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Smart Charging, V2G and second life batteries experimentation

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Summary

Providing flexibility to the electricity grid through stationary storage solutions, smart charging and V2G features of electric vehicles can have a huge impact on the operation of our electrical networks and the integration of renewable energies. The first technological enabler is a high-level communication between the electric vehicle (EV) and its supply equipment (EVSE) to ensure they operate together as a distributed energy resource and is being addressed by the ISO 15118 communication protocol. This paper presents how this DER can be integrated to a real-life experiment, with stationary storage controlled by an EMS, to understand the possible conflicts and evaluate the performance of the different communication modes.

Keywords: Smart Charging, V2G (vehicle to grid), Energy storage, Power management, Standardization.

1 Introduction

Our electrical networks are making the transition from fossil power plants to intermittent renewable energy sources, making the need for storage and flexibility more and more important. Different solutions are developing. First, stationary storage, for large industrial sites or for residential usages, is becoming more and more common, with also the emergence of second life batteries (battery packs recycled from electric vehicles). In parallel, electric vehicles are implementing smart charging and vehicle to grid (V2G) solutions to play a role in the balance between production and consumption. To do so, several architectures are being defined, and the interface between the EV and the EVSE has already been improved with the introduction of the high-level communication protocol ISO 15118 [1] and the feature allocation [2]. Based on these technical elements, there is a strong need of testing the full picture, with an end to end experimentation implementing several use cases to understand where the value is, and the possible conflicts between different optimization levels. This paper describes the experimentation configurations architectures and objectives. It also presents the communication protocols used for each configuration and the modifications on standard communication protocols necessary for an end to end test of each use case, specially reversibility.

2 Configuration 1: base setup

The experimentation described here is based at the Renault Technical Center in Guyancourt (France). It iteratively adds new elements, with three configurations, that enable to evaluate the impact of each element and the results of the optimization.

The main goal of the first configuration is to test the different interfaces and validate the integration of the EMS. This configuration will be used as a "base scenario" to compare the added value of the other elements (stationary storage, ISO 15118, reversibility…).

2.1 Configuration architecture

In the first configuration, the system includes:

- 60m² of photovoltaic panels with a 10kW inverter
- Two 22kW AC EVSEs (EVSE 1 and EVSE 2)
- Two non-modified ZOEs (EV 1 and EV 2) capable to charge at 22kW AC
- An Energy Management System
- A grid connection

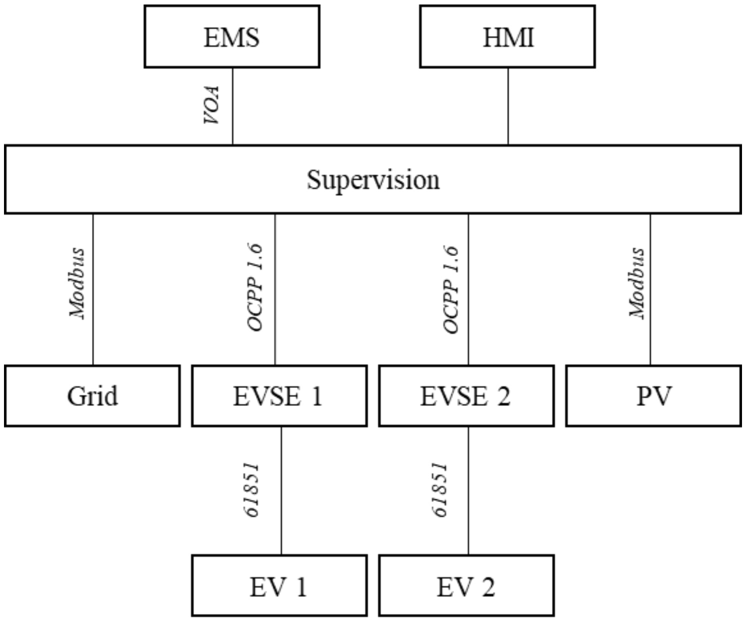

Figure 1: Configuration 1 architecture

The EVs communicate with the EVSEs using IEC 61851-1. The mobility needs (energy required before a given departure time) of the EVs are thus not known by the EMS.

The EMS has 3 modes. The boost mode ensures the EVs are always charged at the maximum power (22kW), using in priority power from the PV production and completing with the grid. The economical mode tries to minimize the price of the charge, and the environmental mode aims at minimizing the footprint of the system by maximizing the self-consumption and consuming on the grid only when the national electricity is decarbonized.

The algorithm in the energy management system has the following inputs:

- PV: power produced (real time and prediction), feed-in tariff
- Grid: available power (real time and prediction), electricity price, CO2 content (g/kWh – real time and predicted)
- Stationary storage: SOC minimum and maximum, current SOC
- EVs: SOC minimum and maximum, mobility needs
- EVSE: maximum power, current power

Based on these parameters, we can test various use cases. For example, by putting the feed-in tariff of the PV to 0, or the available grid power to 0, we force the maximum self-consumption. Another example would be to put the available grid power to a value smaller than 44kW needed if two EVs are connected, to create a "boost" function and charge more quickly the EVs when PV power is available.

2.2 Results

In the example below, a first EV is plugged to the EVSE 1 from 2:30pm to 4pm with an initial SOC of 30%, and a second one is plugged to EVSE 2 from 3:30pm to 6pm with an initial SOC of 43%. The goal of this example is to show different cases of plugin status: zero, one or two EVs connected simultaneously. If two EVs are plugged in simultaneously, the available power will be equally divided between the two vehicles.

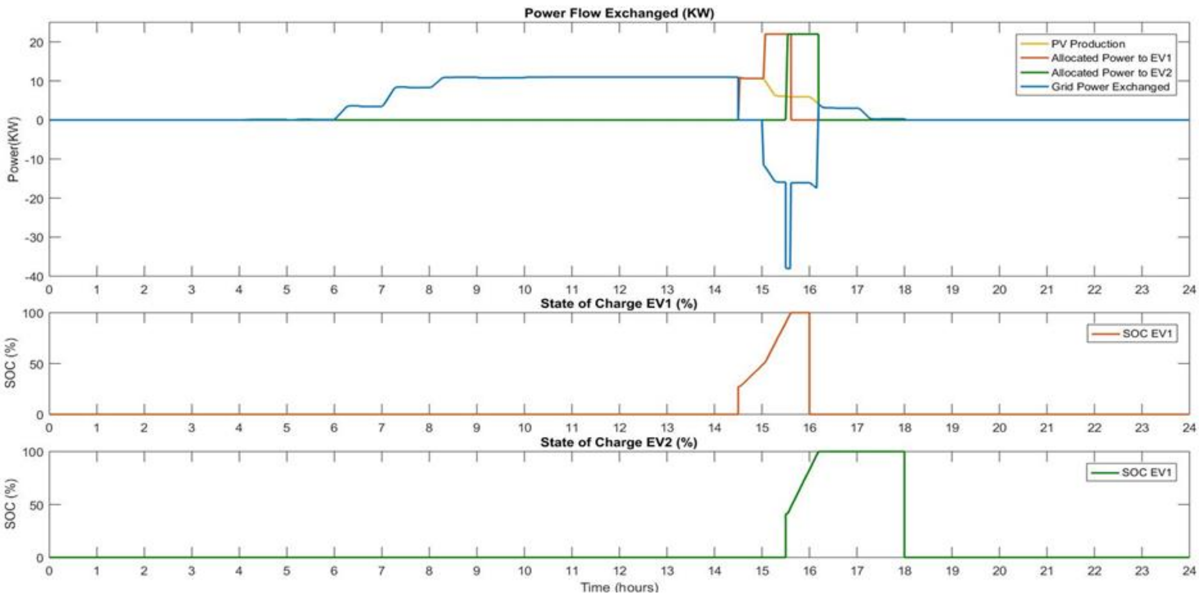

Figure 2: Power Flow exchanged through PV, the grid, EVs, and SOC evolutions (Environmental strategy)

The optimization strategy tested in Figure 2 is environmental. We chose to charge the EV with 100% solar power between 12am and 3pm, and outside this time slot we can use the available power grid to fill the difference needed for the charge. We consider a limited grid power of 50kW.

In Figure 2, we can see that before 3pm, we charged only with solar power. And after 3pm, we provided the power needed using both power from the sun and the grid. The EMS managed to fully charge the 2 EVs before their defined departure time.

Another use case with economic purposes has been tested, the results are presented in Figure 3. The algorithm prevents the use of the grid in peak-hours (between 7am and 9am, and between 3:45pm and 4:45pm in this example), and allows its use in off-peak hours.

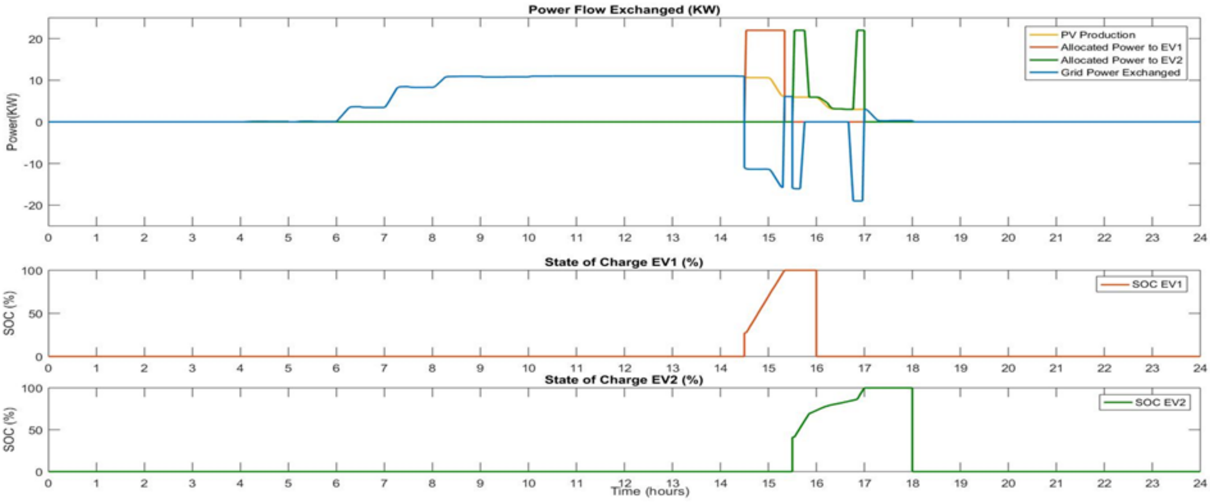

Figure 3: Power Flow exchanged through PV, the grid, EVs, and SOC evolutions (Economic strategy)

Other use cases can be tested as well, for instance the charge in 100% solar power, or the limitation of the power grid used whenever we exceed a specific amount of gCO2 per Wh consumed.

2.3 Configuration conclusions and limitations

The results of this configuration show the various parameters that can be changed depending on the use case that needs to be tested. It allows to apply different strategies on electricity mix: vehicles can be charged only on solar or use energy on the grid during off peak hours or even anytime. The presence of multiple charging points allows to play on the energy distribution strategy when more than one EV is connected: max power for first EV plugged, max power for last EV plugged or equal share of power for both EVs.

The main drawback of this configuration is that when no EV is connected, the PV production is fed back into the grid, instead of being consumed onsite. Self-consumption is therefore limited to times when at least one EV is charging, meaning that EVs should be charged during daytime. Additionally, the mobility needs of the EV users are not know and cannot be guaranteed.

3 Configuration 2: stationary storage

3.1 Configuration architecture

To prevent the PV production from being fed back into the grid, two 11kWh second life batteries (recycled from Renault Kangoo ZE) are added for the second configuration, with the necessary power electronics, developed within the European project ELSA [3]. This stationary storage can charge and discharge at 22kW (equivalent to a C-rate of 1C for the whole pack).

This available energy storage capacity is well sized relative to the PV production as it enables to store almost one average day of PV production (20-40kWh of PV production per day) and therefore allows to shift the use of this electricity for about 24 hours. Self-consumption can then be pushed to almost 100% as long as enough EVs are charging.

In this configuration, the system will be used to evaluate the added value of the stationary storage, both on an economical and an environmental point of view. The stationary storage can also be seen as a virtual EV to begin testing future configurations.

The stationary storage communicates to the supervision via Modbus. This allows to:

- Control the active power setpoint (positive and negative)
- Control the reactive power setpoint
- Retrieve the storage data: status, current measured active and reactive power, maximum available charge and discharge power, available charge and discharge energy, system error

Figure 4: Picture of the experimentation in configuration 2

3.2 Configuration conclusions and limitations

This additional element enables to improve the self-consumption rate by storing the surplus PV production. Additionally, this improves the user experience in the environmental and economical modes, as the power transmitted to the EVs can be increased by discharging the stationary storage. The EVs be charged at a higher power cumulating power produced from the PV and energy coming from the storage. When only using energy from PV, maximum power for the two EVSEs is 10kW (max power of the PV inverter), but with the additional stationary storage this limit increases to 32kW before having to take energy from the grid.

However, the mobility needs of the EV users are still not known which involves charging the vehicles at times when it is not necessary or not charging the EVs fast enough.

4 Configuration 3: mobility needs and reversibility

4.1 Configuration architecture

In order to get the mobility needs of the EV users and improve the optimization strategies, the configuration 3 includes a modified EV (EV3), equipped with a bidirectional on-board charger and a reversible 11kW AC EVSE (EVSE3) [2], communicating using ISO 15118-20 (new chapter of ISO 15118 allowing bidirectional power transfer).

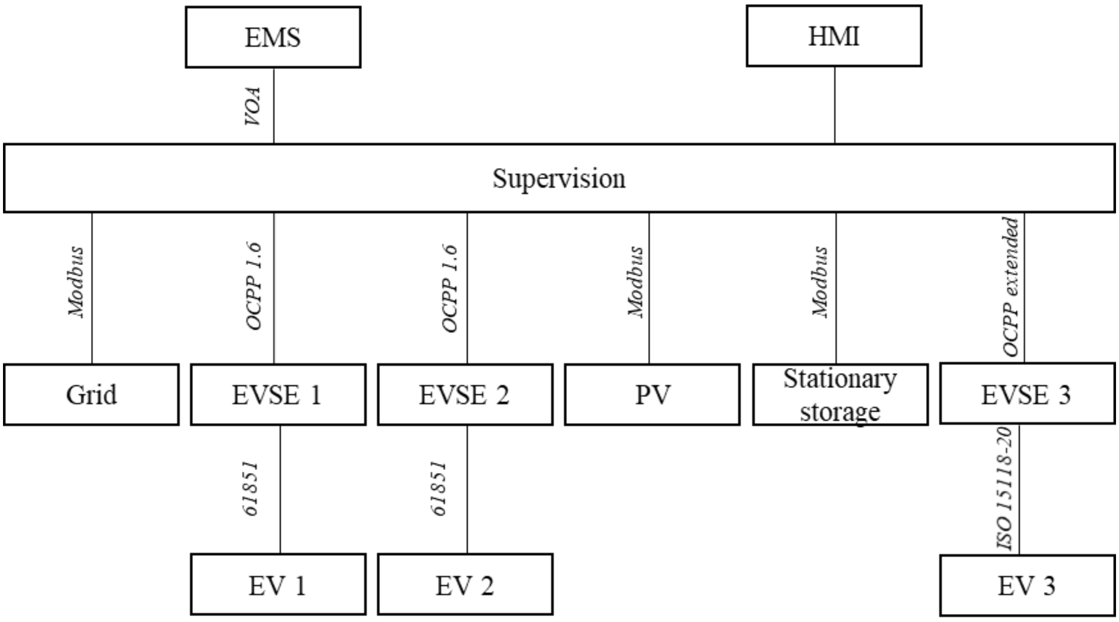

Figure 5: Configuration 3 architecture

In the third configuration, the goal is to understand how the addition of a high-level communication like the ISO 15118 can impact the gains and optimization strategies of an EMS. It is particularly important to test the schedule mode, introduced in the on-going ISO 15118-20 (see Figure 7), in real life, and specifically the renegotiation phase.

This configuration will also enable to test a complete system with reversibility and understand the conflicts between a centralized optimization (done by the EMS) and a decentralized optimization (done by the EVs). It will be used to understand the viability of the dynamic mode of the ISO 15118 and ensure that the needs of the grid and the EV users can be met in this mode.

4.2 Communication protocols

4.2.1 ISO 15118-20

Before going further, it is important to understand the two control modes offered in the on-going version of ISO 15118: part 20. 7 illustrates the two control modes:

- Schedule mode: the EV receives tariffs of electricity over time and maximum power available, decides a charging profile and communicates this profile to the EVSE before starting to charge using that profile
- Dynamic mode: the EV is under the control of the EVSE, it follows power commands received at regular intervals

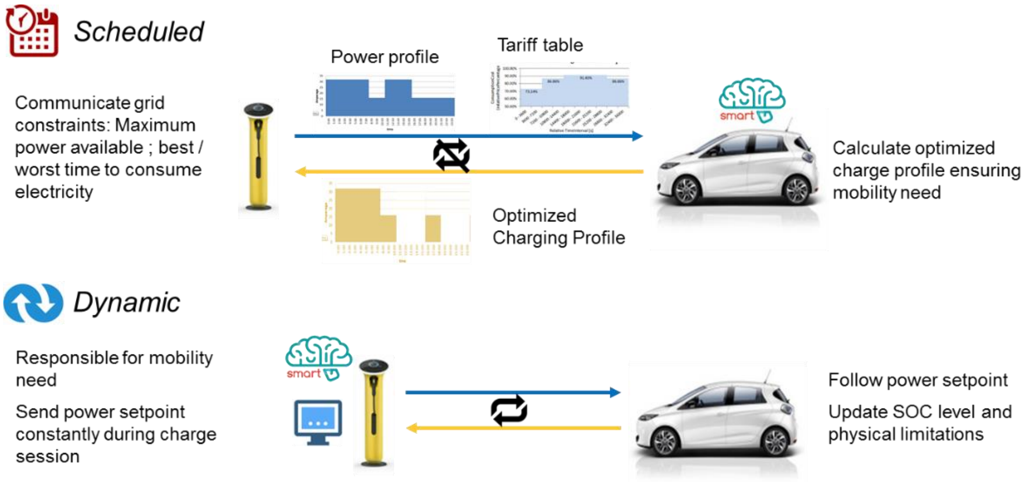

Figure 6: Schedule and dynamic modes of ISO 15118 edition 2

Both modes can also operate during a bidirectional power exchange. In this case for Schedule mode, two tariff tables are communicated, one for consuming and one for feeding-back electricity, along with two power tables, indicating the maximum allowed charging and discharging power. For Dynamic mode, the power commands can be positive for charging or negative for discharging.

4.2.2 OCPP extended

To use the full potential of ISO 15118-20 for AC charging (both control modes as well as bidirectional power transfer), it is necessary to communicate new parameters from the EMS to the EVSE. We therefore introduced a modified version of OCPP based on version 1.6 [4] that we refer to as OCPP 1.6 extended.

This extended version varies from the official 1.6 version in two ways:

- by modifying existing messages
- by using the DataTransfer message to exchange new sets of information

Illustration of modification to existing OCPP 1.6 messages:

- In the StopTransaction function, the optional TransactionData element should now carry charged energy as well as discharged energy meter readings. To do so, we introduce a new measurand value: Energy.Active.Export.Register to transfer the feed-in energy seen by the charge point meter, in parallel with the existing value: Energy.Active.Import.Register used for the consumed energy
- Introduction of the configuration keys for the Get.Configuration function for new services like supported.Control.Modes that allows the station to indicate if its supports Dynamic and Schedule control modes
- Reusing the SetChargingProfile function in order to set charging maximum power table but also discharging one by using the element CharingProfilePurpose set to DischargingProfile

Illustration of new function introduced using DataTransfer message:

- To transfer a power command in Dynamic mode, a DataTransfer.req is sent by the OCPP server (Supervision) with data set to setWorkingPoint and values for active and reactive power setpoints. The request is acknowledged by the EV using the DataTransfer.conf.
- The transfer of electricity tariff tables is also based on DataTransfer message. For this the data field command is set to setTariffSchedule and the table is communicated as described in table 1 below.

Table 1: OCPP extended tariff Schedule

Field Name	Type	Description	Cardinality
tariffSchedulePurpose	V2GOpenAPItariffSchedulePurpose	Table id	1..1
saScheduleId	Int	Secondary actor schedule id	1..1
said	Int	Secondary Actor Id	0..1
nbOfPriceLevel	Int	Number of different price levels used in the table	1..1
duration	Int	Total duration of the table	1..1
lastPrice	Int	Price to apply after the end of the table	1..1
entries	V2GOpenAPItariff	Price against time (cf table 2)	0..*

Table 2: V2GOpenAPItariff Type

Field name	Type	Cardinality	Description
time	Int	1..1	Time
price	Int	1..1	Price

Based on this, it is now possible to fully use all features of ISO 15118-20 for AC charging and discharging.

4.2.3 V2G Open API

To make this OCPP extended communication transparent for the EMS or the aggregator, we also developed an API called VOA (V2G Open API). This API enables to send charging and discharging orders to the supervision via a JSON API, without knowing the OCPP extended language. The supervision then translates these API orders into OCPP extended messages to the EVSEs.

4.3 Use cases

The pair of reversible EV and EVSE operate as a distributed energy resource and can provide additional energy services like smart charging or V2G in schedule or dynamic mode. The EMS is here in charge of gathering all the necessary data (PV production, stationary storage state, EVs mobility needs etc). Based on this, the algorithm calculates the orders sent to the stationary storage and the EVSEs.

4.3.1 Schedule mode

The schedule mode of the ISO 15118-20 can be used for predictable services, such as demand-response.

The parameters needed in the *ServiceDiscovery*, *ServiceDetail* and *PaymentServiceSelection* messages of the ISO 15118-20 can be provided by the EMS using a the *EVSEConfiguration* request. The supervision can then transmit these to the EVSE using the *ChangeConfiguration* request, where the types of the *supportedTransportProtocols*, *supportedProtocols*, *supportedPayments*, *supportedChargeTypes*, *supportedServices* and *supportedControlModes* keys have been modified to include the new values required by the ISO 15118-20.

Once the EV sends the *ChargeParameterDiscovery* message, the EMS can send the available power and tariffs schedules to the supervision with the *SASchedule* request. The supervision can then transmit the available power schedules to the EVSE using the *SetChargingProfile* request, where the *ChargingProfilePurposeType* has been extended. To transmit the tariff tables, the supervision uses a *DataTransfer* request.

To receive the schedule calculated by the EV, the supervision uses the *GetCompositeSchedule* request, extended to include negative values. The EMS can then retrieve this schedule using an *EnergyTransfer* request.

Finally, at the end of the power transfer, the EVSE sends the exported and imported meter values to the supervision with the *StopTransaction* request, modified as explained in section 4.2.2. The EMS can retrieve these values with an *EnergyTransfer* request.

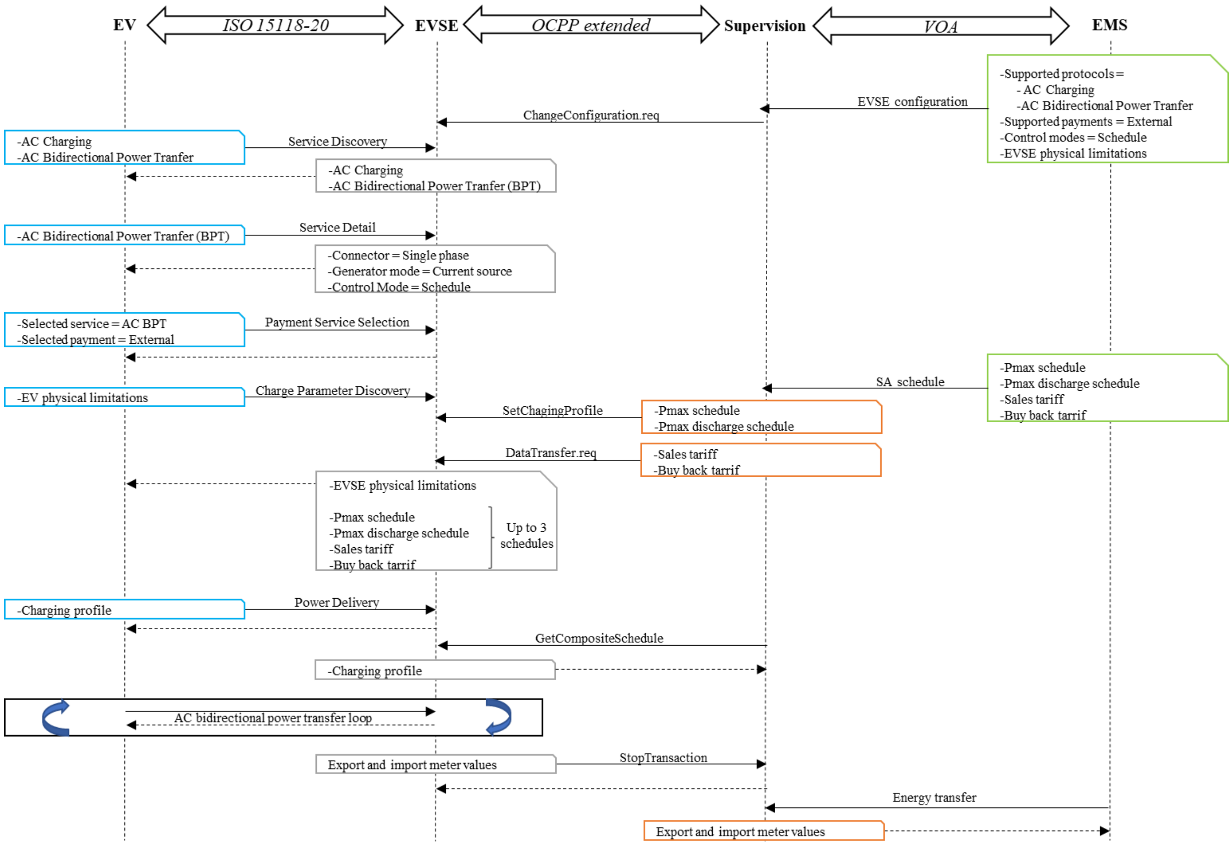

Figure 7: Sequence diagram in Schedule mode

4.3.2 Dynamic mode

Some of the V2G services, like frequency containment reserve (FCR), are fast-response services and involve a different allocation of roles between the EV and the EVSE. This is tackled in the ISO 15118-20 by the dynamic mode, where the setpoint is calculated by the EVSE, which is therefore responsible of ensuring the mobility need of the EV will be reached.

In the dynamic mode, the beginning of the charging session is very similar to the schedule mode. At the *ChargeParameterDiscovery* message, the EVSE does not send a schedule to the EV. Instead, during the AC bidirectional power transfer loop, the EV dynamically sends to the EVSE its physical limitations and the evolution of its batterie SOC (regular update of the energy amount required by the next departure time). These are transmitted to the supervision with a *DataTransfer* request and to the EMS with the *EnergyTransfer* request. The EMS then calculates the active and reactive power setpoints and sends them to the supervision with the *EnergyTransfer* request. This working point is transmitted to the EVSE with a *DataTransfer* request.

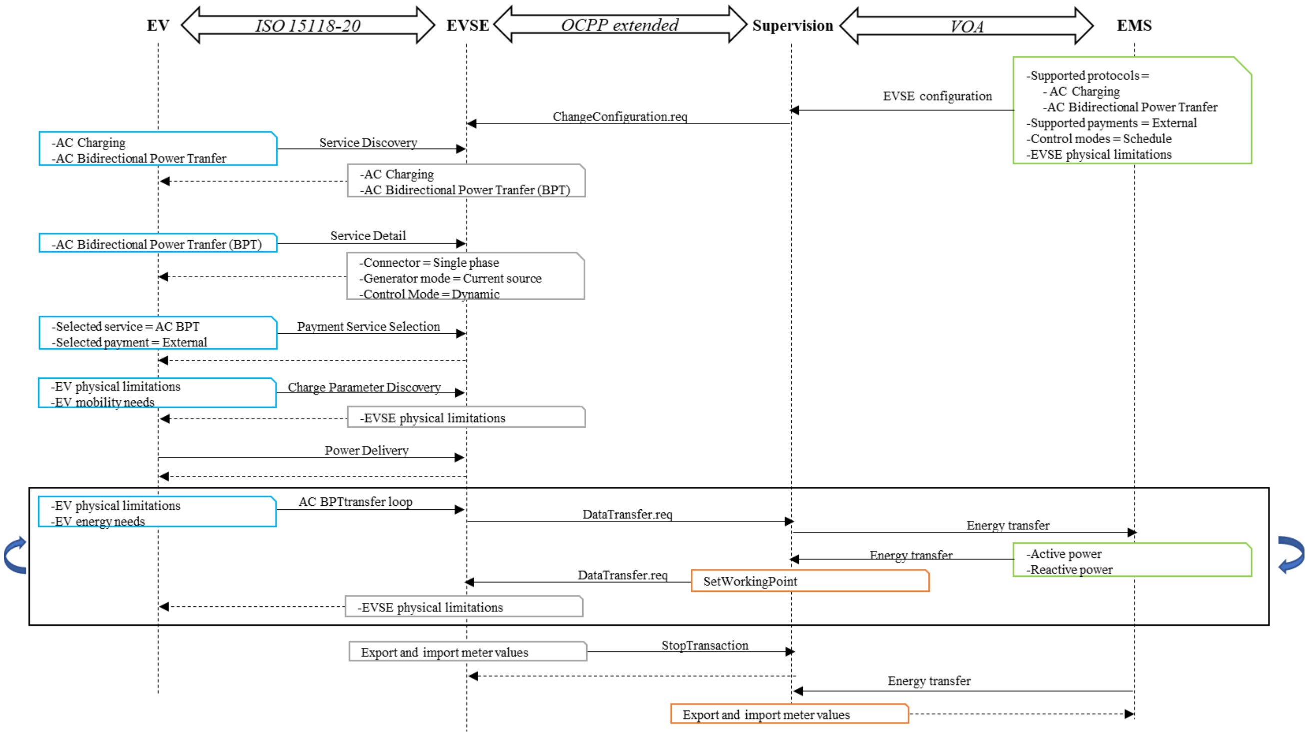

Figure 8: Sequence diagram in Dynamic mode

4.4 Configuration conclusions and limitations

The main advantage of this configuration is that we can use the Smart Charing and V2G functions as described in ISO 15118.

Using a combination of tariff tables and power tables, the supervision can influence the charging behavior of the EV. This requires the EV to know its next departure time. The EV has available flexibility if the departure time is further than the time required to fully charge the EV, considering the maximum charging power available given by the power table and the on-board charger capability. In dynamic mode, this flexibility is managed by the EMS.

By developing EMS strategies, we quickly noticed that the schedule mode is better suited for smart charging features, whereas the dynamic mode fits much better with V2G services. This is confirmed when looking at current supervision of stationary storage systems, controlled by direct orders, as proposed in the dynamic control mode.

5 Conclusion

This paper describes the hardware and communication protocols used in an experimentation aiming at testing the full value chain of flexibility services, provided by stationary storage and electric vehicles. Three configurations of the experimentation are presented to demonstrate the advantages and limits of each setup and communication protocol. Based on these configurations, we can test a variety of use cases, with and without stationary storage, mobility needs or reversibility. It is also very beneficial to formulate comments for ongoing or future standard development (ISO 15118-20, future version of OCPP, 63110).

The OCPP extended and VOA communications can be used on other experimentations. For example, they will be used on a field experiment on the island of Porto Santo in Madeira. There, Renault is providing V2G capable vehicles along with stationary storage to EEM (Empresa de Electricidade da Madeira). These assets will be used to stabilize the grid in the specific context of a small island, with high constraints on voltage and frequency regulation.

References

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