES operator has or wants with the driver, its involvement in the charge process, and the degree of interoperability it offers for charging. These configurations offer variations to who determines the charging strategy (decision), and to who controls the charge point (execution). This means multiple configurations of the integration of V2G in a LES are possible, depending on the relation and interaction with the driver, who determines the charging strategy (decision), and on who controls (execution) the charge point.

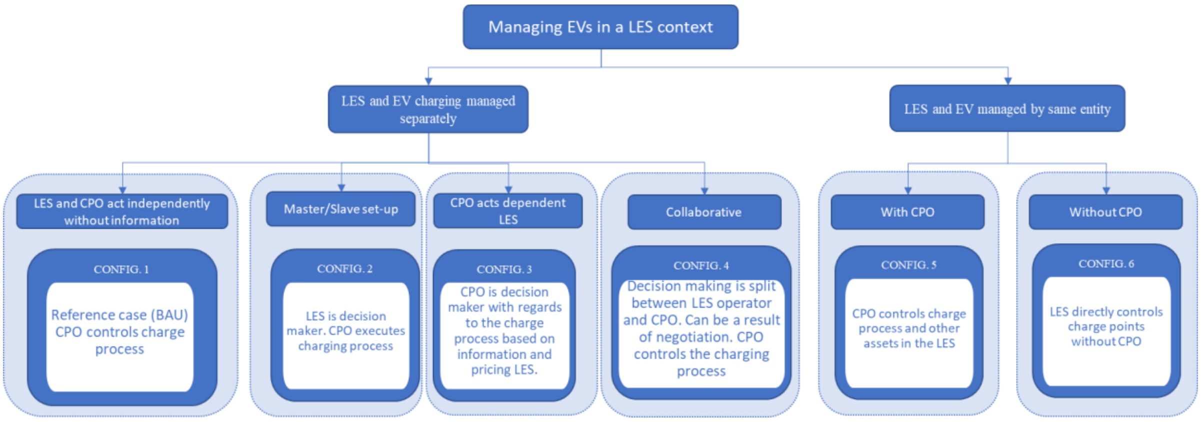

Figure 2: Tree showing the different possible configurations for the integration of V2G in a LES

The first distinction to make is whether there is an additional entity present that controls the charge process apart from the entity that manages the LES, a LES operator. If this is not the case, one operator will control the individual charge points, either in a centralized, decentralized or hybrid way. Literature has described ‘centralized’ and ‘decentralized’ control for V2G, where centralized control means that one entity has complete control on the charge process, decentralized control means that there is a back and forth communication between drivers and the unit to schedule the charge process [7], and hybrid control which is a mix of previous control strategies[8]. One option is the LES operator decides to intergate the charge process in it management of the LES, here listed as configuration 5. The other option is the CPO will manage the other assets in the LES on top of controlling the charge process, which is here listed as configuration 6. Configuration 5 and 6 are structureally the same but approach it from a different domain (from the energy domain in the first case and from the mobility domain in the latter case).

However, because of practical reasons, reasons of interoperability, site management or other, the LES operator can opt not to integrate (control) the charge process himself but work through the regular channels, i.e. a CPO. The next destinction made is between where the intelligence and decision with regards to the charge process resides. One way is in case the CPO will only execute the charge process according to the commands of the LES operator (master), listed here as configuration 2. A second way is where the CPO optimizes the charge process according to some constraints from the LES, listed here as configuration 3. A third way would be that the decisions are part of a negotiation between the system operator and CPO, in Figure 2 listed as config. 4. The last way is the case where the CPO and LES operator act independently from each other , listed as config. 1, which the business as usual case. For this usual case, it is not possible to apply smart or bi-directional charging in an optimized way. It serves as the reference case.

3 EV charging infrastructure market and technology

3.1.1 EV charger

EV charger technology is still evolving with both a trend towards higher power levels for both AC and DC to service the increasing battery capacities in EVs [9]. Because of the higher cost associated with higher power level charging because of the grid connection, the charger, and on-board charger (in case of AC charging), AC charger is generally low power (<22kW) and DC charging higher power. Only a few equipment manufacturers currently have vehicle-to-grid chargers on the market, but these chargers tend to be DC and low power (around 10kW). Hereby they respond to the idea that in the future AC charging will be limited to home and opportunity charging at low power ≤11kW, and all smart, bi-directional and high power charging DC. However, early pilot projects with vehicle manufactures did invest and investigate in AC bi-directional charging technology for chargers and vehicles [10], [11].

3.1.2 Standards

EV charging standards with regards to charging have been quite well established over recent years [12], [13]. EV charging standards with regards to connectors and communication between vehicle and supply equipment are well established, while standards regarding the communication between supply equipment and the charge point operator (CPO), the de facto standard OCPP, has been adopted and currently under revision for a next version to be formalized in a standard [12]. Communication protocols between CPOs and mobility service providers (MSP) and between MSPs themselves, are the de facto standard OCPI, while communication between CPOs or MSPs and the interoperability platforms Girève, Hubject, and e-clearing.net each have there own communication protocol (OCHP, OICP, eMIP respectively) [10].

4 Requirements and standards for V2G in LES

This paragraph will go more into deep in the requirements with regards to communication for the integration of V2G in a LES for each of the distinct configurations presented in Figure 2. Figure 3 presents an overview of the actors and communication streams in each of the 6 configurations identified and described in Figure 2. It presents the system of charging infrastructure as layers (LES, CPO, CP, EV, Driver, MSP + HUB) as blue frames where actors (LES, CPO, CP, Driver, MSP, Hub) play certain roles (Decision, Execution, Mobility, Interoperability, Billing). The blue arrows indicate in what way communication is/should be established while the orange markings indicate the current standard protocol used for this communication. In case no protocol is at hand, the minimum parameters are indicated.

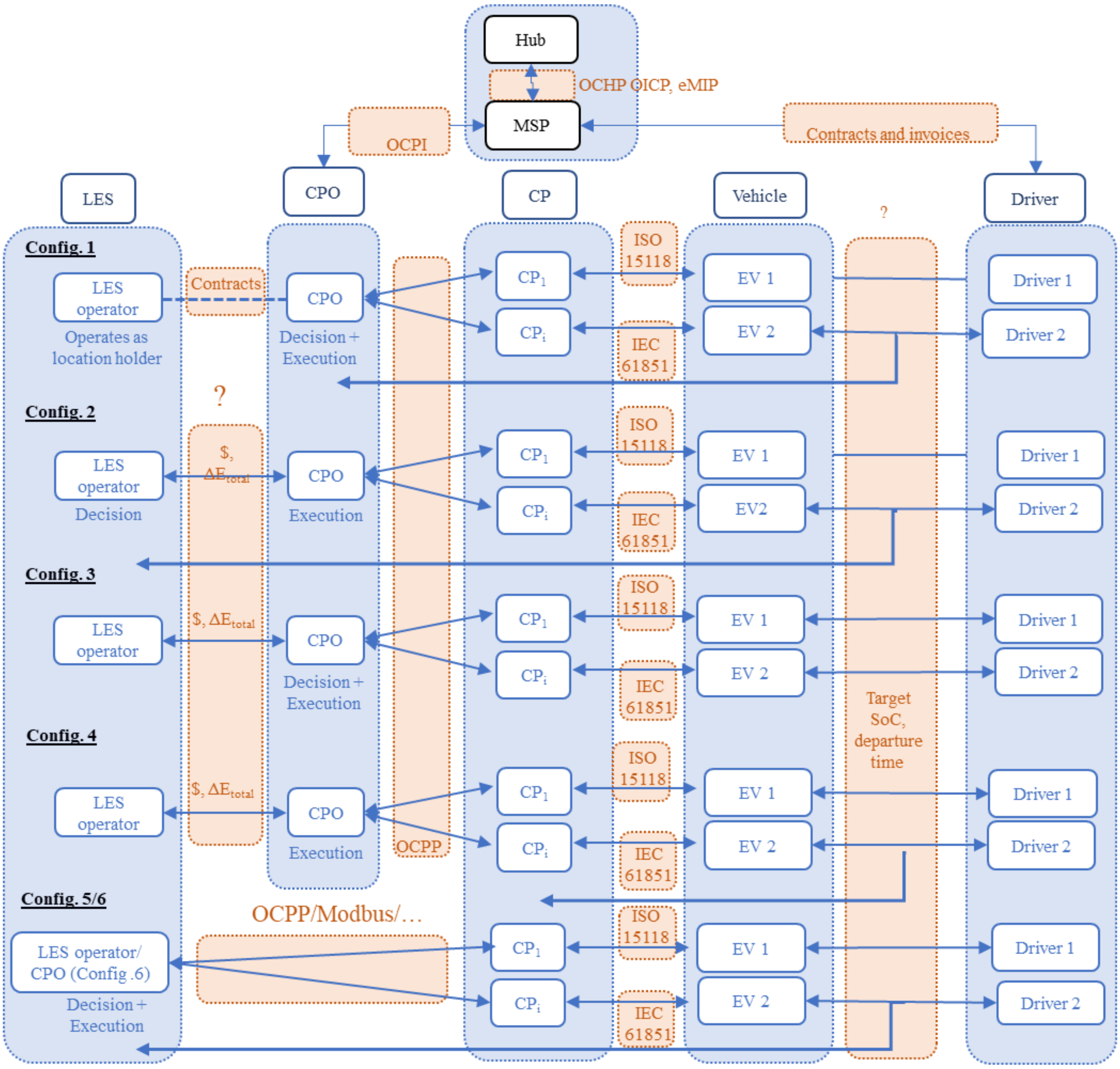

Figure 3: Vehicle-to-grid in LES

4.1 Requirements for communication local balancing

From literature, intelligent and bi-directional charge scheduling algorithms typically use the following catergories of information in their models [14]–[16] [17]–[22]:

Driver's preferences: the driver preferences consist of the driver's choice with regard to the type of charging scheme he wishes to enter (full power, smart charging, or bi-directional) and his constraints within the scheme of choice based on his mobility needs and tariff limits. A minimum requirement to understand the mobility need is the additional required driving range (expressed in km or in target state-of-charge) and the estimated time of departure. However, a great number of additional constraints, such as a minimum threshold for the state-of-charge (SoC), tariff boundaries, time boundaries could be useful to increase user's confidence and satisfaction.

Models for charge scheduling algorithm for smart and bi-directional charging typically have some kind of representation of the driving preferences [16]. This means this information should be communicated from the driver up to the decision maker in the scheme (CPO or LES):

Contracts

- For configuration 3: either through driver-vehicle-CP-CPO or driver-CPO
- For configuration 2, 4: either through driver-vehicle-CP-CPO-LES or driver-CPO-LES
- For configuration 5: either through driver-vehicle-CP-LES of driver-LES

Vehicle state: this category refers to vehicle parameters that describe the current state of the vehicle impacting on the required quantity of energy charged per driven km. Smart charging without explicit knowledge of the vehicle state is possible as power can be reduced by the scheduler according to the minimum driver's preferences (additional range and estimated time of departure). However, for the introduction of any more intelligent scheduling and for bi-directional charging, knowledge on the current SoC of the vehicle is a minimum in order to estimate the flexibility (demand/supply). Additional information of the vehicle state, such as state of health, charging losses, energy consumption (kWh/km) will allow to estimate the flexibility much more accurate and therefor increasing the flexibility by reducing the safety margin.

Models for charge scheduling algorithm for smart and bi-directional charging typically have some kind of representation of the vehicle state [14]–[16] [17]–[21]. This means this information should be communicated from the driver up to the decision maker in the scheme (CPO or LES):

- For configuration 3: either through vehicle-CP-CPO or driver-CPO
- For configuration 2, 4: either through vehicle-CP-CPO-LES or driver-CPO-LES
- For configuration 5: either through vehicle-CP- LES or driver-LES

Variable tariffs: there are mainly two aspects that have an impact on the charging tariffs: the charging scheme chosen by the driver, and the LEC electricity prices. Driver's choice could be influenced by different charging scheme tariffs, hence the price for each charging scheme should be communicated to the driver. Electricity prices change due to the energy assets in the LEC, which results in variable tariff in time, which should be communicated to the driver. A minimum requirement to apply variable tariffs is the ability to update tariffs, but also to display several different tariffs to the driver, and finally, to be able to display negative tariffs (when discharging the vehicle). Additional information such as final cost of charging for the different charging scheme could help driver's choice.

Models for charge scheduling algorithm for smart and bi-directional charging typically have some kind of representation of pricing mechanism [22]. This means this information should be communicated from the decision maker in the scheme to the driver:

- For configuration 3: either through CPO-CP-vehicle-driver or CPO-driver
- For configuration 2, 4: either through LES-CPO-CP-vehicle-driver or LES-driver
- For configuration 5: either through LES-CP-vehicle or LES-driver

Modular and bi-directional power set values: A fundamental parameter to set when charging is the power or the current. With the introduction of smart and bi-directional charging, the communication of power becomes slightly more complex. A minimum requirement is the ability to set charging profiles (defined as a power over time curve), but also to set a negative power. Another minimum requirement is the comminucation of the maximum power of the CP, but also the maximum power of the vehicle, for charging and discharging.

Being able to modulate power is an essential for optimizing the charge process. This means this information should be communicated from the decision maker in the scheme to the CP:

- For configuration 3: either through CPO-CP-vehicle
- For configuration 2, 4: either through LES-CPO-CP-vehicle
- For configuration 5: either through LES-CP-vehicle

4.2 Standards for communication in V2G context

4.2.1 CP-EV(-Driver)

From the requirements we understand that the driver is responsible for the communication of driver's preferences, vehicle state, variable tariffs either through the vehicle and CP or directly with the CPO or LES, in all configurations presented in Figure 3.

The current standard for communication between the CP and EV is established by IEC61851 . However, this protocol does not communicate any information regarding the driver preferences and needs, which would be required for smart – and bi-directional charging (such as variable tariff, real-time metering, battery the driver preferences , vehicle state and variable tariffs (as described in 0.)). It merely defines the control of the actual charge process (controlling power, safety,…). A new standard for communication between the EV and the supply equipment for V2G application, ISO15118 – Road vehicles – V2G communication interface, has been defined but is currently not yet adopted by the car manufacturers for their current vehicles on the market. ISO 15118 describes the base use cases for V2G and introduces the concepts of "mobility needs" and "flexibility operator" which are driver requirements and a decision making actor required for V2G. It introduces a high level communication (HLC) where information needed for V2G (such as the mobility needs) can be exchanged between relevant actors. This HLC is about information and decision exchange, but will not execute the charge process itself.. The standard also does not specify the exact content (parameters) of the HLC.

In attendance of the implementation of ISO15118 in Europe, high level information on the driver, vehicle and tariffs will thus need to be communicated to the operator with other means of ad-hoc development for communication.

4.2.2 Driver – Operator (CPO or LES)

With the absence of implementation of ISO15118, the driver's preferences and vehicle state will have communicated from the driver to the decision maker (CPO in configuration 1,3, LES in configuration 2,5) and both LES and CPO in configuration 4. This type of communication will likely be established by ad-hoc developments using dedicated APIs or establishing smartphone apps to where information is transferred using a smartphone app or HMI on the charger itself. In the light of increasing interoperanility (switching between CPOs, switching between decision makers,…) communicating the driver's input information firstly from the driver to the CPO (except for configuration 5) and then from CPO to the LES (as opposed to immediately between driver and operator) as a standard, it would increase interoperability.

4.2.3 CPO – CP communication

The communication between the CPO and CP is in Europe the de facto standard OCPP. This protocol is currently widespread adopted in its version 1.6 and has released a version 2.0 that enables smart charging by introducing CPO induced variable charging power and variable tariff. OCPP2.0 refers to the ISO15118 standard for the definitions of the exchanged records in the communication standard.

4.2.4 LES-CPO

The information that needs to be communicated between the CPO and the LES will depend on where the decision making resides. If the decision making resides at the LES (configuration 2), the CPO will need to communicate vehicle states, driver' preferences to the LES, while the LES will need to communicate variable tariffs to the CPO (and from the CPO downstream to the driver). If the decision for the charge scheduling resides at the CPO (configuration 3), the LES only needs to communicate electricity prices and power boundaries to the CPO. In configuration 4, the optimization of the charge process is is a result of a collaborative effort or negotiation. Therefore extensive comminucation in both directions with regards to prices and demand are required. There is currently no established communication protocol specifically for this interaction. Any type of high level communication with custom registers would be applicable. Working with ad-hoc developed APIs reduces interoperability. OCPI would be a good candidate as it is already widely used by CPOs to communicate with MSPs. However, although OCPI does contain variable load profiles and prices, it lacks the registers for the vehicle state and driver preferences as is needed for V2G.

4.2.5 LES – CP

This line of communication only needs to be established in configuration 5 , where the LES itself controls the CPs as part of his assets, This could be established by OCPP (like for the standard CPO-CP communication). However, this would require additional developments from the LES side whereas if the CP is considered a hardware asset, control of the CP by any of the existing protocols used to control assets (hardware) in microgrids, such as Modbus or BACnet, could be used for this type of of rapid, bi-directional communication. Modbus would have the adavantage over OCPP to be fast response, as is required for some other (ancilarry) service that could potentially be done with EVs, but which are outside of the scope of this paper.

4.2.6 The special case of CPO-MSP-HUB-MSP-Driver communication

Sections above have so far neglected for the most part the roles of te MSPs, which are important in the quest towards interoperability of the charing infrastructure, and only respond to the ad-hoc interoperability and payment as stipulated by the EU Directive [23] as explained in [6]. Above sections consider direct communication (through apps or HMIs) between driver or EV and the operator (be it the LES or the CPO). This is perfectly reasonable in a LES setup that wants to operate outside of the current practice for interoperability of public infrastructure, where drivers have the option to pay through there preferred MSP (and interoperability platforms connect MSPs and CPOs). However, it is unclear at the moment if MSPs have a clear interest in applying smart – and bi-directional as part of their service to the driver, and what there role would be in that case. Would they actively enter a negotiation and be the owner of the driver's mobility needs e.g, or just merely apply fees on whatever tariff is negotiated between a CPO and LES locally? In the first case, information such as driver's preferences and variable tariff (as described in section 0) would have to be passed through OCPI (which only contains record for variable tariffs at the moment) for direct MSP-CPO communication or through the HUB (so through either OCHP, OICP, eMIP, which do not contain the records for this type of communication). In the latter, driver's preferences and variable tariffs should still be performed by ad-hoc (or in the future stanardaized) communication between the driver and the operator (be it CPO or LES). The latter case also induces problems with regard to transparency of tariffs, as variable tariffs announced locally, are not necessarily the same as charged by an MSP.

5 Conclusions

This paper presents the requirements for communication and the status of the current communication standards for the integration of smart - and bi-directional charging (vehicle-to-grid) in local energy systems. It identifies 6 distinct configurations for this setup. It defines the minimum requirements for information to be exchanged between actors in the system.

One of the challenges is the upstream or downstream of information between the layers. Information coming from the EV or driver which is required at the LES in order to perform V2G, for example, must either be established directly between those actors or be protocol enabled in every layer in between. Establishing communication between actors in layers not immediately adjacent, will lead to ad-hoc solutions and reduced interoperability. However, the current established standards are not always suited to enable the exchange of the required information between adjacent layers. New versions of current standards such as OCPP and OCPI or the new standard ISO15118 do include such information but are currently under development. Furthermore, the communication between a CPO and LES is new and does not have a fixed adopted standard. As a result, actors rely custom developments in advance to the adoption of new standards for the implementation of V2G, such as APIs.

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Thierry Coosemans obtained his PhD in Engineering Sciences from Ghent University in 2006. After several years in the industry, he became a member of the MOBI research team at the VUB, where he works now as the 'Electric and Hybrid Vehicle' team leader. He is currently involved in the scientific support for the Green Energy Park Zellik, Flanders Make and had an active role in the Living Labs Electric Vehicles Flanders. On a European level, Thierry was and is involved in the H2020 and FP7 projects SafeDrive, OPERA4FEV, SuperLIB, Smart EV-VC, Batteries20202, GO4SEM, FIVEVB, ELIPTIC, MOBILITY4EU, COLHD, FUTURE-RADAR, OBELICS, REDIFUEL CEVOLVER and GO4SEM, which he coordinated. His main research interests are electric and hybrid propulsion systems, performances of electric-vehicle fleets under real-life conditions, including in a V2G perspective, as well as the development of CO2-neutral Local Energy Systems. Thierry Coosemans is an active member of EARPA and EGVIA.

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