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Abstract:
Description of FastV2G tool, which is an Electric Vehicle Supply Equipment which is able to charge any EV compatible with CHAdEMO standard as well as taking the energy from its batteries in order to inject it to the grid. This allows the Electric Vehicle to act as a distributed storage system which can flatter the demand curve, maximize the integration of renewable energies and offer auxiliary services to the grid. The related tasks are T8.2 and T8.3.

Keywords:
V2G (Vehicle to Grid), OCPP (Open Charge Point Protocol), Electric Vehicle, EVSE, Bidirectional charging, CHAdeMO

Revision History

Revision	Date	Description	Author (Organisation)
V0.1	17.04.2018	First Version	ITE
V0.2	25.04.2018	Added contributions of peer reviewers	PARTAGO, EMOTION
V0.3	30.04.2018	Executive summary included	ITE

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EXECUTIVE SUMMARY

The increase in the electric vehicle market is already a reality due to various factors such as growing environmental concerns, compliance with decarbonisation objectives and the increase in the price of oil among others. This requires increasingly advanced and efficient responses that shall be able to manage effectively this type of dynamic load.

With this new scenario where electric mobility is becoming increasingly important, the use of new technologies to optimize the massive presence of electric vehicles connected to the grid acquires special relevance. One of these solutions is the Vehicle to Grid mode, where bidirectional stations are able not only to recharge the batteries of electric vehicles but also to take advantage of this stored energy in order to inject it into the grid. This opens a new opportunity for the Smart Cities, where each electric vehicle connected to the electricity grid can act as a distributed storage system, thus being able to smooth the demand curve, optimize the integration of renewable energies and offer auxiliary services to the grid.

Another of these technologies is dynamic charging, where the EVSE is able to limit the power supplied to the electric vehicle attending to orders received from a Control Center, in order to optimize the grid management by performing energy balancing between different charging stations.

In order to comply with these requirements, FastV2G station is being developed in WiseGRID project. This EVSE is able to perform charging and discharging sessions (Gird to Vehicle and Vehicle to Grid) with the following main specifications:

- Bidirectional mode and dynamic charging
- 10kW nominal power
- CHAdeMO compliant
- OCPP v1.6 communications with WiseEVP
- 5,7” Human Machine Interface (HMI)

The design of FastV2G is based on a Fast Station previously developed by ITE where the following tasks are being developed in order to meet the WiseGRID requirements and to adapt the EVSE to the new standards and functionalities:

Graphical User Interface

In this section, a 5,7” display has been programmed where the user can display and set the basic parameters of the charging session, such as the charging strategy (Full Battery or Smart Charging).

Programmable Logic Controller

One of the main cores of FastV2G which is in charge of the management of HMI, OCPP module and the peripherals inside the EVSE such as the RFID reader and Energy Analyzer.

Communications Subsystem

Second main core of FastV2G which is in charge of the CHAdeMO communications with EV, as well as managing the power electronics modules.

OCPP programming

Communications with WiseEVP meet the requirements of OCPP standard, in its version v1.6 using JSON. Profiles developed in FastV2G include Core, Smart Charging and Local List Authorization.

Power Electronics

The power of the FastV2G station has been downgraded from 50kW to 10kW in order to meet CHAdeMO standards. This implies that the DSP (Digital Signal Processing) firmware programming that manages the power electronic devices needs to be adapted and optimized to achieve the maximum efficiency.

1 INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

This document contains the technical design of the FastV2G bidirectional charging station, describing the specifications and identifying the necessary requirements in order to carry out the development. This report contains all necessary technical specifications and design requirements.

1.2 SCOPE OF THE DOCUMENT

The present document summarizes the main objectives, functionalities and requirements of the FastV2G EVSE, and describes the preliminary design of the main parts of the bidirectional EVSE: Programmable Logic Controller, HMI, OCPP module, Electronic Control Unit and Power Electronics Control.

1.3 STRUCTURE OF THE DOCUMENT

The main content of the deliverable is structured in 2 main chapters. The first chapter is Chapter 2 , starting with an introductory section describing the background of FastV2G, explaining that this project starts from a previous prototype of charging station developed between 2012 and 2014. The subsequent section details the main requirements of FastV2G, with all relevant information regarding standards, regulations and communications. One of the most important parts of the document is section 2.2.4, where a comparison is made between the previous EVSE and FastV2G, listing the necessary developments in order to achieve the goals of the project. With all this previous background, the technical features of the EVSE are described, as well as the installation requirements in Crevillent pilot site. The last part of Chapter 2 consists of a full description of the FastV2G architecture, showing the diagram blocks of the station, explaining each module that makes up FastV2G.

The second main chapter of the deliverable is Chapter 3. In this section, all the designs of FastV2G are explained, per module that is being developed: HMI, PLC, OCPP, Subsystem-programming and Power Electronics adaption and optimization.

Finally, the document ends with the conclusions section. It must be remarked that the present document does not include all information regarding the developments (this document mostly focuses in the design stage), as these are still in progress and will be concluded by July 2018.

2 BACKGROUND

2.1 OVERVIEW

WiseGRID FastV2G is an EVSE (Electric Vehicle Supply Equipment) that is able to:

- Perform a fast DC charging session.
- Inject electricity from the EV's battery to the network (V2G functionality).
- Perform a dynamic charging session (power modulation) in both directions: G2V and V2G.
- Receive "charging orders" from a hierarchically superior component.
- Send performance information to a hierarchically superior component.

The main objective of FastV2G is to provide auxiliary services to help in the distribution network operation and to maximize renewable resources integration, by providing:

- Regulation services.
- Spinning reserves.
- Peak-shaving capacity in order to flatten out the demand curve.

The WG FastV2G is based on a previous ITE development in the scope of a project [1] where a prototype of a Smart Charging Station was designed, developed and built, as shown in the following Figure:

Figure 1 – Previously developed Smart Charging Station that served as a basis

However, the development of this previous charging station started in 2012, when electrical mobility wasn't as consolidated as it is today and when some of the main standards of EV charging were not even released. For example, the CHAdeMO output of the Smart Charging Station was based on the standard JIS TS D0007:2012, which was previous to the current CHAdeMO standards starting from version 0.9.

Therefore, the objective of this Work Package is to adapt the previous Smart Charging Station to the new standards and technologies and to carry out all the necessary developments so that the FastV2G meets the desired requirements to achieve the WiseGRID goals.

2.2 REQUIREMENTS

2.2.1 Standards and Rules

The previous EVSE was designed considering the following regulations and standards:

IEC 61851-1:2012

IEC 61851-1:2012 applies to on-board and off-board equipment for charging electric road vehicles at standard AC supply voltages (as per IEC 60038) up to 1 000 V and at DC voltages up to 1 500 V, and for providing electrical power for any additional services on the vehicle if required when connected to the supply network. It includes characteristics and operating conditions of the supply device and the connection to the vehicle; operators and third party electrical safety, and the characteristics to be complied with by the vehicle, with respect to the AC/DC EVSE, only when the EV is earthed.

IEC 61851-23

Electric vehicle conductive charging system - Part 2-3: DC electric vehicle charging station

IEC 61851-24

Electric vehicles conductive charging system - Part 24: Control communication protocol between off-board DC charger and electric vehicle.

IEC 62196-1

IEC 62196-1:2011 is applicable to plugs, socket-outlets, connectors, inlets and cable assemblies for electric vehicles (EV), herein referred to as "accessories", intended for use in conductive charging systems which incorporate control means, with a rated operating voltage not exceeding:

- 690 V AC 50 Hz - 60 Hz, at a rated current not exceeding 250 A,
- 1500 V DC at a rated current not exceeding 400 A.

IEC 62196-3

Plugs, socket-outlets, and vehicle couplers - conductive charging of electric vehicles - Part 3: Dimensional compatibility and interchange ability requirements for dedicated DC and combined AC/DC pin and contact-tube vehicle couplers.

JIS TS D 0007:2012

This technical specification (TS) by the Japanese Standards Association specifies the basic functionality that shall be incorporated into designs of electric vehicles and quick chargers in order to enable safe and rapid charging between the electric vehicles and the quick chargers. This TS is related to CHAdeMO.

ISO/IEC 15118

ISO/IEC 15118 specifies the communication between EV and EVSE. The communication parts of this generic equipment are the electric vehicle communication (EVCC) and the supply equipment communication controller (SECC). This standard is oriented to the charging of electric road vehicles. However, this standard is open for other electric vehicles such as electric boats as well. The three parts that consists this standard are:

- Part 1: General information and use-case definition.
- Part 2: Technical protocol description and open systems interconnections (OSI) requirements.
- Part 3: Physical and data link layer requirements.

ITC-BT-52

This ITC (Complementary Technical Instruction) is a Spanish technical instruction that establishes the requirements applicable to facilities for recharging electric vehicles. The main aspects to be considered for this project are related with the safety of the installation and during operation, and also determine the voltage and current levels available for this kind of facilities.

In addition to the standards of the previous EVSE, during WiseGRID development the following regulations will be included to the FastV2G stations.

CHAdeMO

This standard which will be explained in detail further in this document uses CAN bus communications in order to exchange information between EV and EVSE.

FastV2G station will be compatible with the following versions of CHadeMO standard, which will be explained in detail further on in this document:

- Version 0.9
- Version 1.0
- Version 1.1
- V2H charge/discharge mode

OCPP

Open Charge Point Protocol developed by OCA (Open Charge Alliance), a global consortium of public and private EV infrastructure leaders that have come together to promote open standards. OCA provides open and interoperable communication protocol for the EV charging infrastructure, which support all the functionality needed by today's advanced charge management systems. FastV2G will support the latest released version of OCPP, v1.6 in JSON implementation.

2.2.2 Output standard selection

One of the first decisions to be taken into the design of FastV2G EVSE is which communication standard with the EV should be followed.

Currently, there are two main standards regarding DC charging: the first is the Japanese standard CHAdeMO, which is present in most of the Asian Electric Vehicles such as Nissan, Toyota Kia, and Mitsubishi. The second is the European Standard CCS Combo, used by European Manufacturers such as BMW, Mercedes, Volkswagen, Audi or Porsche.

In this section, both standards will be compared regarding two main functionalities which shall be fulfilled by FastV2G EVSE:

- Dynamic charging, where the maximum power sourced to the EV can be limited by the EVSE following instructions from a superior Control Centre, in this case WiseEVP
- Bidirectional current flow: the EVSE shall be able to charge the batteries of the EV as well as taking the energy from the batteries to inject it to the grid, which is known as Vehicle to Grid performance (V2G)

2.2.2.1 CHAdeMO

2.2.2.1.1 Introduction

The CHAdeMO association [2] was formed in 2010 by the Tokyo Electric Power Company, Nissan, Mitsubishi and Fuji Heavy Industries, and after these executive members Toyota joined as the fifth member.

CHAdeMO is the acronym for "CHArge de Move", which is an association that aims to increase the number of quick-charger installations around the world, and by doing so trying to enable electric mobility on a global scale. To achieve it they pretend to standardize EV quick charge with their charge protocol.

CHAdeMO is also a DC charging standard for EVs. It enables seamless communication between the EV and the EVSE. It is developed by CHAdeMO Association, which is tasked with certification, ensuring compatibility between the EV and the EVSE.

Just as the majority of EV's, CHAdeMO Electric vehicles have an on-board charger that uses a rectifier circuit for transforming AC current into DC current, suitable to recharge the EV's batteries. Besides, the CHAdeMO connector also makes a data connection through CAN protocol, transmitting the battery parameters to the EVSE and vice versa.

Its charging method for EV batteries delivers up to 62.5 kW, 500 V and 125 A direct current, via a special electrical connector. The connector has the following appearance:

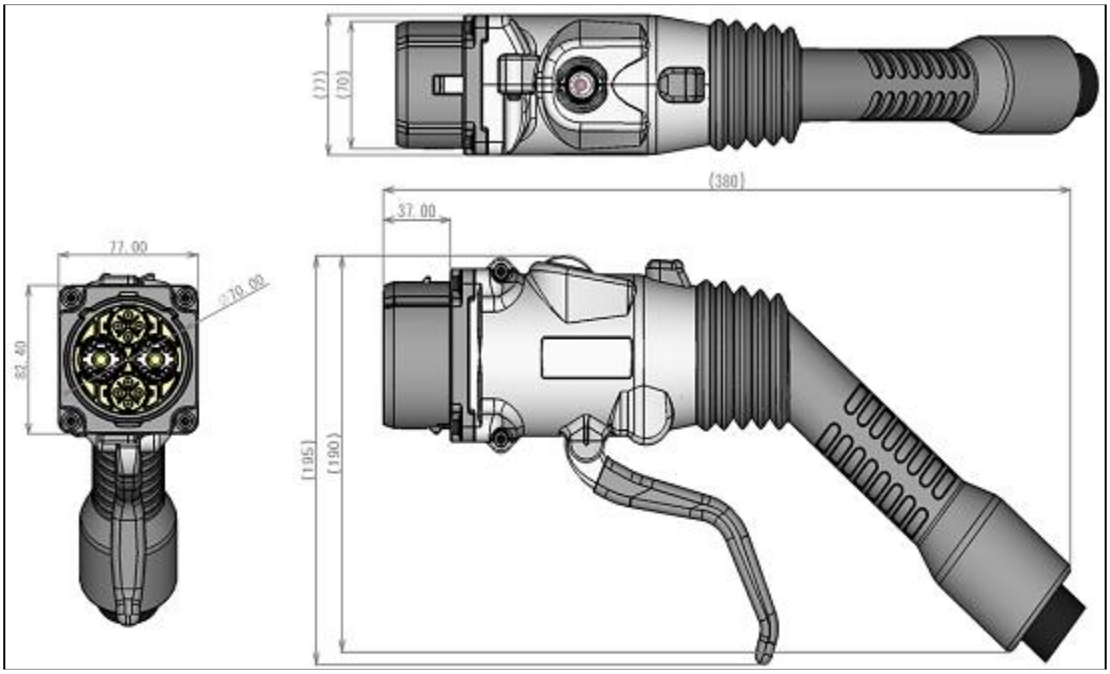


Figure 2 – CHAdeMO connector

As shown in Figure 3, there are 10 pins in the CHAdeMO connector and one of them is not connected (Pin 3):

Pin	Description
1	Ground wire
2	Charge Sequence Signal 1
3	Not connected
4	Vehicle Charge Permission
5	Power Supply (-)
6	Power Supply (+)
7	Connector Proximity Detection
8	CAN High
9	CAN Low
10	Charge Sequence Signal 2

Table 1 – CHAdeMO Pinout

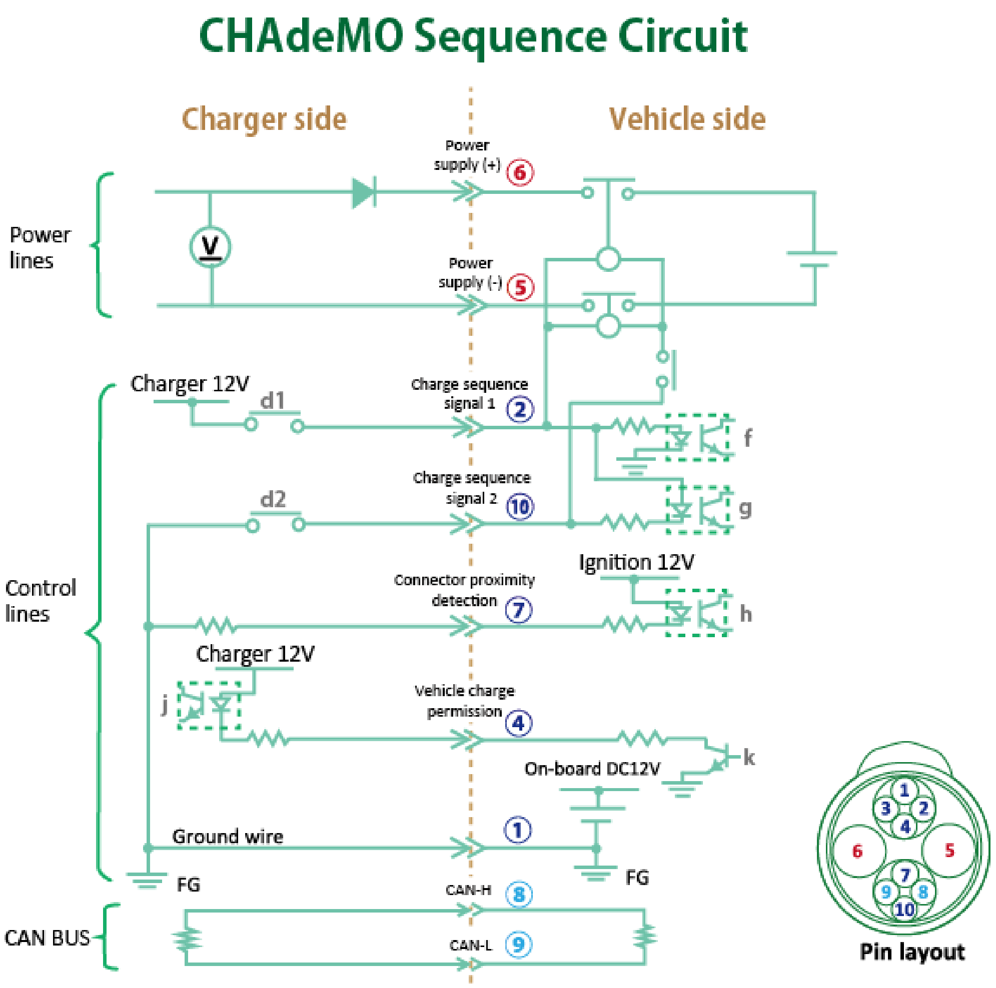


Figure 3 – CHAdeMO sequence circuit and pin layout

This circuit establishes the exchanged parameters, which are necessary during charging control. For the communications, the EV and the Fast DC Charging EVSE are equipped with Terminating Resistors. There are also noise filters to reduce the conducted noise in common and differential modes. Twisted pair line is used as the communication line between the EV and the EVSE to reduce differential mode noise.

Specifications for circuit sequence:

EVSE

Terminal	Min. Value	Typ. Value	Max. Value	Units
Charge Sequence Signal 1	10.8V	12.0	13.2	V
Connector Proximity Detection	190	200	210	Ω
Vehicle Charge Permission	950	1000	1050	Ω
Charge Sequence Signal 1	2		2000	mA
Charge Sequence Signal 2	2		2000	mA

Table 2 – CHAdeMO EVSE Specifications

EV

Terminal	Min. Value	Typ. Value	Max. Value	Units
Charge Sequence Signal 1	10		2000	mA
Charge Sequence Signal 2	10		2000	mA
Connector Proximity Detection	950	1000	1050	Ω
	8	12	16	V
Vehicle Charge Permission	190	200	210	Ω
Vehicle Charge			2	mA

Permission			0.5	V

Table 3 – CHAdeMO EV Specifications

The connection between the EVSE and the EV has the following characteristics:

- The control power is supplied to EV contactors by means of an EVSE. The EV contactors will never close and there is zero voltage unless a vehicle is connected to the EVSE.
- During pre-charge, an automatic safety check is carried out to verify the insulation of the circuit and the short circuit between the EV contactors and the EVSE.
- While EV is charging, the vehicle connector is locked to the vehicle inlet through a mechanical latch by an electrical lock. When charging is finished, the electric lock is released after confirming a correct voltage. If the voltage does not fall to a safety level, the latch will not be released.

2.2.2.1.2 Dynamic Charging

Dynamic charge was included since version v1.1 and later versions of the protocol. Before this version, only static charging was permitted in CHAdeMO standard. In this mode, the maximum power supplied by the EVSE to the EV would remain constant during all the charging process. The master would always be the EV, while the EVSE would act as a slave following the demand current required by the car.

In this static mode used in versions v0.9 and v1.0, an initial handshake between EV and EVSE is performed, in order to share EV information such as Voltage, SOC or EV model. During this process, the maximum power to be supplied by the charging station is set and cannot be modified at any other point of the charging session.

Once the charging process has started, the EV requires CAN messages each 100 ms with the necessary current to charge the batteries considering the actual State of Charge (SoC). The Charging Station will then have to supply this current with an error of ±2.5A.

The following figure shows an example of Static Charging

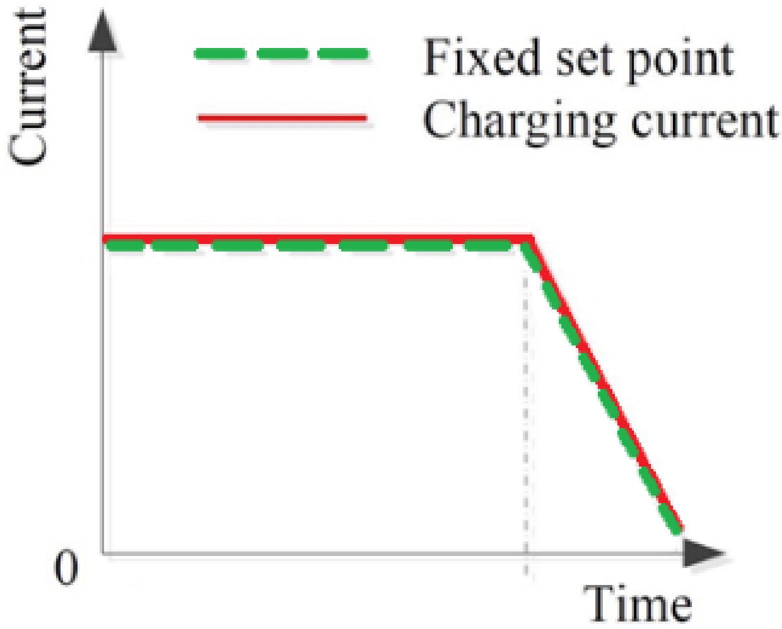


Figure 4 – CHAdeMO static charging process

The dashed green line represents the current request set by the EV, while the red line represents the charging current supplied by the EVSE to the EV. Both values must be equal during the charging period.

Dynamic charging works differently. Version 1.1 supports this type of charging, as well as the charging/discharging mode present in CHAdeMO V2H protocol, version v2.0, which has the following features:

- The EV sets constantly the maximum charge and the maximum discharge current depending on the status of the battery.
- The EVSE is free to set the actual charge/discharge current within the limits set by the EV. It has to inform the EV of this parameter which will be constantly updated, but in this case the EVSE is the master of the process.
- It is possible to switch from charging to discharging mode during the session.
- Delay time is 100 ms from EVSE plus 1 additional second in case delay between EVSE and EV due to communication error.

2.2.2.1.3 Vehicle to Grid

CHAdeMO protocol supports Vehicle-to-Grid Mode. In fact, the Japanese association has released a technical document “Guidelines of Charge/Discharge System for Electric Vehicle V2H DC version – Version 2.1” where all the technical requirements of this bidirectional charging are defined. In section 6.1 of that document, which is private and accessible only for CHAdeMO members, the *“Rated values of the voltage, frequency and power”* are defined. In this scenario, the power of V2G mode is limited to 10kW, so this will be a restriction for the FastV2G EVSE and will set the nominal power of the charger to this value.

2.2.2.2 CCS COMBO

2.2.2.2.1 Introduction

The Combined Charging System (CCS) is based on open and universal standards for electric vehicles and is a quick charging method delivering high voltage [3].

In October 2011, during the 15th International VDI-Congress of the Association of German Engineers, a proposal for a Combined Charging System was published. This proposal defined a connector on the vehicle able to offer enough space for a type 1 and 2 connector along with space for two pin DC connector, allowing up to 200 A. Several car manufacturers (Audi, BMW, Daimler, Ford, General Motors, Porsche and Volkswagen) accepted the proposal and it was agreed to introduce CCS in 2012. Finally, the prototype was shown in May 2012 on the EVS26 in Los Angeles and it gives a range up to 125 A with up to 850 V, complying the regulation IEC 62196-3.

ISO/IEC 15118-3 describes the physical and link layer requirements stipulating Power line communication (PLC) as main method, proposing the solution: HomePlug GreenPHY (GP). The seven manufacturers agreed to use the HomePlug GreenPHY as the communication protocol to establish the communications between the EVSE and the EV during a charging process based on ISO/IEC 15118 over Broadband PLC via the control pilot line (CP) and Protective Earth (PE). The main features of HomePlug GP are:

- Operation with 75% less power consumption (than current HomePlug AV implementations).
- Provides Internet (IP) networking supporting 802.2, IPv6.
- Provides 256 kbps minimum effective networking throughput.
- Provides 10 Mbps peak PHY rate.

The plug of a CCS is hence a combination of an AC connector with a DC connector, therefore the resulting connector is also called Combo Coupler or connector, with the variant with Type 2 being abbreviated as Combo2. The appearance of the Combo connector is as follows:

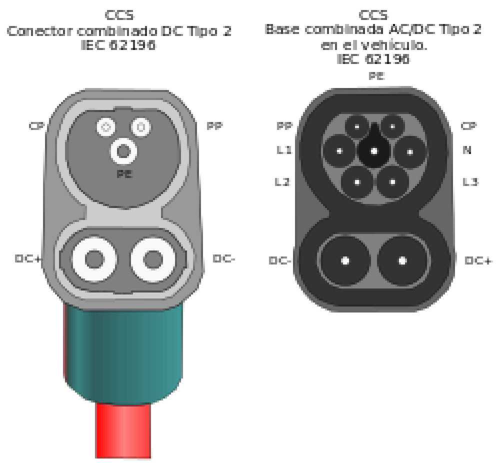


Figure 5 – Combo Connector

As is shown in the previous figure the connector has several pins, but the functionality of each one of them can be understood in Table 4.

Signal	Functionality
PE	Protective Earth
CP	Control Pilot
PP	Proximity Pilot
N	Neutral (optional)
L1	AC line 1 (optional)
L2	AC line 2 (optional)
L3	AC line 3 (optional)
DC+	Positive CC (+)
DC-	Negative CC(-)

Table 4 – CCS Pinout

The EVSE provides to the EV the information about the maximum current allowed through a PWM modulation in the Control Pilot (CP) signal.

The following figures provide the basic operation of the CP circuit, once in a typical layout, and once in a simplified layout:

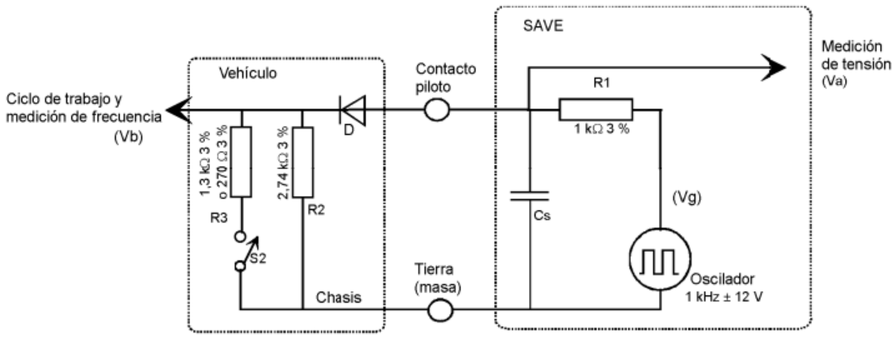


Figure 6 – Typical circuit for Control Pilot

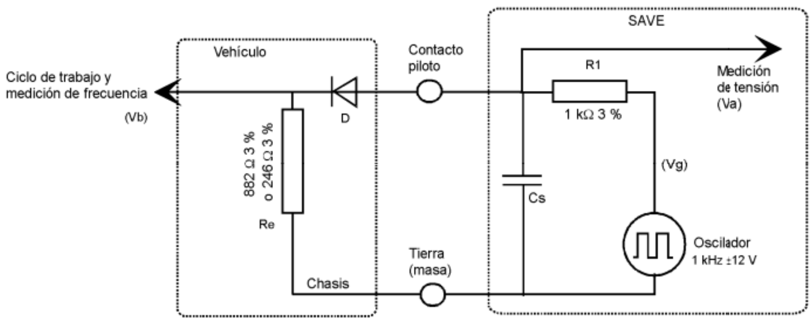


Figure 7 – Simplified circuit for Control Pilot

It is important to know that the simplified circuit cannot be used for EVs with a current bigger than 16 A monophasic.

In the following tables, the results of the CP circuit can be observed:

Parameter	symbol	Value	Units

Positive voltage of the generator in open circuit	Voch	12,00(±0,6)	V
Negative voltage of the generator in open circuit	Vocl	-12,00(±0,6)	V
Frequency	Fo	1000(±0,5%)	Hz
Pulse width	Pwo	4(±25µs)	µs
Maximum raise time (10% - 90%)	Trg	2	µs
Maximum fall time (90% -10%)	Tfg	2	µs
Minimum time for establishing 95% of the permanent regime	Tsg	3	µs
Equivalent source resistance	R1	1000±3%	Ω
EMI Suppression recommended	Cs	300	pF
Total cable capacity + CS	Cs+Cc	3100	pF

Table 5 – Parameters and values of the CP circuit (EVSE)

Parameter	symbol	Value	Units
Permanent resistance value	R2	2,74K (±3%)	Ω
Value of the switched resistance for vehicles that do not need ventilation	R2	1,3K (±3%)	Ω
Value of the switched resistance for vehicles that need ventilation	R3	270 (±3%)	Ω
Equivalent resistance value without ventilation	Re	882 (±3%)	Ω
Equivalent total resistance with necessary ventilation	Re	246(±3%)	Ω
Voltage drop in the diode (2.75 -10mA, -40ºC to + 85ºC)	Vd	0,7((±15)	V
Maximum total equivalent input capacity	Cv	2400	pF

Table 6 – Parameters and values of the CP circuit (EV)

Vehicle State	Vehicle connected	S2	Charge possibility	Va	
A	No	Opened	No	12V	Vb=0V
B	Yes	Opened	No	9V	R2 detected
C	Yes	Closed	Vehicle prepared	6V	R3=1,3KΩ±3%

D				3V	R3=270Ω±3%
E	Yes	Opened	No	0V	Vb=0:
F	Yes	Opened	No	-12V	EVSE not available

Table 7 – Pilot functions referred to Figure 8

The communication mode between the EVSE and the EV is through PLC, where CP and PP are necessary. The use of these two signals is managed by the PWM. The PWM states indicate if an EV is connected or not, and if the communication through CP is processed correctly on the EVSE and EV side. The way of acting of the CP is shown in Figure 8, where a variable PWM for switching between the different states can be seen. The conditions for jumping to the different states are defined in Table 8.

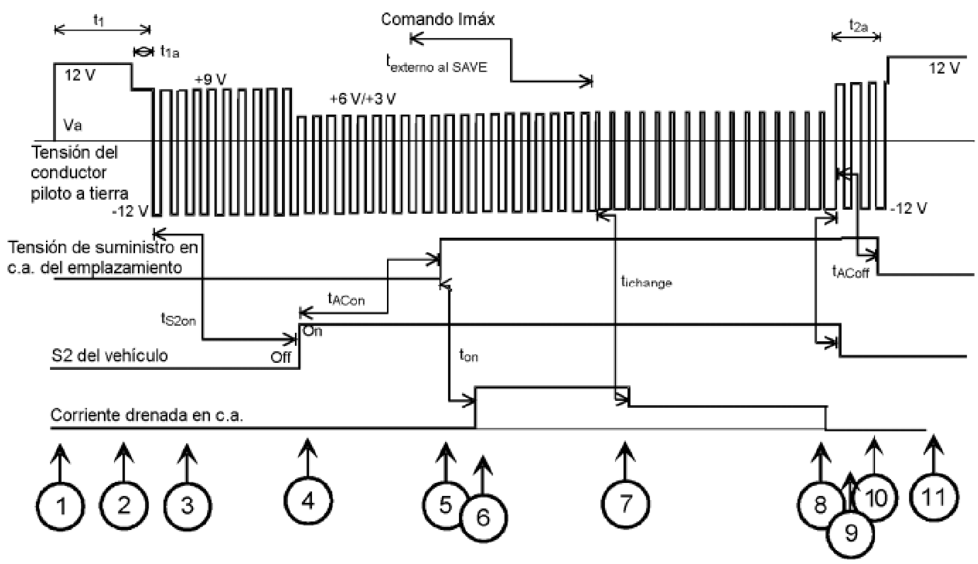


Figure 8 – Typical charge sequence

	State	Conditions
1	A	Vehicle not connected
2	B	Plug is plugged.
3	B	Communication currently established
4->C,D	B	Vehicle closes S2 and Station and EV ready to charge
5	C,D	Station closes circuit. Pre-charge
6	C,D	Current demand
7	C,D	Stop charge request
8	C, D	Stop charge, EV not ready to charge
9	C, D ->B	Vehicle request for disconnection
10	B	Station detects state B, station not ready to charge
11	A	Plug is pulled

Table 8 – Progress State CCS

2.2.2.2.2 Dynamic Charging

Dynamic charging in Combined Charging System is exemplified by Figure 9:

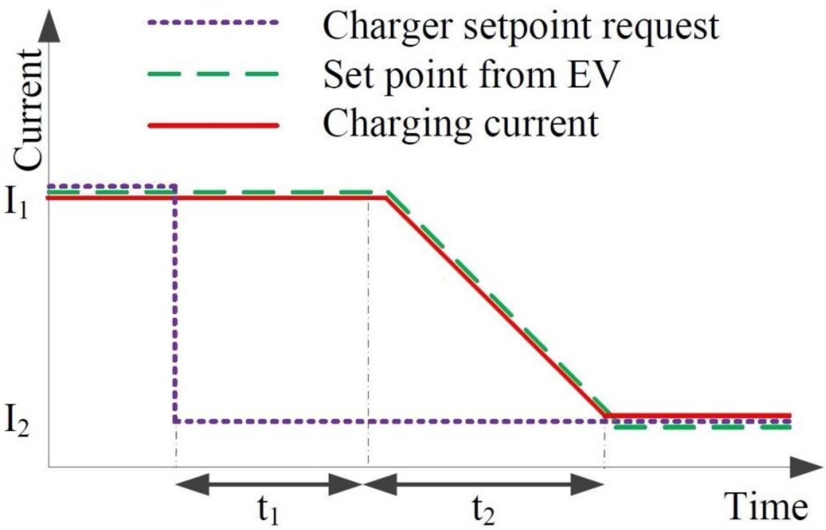


Figure 9 – CCS dynamic charging process

In this case, dynamic charging is based on the following sequence:

- As in CHAdeMO, an initial handshake takes place where information regarding EV is exchanged, and maximum charging current is set.
- Once the handshake has finished, a process of continuous negotiation (different from CHAdeMO) begins between EV and EVSE to set charging/discharging current.
- EVSE can request a change of current set point for dynamic charging, but this new value must be validated by the EV. The time taken to validate this set point depends on 2 different timers:
    - *t1* → response time of the EV. This value can be up to 60 seconds
    - *t2* → time to change from I_1 to I_2. In this case, there is no limit specified by the CCS standard

Figure 11 shows two examples of dynamic charging in CCS mode, taken from [4]. “IRef” is the current command from EVSE, while “Iset” is the is the current set by EV. In the first example, the response time of EV is 100ms (t1), while the maximum t2 is over 10 seconds. For decreasing current, timer t2 is much shorter, 2 seconds approximately. In the second example, the initial increase t1 + t2 is over 38 seconds. During the rest of the charging process, response time is much quicker, around 100ms.

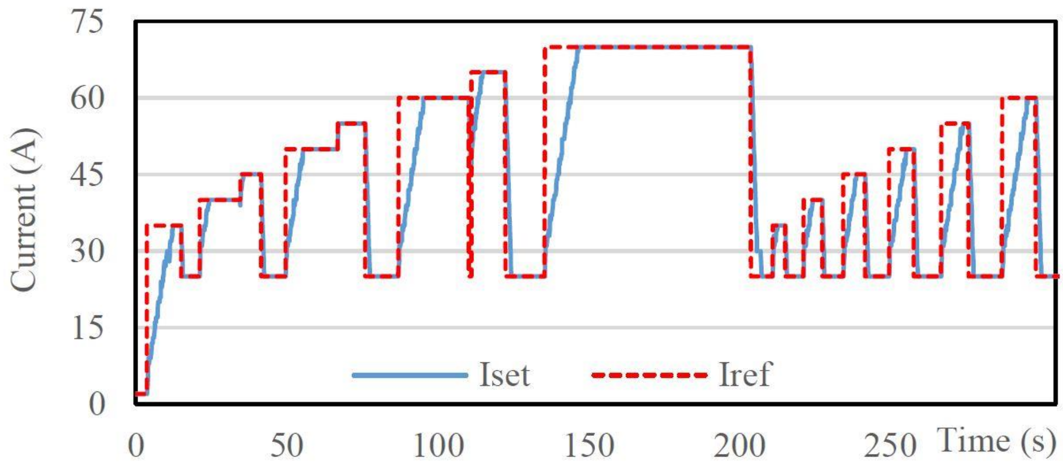


Figure 10 – Example 1 of CCS dynamic charging

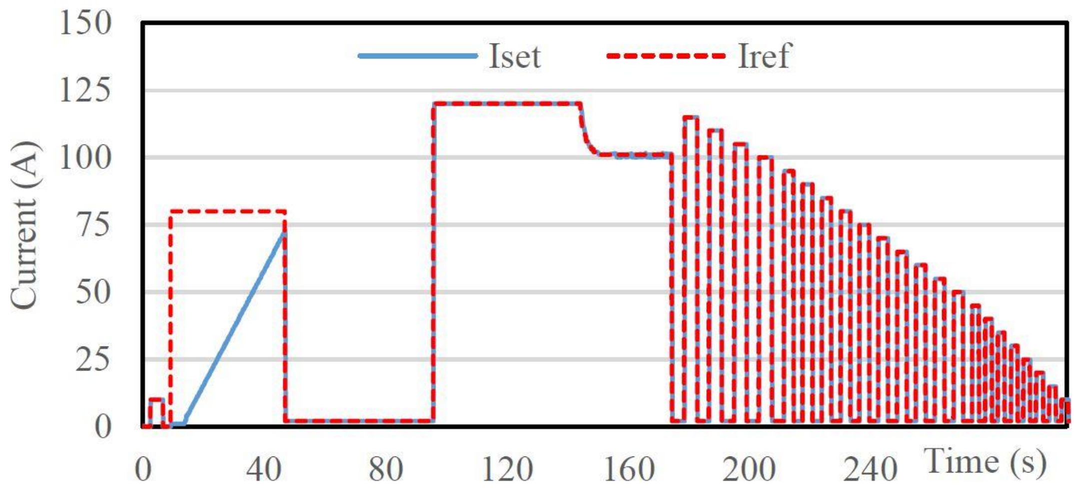


Figure 11 – Example 2 of CCS dynamic charging

2.2.2.2.3 Vehicle to Grid

In the case of Combined Charging System CCS, Bidirectional Charging is not part of the related standards (DIN 70121, ISO 15118), so it is not possible to perform V2G with this standard output at this moment. The European association is planning to update the standards to include this technology, but this will not be possible until the new release.

2.2.2.3 Comparison and choice

A summary of the main advantages and disadvantages of each DC standard output CHAdeMO and CCS COMBO regarding dynamic charging and V2G is shown in the following table:

	Advantages	Drawbacks
CCS Combo	Dynamic charging is possible	Bidirectional Charging is not part of the related standards (DIN 70121, ISO 15118),

		which will not be released in the short term Response times can be over 60s
CHAdeMO	Dynamic charging is possible Response time: 100ms (1sec error) V2G standard released	V2G limited to 10kW

Table 9 – CHAdeMO vs CCS comparison

In order to achieve the goals of WiseGRID project, where V2G is completely necessary and must be developed under the current standards, and where dynamic charging will require the sufficient rapidness to follow instructions from WiseEVP, it is clear that the most appropriate standard is CHAdeMO. As charging profile will be updated every 15 minutes, a delay time of 60s (that could occur in CCS charging) represents almost a 7% of this time, which is considered too high. For this reason, the FastV2G developments will be focused on this direction. However, this choice will limit the nominal power output of the EVSE to 10kW. This is not really a drawback, as right now there is no commercial V2G station that is able to provide a higher power as it is limited by CHAdeMO standard, which is not expected to be updated in the short term. In addition, it will not have an impact in the project, as the scope of WiseGrid is to achieve energy optimization by limiting the maximum power supplied to each EV during long sessions rather than performing ultra-fast charging.

2.2.3 OCPP Communications with Control Centre

The communication standard between FastV2G EVSE and the management tool WiseEVP is OCPP (Open Charge Point Protocol).

In Europe, this is the preferred EV communications protocol. The first version of this protocol was released as OCPP 1.2. This first version was developed by the Dutch foundation E-laad. When this first version was issued in year 2009, E-laad provided a free version of the protocol and a software simulator to enable EVSE and EV manufacturers to implement this protocol. The interest in the protocol was rapidly extended, and in year 2013, E-laad (Netherlands), ESB (Ireland), and Greenlots (North America) founded the Open Charge Alliance (OCA). This is a global consortium of public and private entities related to EV and EVSE that have worked to promote the common adoption of a unique communication protocol, which is OCPP.

Since the first version of OCPP protocol was issued, three more versions have been developed, which are 1.5, 1.6 and 2.0 OCPP. The last one, OCPP 2.0, has not been released yet, so due to this fact within WiseGRID project, OCPP is going to be developed with version 1.6.

OCPP, as standard open protocol, is designed to enable communication among the EVSE and the EV, and is applicable with all of the existing charging techniques. The 1.6 version introduces new features compared with its previous one, such as smart charging, usage of JSON over Websockets, better diagnostics possibilities, more EVSE status and trigger messages. OCPP 1.6 is based on OCPP 1.5, with some new features, and due to the new features introduced in this new version, OCPP 1.6 is not backward compatible with OCPP 1.5. Within this version there are two possibilities of OCPP implementation, which are SOAP-based implementations, or JSON-based implementations. The new JSON implementation is more compact than the SOAP implementation. Consequently, FastV2G will be developed with JSON.

The following table shows a comparison between versions v1.6 and v2.0 of OCPP protocol.

	Advantages	Drawbacks

OCPP v1.6	Final version Compliancy Testing Tool Additional features not supported by the protocol can be solved by “Data Transfer” message.	OCPP v2.0 coming soon V2G not supported in the standard messages. Can be implemented by other methods.
OCPP v2.0	Last review of the protocol Improved features, such as “Smart Charging” support vehicle to grid	It is not a final version (draft) Compliancy Testing Tool do not support v2.0 The protocol may change in following reviews Some of the improved features are not important for WiseGRID

Table 10 – Comparison of OCPP versions v1.6 and v2.0

The main reason for having chosen version v1.6 is the fact that versions v2.0 is still in draft process, so the final version is not yet released. Conversely, version v1.6 has no specific messages or profiles for V2G. However, this problem can be easily solved with the DataTransfer message of Core profile, which is the structure defined to exchange any information that is not included in the protocol, allowing to extend the features of the OCPP v1.6 with the ones not supported by the standard. In addition, in the charging profile sent from WiseEVP to FastV2G, the sign of the maximum power will define the direction of the current: From EVSE to the EV or from EV to EVSE.

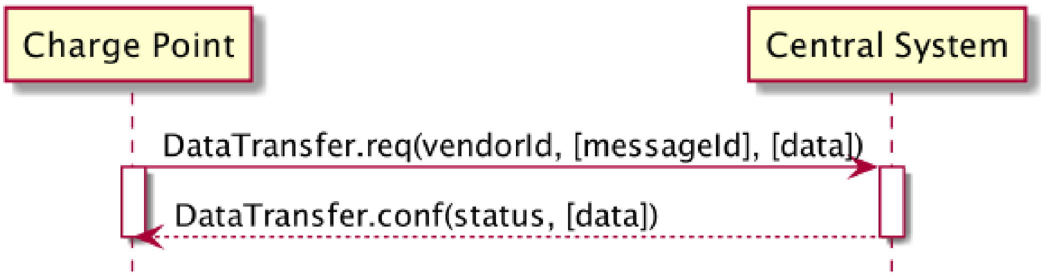


Figure 12 – Data Transfer message

2.2.4 From Smart Charging Station to FastV2G Station

As explained before, the FastV2G station is based on a smart EVSE previously developed during the years 2012 to 2014. This station must be developed and adapted in order to meet the requirements of WiseGRID project.

Table 11 shows the evolution of the Smart EVSE to the FastV2G EVSE developed in WiseGRID project, where all the necessary developments and changes can be seen.

	Smart Charging Station	FastV2G Station
Bidirectionality	Hardware tested	Integrated in standard communications with EV (CHAdeMO charge/discharge mode)

Charging Strategy	Static charging	Static Charging and Dynamic charging
Output standard	JIS (previous to CHAdeMO)	CHAdeMO versions v0.9, v1.0, v1.1 and V2H charge/discharge
OCPP	Not implemented	Version v1.6
User Interface	OMRON SCADA	Adapted to FastV2G requirements. User Interface is on the EVSE screen
Power Output	50 kW	Always 10kW as maximum. Power control must be adapted
Communication modules	PLC Integrated	Separate module for external communications

Table 11 – Comparison of FastV2G with its predecessor Smart EVSE

2.2.5 FastV2G technical features

Regarding all the considerations taken into account in the previous sections, such as the output standard selection and its limit to the nominal power of the station and the communications with WiseEVP, the final technical features of the FastV2G EVSE are the following:

INPUT

- Voltage: 400 VAC 3P+N+E
- Voltage tolerance: ±10%
- Frequency: 50Hz
- Nominal input power: 10.7 kVA
- Power factor: >0.95

OUTPUT

- Maximum Power: 10kW
- Maximum Charging Current: 31A DC
- Maximum Discharging Current: 13.5A AC
- Output voltage: 50 – 500 VDC
- Standard output: CHAdeMO

ELECTRICAL REQUIREMENTS

- Isolation: 20kVA transformer 50Hz (low frequency)
- Converter technology: IGBTs
- Charging/discharging mode: MODE 4
- Protections:
    - Short-circuit
    - Over-current
    - Overvoltage
    - Earth fault
    - Isolation and welding protection
    - Emergency Stop

2.2.6 Installation requirements

Due to the size, weight and the brittleness of some of the components of the FastV2G EVSE, it will only be installed in one pilot site: Crevillent.

The following table shows the technical requirements of the installation:

Parameter	Required value
Power supply	400 VAC 3P+N+E
Power connection	Cable: XLPE 6 mm2 Tubular installation
Input Current	16 A/phase
Input frequency	50 Hz
Enclosure dimensions	2000 x 1200 x 800 mm
Fixing	M10, Length = 80mm
100kVA transformer dimensions	Not needed
Environmental conditions	-10 to 40ºC; 90% Max HR
Place of installation	Indoor / outdoor covered
Mains Protection	Circuit Breaker 4 x 32 A –D Curve 10 kA

Ethernet Data Cable	Cat 5e FTP
Electric vehicle for test	Nissan Leaf 2018 40kWh version

Table 12 – Installation requirements

2.3 ARCHITECTURE

FastV2G station has a modular design, made up of different modules and subsystems that interact with each other by means of internal bus communications. The EVSE contains a complex but robust architecture, which is also designed with the possibility of expanding the features of the charger in future developments.

The following figure shows the diagram blocks of FastV2G:

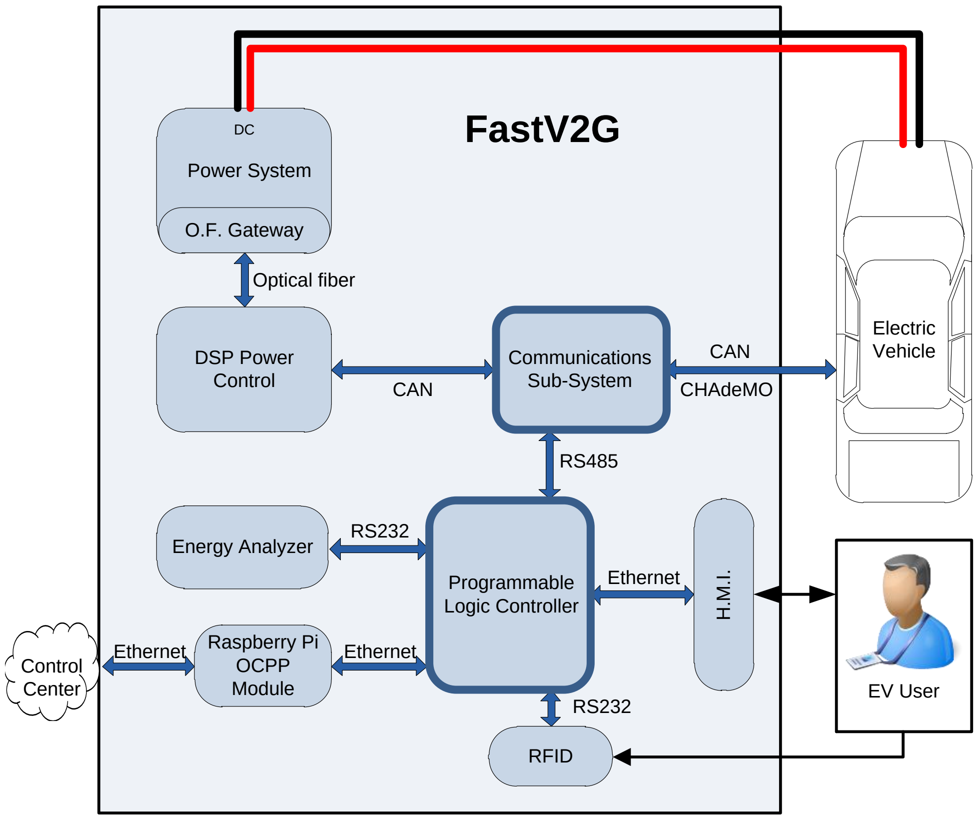


Figure 13 – FastV2G Diagram Blocks

FastV2G EVSE is based on two main cores: Communications Sub-System and Programmable Logic Controller. These intelligent blocks manage all the other electronic modules and peripheral devices inside the station.

2.3.1.1 Communications Sub-System

The communications sub-system is an electronic device that is in charge of CHAdeMO communications with the EV by the CAN BUS, as well as the management of the power electronics stage of the charging station. This module communicates with the other main module of FastV2G, the Programmable Logic Controller, by Modbus485. During the WiseGRID project, the entire firmware of this electronic module will be programmed in order to implement all the new CHAdeMO standards (v0.9, v1.0. v1.1, and V2H) and to manage and optimize the new 10kW power condition of the station. Obviously, communications with PLC also will have to be programmed to meet the new requirements.

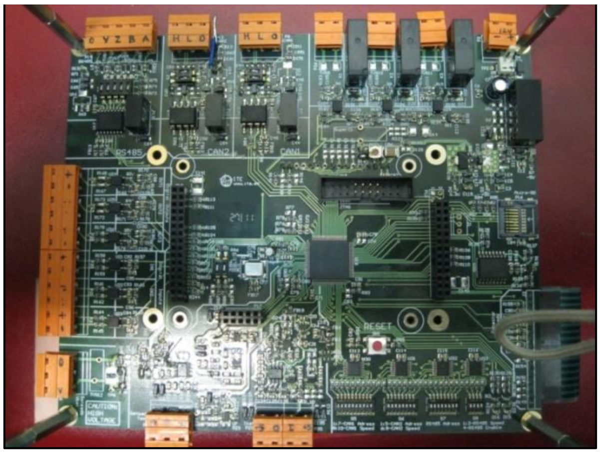


Figure 14 – Communications Sub-System Device

The core of this module is a 32bit ARM microcontroller as high data processing is needed. The following figure shows the different blocks of the Communications Sub-System and its physical location in the electronic PCB:

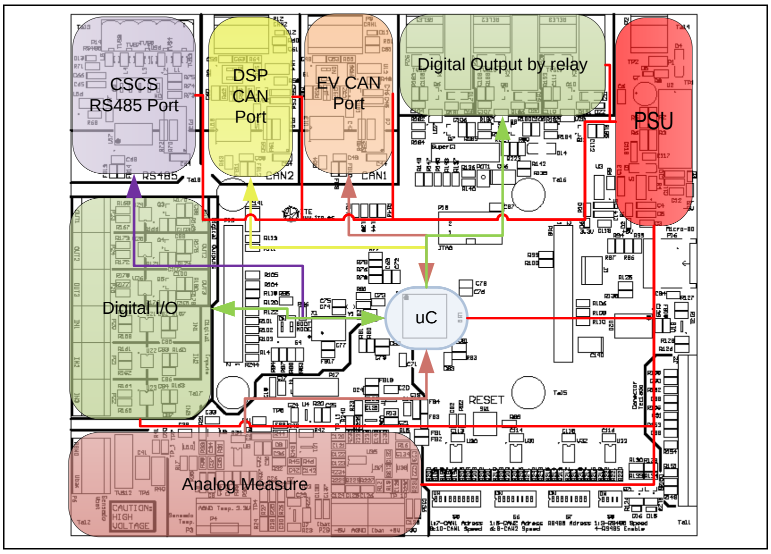


Figure 15 – Functional blocks of Communications Sub-System

As shown in Figure 15, Communications Sub-System contains the following blocks:

- **uC.** 32 bit ARM Microcontroller
- **PSU.** Power Supply Unit, in charge of generating the internal voltage levels such as ±5VDC and 3,3VDC from the 12VDC power input.
- **Digital Output by relay.** This block controls the three output signals needed to comply with the communication standards: CL, CS1 and CS2.
- **EV CAN Port.** Isolated CHAdeMO communications with Electric Vehicle based on CAN 2.0A, working at 500kbps.
- **DSP CAN Port.** Isolated communications with Power Electronics Stage based on CAN 2.0A, working at 1Mbps.

- **CSCS RS485 Port.** Modbus RS-485 communications with Programmable Logic Controller, based on an isolated transceiver that is compatible with half duplex or full duplex connection.
- **Digital I/O.** Digital input and output lines that are needed for EV communications control as well as for complying with isolation test. These signals are opto-coupled, and they need to be externally supplied with an isolated power line.
- **Analog measure.** Analog inputs in order to measure the isolation test voltage and current.

As a summary, the following table shows the technical features of the Communications Sub-System.

Parameter	Value
Power supply	12V
Power consumption	12W
Digital Inputs	CHAdeMO VCP (Vehicle Charge Permission)
	CHAdeMO VCL (Verification Connector Lock)
Digital Outputs (Relay)	CHAdeMO d1
	CHAdeMO d2
	CHAdeMO CL (Connector Lock)
Digital Outputs (Opto)	ISP (Isolation test System Power)
	ISA (Isolation test System Activation)
Analog Input	Isolation Test V
	Isolation Test I
CAN Port (CHAdeMO)	1
CAN Port (DSP)	1
MODBUS Port	1

Table 13 – Technical features of Communications Sub-System

2.3.1.2 DSP Power Control

Custom made PCB device based on DSP with the necessary input and output interfaces to manage the power converters. It monitors electrical measurements of the station to carry out the power control of the converters by means of PWM modulation transmitted by optical fiber.

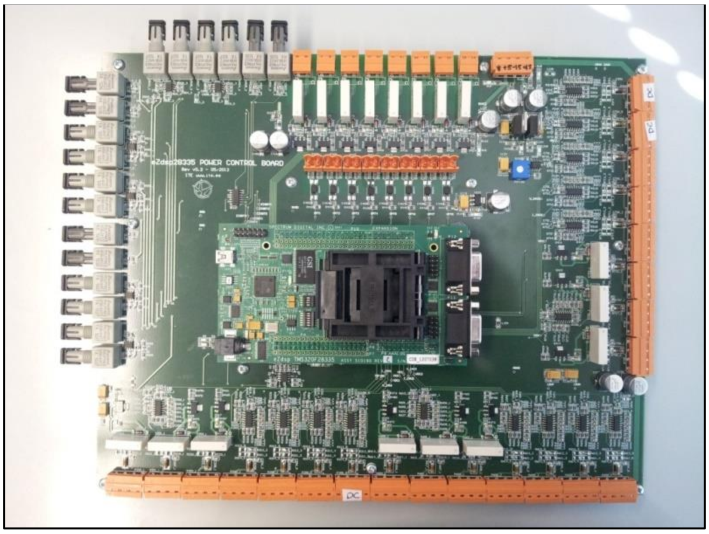


Figure 16 – DSP Power Control PCB

As a summary, the following table shows the technical features of the DSP Power Control PCB.

Parameter	Value
Power supply	±15V,+5V
Power consumption	25W max.
PWM outputs	12 IGBT trigger output
Digital outputs (relay)	AC mains contactor
	AC pre-charge contactor
	DC Fan activations
	Inverter/rectifier heater
	Diode bypass
	Discharge Bus
	230C
	Power supply skip
Isolated digital inputs	Earth fault detector
	13 free inputs
Analog inputs	V_R, V_S, V_T, I_R, I_S, I_T, V_{bat}, I_{bat}, I_{O_L1}, I_{O_L2}, I_{O_L3}
	4 free inputs
CAN port	1
DSP TI 28335	1

Table 14 – Technical features of Communications Sub-System

2.3.1.3 DC Power System

The first part of the DC Power System is an optical fiber to the electrical signal Gateway. This PCB is in charge to convert the PWM optical fiber signal from the DSP Power Control Device to electrical signal in order to trigger the IGBT power semiconductors.

Figure 17 – Optical Fiber Gateway

This electronic PCB is powered with 24VDC and has a consumption of 3W. It is made up of 6 digital PWM output, 1 digital output and 5 analog outputs, as well as a gateway with Semikube IGBT driver.

The DC Power System is in charge of the conversion of AC input current into DC current for DC battery charging and in the opposite direction, which implies extracting energy from DC batteries in order to inject it to the AC grid.

Figure 17 shows the diagram connections between all the elements that are part of the DC Power System.

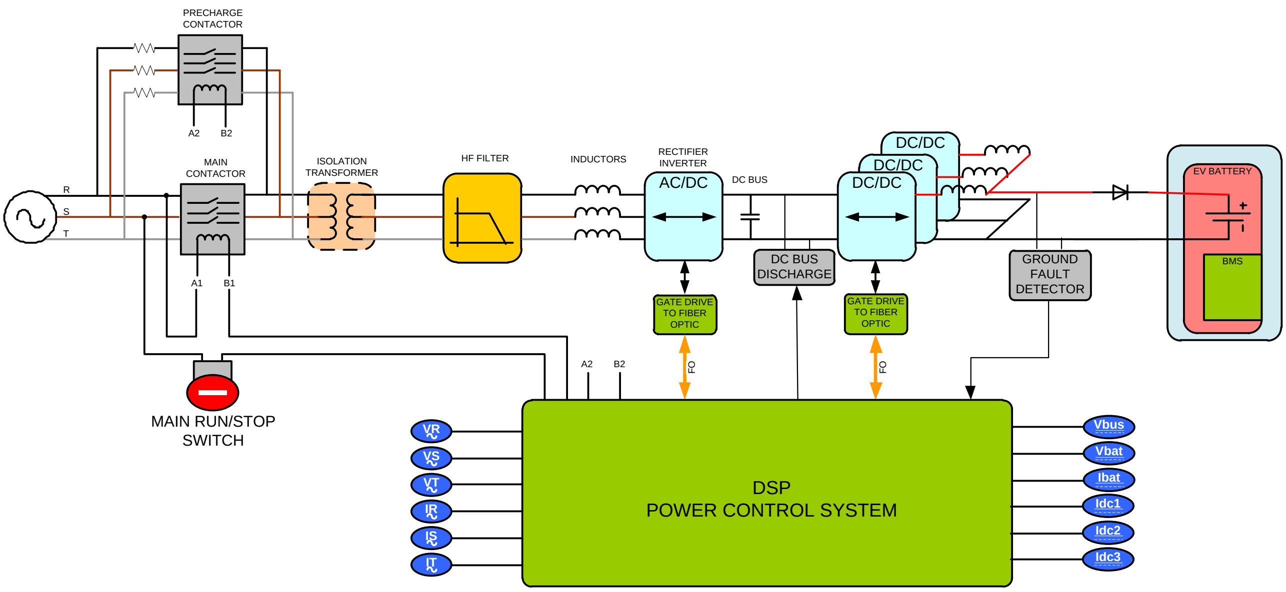


Figure 18 – DC Power System Diagram

DC Power System is made up of the following components:

- Mains Contactor LC1F2254 400VAC/225A.
- Precharge Contactor LC1D32U7 Bus DC 400V/32A.
- Isolation transformer 20KVA.
- 3-Phase Schaffner HF 400V/120A (EMC).
- 3-Phase Inductor Filter 120A.
- SEMIKRON Semikube 0.5 IGD-1-424-P1N4-DL-FA (IGBT Rectifier).
- 3 x IGBTs for DC/DC converter.
- Inductor Filter CC EREMU 70A.
- Filter Capacitors SEMIKRON SKCF-420-110-A04N-01 2400uF/900Vdc.
- Output Diode Vishay Vs-240UR100D (1kV, 320A).
- CHAdeMO DC Earth Fault Detector: SDLOA-1A-E KBK Europe GmbH.

2.3.1.4 Programmable Logic Controller

The Programmable Logic Controller is the second main core of the FastV2G EVSE, as it is in charge of managing the Human Machine Interface, the OCPP modules as well as all the peripherals inside the EVSE such as the Energy Analyzer and the RFID reader.

This PLC is also responsible for registering all the data collected during the charging sessions and sending it to the WiseEVP by means of the OCPP module.

The PLC is made up of the following modules [5]:

- Omron CPU CJ2M CPU31-ETN, with 10Ksteps of program capacity and 64K words of memory capacity.
- Omron Power Supply CJ1W-PA202. Converts AC input (85-264VAC; 47-63HZ) into 5VDC and 24VDC output, with 14W of maximum power output.
- 128MB Compact Flash memory card.
- Communication device SCU31-V1 for data exchange with Energy Analyzer.
- Communication device SCU41-V1 for MODBUS communication.
- DeviceNet communication device DRM-21.
- Analog input device DRT2-AD04 for 0-5V, 1-5V, 0-10V, 0-20mA, 4-20mA measurements.
- Digital input device CJ1W-ID211 CHN, with capacity for 16 digital inputs (24VDC 0,5A max).
- Digital output device CJ1W-OD212 CHN, with capacity for 16 digital outputs (24VDC 0,5A max).

2.3.1.5 Human Machine Interface

The HMI module is the display from which the EV user can set the basic parameters of the charging session, and see the state of the charging process.

The communications between Programmable Logic Controller and HMI is by Ethernet. The data exchange between the PLC and the display is automatically handled by FINS frames.

The model of Human Machine Interface device is NQ5-TQ010-B, which is a 5, 7 inch colour TFT with a resolution of 320 x 240 (QVGA) [6].

Figure 19 – Omron NQ5-TQ010-B

2.3.1.6 RFID Reader

User identification in FastV2G is performed by RFID, where the reader will obtain the user identification from the RFID tag of the user in order to validate if the user has permission to charge. When the user is authenticated, the charging station will check if the RFID tag is in the whitelist of the station, and if not will send a request to WiseEVP to ask for new authorization. The RFID model is Kimaldi KRD13Mv2 [6], which uses ISO14443A Mifare technology.

Figure 20 – Kimaldi KRD13Mv2 RFID reader

2.3.1.7 Energy Analyzer

The device used to perform the electric measurements of the FastV2G EVSE is the Energy Analyzer CVM-MINI-ITF-RS485-C2 M52021 (Circutor manufacturer) [7], which is an industrial analyzer Class 0.5 rated for use in low voltage networks. The purpose of this device is to measure critical parameters in the primary circuit such as Total Harmonic Distortion, Power, Current, Voltage, etc. The energy analyser is not a certified metering system used for pricing, but enables FastV2G to collect electric data that will be sent to WiseEVP for further processing.

Figure 21 – Circutor CVM-MINI-ITF-RS485-C2 M52021 analyzer

Communications between the Energy Analyzer and the PLC is done by Modbus/RTU protocol using serial RS485 bus.

The following table shows the list of parameters read by the Energy Analyzer, indicating in which input phase each parameter can be measured as well as the internal code.

Name	Phase	Code
Voltage	L1	1
Current	L1	2
Active power	L1	3
Reactive Power L/C	L1	4
Power factor	L1	5
Voltage	L2	6
Current	L2	7
Active power	L2	8
Reactive Power L/C	L2	9
Power factor	L2	10
Voltage	L3	11
Current	L3	12
Active power	L3	13
Reactive Power L/C	L3	14
Power factor	L3	15

% THD V	L1	25
% THD V	L2	26
% THD V	L3	27
% THD A	L1	28
% THD A	L2	29
% THD A	L3	30
Apparent power	L1	38
Apparent power	L2	39
Apparent power	L3	40
Temperature		41
Voltage	L1/L2/L3	90
Current	L1/L2/L3	91
Active power	L1/L2/L3	92
Reactive Power	L1/L2/L3	93
Power factor	L1/L2/L3	94
Composed voltage	L1/L2/L3	95
% THD V	L1/L2/L3	96
% THD A	L1/L2/L3	97
Apparent power	L1/L2/L3	98

Table 15 – Analyzer data list

2.3.1.8 OCPP Module

OCPP communications with WiseEVP will be developed in the Raspberry Pi 3 – Model B [8]. The reason for having chosen this electronic device instead of an industrial PC is mainly due to its low price, under 40€, which is much lower than PC which will surely cost more than 300€ depending on its features.

This OCPP module will communicate by Ethernet with the PLC as well as with the WiseEVP. In case there is no Ethernet connection available in the installation, a 3G or 4G modem with Ethernet connection could be used instead.

The Raspberry Pi 3 Model B has the following features:

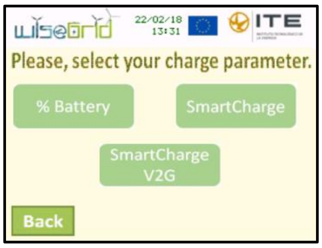
- Quad Core 1.2GHz Broadcom BCM2837 64bit CPU
- 1GB RAM
- BCM43438 wireless LAN and Bluetooth Low Energy (BLE) on board
- 40-pin extended GPIO
- 4 USB 2 ports
- 4 Pole stereo output and composite video port
- Full size HDMI
- CSI camera port for connecting a Raspberry Pi camera
- DSI display port for connecting a Raspberry Pi touchscreen display

- Micro SD port for loading your operating system and storing data
- Upgraded switched Micro USB power source up to 2.5A

3 FAST V2G DESIGN

3.1 GRAPHICAL USER INTERFACE

FastV2G station includes a 5,7" display for Human Machine Interface for selecting the user data, setting the charging parameters, visualization of information about the charge, etc. A fully detailed description of the different screens present at the user interface can be seen in the following table.

Screen	Description
 	Main screen: It indicates if the status of the station is reserved or free, so it determines if the EVSE can be used or not.
 	Validation screen: if the status of the EVSE was free and the RFID reader has read the tag, this screen will appear. There are 2 possibilities now: 1. The user is registered (you can continue with the charge). 2. The user is not registered (you can't continue the charge). To determine if the user is registered, the charge point will check it the tag ID is in the local data list, previously sent by WiseEVP. If not, the WISEEVP will decide if the tag ID has the authorization or not.
	Connection instruction screen: after validating the permissions of the user, the screen shows the instructions to connect the EV to the EVSE. Once the user has followed the instructions of the screen, he will have to press the button "next" to initiate the connection between the EV and the EVSE. The user also has the option to end the process pressing the "back" button.
	Charge parameter screen: the user selects one of following charge preferences: 1. %Battery: the user decides the percentage of battery desired. When this percentage is reached, the EVSE stops the charging process. 2. SmartCharge: the user introduces a combination of SoC and time, with no V2G

	option. 3. SmartChargeV2G: the user introduces a combination of SoC and time, with V2G option.
	Battery screen (1): the user can introduce the desired percentage of battery, confirming this selection through “Next” button. Moreover, the user can see the current percentage of his battery.
	SmartCharge (2) and SmartChargeV2G (3) screen: through this screen the user introduces the charge parameters of the station (Combination of time of charge and battery percentage)
	Validate charge screen: once the user has introduced the charging parameters, they will have to be validated in this screen. If the user agrees with the charging parameters, the “Validate” button must be pressed for confirmation. Otherwise, the parameters can be modified by means of selecting the “Change” button. Figures are just placeholders depicting the place where the actual numbers will appear (999 value is not a real value).
	Charge not possible screen: if charging session cannot be started for any reason, for example due to invalid parameters introduced, this screen will inform of this situation.
	Charge screen: when the charging is succesfully started, the screen shows the process of charge, by showing the battery percentage and the time to finish the charging process. Moreover, the user has the possibility to stop the process by pressing “End process”.

	Failure screen during the charge: if some failure has been occurred during the charge, this screen is shown, guiding the user with visual instructions on the screen to solve the failure.
 	End screen: this screen is shown whenthe station has finished the process correctly. Once the user has followed the instructions to disconnect the EV, "Next" button must be pressed to conclude the charging session.

Table 16 – HMI screens

3.2 PROGRAMMABLE LOGIC CONTROLLER

As explained before, the Programmable Logic Controller is one of the main cores of the FastV2G EVSE, as it manages the HMI, peripherals, OCPP module and communicates with the Communication Sub-System.

The following Figure shows the process of information exchange between PLC and the 32 bit ARM microcontroller of Communications Subsystem by Modbus protocol.

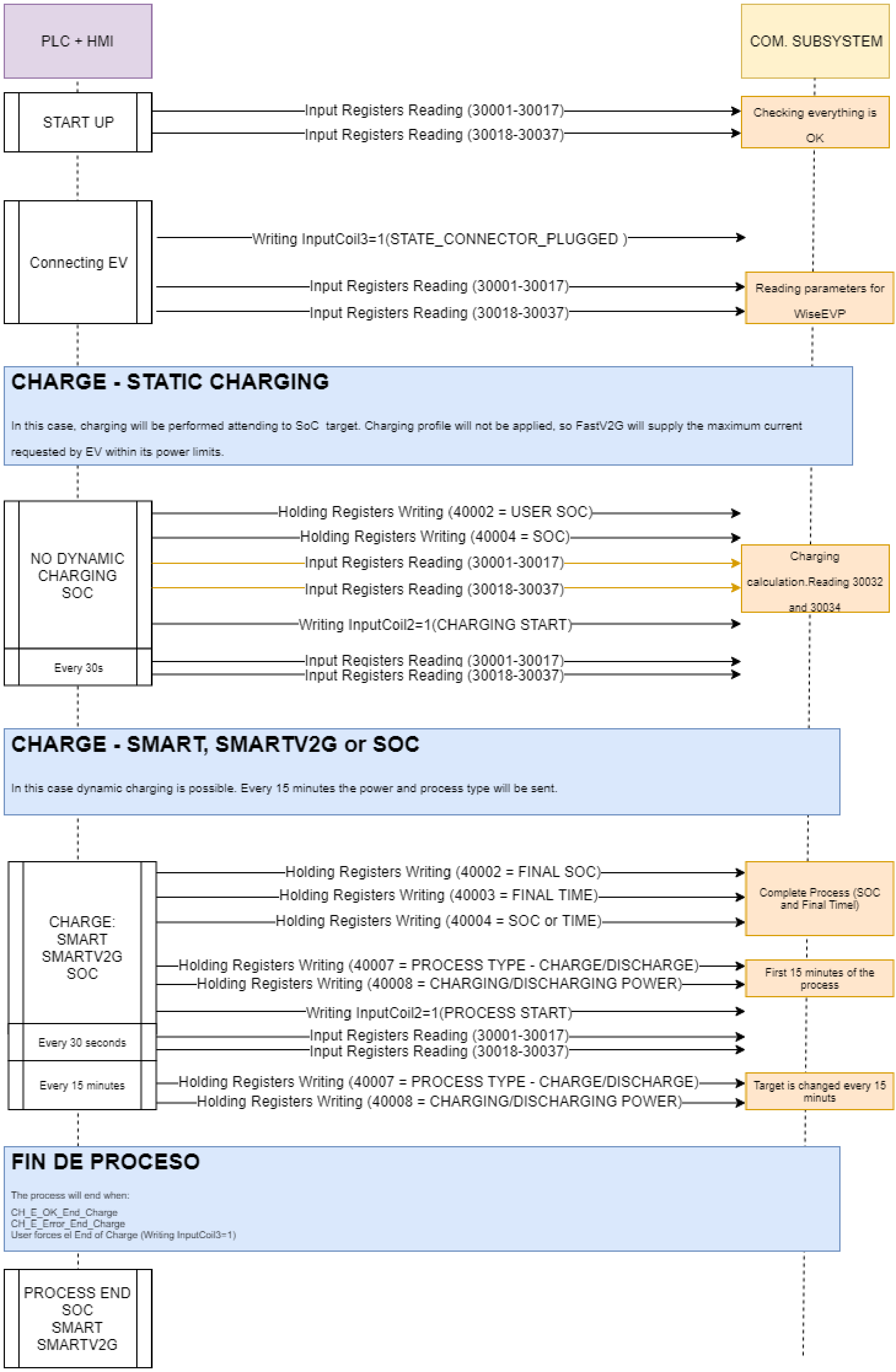


Figure 22 – PLC-Communications Subsystem

The main flowchart developed in the CPU of the Programmable Logic Controller is showed in Figure 23.

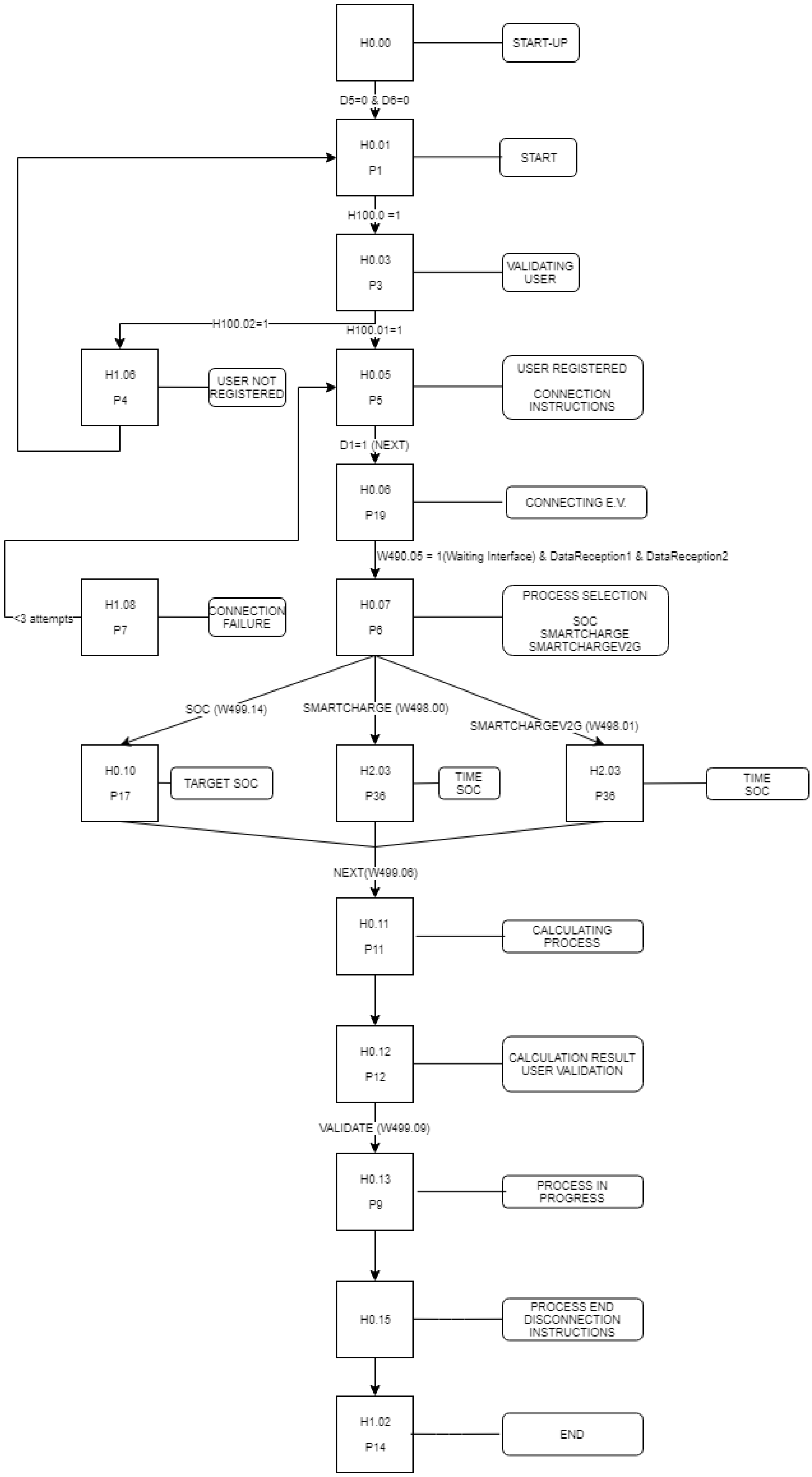

H0.00
START-UP
D5=0 & D6=0
H0.01
P1
START
H100.0 =1
H0.03
P3
VALIDATING USER
H100.02=1
H100.01=1
H1.06
P4
USER NOT REGISTERED
H0.05
P5
USER REGISTERED
CONNECTION INSTRUCTIONS
D1=1 (NEXT)
H0.06
P19
CONNECTING E.V.
W490.05 = 1(Waiting Interface) & DataReception1 & DataReception2
<3 attempts
H1.08
P7
CONNECTION FAILURE
H0.07
P6
PROCESS SELECTION
SOC
SMARTCHARGE
SMARTCHARGEV2G
SOC (W499.14)
SMARTCHARGE (W498.00)
SMARTCHARGEV2G (W498.01)
H0.10
P17
TARGET SOC
H2.03
P36
TIME
SOC
H2.03
P36
TIME
SOC
NEXT(W499.06)
H0.11
P11
CALCULATING PROCESS
H0.12
P12
CALCULATION RESULT
USER VALIDATION
VALIDATE (W499.09)
H0.13
P9
PROCESS IN PROGRESS
H0.15
PROCESS END
DISCONNECTION INSTRUCTIONS
H1.02
P14
END

Figure 23 – PLC main flowchart

3.3 COMMUNICATIONS SUB-SYSTEM FIRMWARE PROGRAMMING

3.3.1.1 CHAdeMO versions developed

The FastV2G works in V2H DC 2.1 version of CHAdeMO. Nevertheless, it is compatible with previous versions of CHAdeMO standards. As seen in Figure 24, nowadays there are 4 versions of CHAdeMO, from version 0.9 to V2H:

- Version 0.9 and 1.0: for vehicles with this version, the FastV2G works as a slave. The EVSE shall set its maximum supply power during initial handshaking and the EV will set the input current. Once the charging process has started, the FastV2G cannot change the maximum current output.
- Version 1.1: EVs with this version allow to change the current demand while the charging process is taking place. The FastV2G should set the output power according to WiseEVP value. In addition, the FastV2G can choose to change the output current during charging or not.
- Version V2H: the user has the option to decline or accept the V2H before the charging/discharging process is taking place (*V2H Selection* in Figure 24). If the user decides to decline it through a decline button, the FastV2G shall continue the charge process according to version 1.1. In other words, the user will leave the FastV2G without the possibility to perform the discharging process. By contrast, if the user accepts it through the accept button, the EVSE shall set the output power according to WiseEVP. A positive sign of the WiseEVP value will determine that the EV is charging and a negative sign will determine that the EV is discharging, as described furtherly in Figure 28.

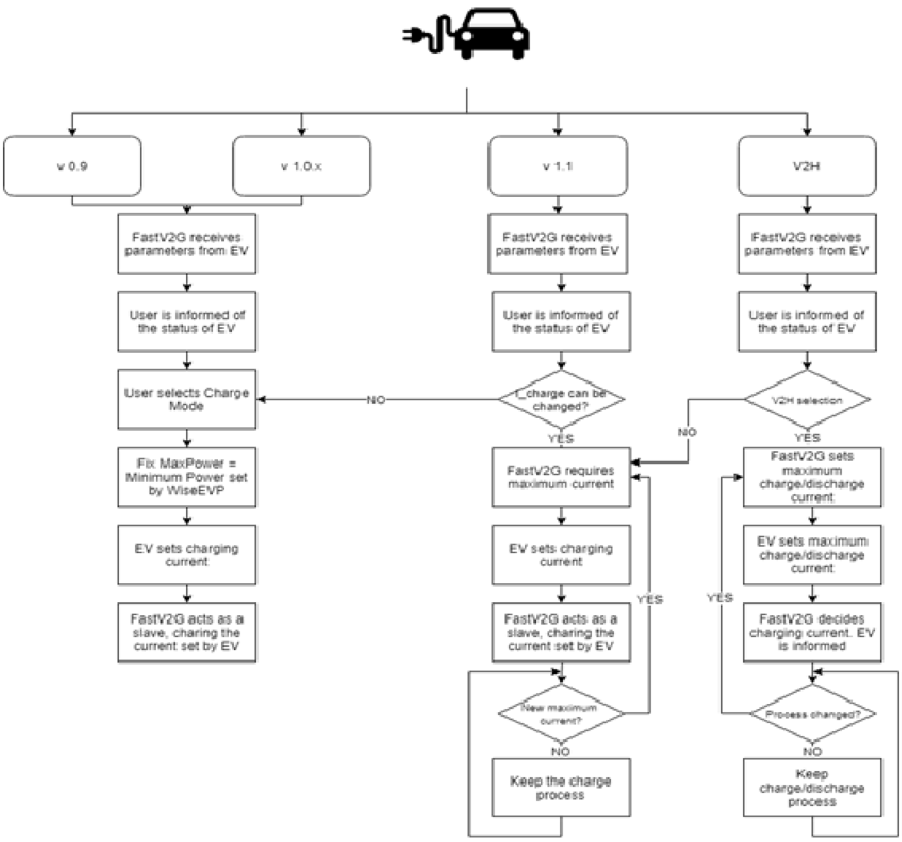


Figure 24 – CHAdeMO protocol versions

3.3.1.2 Differences between V2H and lower versions

FastV2G has to apply one of the different versions of CHAdeMO protocol and this version shall be set according to the EV version. In this section a comparison will be made between two different versions, charging corresponding to CHAdeMO 1.1 version (and previous versions) and V2H corresponding to CHAdeMO 2.0 version.

As it can be seen in Figure 25, Figure 26 and Figure 27, the performance of these versions is almost the same, except for a few differences which shall be carefully considered. The following flowcharts are divided into 3 groups showing the different steps that are taking place during the charge/discharge process:

1. Charging/Discharging preparing process
    a. Blue: Information Exchange before Charging.
    b. Orange: Connector Lock & Insulation test.
    c. Green: Charge Preparation.

2. Charging/Discharging process
    a. Red: Charging/Discharging.

3. Charging/Discharging finish process
    a. Pink: Charge/Discharge stop processing.
    b. Black: Connector unlock process.

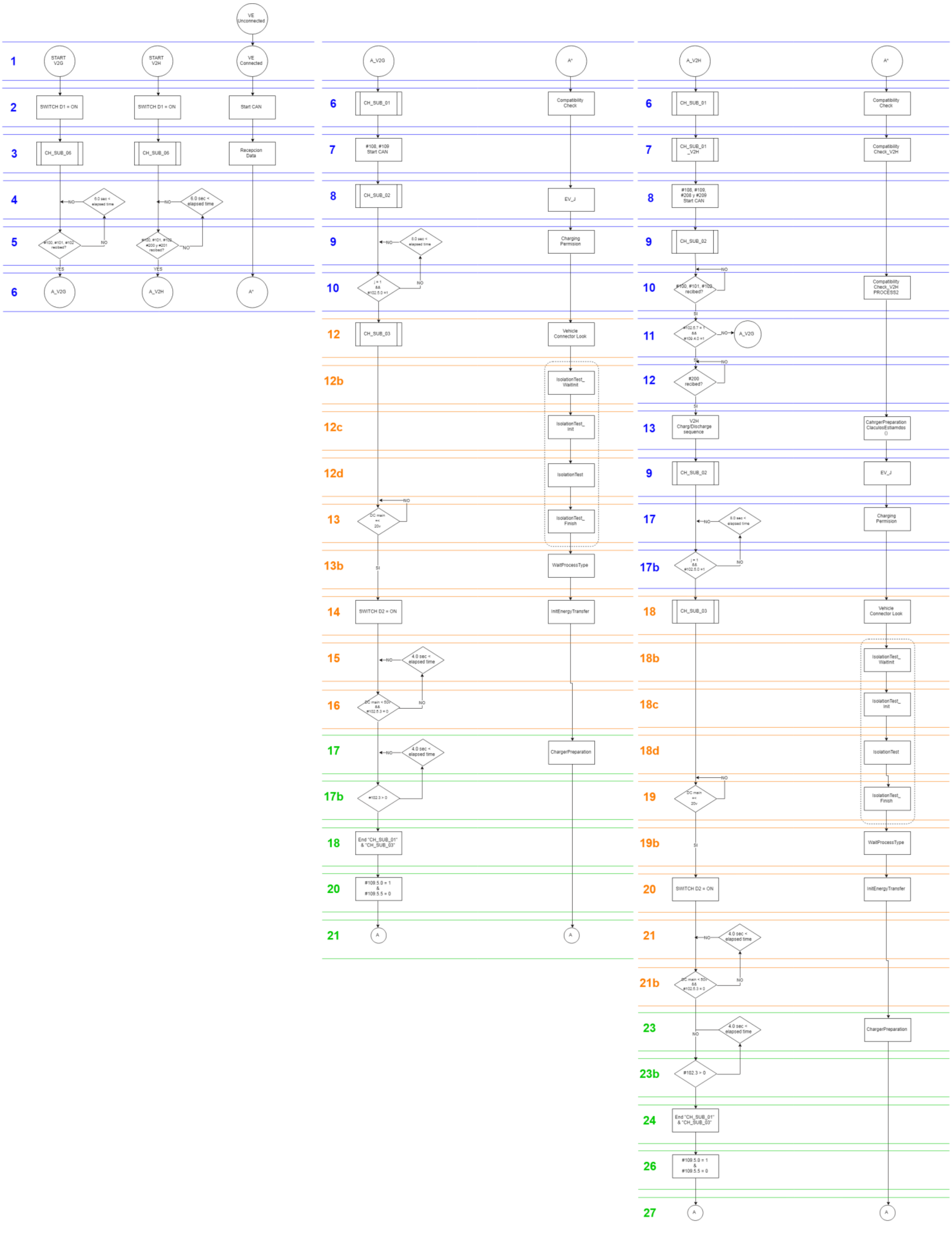


Figure 25 – Charging/discharging preparing process (part1)

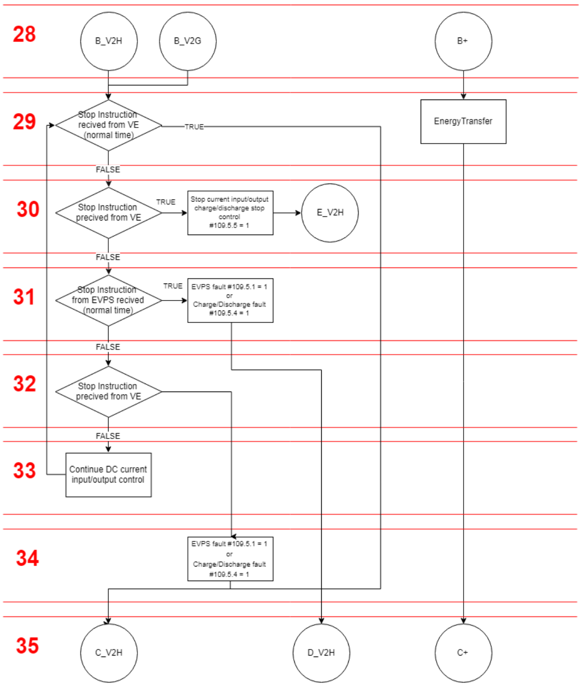


Figure 26 – Charging/Discharging preparing process (part 2)

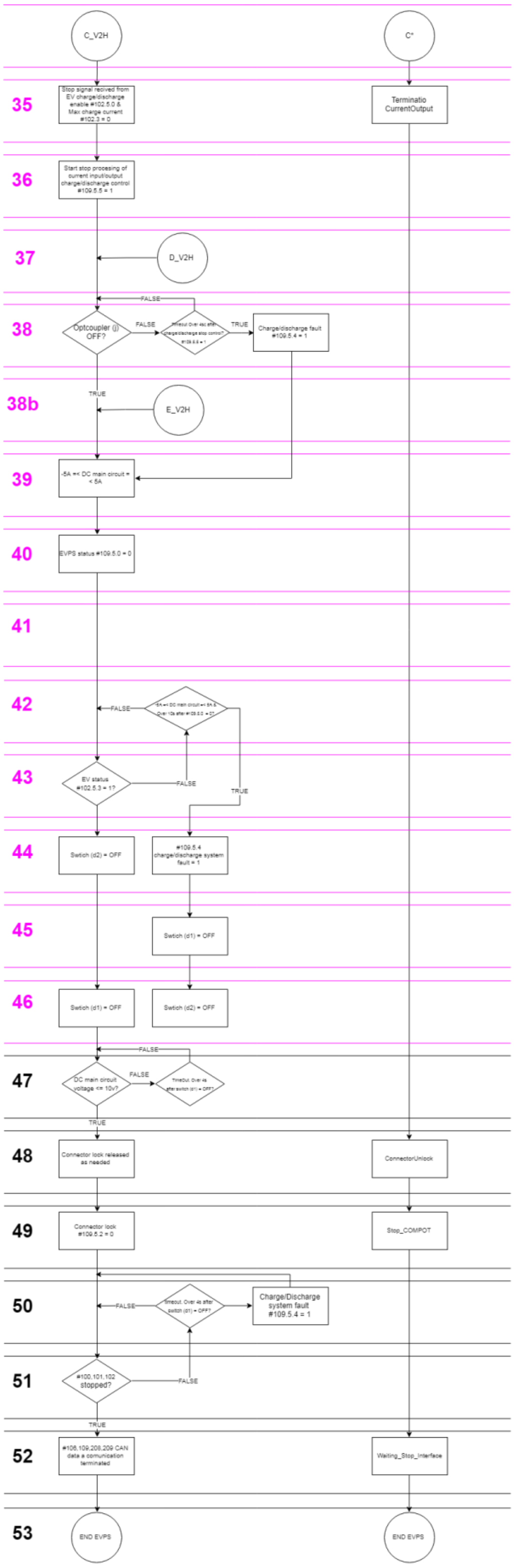


Figure 27 – Charging/Discharging preparing process (part 3)

3.3.1.3 V2H mode

As seen in Figure 28, during the process there is the possibility to switch from charge mode to discharge mode. This decision is taken by the user.

For charging mode, first WiseEVP fixes the value of the maximum power supported by the electric distribution grid and this value is used to calculate the "Available output current". Based on this value, the EV calculates the "Maximum charging current", a value between the "Minimum charger current" and the "Available output current". The "Maximum charging current" is sent to the Power Electronics of FastV2G.

To change from charge mode to discharge mode, the Power System must order the "Stop Charge" process first. This restarts the bidirectional AC/DC converter and waits until the discharge process starts.

For discharge mode, the initial value "Available input current" is set to a current equivalent to 10 kW power. According to this value and the SOC, the EV sets the "Maximum discharge current". Once this value has been set, the target is set to the most unfavourable value between the "Maximum discharge current" and the "WiseEVP".

As seen in figure 29, when the Available output current changes its value by the Power electronic system, the maximum charging current changes its value too. This action is performed by the EV. During a short time, a higher value for the Maximum Charging Current can be seen compared to Available Output Current, because the EV needs a little time to calculate the new Maximum Charging Current.

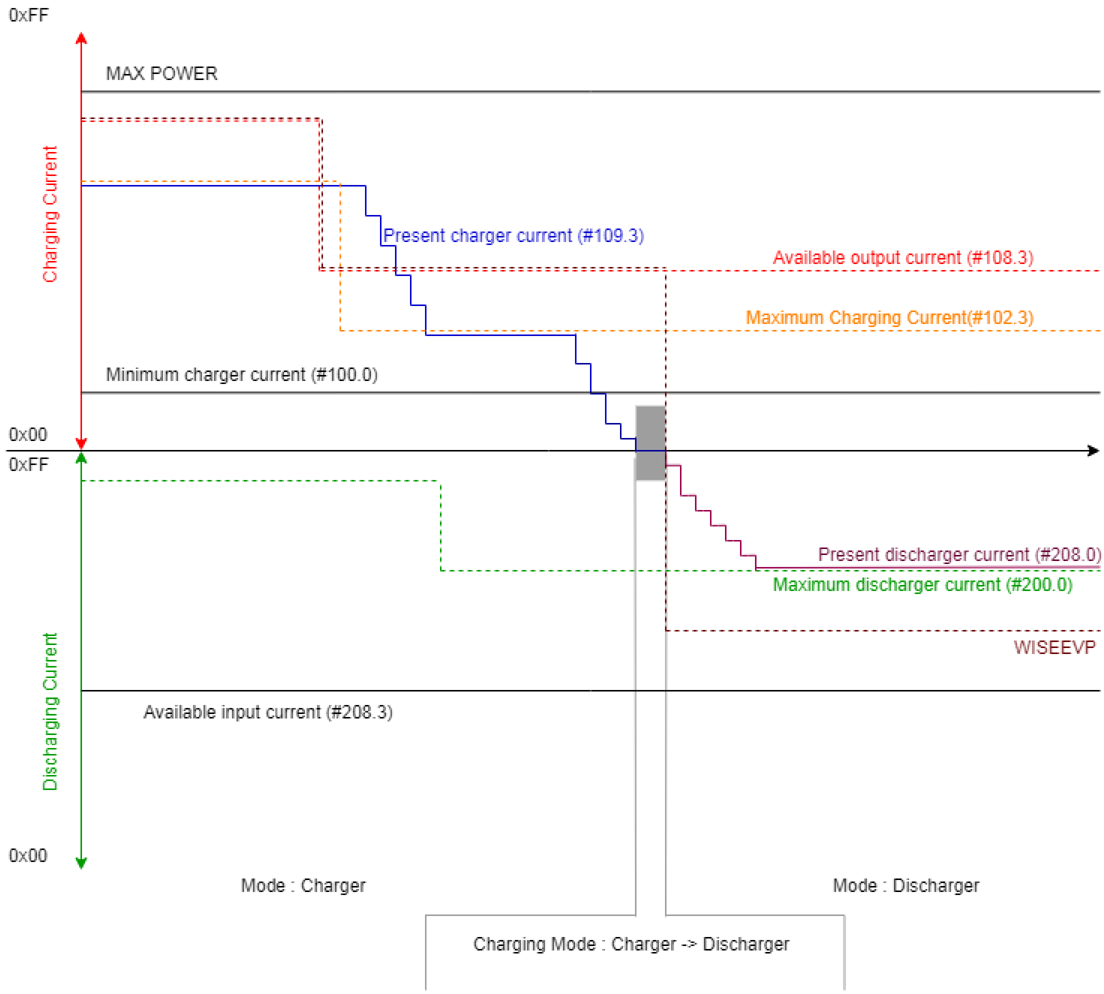


Figure 28 – Switch process of charge mode to discharge mode

The can messages of the charge/discharge mode are reflected in the Table 17:

ID	ITEM	Electric Vehicle Power System (EVPS) processing
100.0	Minimum charger current	When the remaining battery capacity is less than the minimum remaining battery capacity for discharging, the charge-discharge control shall be moved to stop control. However, if 0x00 is received, the present charge current equivalent to 1.5 kW shall be ensured.
102.3	Maximum charging current	During V2.H charge/discharge mode, current shall be implemented using this value as the upper limit. If this value is higher than the available output current of the EVPS, an emergency stop by EV is performed.
108.3	Available output current	This value is used to calculate the "maximum charging time"
109.3	Present charger current	This value shall be received as the information of EVPS.
200.0	Maximum discharger current	During V2H charge/discharge mode, current shall be implemented using this value as the upper limit. Vehicles with previous versions to the V2H guideline 1.1 have initial values not set to 0. The control error will in this case be avoided by masking the initial value. If this value is bigger than the available input current of the EVPS, an alternative stop is performed.
208.0	Present discharger current	This value is compared to the value of the current measured by the EV. It determines the stopping condition, when the SOC requested value is reached. If this value and the present charge current are set to 0 for a long period of time, this value can be used to determine the timeout for stopping the charging process.
208.3	Available input current	This value shall be received as the information of EVPS.

Table 17 – CAN messages for charge/discharge mode

3.3.1.4 Firmware tasks

This topic deals with the Firmware developed to establish the communications between the FastV2G and the EV via the CHAdeMO protocol.

Mainly, the firmware can be divided in 4 tasks, as shown in Figure 29.

- Task 1: Task responsible for following the requirements applied by the Electric Vehicle Power Supply System Association (EVPOSSA) standard in the Version 2.1 "Guidelines of Charge/Discharge System for Electric Vehicle V2H DC version".
- Task 2: Communication between FastV2G and power electronics through CAN protocol.
- Task 3: Communication between FastV2G and EV through CAN protocol.
- Task 4: Communication between FastV2G and PLC through MODBUS.

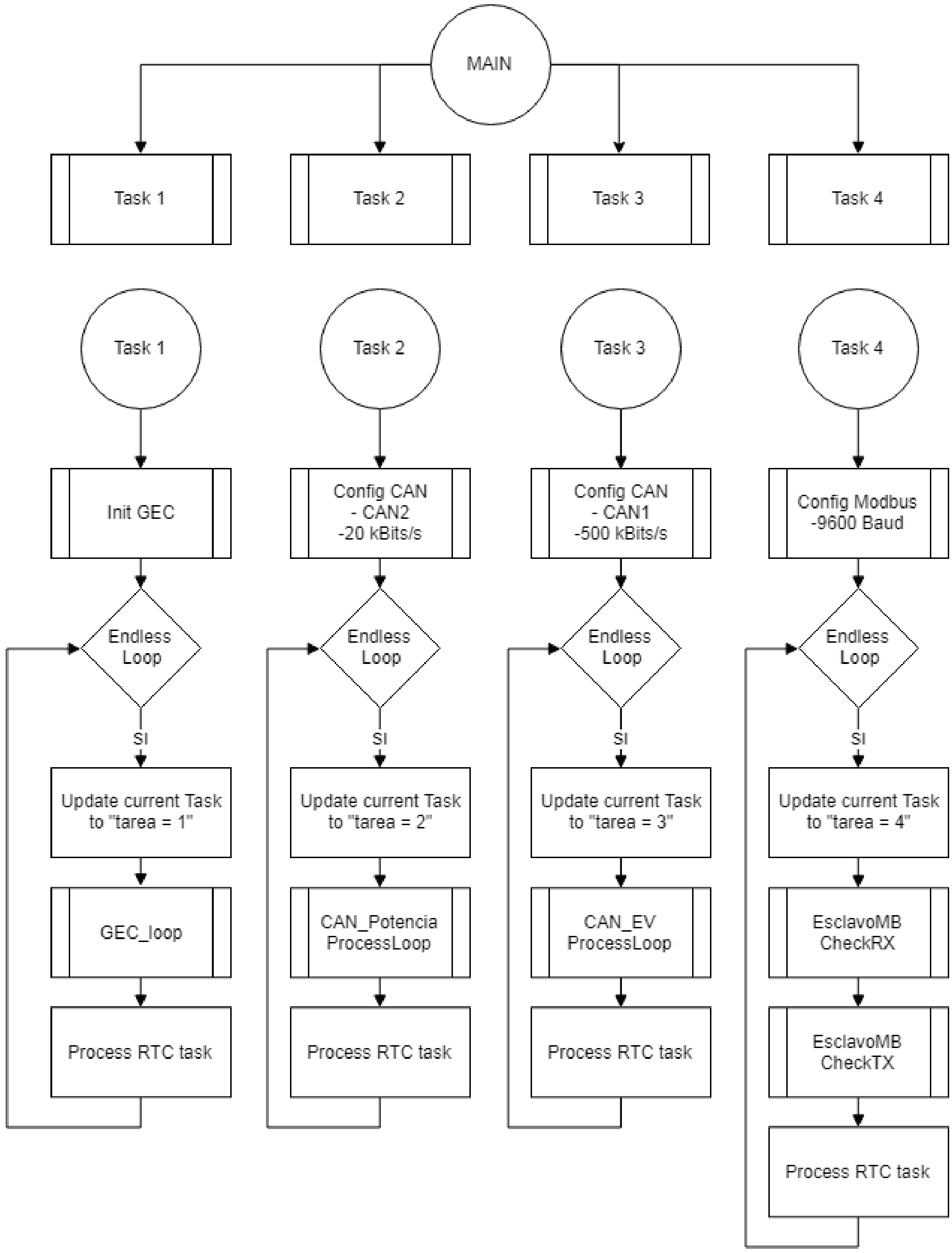


Figure 29 – Main Tasks

The Firmware developed in the FastV2G EVSE is programmed by a Finite-State Machine (FSM) because with this kind of programming, a transition condition to jump to a different state is needed. Therefore this is the condition needed to comply with the requirements established for the CHAdeMO protocol, where there are certain conditions (for example digital inputs set to ON/OFF) that must be fulfilled before moving to the next step, as seen in Figure 30 [9].

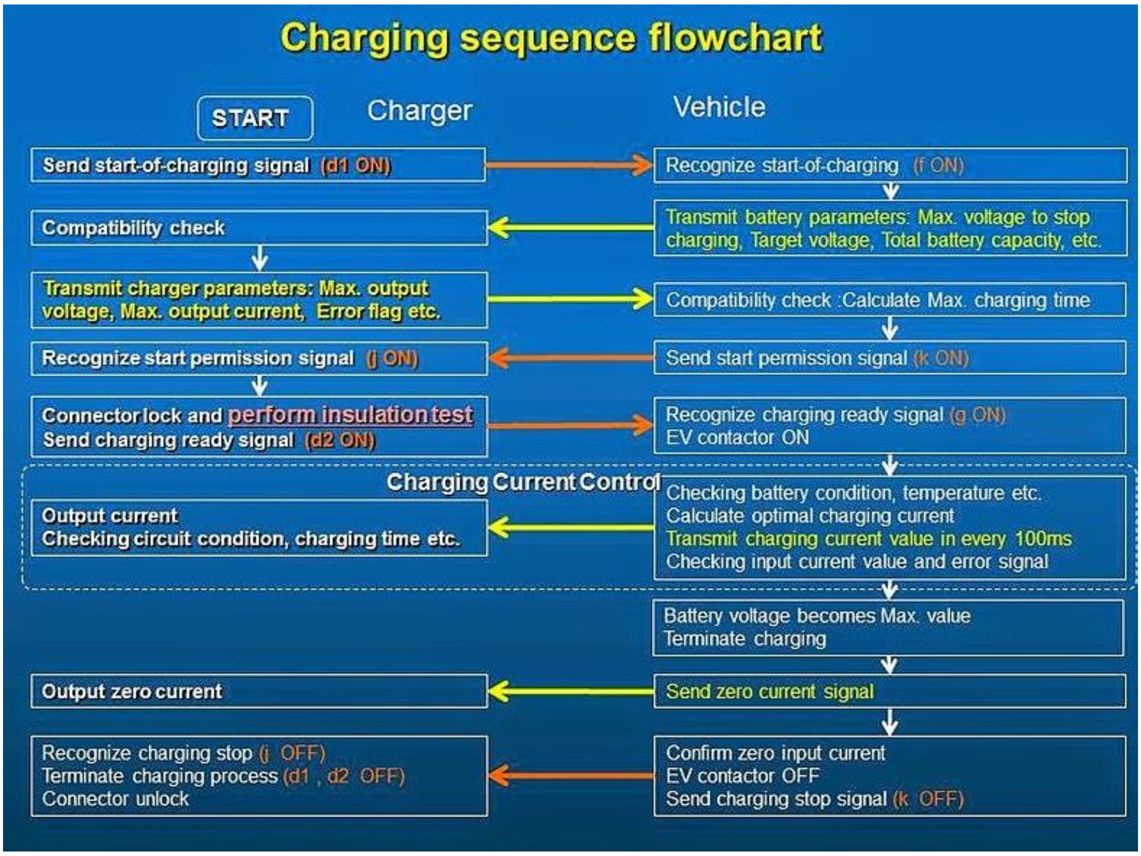


Figure 30 – Charging sequence flowchart

It should be noted the importance of the task 1, because it is responsible for the correct operation of the State Machine.

Figure 31 shows the complete flowchart of the task 1, except for the error processing. There are three outstanding features:

1. Before moving to the next step, a previous condition must take place. These conditions are determined in the CHAdeMO protocol.
2. CHAdeMO connector is blocked first, to assure that the EV is not disconnected from EVSE at any time of the process.
3. The variability of the process “GeneralPhase”, because in the absence of this change the communication with the EV will be impossible, due to the very short timeout of the communication frames between the EV and FastV2G(milliseconds). In conclusion, a very fast process is needed.

There are 2 possible states for this process: “CONFIGURATION” and “EXECUTING”. When the process is set to “CONFIGURATION” the FastV2G has to collect the user data and notify the status of the EV’s through Modbus. The value shall change to “EXECUTING” after the user selects the charging/discharging mode process. This step resets the Machine State with the new configuration and starts the charge/discharge process.

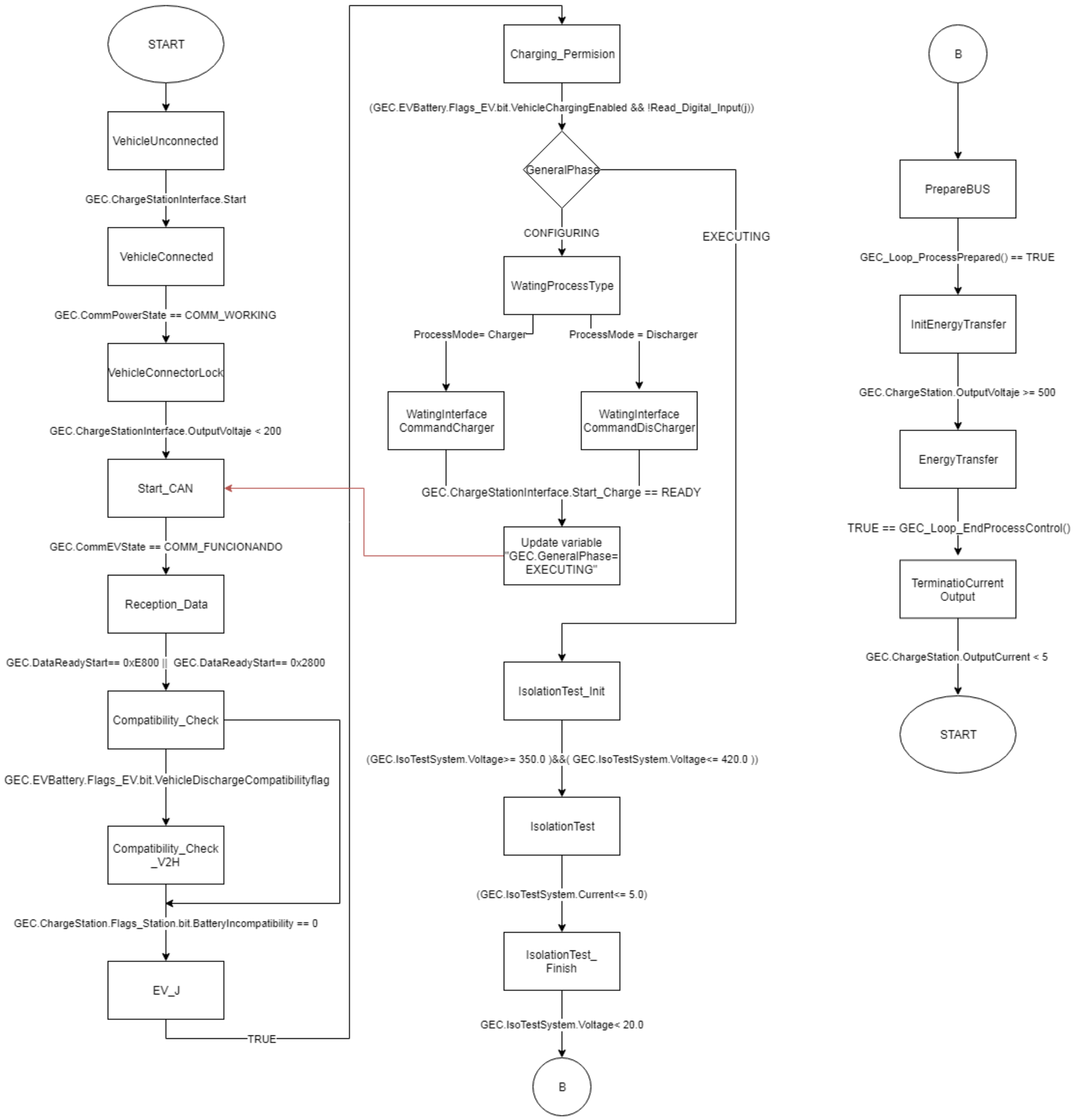


Figure 31 – State Machine

3.4 COMMUNICATIONS WITH WISEEVP: OCPP

OCPP programming is being developed in the Raspberry Pi 3 – Model B, with version v1.6 as it is the latest version released by OCA, and with JSON implementation. Although this version does not support V2G mode, all the exchanged information that is not specifically part of the protocol will be implemented with the Data-Transfer command. Despite the fact that version v2.0 is compatible with V2G, this version is still in draft so it will not be developed in this project.

The following images show the OCPP Flow Charts. In Figure 32, the main program is depicted, where the Raspberry Pi loads the configuration, starts communications with PLC and WiseEVP and starts checking messages by Central System (CS), process which is shown in Figure 33. Figure 34 shows the flow of the charging process.

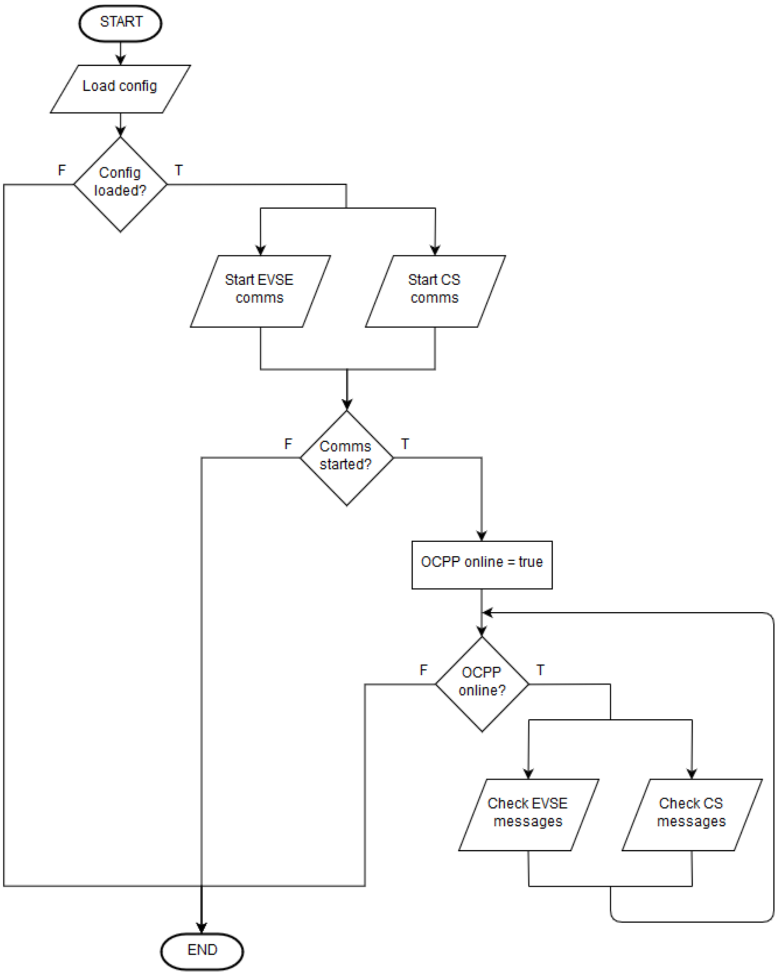


Figure 32 – OCPP Flow chart - Main program

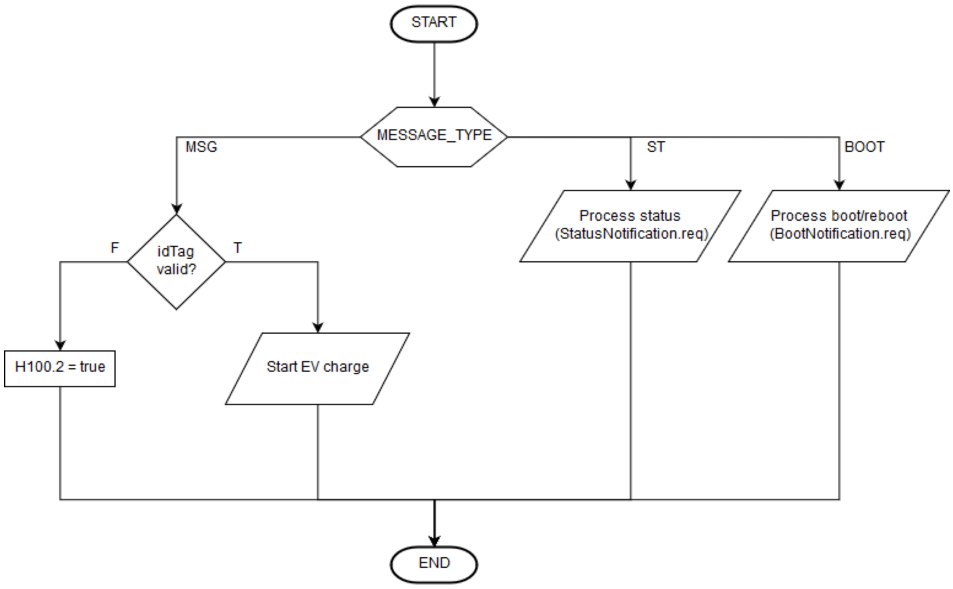


Figure 33 – OCPP Flow chart – Check EVSE Message

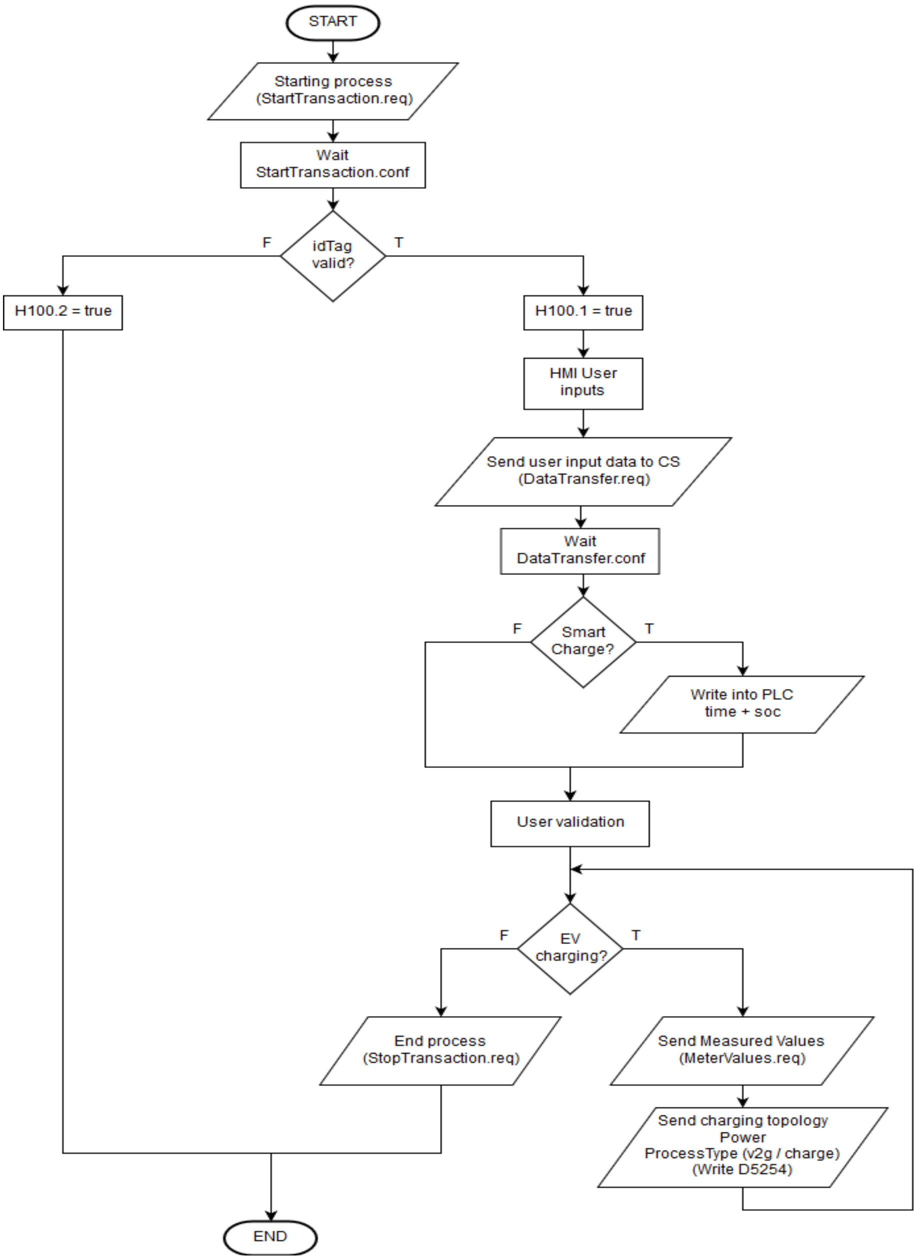


Figure 34 – OCPP Flow chart – Start EV Charge

Attending to the specifications document of OCPP v1.6 [10], the protocol is made up of 6 different profiles, which can be seen in the following table:

Profile Name	Description
Core	Basic Charge Point functionality comparable with OCPP 1.5 without support for firmware updates, local authorization list management and reservations.
Firmware Management	Support for firmware update management and diagnostic log file download.
Local Auth List Management	Features to manage the local authorization list in Charge Points.

Reservation	Support for reservation of an EVSE.
Smart Charging	Support for basic Smart Charging, for instance using control pilot. Control pilot detects the presence of the EV and controls the charging process.
Remote Trigger	Support for remote triggering of EVSE initiated messages

Table 18 – OCPP v1.6 Profiles

The Core profile is the only one which is mandatory in order to be OCPP compliant. However, due to the requirements of WiseGRID project, Local Auth List Management, Smart Charging and Reservation will be also developed, although in this case all the reservations will be managed from WiseEVP which will only inform the FastV2G of its current status.

The messages of Core profile that will be initiated by FastV2G are:

Authorize.req

If the identified user is not in the White List received in the WiseEVP Auth List Management profile, FastV2G will request WiseEVP if the user has permission to use the EVSE.

BootNotification.req

Sent every time the FastV2G boots or reboots.

DataTransfer.req

This message is used to exchange information that is not supported by OCPP. In this case, this message will contain information regarding the user's selection of SoC and Time, so that this combination will be calculated and returned back from WiseEVP.

DataTransfer will have the following structure:

<u>DataTransfer request (from FastV2G)</u>

data: {

proposedTime: int (minutes)

proposedSOC: int (%)

currentEVSOC: int (%)

EV battery capacity: int (kWh)

maxPowerEVCharge: int (kW)

maxPowerEVDischarge: double (1 decimal) (kW)

EVSoftwareVersion: enum(SWVersion)

processType: enum(Process)

}

Enum SWVersion

- 0: CHAdeMO version 0.9
- 1: CHAdeMO version 1.0
- 2: CHAdeMO version 1.1
- 3: CHAdeMO version V2H (v2.0)

Enum Process

- 0: Non defined
- 1: SmartCharge
- 2: SmartChargeV2G
- 3: SOC

DataTransfer response (from WiseEVP)

data: {

processTime: int (minutes),

processSOC: int (%),

}

Heartbeat.req

In JSON implementation it is not mandatory (it is mandatory in SOAP), but it will be sent once a day for clock synchronization.

MeterValues.req

Electrical parameters measured by FastV2G that will be sent to WiseEVP every 15 minutes during the charging process.

Table 19 shows all the values that can be exchanged between FastV2G and WiseEVP. Not all of them will be sent, only the necessary ones to meet the project requirements.

Value	Description	Data Origin
Current.Export	Instantaneous current flow from EV	EV
Current.Import	Instantaneous current flow to EV	EV
Current.Offered	Maximum current offered to EV	
Energy.Active.Export.Register	Energy exported by EV (Wh or kWh)	Energy meter
Energy.Active.Import.Register	Energy imported by EV (Wh or kWh)	Energy meter
Energy.Reactive.Export.Register	Reactive energy exported by EV (varh or kvarh)	Energy meter
Energy.Reactive.Import.Register	Reactive energy imported by EV (varh or kvarh)	Energy meter
Energy.Active.Export.Interval	Energy exported by EV (Wh or kWh)	
Energy.Active.Import.Interval	Energy imported by EV (Wh or kWh)	
Energy.Reactive.Export.Interval	Reactive energy exported by EV. (varh or kvarh)	
Energy.Reactive.Import.Interval	Reactive energy imported by EV. (varh or kvarh)	
Frequency	Instantaneous reading of powerline frequency	
Power.Active.Export	Instantaneous active power exported by EV. (W orkW)	Energy meter
Power.Active.Import	Instantaneous active power imported by EV. (W or kW)	Energy meter
Power.Factor	Instantaneous power factor of total energy flow	

Power.Offered	Maximum power offered to EV	
Power.Reactive.Export	Instantaneous reactive power exported by EV. (var- kvar)	Energy meter
Power.Reactive.Import	Instantaneous reactive power imported by EV.(var-kvar)	Energy meter
RPM	Fan speed in RPM	
SoC	State of charge of charging vehicle in percentage	Energy meter
Temperature	Temperature reading inside EVSE.	
Voltage	Instantaneous AC RMS supply voltage	

Table 19 – Meter Values

StartTransaction.req

Request sent from FastV2G to begin the charging process. This start request can only be initiated from FastV2G.

StatusNotification.req

This message is used to inform the WiseEVP the status of the station:

- Available
- Preparing
- Charging
- Suspended EVSE (Charging is not allowed by Control Center due to, for example, a smart charging restriction).
- Finishing
- Reserved
- Faulted

FastV2G is able to identify the following errors in the EVSE:

- Connector Lock Failure
- EVCommunicationError
- GroundFailure
- HighTemperature
- InternalError (in the DC Power Block)
- LocalListConflict
- OtherError (other errors generated by EC such as battery overheating, incompatibility between EV and FastV2G, timeout error, overvoltage and undervoltage detected by EV, etc).
- OverCurrentFailure
- OverVoltage
- UnderVoltage
- PowerMeterFailure (communication error with Energy Analyzer)

- ReaderFailure (RFID failure)

StopTransaction.req

Request sent from FastV2G to stop the charging process. This stop request can only be initiated from FastV2G.

Currently, commands initiated by WiseEVP to FastV2G are being defined.

3.5 POWER ELECTRONICS

The system currently consists of a header transformer responsible for carrying out the isolation of the network, as well as to change the topology of the star network to a triangle topology necessary for the power stage in charge of the switching process. The current transformer has a nominal power of 100kVA so that it can supply the required current to recharge the electric vehicle with up to 50kVA. Having a working power (50kVA) lower than the nominal power (100kVA) allows the transformer not to work in its maximum working point, which could lead to a possible saturation or system instability, either due to losses or fluctuations in the control system. All the sensing is dimensioned to the maximum working currents of the transformer so that it can work in all its range and therefore obtain the maximum resolution necessary for the control.

In order to adapt the current topology to the needs of the project, which is proposed as a bidirectional system of up to 10kVA, it is necessary to adapt the transformer so that it can work closer to nominal values and where losses are minimized. Thus it is necessary to replace the current 100kVA transformer with a 20kVA transformer, which, as in the previous case, is intended to have an edge regulation variations with respect to the nominal power can be proposed. The topology of the transformer is conserved in the same way, star-triangle. It is also necessary to change the sensors used for current measurement so that they can adapt to the new working ranges and thus be able to have the greatest precision in the measurement. The change of transformer and sensors implies a modification in the control algorithms that ensure the stability and the minimum generation of harmonics. Although the topology is the same, the behaviour of the transformer differs as the nominal power is different, and therefore its modelling must be taken it into account during different control calculations, such as the magnetization currents, divergence between phases, delay in the generation current with respect to the voltage, as well as in different parameters that are necessary to minimize losses and obtain a precise control both in the vehicle charging and power injection to the grid.

3.6 LABORATORY TESTS

The last stage of FastV2G developments consists of laboratory tests in order to validate all the tasks that have been developed during the scope of the project.

The main problem faced when looking for the appropriate tools to test FastV2G is the fact that very few models are compatible with bidirectional V2G operation and dynamic charging.

First of all, the main requirement of the EV is its compatibility with CHAdeMO technology, as FastV2G only supports this standard in any of its versions. The EVs and PHEVs compatible with CHADeMO protocol, attending to [11] are:

- Mitsubishi Fuso Ecanter
- Nissan Leaf
- Mitsubishi Outlander
- Toyota Prius
- Nissan E-NV200
- Kia Soul

- Tesla Model S (with CHAdeMO adapter)
- Mitsubishi I-MIEV
- Mahindra E20
- Peugeot Partner
- Peugeot Partner Tepee Electric
- Citroen C-Zero
- Peugeot Ion
- Citroen Berlingo
- Mitsubishi Minicab-MiEV Truck
- Mitsubishi Minicab-MiEV
- Mazda Demio
- Bollinger B1
- Honda Fit
- Subaru Stella
- BD Otomotiv eKangoo
- BD Otomotiv eDucato
- BD Otomotiv eFiorino
- BD Otomotiv eTrafic

From the model listed above, the only ones that are 100% compatible with V2G and dynamic charge are Nissan Leaf and Nissan E-NV200.

Nissan has been contacted and they have accepted to lend a new Nissan Leaf 40kWh during the month of June 2018, when the developments will be almost finished and the first tests could be performed.

Figure 35 – New Nissan Leaf 40kWh for laboratory tests

4 CONCLUSIONS

FastV2G EVSE has been presented in this deliverable. The aim of this EVSE is not only to charge the EV in the required time but also to perform bidirectional operation, where the energy from the batteries can be used to inject power to the grid. This allows the EV to act as a storage system, which can provide several advantages such as peak shaving capacity, where the demand curve can be flattened, or to increase the integration of renewable energy sources in the local grid.

One of the main goals and tasks of FastV2G EVSE is to perform dynamic charging. Until very recently, EVs only allowed static charging, where the maximum power supplied by the EVSE would be previously set during the initial handshake and would remain constant during all the charging process. However, the latest EV standards have included in the new releases the possibility of performing dynamic charging, where the EVSE has the option to limit the power supplied to the EV at any moment during the charging process in order to performing energy balancing.

FastV2G station, which is a 10kW bidirectional station CHAdeMO compliant, is based on the Smart EVSE developed by ITE in the past. However, this prototype was far away of meeting the requirements of WiseGRID project. The goal of this Work Package is to perform all the developments so that FastV2G EVSE does comply with WiseGRID goals. This means to develop all current CHAdeMO standards, including charging/discharging mode and dynamic charging. In addition, communications with control center WiseEVP are also being developed following the OCPP protocol in its latest released v1.6. Power electronics stage also needs to be adapted as the nominal power of FastV2G is 10kW instead of 50kW, so the isolation transformer must be changed and the DSP firmware must be reprogrammed for algorithm optimization.

Laboratory tests will be performed using a new Nissan Leaf model in order to validate the developments before moving the station to the pilot site in Crevillent.

5 REFERENCES AND ACRONYMS

5.1 REFERENCES

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5.2 ACRONYMS

Acronyms List	
AC	Alternating Current
BT	Low Voltage
CAN	Control Area Network
CCS	Combined Charging System
DC	Direct Current
DSP	Digital Signal Processor
EV	Electric Vehicle
EVCC	Electric Vehicle Communication Controller
EVSE	Electric Vehicle Supply Equipment
HMI	Human Machine Interface
I/O	Input/Output
IEC	International Electrotechnical Commission
IGBT	Insulated Gate Polar Transistor
ISO	International Organization for Standarization
ITC	Complementary Technical Instruction
JIS	Japanese Industrial Standards
JSON	JavaScript Object Notation
OCA	Open Charge Alliance
OCPP	Open Charge Point Protocol
OSI	Open Systems Interconnections
PCB	Printed Circuit Board
PLC	Programmable Logic Controller
PSU	Power Supply Unit
PWM	Pulse Width Modulation
RCMU	Residual Current Monitoring Unit
RD	Spanish Royal Decree
RFID	Radio Frequency Identification
SECC	Supply Equipment Communication Controller
SOC	State of Charge
V2G	Vehicle to Grid
V2H	Vehicle to Home

Table 20 – List of Acronyms