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System architecture for Electric Vehicle used as a distributed energy resource – V2G AC

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Summary

This paper focuses on Vehicle-To-Grid (V2G) operated by BEV equipped with an on-board reversible converter and therefore capable to supply or consume power to and from the electrical network.

The article emphasizes on the analysis of the requirement that shall apply to such a system and proposes a system architecture and function distribution between the BEV and the installation.

The analysis of grid codes and relevant standards are presented in order to design a coherent functional architecture.

Finally, this article points out the required standards to be impacted for such a system to become interoperable and suggest harmonization and additional requirements necessary for the integration of this new form of Distributed Energy Resource (DER) into the grid.

Keywords: V2G (Vehicle-To-Grid), energy storage, EVSE (Electric Vehicle Supply Equipment), infrastructure, standardization

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Introduction

Considering the recent booming of Battery Electric Vehicle (BEV) market in Europe and around the world and the global interest of public and policy makers for eco-friendly technologies, the storage and power capacity represented by the global fleet of BEV could play a significant role in the development of Smart Grid and therefore contribute into reducing electrical distribution network investments and improve its stability.

V2G appears to be a very promising instrument that will align both objectives of electrical industry (keeping grids stable with investments at the right level) and automotive industry (reduce CO_2 emissions and sell cars), if economically affordable.

This paper presents the joint work of partners and stakeholders of the electric vehicle ecosystem. It will focus on V2G operated by BEV equipped with an on-board reversible converter and therefore capable to supply or consume power to and from the electrical network, without the need of an off-board inverter, reducing significantly the cost, hence improving significantly the net benefit to the BEV driver. This, we believe, is a game changer to reduce the Total Cost of Ownership of BEVs and take advantage of the large amount of storage available in the global fleet of BEV.

1 Study of grid codes

Feeding energy back to the grid or even only to an electric installation is not an *innocent* action, because grids were originally built to have a downstream flow of electricity from centralized power station to end-users loads.

The main points to focus on are the voltage profile in the grid, the security of grid workers with the detection of the islanding situation and the frequency stability.

These subjects are handled by standards that each country promotes locally, Germany being one of the most advanced. In this paper, we will focus on European context. CENELEC has written standards [6] that gather the most common requirements, but also emphasizes that settings may be different, at country level, but also down to local distribution grid level.

All these rules may not be relevant for V2G as it is quite low power, but the tendency is to require more and more features for DER.

As of today (2017), CENELEC is actively working on improving the standards to be able to address the European regulation of April 2016. A new release of EN50549 is in draft version and one of the key indicator, the grid frequency, is in the scope of new documents to standardize its measurement for different use cases.

2 Function identification

Thanks to the study of existing standards and publications, we could make a list of the functions needed to be able to safely feed current back to the grid with the energy stored in a BEV. Among others, anti-islanding and local parameters handling were key. Keeping in mind that to generalize V2G-AC, the overall cost of the system has to remain as low as possible, our goal was to minimize both the effort needed to upgrade an existing EVSE (Electric Vehicle Supply Equipment) and the extra-cost for the vehicle.

Table1: List of identified functions for DER

Category	Function	Description
Connection rules	Decoupling protection	Check if grid is still present by checking if voltage and frequency is in nominal range
	Islanding detection	Detect non-intentional islanding (loss of mains but stable situation for voltage and frequency)
	Connection / Reconnection / Synchronization	Voltage and frequency have to be nominal a long time enough, and conditions of synchronization have to be met before connecting
	Voltage events and ROCOF immunity	Low Voltage Ride Through and High Voltage Ride Through during which the source has to stay connected, and immunity to high rate of change of frequency (ROCOF)
	Support to voltage	Reactive power compensation to adjust voltage profile
	Support to frequency	Active power compensation for under and over frequency
	Remote trip / Remote setpoint	Ability of the system to be controlled by a remote system
Grid connected Services	load shedding, ancillary services, peak shaving, demand-response	Adjust reactive and active power setpoint for the most relevant service at the moment

3 System architecture

3.1 Proposals

The fact that a vehicle is mobile but some of the grid codes requirements are local, country specific and sometime even Distribution Supply Operator specific, can be seen as a barrier for V2G AC vehicles. But taking advantage of the fact that the charging station is a fixed installation and using a High Level Communication (HLC) protocol provide solution to overcome this barrier. We studied two possible architectures:

- Architecture 1: Local parameters are stored in the charging station and sent to the BEV in the initial stage of communication, see figure 1.

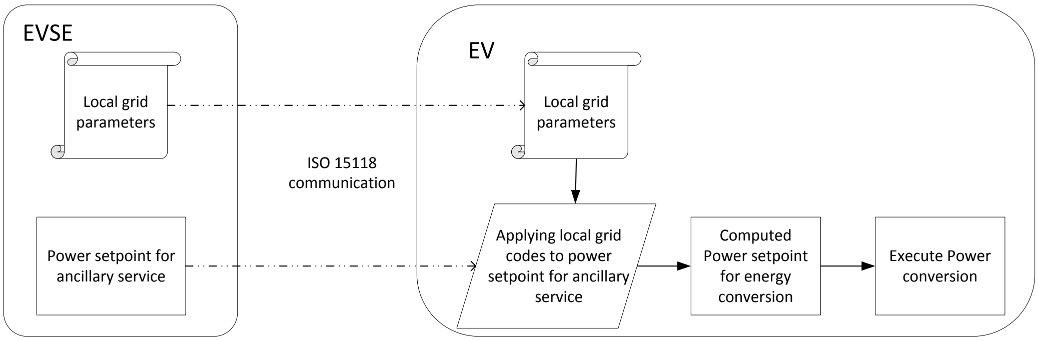


Figure1: Architecture 1

- Architecture 2: Local parameters are stored in the charging station and interpreted by the charging station controller in order to send active / reactive power setpoints to the BEV, see figure 2.

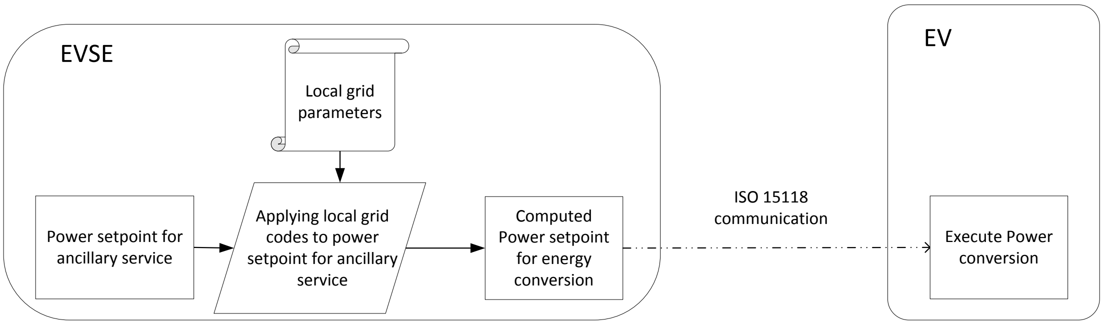


Figure2: Architecture 2

In both architectures, the EVSE receives a power setpoint from either a secondary actor as defined in ISO15118 (e.g. flexibility operator, electricity supplier) or a local EMS (Energy Management System). In the first use case, the BEV could offer ancillary services to the grid whereas in the case of the local EMS, the BEV could be providing energy storage in order to optimize energy of the building / house. The power setpoint represents the requested active (in W) and, possibly, reactive power (in VAR) required to best serve the contracted service. This setpoint does not consider the application of local grid codes but only responds to the service the BEV was enrolled in.

Then, using local measurement of voltage (V) and frequency (f), the grid codes have to be applied and integrated to the setpoint commands by merging the power setpoint and the possible power compensation required by the grid codes considering current grid conditions. In the first architecture the BEV is playing this role of measuring V and f, interpreting the grid codes and combining the result with the power setpoint received through high level communication (ISO15118). In the second architecture, the EVSE is in charge of this task and the EV is only receiving the combined active and reactive power it has to deliver or absorb.

3.2 Limitation of architecture 1

The first architecture presents less flexibility for future evolution of grid codes as we cannot add a new parameter into that list without impacting the communication protocol and therefore both the BEV and EVSE controllers. On the other hand, in the second architecture the consideration of grid codes mostly resides in the EVSE, the BEV only follows active / reactive power commands.

Another hurdle to implement the first architecture resides in communicating the grid codes from the EVSE to the EV. One could argue that the EVSE could communicate the applicable standards for this location but most parameters in grid codes could be adjusted by DSO within a given range For example, several reactive compensation methods are described in VDE AR-N4105 and EN 50549 but the standards do not specify which one to be used.

3.3 Preferred solution: architecture 2

This choice of architecture leads to communication requirements between EVSE and EV. This communication is supported by the IEC / ISO 15118 standards. Renault is strongly engaged in the on-going revision of this standard and is currently working to introduce requirements and messages to fully support V2G energy transfer taking into consideration the architecture selected (Figure2).In the current version of IEC / ISO 15118 (edition 1 - 2014), the BEV is defining its charging schedule based on grid constraints communicated through the power and tariff timetables at the beginning of the charging session. The BEV will define its charging schedule based on its mobility need (time of departure / energy to charge) and favoring the cheapest electricity price first. This method finds its limit with reversible and unpredictable use cases. For example when participating in primary reserve service, the DER has to quickly react to frequency deviation and therefore the control mode has to change to put the BEV in a slave position.

The current draft of edition 2 introduces a new mode of operation called “dynamic” that reverses the roles. The BEV is not anymore in charge of calculating the charging / discharging profile. A secondary actor through the EVSE can decide to dynamically command power setpoint to the BEV. Therefore this secondary actor becomes responsible to take into account the driver mobility need while operating the service it is enrolled in. In this dynamic mode, the BEV communicates its power (W) and current (A) limitations along with the present active / reactive power consumed or produced. In return the EVSE responds with the updated active / reactive power setpoint. This message exchange happens at least every 500ms.

Figure 3 presents this message pair for an AC EVSE (BEV with Bidirectional On-Board-Charger (B-OBC)).

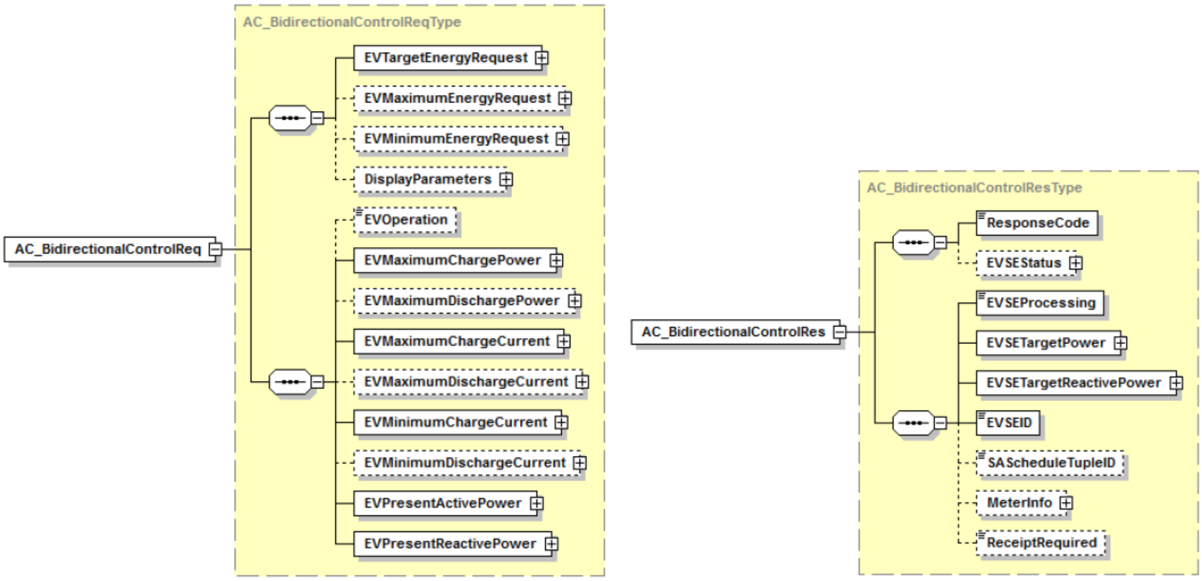


Figure3: Control loop message pair from IEC / ISO 15118 edition2

Architecture 2 is supported by the current draft (CD2) of IEC / ISO 15118.

4 Function allocation

4.1 Overview

Considering that EVSE are installed by professionals, as for solar inverters, we can rely on that installer to properly configure this DER unit for local power injection parameters. Therefore most of the functions identified in part 2 should be affected to the EVSE taking advantage that it is not mobile, whereas the BEV could be used in different countries.
Our analysis leads to the function allocation presented in table 2 below.

Table2: Function allocation to EV / EVSE

Category	Function	Allocation
Connection rules	Decoupling protection	EVSE
	Islanding detection	B-OBC
	Connection / Reconnection / Synchronization	EVSE
	Voltage events and ROCOF immunity	B-OBC
	Support to voltage	EVSE / B-OBC
	Support to frequency	EVSE / EV OR B-OBC*
	Remote trip / Remote setpoint	EVSE
Services	Grid connected : load shedding, ancillary services, peak shaving, demand-response …	EVSE / B-OBC

EVSE / B-OBC: Setpoint computed by EVSE / Power conversion done by B-OBC
*: depending on required response time

4.2 Detailed presentation

4.2.1 Decoupling protection

Decoupling protection can operate as a standalone function, monitoring the voltage and frequency, generally at the distribution point of the installation. In the photovoltaic systems, it could be also embedded in the inverter. The min/max voltage and frequency thresholds, as well as the delay to react can be adjusted for each site. This delay is generally quite short (200ms for example).

It makes much more sense to put this function in the EVSE or upstream in the main distribution board.

Connection and reconnection rules are also fulfilled by that device, because the voltage upstream has to be monitored, making it impossible for the EV (there is at least the main contactors of the station between the EV and the grid, as illustrated on figure5).

4.2.2 Islanding detection

Non-intentional islanding is a rare event as it requires an equilibrium between loads and generators at the time the connection to the grid is lost. But this event is feared because the voltage and frequency are no more fixed by the grid, there is voltage where there shouldn’t be (making it potentially dangerous for grid workers) and the grid protection (earth faults for example) could be blinded.

This function is generally implemented with active methods that are tested with the resonant circuit defined in IEC62116. As there are no power electronic in the EVSE, B-OBC is much more relevant to perform this function. Also the detection delay is usually of several seconds, making it compatible with function embedded in the B-OBC and communication to the EVSE.

4.2.3 EMC topics

As power conversion will be performed by the B-OBC of the EV, all EMC requirements have to be supported by EV.

These requirements are currently worked by IEC SC77A. The main new point is about DC current injection that is forbidden. This has to be taken into account in the design of the B-OBC.
Also the B-OBC has to be able to function on a quite wide frequency and voltage range, but this is not a big issue for power electronic. It has also to support the voltages dips and swells (so-called Low Voltage and High Voltage Ride Through: LVRT and HVRT) and stay connected (voltage events immunity), and ROCOF even if decoupling protection is set to disconnect the generator very quickly.
Most likely, decoupling protection will be intentionally delayed so as to keep generators connected and feed back energy quickly.

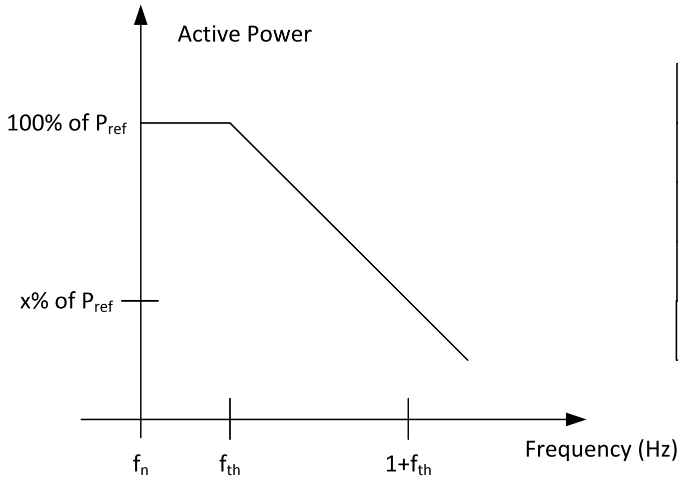
4.2.4 Support to voltage and services

Support to voltage by means of reactive power is a "slow" function with timings between several seconds and tens of seconds.
Most of the different services also need dynamic reaction at these speeds or slower.
B-OBC has to be able to follow quite accurately the dynamic setpoint provided by the EVSE. In normal charge, the only requirement is to be lower than the current setpoint (cf. ISO 17409), provided either by basic signaling or high level communication, but in bi-directional charge, the setpoint has to be followed as accurately as possible.

4.2.5 Support to frequency

The main limitation of this setup is the communication timing. Any task requiring faster response time than allowed by the communication cannot be hosted in the EVSE if it has to be executed by the B-OBC. We said earlier that the communication loop during energy transfer session happens every 500ms.
The only grid code function identified that requires action by the B-OBC with a faster measurement to reaction time is the Limited Frequency Sensitive Mode, both for overfrequency and underfrequency (requirement currently worked in CENELEC for battery storage).

For such a function, where and when required the solution would be to derogate to the chosen architecture and to communicate relevant parameters to the EV before the energy transfer loop. A proposed implementation could look like the one illustrated in figure4 below.



Parameters sent by EVSE to EV	
f_{th}	Frequency threshold to activate power reduction
P_{ref}	Maximum or actual power
x	Power reduction gradient
t_{delay}	Intentional delay

Figure4: active power response to overfrequency

This P(f) function appears to be a function rarely used, because it would be to support the grid when it's close to crash, excursions above 50.2 Hz are very rare (50.2Hz is the default frequency threshold in Europe). Finally this situation has to be handled carefully because in such cases, the B-OBC would reduce OR increase its power without taking into account the setpoint delivered by the EVSE for services.

4.2.6 Remote command

For the last grid code requirement, the ability to be remotely commanded by the grid operator is to our knowledge only required for big production plant. For example, in France, it applies only to HVA grids and power above 5MW. This is not relevant for V2G. This is explained because a special dedicated communication line has to be implemented, and this is quite expensive.

5 Component architecture

5.1 Generalities

For a V2G-capable AC EVSE, several components need to be added. These components might be hardware or software.

It’s important to remind that several architectures are possible for the installation of a conventional AC-EVSE (compliant with IEC 61851-1 and IEC 60364-7-722). Basically, both thermic-electric and fault protection have to be covered by the system “installation + EVSE”. We will take here the example of an EVSE that incorporates both, i.e. CB (circuit breaker) and RCD (Residual Current Device).

Also we assume that the installation is done by a qualified electrician and that all installation checks are done (grounding, cable sizing, need for overvoltage protection …). The interconnection requirements study has to be performed beforehand, to check with the local grid operator / DSO (Distribution Supply Operator) if the selected site is suitable for power injection. This will mean for instance maximum power, need for reactive power compensation, contribution of the generator to short-circuit, harmonic injections …

5.2 List of needed hardware components

The general overview focusing on switches of a grid-connected V2G-AC system is summarized on the figure5.

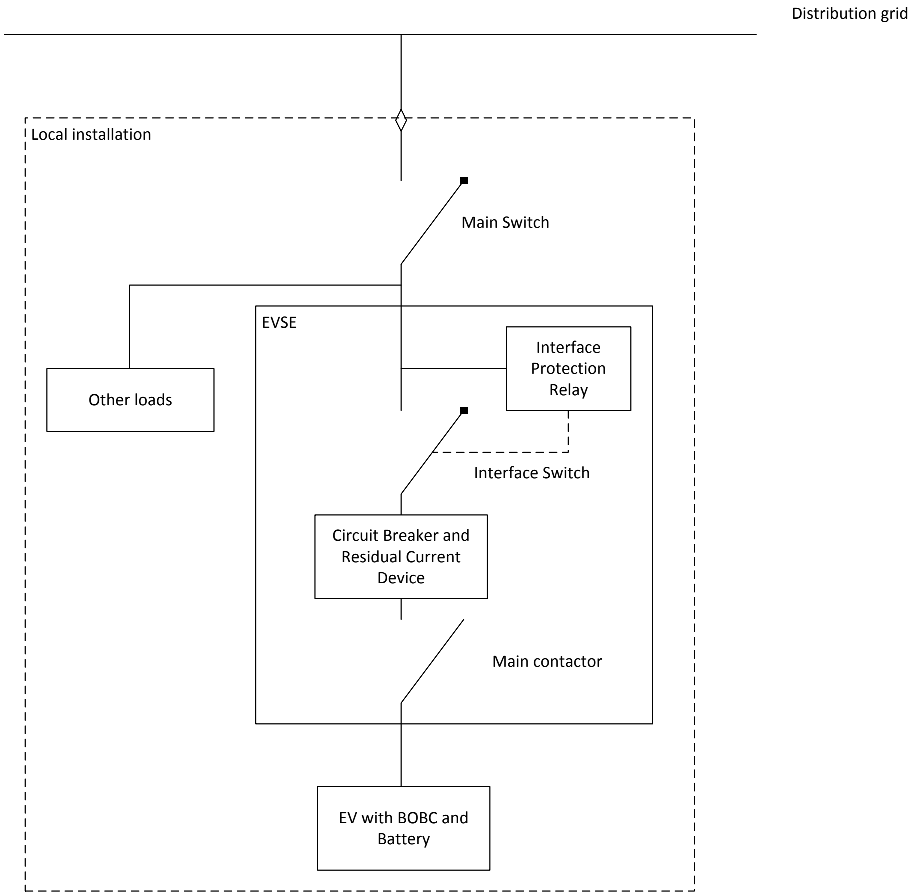


Figure5: Schematic view of switches

5.2.1 Certified interface protection relay

This refer to the “voltage and frequency monitoring” or decoupling protection.
Depending on the country, the relevant standard is today different.
For example,

- in UK, G59 and G83,
- in France DIN 0126-1-1/A1 with specific threshold (VFR 2014)
- in Germany, DIN 4105

Most of these relays rely on the same principles (voltage and frequency measurement) but with specific thresholds / timings.
This lead to the conclusion that a V2G capable AC-EVSE has to embed locally relevant decoupling relay

5.2.2 Interface switch

This switch is to separate the local installation from the fallen grid, to avoid feeding back energy to the grid and sustain an island with non-regulated voltage and frequency. As it is necessary to ensure single-fault tolerance, this switch can be in fact 2 series-connected switches

5.2.3 Bi-directional meter

Depending on the service addressed, this component might be needed for settlement to the TSO/DSO with the bi-directional energy flow.

5.2.4 Communication interface towards back-end

This could be either simple Ethernet connection (LAN or WiFi) or GPRS modem.

5.2.5 PLC modem compliant with ISO15118

To be able to properly allow bi-directional power flow, the mobility need, the limits of the EV and the EVSE have to be exchanged together with the actual power setpoint or schedule.

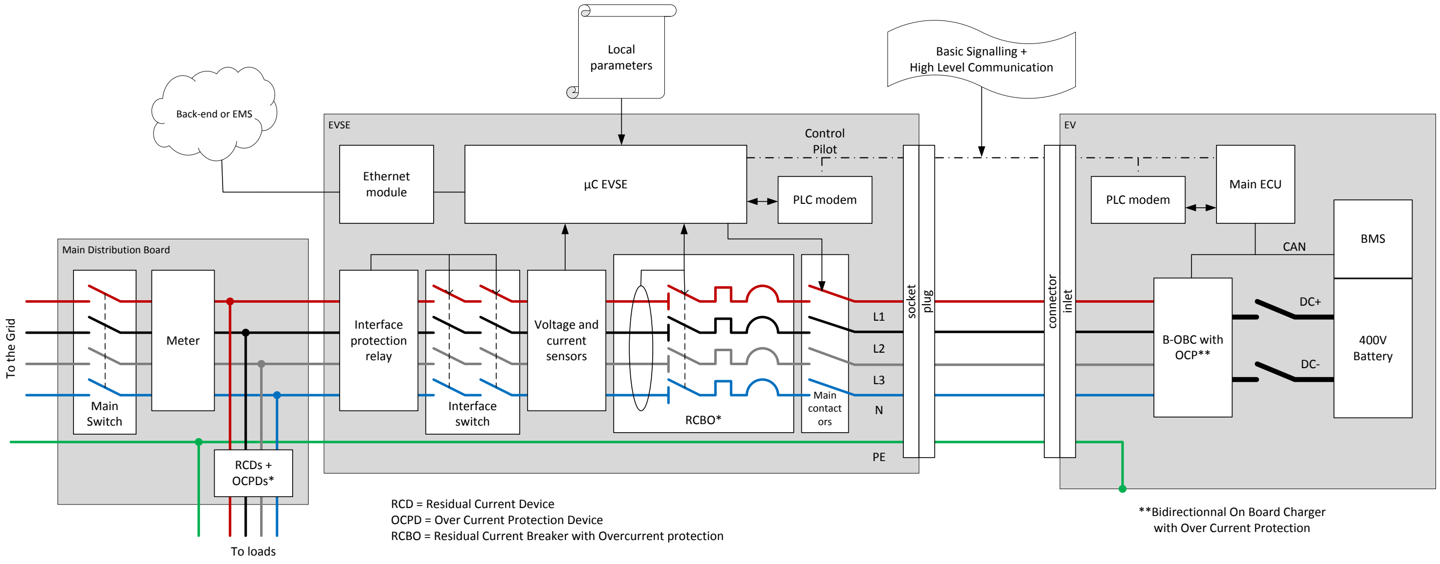


Figure6: Example of component diagram

6 Functional Safety

We studied the relevancy of the High Level Communication defined in ISO15118 to support functions related with safety. The feared event would be that the on-board-charger starts discharging on a site without the proper protections described above.
Our view on this important matter is that distinction has to be done between global communication coherence with messages integrity and low-level fast control.

1. For the discharge to be enabled, a global coherence between the different messages has to be ensured, for example, both the car and the EVSE have to be “bidirectional capable” and after this first negotiation phase, a discharge order has to be sent by the EVSE before the OBC start sending back power to the grid.
   It’s already possible that only HLC is used to transfer the information about the max current that the EV is allowed to draw from the EVSE. This is tagged as safety relevant by ISO 17409.
   HLC also supports TLS to avoid hacking and highly sensitive messages related with contracts are already transferred, especially in the Plug and Charge Identification mode.
2. Then, if talking about pure safety that needs fast reaction, one can already count on the control pilot signal which is known as “basic signaling” in IEC 618651: If EV detects a failure, it will force a change of state from C to B, asking the EVSE to disconnect. The same is possible if EVSE detects a failure. This Control Pilot signal is already key for the safety for “normal” charge.
3. Finally we can also argue that EV has no mean to check whether the EVSE is properly installed with the right protections (RCD and MCB mentioned above), it has to trust the control pilot signal.

We can conclude that the ISO 15118 High Level Communication can be safely used for bi-directional power transfer.

Conclusions

The authors have proposed a system architecture which is the most relevant and able to comply with local grid codes. In this architecture, it’s always at the EVSE level that local parameters are handled. Some parameters affect EVSE functions, such as decoupling protection. Other will impact the P/Q setpoints sent by the EVSE to the EV, for example support to the voltage with reactive power. In the case of requirements that would need faster reaction than allowed by the communication, these parameters could be sent to the EV at the beginning of the bidirectional charging session, this could be for active support to the frequency. Requirements for the bidirectional on board charger are also identified, there are mostly islanding detection by means of active method, robustness to LVRT and HVRT, and specific EMC muteness requirements (e.g. DC current emission). Of course, this architecture relies also on the fact that the EV follows accurately the given setpoint.

Work is ongoing in several standard committee to take that vision to the next step. The most relevant standards are CENELEC EN50549-1, IEC 61851-1, IEC 60364-7-722, ISO 15118 and ISO 17409, that are currently under revision.

Certification of compliance of EVSEs will surely be needed in order to ensure that it meets the requirements of the grid operators. EVs could also need to be certified if they support dedicated functions. This will be checked with grid operators.

Renault is working towards several experimentations of V2G AC, this will lead to the design and test of the described architecture, including a V2G compatible EVSE as well as BEV equipped with bi-directional on-board chargers.

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