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V2G-AC – grid codes compliancy, from lab testing to field experiment

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Summary

In the context of vehicle to grid (V2G) applications, it is important to describe how the electric vehicle (EV) and its supply equipment (EVSE) will be able to operate as a distributed energy resource (DER), and especially how they will comply with grid codes. The high-level communication protocol ISO 15118 ed 2 enables the active and reactive power flexibility needed to solve local electric distribution issues. Based on this technological enabler, this paper will present the grid codes compliance functions implemented in a V2G-AC prototype system, the validation results on a grid emulator and an application project in the specific context of a small island.

Keywords: V2G (vehicle to grid), Generator, EVSE (Electric Vehicle Supply Equipment), Infrastructure.

1 European grid codes compliancy

It is not obvious how a V2G-AC system could comply with requirements designed for fixed Distributed Energy Resources (DER), as explained in [1] and [2]. The general architecture described in these papers is that the EVSE, as the fixed equipment, knows and applies the local rules, and the power conversion is handled by the Bi-directional On-Board-Charger (BOBC) in the Electric Vehicle (EV). Based on this architecture, this section describes the grid codes compliance functions implemented in a V2G-AC prototype, and their characterization based on lab testing results. The next section presents how these functions will be tested on a real-life experiment in Porto Santo.

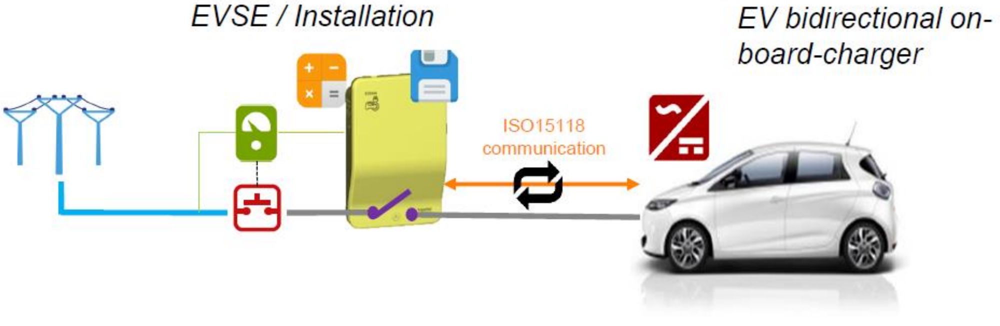

Figure 1:V2G-AC system architecture

The ISO 15118-1 Edition 2 [3] enables a wide variety of V2G use cases (Frequency Containment Reserve, Demand-Response, Self-consumption…). Besides, through the high-level communication the EVSE is able to send active and reactive power targets to the EV in order to fulfil the grid code requirements in case of grid event.

We considered the most recent standards regarding DER connection rules, especially European EN50549-1 recently released in February 2019 [4], German VDE AR 4105 [5], Danish Technical Regulation for battery plants, and UK G83 [7] and G59 [8].

It is important to note that electric safety (electric shock and thermal incidents) as well as usual protection of the generator (overvoltage protection for example) is not part of the scope of this paper.

1.1 Functions implemented

Several functions have been embedded in the charging station to fulfil grid code requirements coming from the previously mentioned standards. In addition to interface protection, some algorithms have been coded to counteract frequency and voltage deviations respectively by adjusting active or reactive power targets that will be sent to the Bidirectional On-Board Charger using ISO 15118 energy transfer loop messages.

1.1.1 Interface protection

One of the key requirements of grid codes is to separate the DER from the grid in case of grid failure. These requirements were already present in the pre-norm DIN VDE 126 released in 2005. The major reason is to avoid that a generator feeds energy back to an island disconnected from the main grid, as frequency and voltage would not be regulated by the grid inertia and could cause damage to the equipment connected. The voltage presence could be also dangerous for potential grid workers who would not be aware of the island still being powered.

To handle these requirements, we used an off-the-shelf protection relay which monitors the grid voltage and frequency and triggers two outputs for redundancy which will be used to open switching devices.

In our case, we used the first output to open the main contactor of the EVSE. The contactor's poles have the openings clearance to properly separate from the grid and are able of breaking the rated current.

The second output is used to ask the vehicle to stop properly the charge/discharge process, through ISO 15118 and Control Pilot.

The grid operator can set-up the voltage and frequency thresholds of the protection relay based on its own constraints.

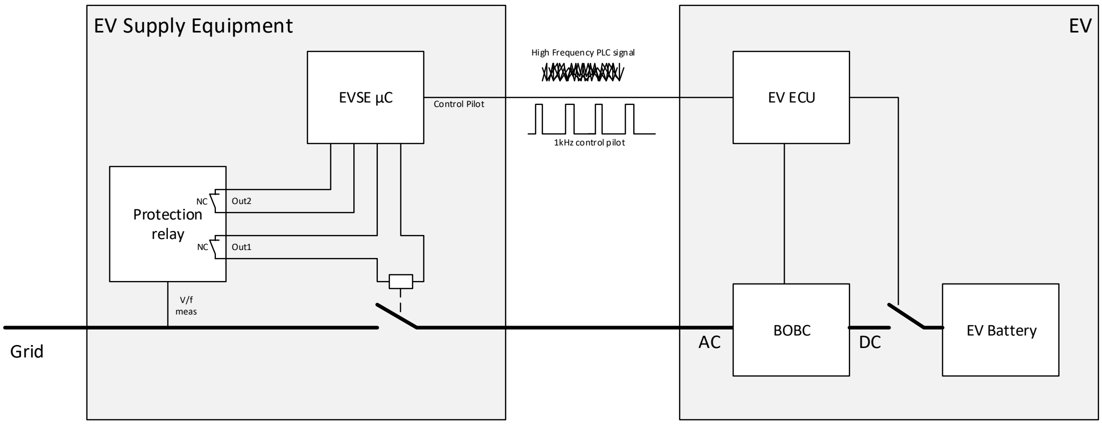

Figure 2: Focus on hardware for interface protection

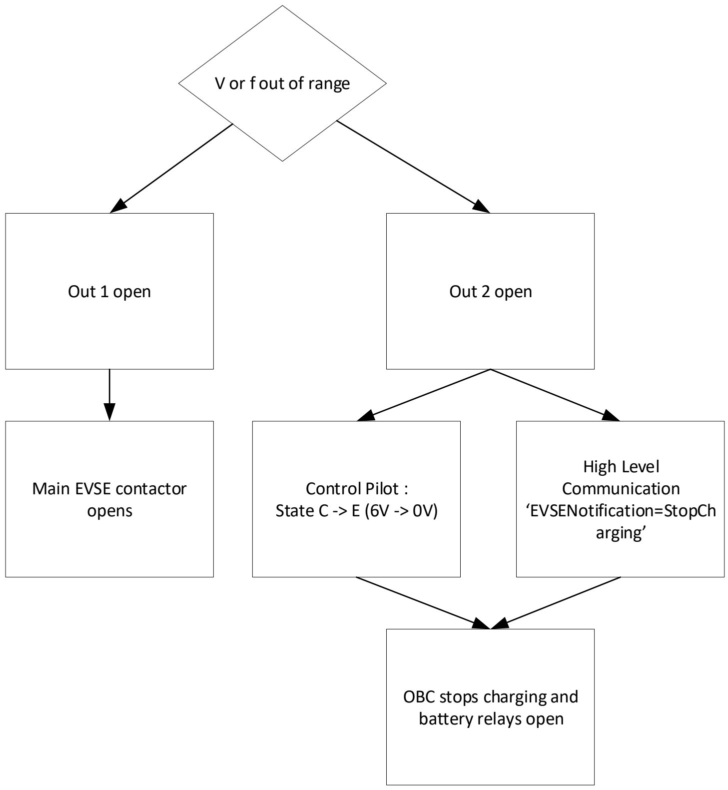

Figure 3: Interface protection logic

Additional requirements were not implemented in our prototype system:

- The protection relay does not include DC current monitoring as required in DIN 126 (2006). This requirement does not exist anymore in recent grid codes standard as it is considered fulfilled by design and type-tested on inverter.
- We did not include any means to detect non-intentional islanding situations where loads and sources were balanced. This situation is commonly tested with the "resonant circuit" and passed thanks to an active method implemented in the inverter. This is a highly hypothetical situation which we should not meet in the experiments of this first V2G-AC prototype system. Nevertheless, this requirement must be handled in mass-product systems.

1.1.2 Reactive Power adjustment

Four different modes have been implemented for the reactive power adjustment. The mode is selected while configuring the charging station, along with the minimum cos(phi) needed whatever the selected mode, depending on the local requirements applied at the EVSE location.

The first mode, "*Direct reactive setpoint*", is used to allow a secondary actor to calculate the reactive power target remotely after having measured local voltage.

The "*Direct cos(phi) setpoint*" mode is used to hard-set a local constant cos(phi) value requested at the charging station location. The reactive power will then depend on the actual active power.

The two other modes are local regulations calculated by the charging station controller: "*Active voltage regulation – Q=f(U)*" mode and "*Automatic power factor control – cos(phi)=f(P)*" mode.

In the "*Active voltage regulation*" mode, the charging station regulates constantly the reactive power target sent to the electric vehicle depending on the voltage measured, by following the below curve:

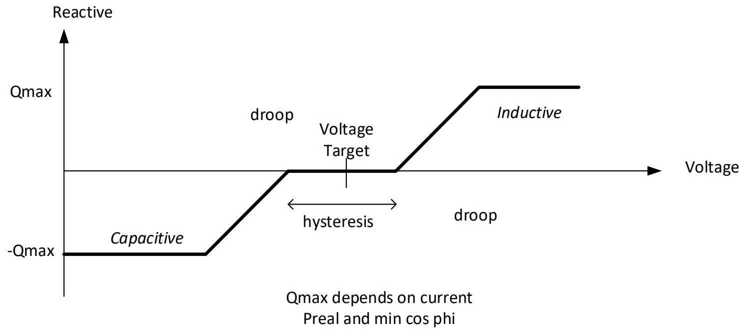

Figure 4: Active Voltage Regulation

In the "*Automatic power factor control*" mode, the cos(phi) is calculated by the charging station based on the active power injection level. The reactive power can be positive or negative but will be generally inductive (Q<0) in order to help reducing the voltage that would increase due to active power injection:

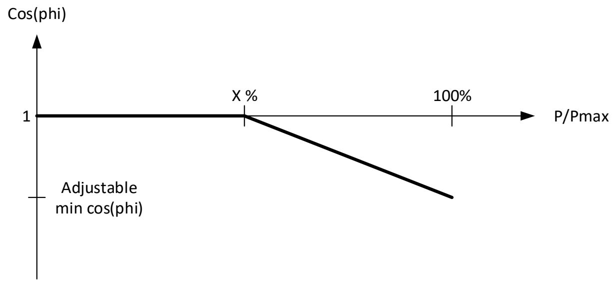

Figure 5: Automatic Power Factor Control

1.1.3 Active Power adjustment

This function is used when frequency deviation occurs. In that case, the reactive power adjustment function described in the previous paragraph is de-activated. The cos(phi) is then set to 1, and the charging station sends a reactive power target equal to zero.

The active power adjustment function should be used very rarely since the over or under frequency emergency events are not frequent. To support those emergency cases, either the *Limited Frequency Sensitive Mode – Over frequency (LFSM-O)* or the Limited *Frequency Sensitive Mode – Underfrequency (LFSM-U)* are used.

In case of LFSM-O activation and increasing frequency the EVSE shall continuously increase the active power target towards the minimum allowed discharge power level according to the selected droop:

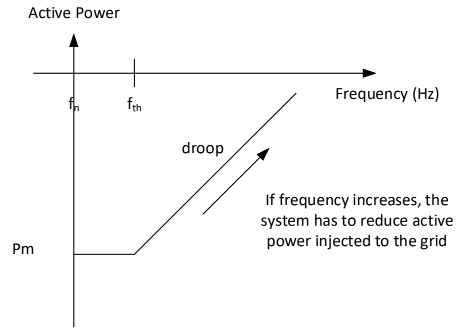

Figure 6: Limited Frequency Sensitive Mode – Over-frequency

In case of LFSM-U activation and decreasing frequency the EVSE shall continuously decrease the active power target towards the maximum allowed discharge power according to the selected droop:

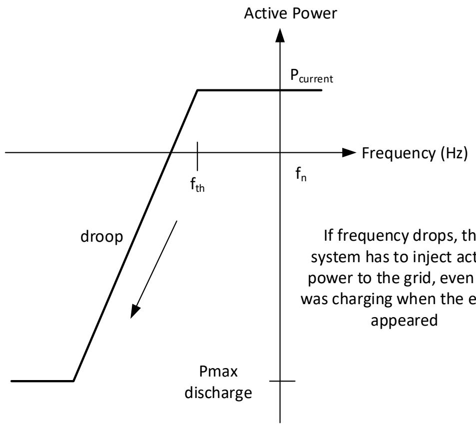

Figure 7: Limited Frequency Sensitive Mode – Under-frequency

1.2 Tests results

The whole system can be assessed exactly like a classical DER. To do so, the EV and EVSE were connected to a grid emulator which allows to vary the frequency and voltage of the grid. The tests involve measuring the active and reactive power transfer during the frequency and voltage deviations thanks to a grid analyser. We especially checked the behaviour of:

- Interface protection
- Reactive power (support to voltage)
- Support to frequency (LFSM-O and LFSM-U: Limited Frequency Sensitive Mode for Over frequency and Underfrequency)
- Harmonics emission

1.2.1 Interface protection

To check the interface protection, we pushed the grid emulator frequency and voltage out of the allowed range.

In the below figure, we can see that when the grid frequency is higher than 50.6 Hz – which corresponds to the threshold in France – the current suddenly drops, which means that the interface protection has opened the circuit.

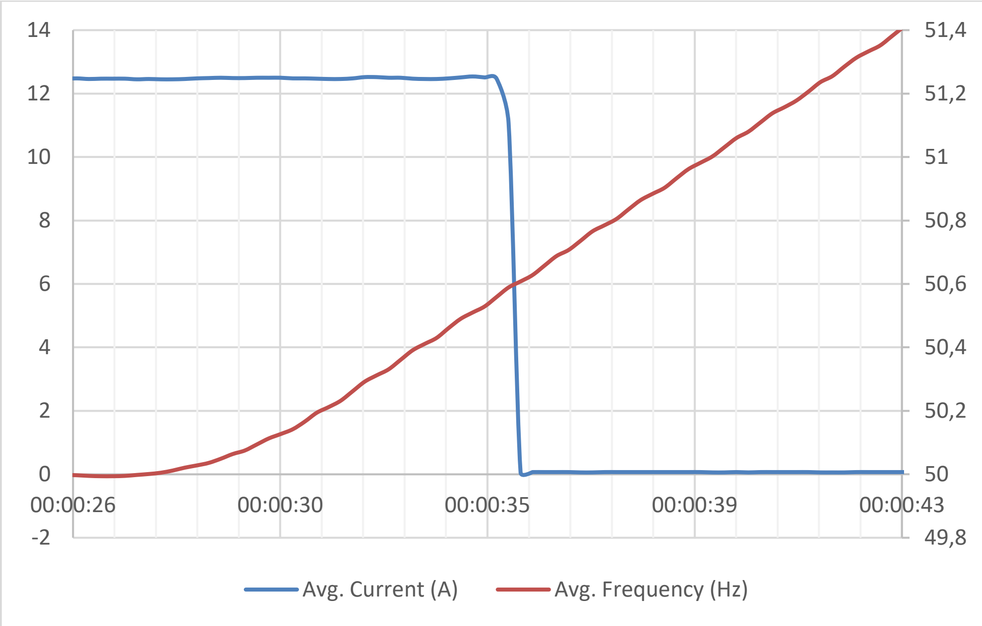

Figure 8: Decoupling due to Overfrequency

We get the same results for the underfrequency, over and under voltage tests.

After the grid disconnection, if the protection relay monitors a grid frequency in the allowed range during at least 60 seconds, a mechanism of grid reconnection should be implemented to switch on the protection relay and re-start the charge with a new ISO 15118 charging session. The reconnection will be followed with a power ramp-up of 10% of the maximum or minimum power $P_{min/max}$. This reconnection mechanism has not yet been implemented in the charging station prototype.

1.2.2 Voltage regulation Q=f(U)

Figure 9 presents the results of primary tests for the active voltage regulation mode.

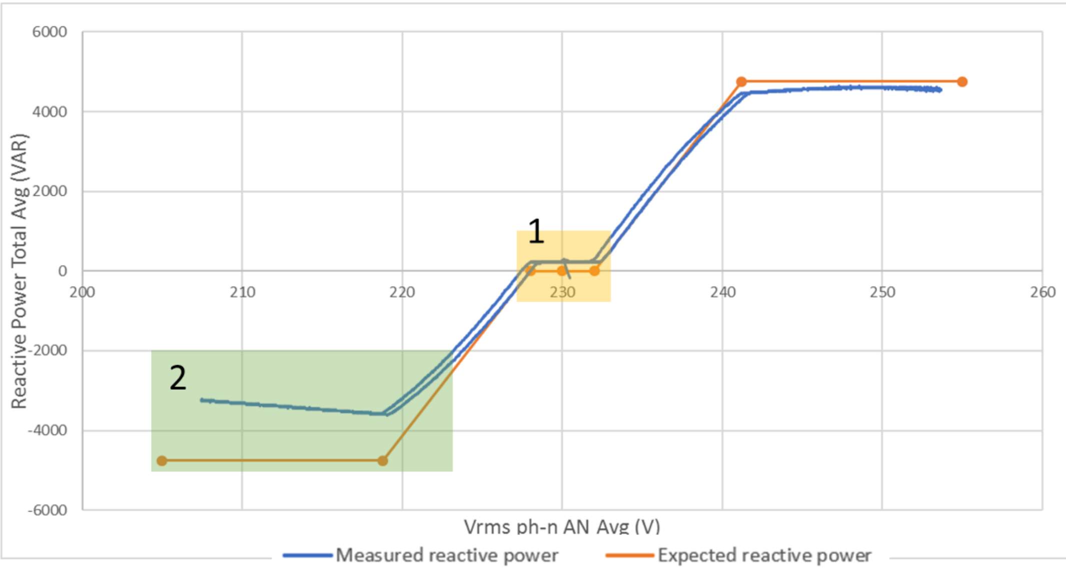

Figure 9: Tests results for Active Voltage Regulation

The results show that the configuration parameters like the droop value or the maximum reactive power which is limited by the minimum cos(phi) are accurately followed by the whole system: charging station calculation, ISO 15118 transmission and bidirectional on-board charger performances. However, some small deviations can be noticed:

1) A static error between the reactive power target sent by the EVSE and the reactive power measurement is due to an inaccurate control of the cos(phi) in the Bidirectional On-Board Charger. This issue will be solved thanks to the addition of a closed loop regulation into the BOBC supervision.

2) The deviation between the actual reactive power and the target increasing as the voltage drops is due to the fact that in ISO 15118, the setpoints are sent in power but these targets are transmitted to the BOBC in current, based on a nominal value for the voltage of 230V. When the voltage drops from 230V, the measured reactive power thus deviates from the power target. This could be solved by adjusting the current target based on the actual voltage.

1.2.3 Frequency support

In the figure below, the active power setpoint remains constant at about 5kW in charge but due to the frequency drop below 49.8Hz, LFSM-U is activated to reduce linearly the charging power. In this test, the power bench was not capable of consuming power, that is why the active power is limited to 0W, but the algorithm asks for a mode change: from charge to discharge. There is also a hysteresis which is due to the filtered frequency measurement.

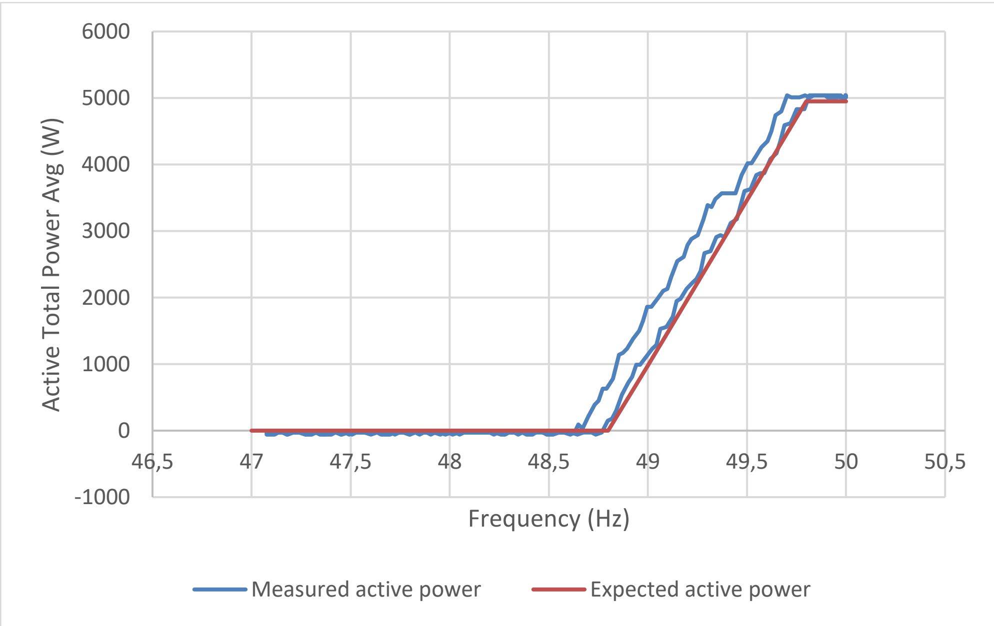

Figure 10: Test results for LFSM-U

1.2.4 Harmonics quality

In addition to “classical” harmonics measurement done in accordance with IEC 61000-3-2 or IEC 61000-3-12, we checked the “SYSTEM” test of IEC 61000-3-15.

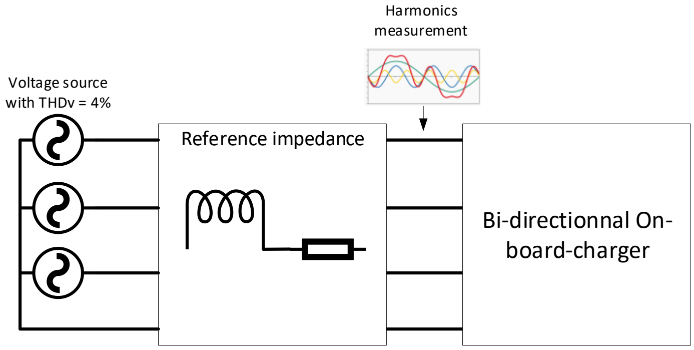

Figure 11: SYSTEM test for harmonics quality

The goal is to check the voltage harmonics distortion increase when the generator is ON. To do so, a power grid simulator is used to simulate a voltage waveform with a THDv of 4%, and a standardized line impedance is added between the "grid" and the generator.

The THDv shall remain below 5%. Test results show that at half power and full power our system fulfils the requirement.

2 Field experiment in Porto Santo

2.1 Overview

In the context of the Portuguese island of Porto Santo, the following grid assets are present:

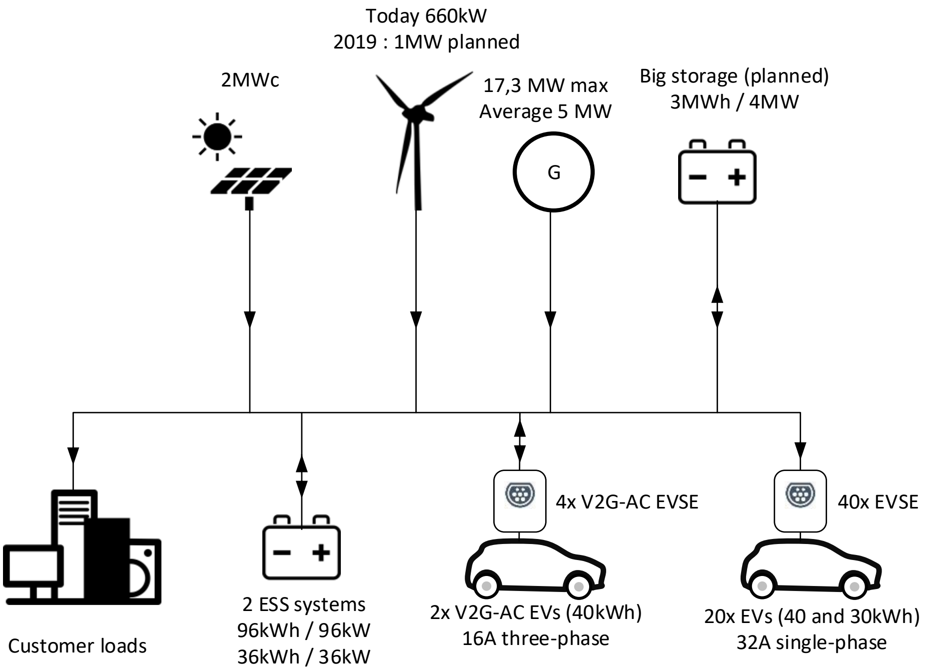

Figure 12: Porto Santo Grid assets

The general idea is to completely avoid producing electricity with conventional generators (G in Figure 12) thanks to the flexibility given by the renewable energy production and the electric storage.

2.2 Frequency issues

It is worth noting that, as this kind of grid is very small compared to interconnected European grid, voltage but especially frequency can greatly vary, and typically decoupling protection have to be set with different thresholds compared to European standards.

As an illustration, figure 12 shows the measured frequency in Porto Santo during one week.

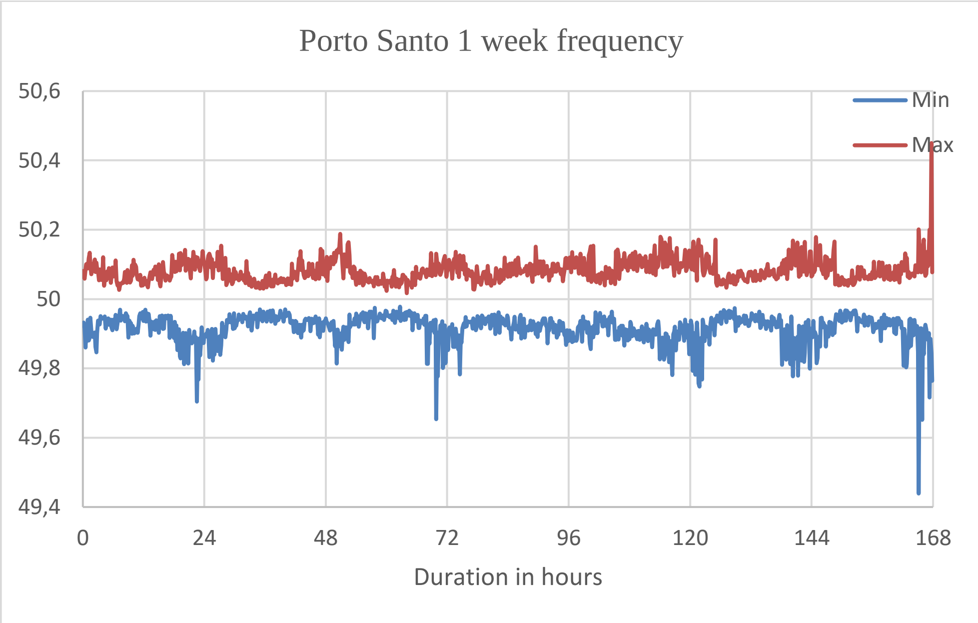

Figure 13: Porto Santo Frequency Measurement

These are 10s measurements aggregated each 10 min: we see minimum and maximum of these 10s values for each 10 min periods. Extreme values can be seen: minimum is 49.4 and maximum if 50.4, these is far from values usually seen on European interconnected grid (generally the frequency does not deviate from [49.9; 50.1] Hz.

As previously explained, the trend is to reduce the conventional production, so the frequency will likely deviate even more from the nominal: the solar production can drop very fast, so fast P(f) functions can greatly help to stabilize the frequency.

2.3 Voltage issues

Besides the “normal” balance trade-off between active power generation and consumption, there are voltage plane issues in the distribution grid that need to be solved with local reactive power injection.

Electric storage “ESS” and V2G-AC systems are capable of injecting or consuming reactive power. Between the different four modes described in section 1.1.2, the grid operator prefers using the Active Voltage regulation - Q=f(U) mode. One purpose is to experiment the Q=f(U) function impact on grid behaviour by testing different configurations of the following parameters:

- droop factor
- deadband
- filtering

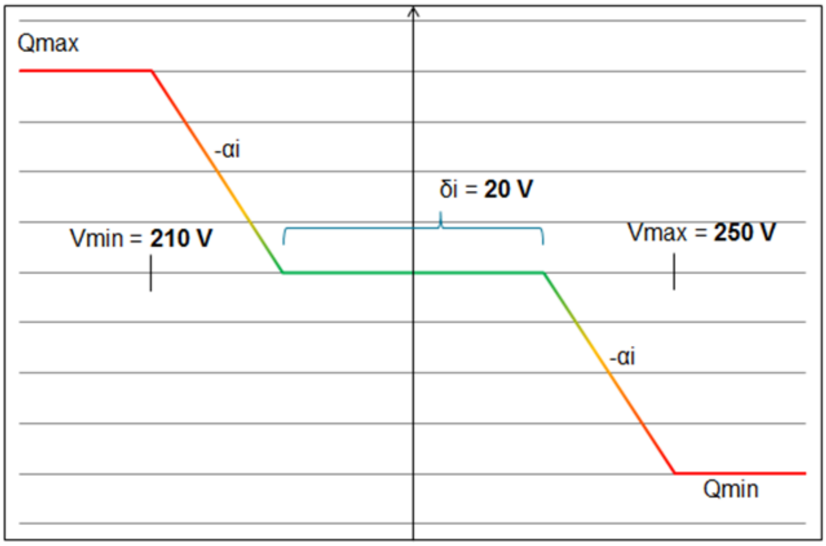

Figure 14: Reactive Power as a function of Voltage

In a small island like Porto Santo there could be significant voltage drops in remote places. The voltage support is key to support the grid.

The results of the section 1.2.2 show that the V2G – AC prototype system should be able to follow the curve presented in Figure 14 in order to help stabilizing the local voltage plane.

3 Conclusion

This paper describes the functions implemented on a V2G-AC prototype for grid codes compliancy. It then presents for each function test results on a grid emulator to characterize the response of the system and measure its efficiency. Finally, the paper presents the major grid issues met in the island of Porto Santo in Madeira, where a field experiment is ongoing, and how our V2G-AC prototype can help stabilizing the frequency and voltage with the grid code functions implemented. The experimentation will allow to measure the impact of the V2G – AC system on these issues.

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Authors

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