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D5.2: Requirements for the infrastructure based on the defined model

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Enel	16.05.2011	08	Added conclusion to section 3.2.1.1. Deleted repeated paragraph below figure 13	
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Executive summary

This report deals with the requirements of infrastructure for both AC and DC recharging stations.

Firstly, an overview of standardisation activities of the IEC task groups for conductive recharging stations for electric vehicles has shown the most significant standards to be considered. Such standards describe the charging modes, 3 in AC and 1 in DC (IEC 61851 “Electric vehicle conductive charging system”), the types of connectors to be used (IEC 62196 “Plugs, socket-outlets, vehicle couplers and vehicle inlets - Conductive charging of electric vehicles”), and the AC electricity metering equipment (series IEC 6205X).

There are standards in progress, as the IEC/TC69/PT61851-23 “DC electric vehicle charging station”, but also a lack for DC electricity metering equipment has been identified. Moreover, the European Commission, through M/468 Mandate, has requested CENELEC, CEN and ETSI to develop European standards or to review existing standards regards to charging connectors

Secondly, the infrastructure requirements for the recharging infrastructure are studied and an assessment of the impact of the recharging process into the distribution network has been done in order to determine necessary requirements due to the introduction of EV within power systems.

On one hand, the charge of electric vehicle batteries from the network needs of power electronics converters. Such power converters draw harmonics to the network, independently if they are placed whether on-board and off-board. High levels of harmonic distortion can lead to problems as overheating, current through neutral conductor and malfunction of devices.

On the other hand, a mass introduction of electric vehicle can originate other power quality problems different from harmonics and the overloading of current infrastructure of the charging is done without any type of control.

The standards that define the limits of current harmonics that a battery charger can draw, as a device connected to the network, has been identified: IEC 61000-3-2 (≤16 A) for AC charging process, and IEC 61000-3-12 (>16 A and ≤75 A) for AC and DC charging process. It should be also mentioned the standard EN 50160 “Voltage characteristics in public distribution systems” that defines the voltage requirements.

A DC charging process has been analysed in order to determine the harmonics drawn resulting in a performance within the current and voltage limits specified in the quoted standards. An approach to the impact on network operation at low-voltage has been done with results from T5.1 in an uncontrolled scenario. The results show an impact on both voltage profile and saturation.

AC charging with on-board charger corresponds to mode 1, 2 and 3 of IEC 61851. DC charging, with off-board charger, corresponds to mode 4 of IEC 61851. The control of the charging stations has been considered controlled for pragmatic and advanced world and not controlled for conservative world. The protection and metering features depends on the place the charging stations are installed: public or private.

Three types of connection for AC charging are distinguished: case A, case B and case C. Two possible configurations of DC charging station are presented: single-output and multi-output. The lack of a standard for DC electricity metering may represent a drawback for the latter option. Moreover, current requirements for DC stations belong to the CHAdeMO association. An international standard of requirements for fast-charging through DC charging stations, IEC 61851-23, is under development.

Thirdly, the requirements of the locations where charging stations are installed are described. These places are divided in two: urban areas, and private/indoor areas. In public areas, recharging infrastructure can be public station stand-alone or public station master/slave. In private/indoor areas, recharging infrastructure can be a simple sockets module or a home station.

Finally, the costs of AC and DC stations are estimated and compared. The costs of charging stations include costs of production, space, grid connection, installation and maintenance for different scenarios in different environments. The comparison is done considering that the different systems provide the same amount of energy. The result shows that the cost of space is a key issue. If it is taken into account, DC station has a lower cost, but if it is not considered, AC station gets a lower cost.

1 Introduction

This deliverable has been produced in the scope of Grid4Vehicle (G4V) project and has the purpose to provide requirements for the recharging infrastructure that shall be deployed in order to charge electric vehicles.

First, it deals with the standardization activities regarding to AC and DC recharging stations. Secondly, it analyses the impact of such station on electric power systems and depicts the technical solutions. Later, the different issues of integration of the recharging stations are described for two main environments: public and private areas. Finally, the cost of each type of recharging station is assessed.

The Grid4Vehicle project focuses on the effects of a large-scale rollout of electric vehicles on the electricity grid. It was therefore chosen not to focus on all aspects influencing the acceptance of electric vehicles, but to focus on those that would have a direct impact the grid. This includes the factors related to the vehicle use, but especially those related to the charging process of electric vehicles. Factors more related to the general acceptance or purchase of electric vehicles are thus not taken into account. Within this category of charging related factors another focus is put on those factors that are user dependent. This means that vehicle or infrastructure dependent factors (like battery lifetime and duration of charging) are less focussed on. Between the categories use and purchase related factors and technical and user related factors, some grey areas exist.

2 Standardisation activities

This chapter summarises the standardisation activities that are being carried out or are planned in short/medium term regarding grid infrastructure issues of the massive introduction of EV. This section will point out most relevant aspects of each activity.

The technical committees of IEC that are involved in standardization for electrical vehicles are:

- TC 69: Electric road vehicles and electric industrial trucks;
- SC 23 H: Industrial plugs and socket-outlets.
- ISO/IEC JWG 22: Vehicle to Grid communication interface (V2G CI)

TC 69 have proposed IEC 61851 “Electric vehicle conductive charging system” in 2001. It defines four different charging modes, 3 in AC and 1 for DC:

- Mode 1: Standardized socket (domestic or industrial) and cable
- Mode 2: Standardized socket and cable with a protection device
- Mode 3: Specific socket on a dedicated circuit
- Mode 4: Direct current (DC) connection for fast recharging

For all modes of charging a residual current device (RCD) and an over-current protection device are required.

About physical interconnection, SC 23 H proposed IEC 62196 “Plugs, socket-outlets, vehicle couplers and vehicle inlets - Conductive charging of electric vehicles” in 2004. The IEC 62196-2 contains categorizations on plug types to be used in the AC charging process. It defines three standard configuration types of inlet/connector and plug/socket-outlet:

- Type 1 – single phase vehicle coupler (vehicle connector and inlet) - reflecting the SAE J1772/2009 automotive plug specifications
- Type 2 – single and three phase vehicle coupler and mains plug and socket-outlet without shutters - reflecting the VDE-AR-E 2623-2-2 plug specifications
- Type 3 – single and three phase vehicle coupler and mains plug and socket-outlet with shutters - reflecting the EV Plug Alliance proposal

Each vehicle inlet shall only mate with the corresponding type of vehicle connector. Each plug shall only mate with the corresponding type of socket-outlet.

The IEC 62196-2 does not contain a proposal for DC charging / Mode 4. This is scheduled for the next part of the standards series named IEC 62196-3 with expectations for the proposal to be published in a time frame ranging from June 2012 to beginning of 2013 and the IEC expecting the functional release in December 2013.

In a review of the existing charging connectors notice that several different charging connectors are available currently, but none of them compliant with all the required functionalities.. This could be problematic as the EV owners expect to be able to charge their EV at any charging station. Therefore, the European Commission, through M/468 Mandate, has requested CENELEC, CEN and ETSI to develop European standards or to review existing standards in order to:

- Ensure interoperability and connectivity between the electricity supply point and the charger of electric vehicles, including of their removable batteries, so that this charger can be connected and be interoperable in all EU states.
- Ensure interoperability and connectivity between the charger of electric vehicle (if the charger is not on board) and the electric vehicle and its removable battery, so that a charger can be connected, can be interoperable and re-charge all types of electric vehicles and their batteries.
- Appropriately consider any smart-charging issue with respect to the charging of electric vehicles.
- Appropriately consider safety risks and electromagnetic compatibility of the charger of electric vehicles in the field of Directive 2006/95/EC (LVD) and Directive 2004/108/EC (EMC).

According to the ISO/IEC agreement concerning standardization of electrotechnology for road vehicles and the cooperation between ISO/TC 22 “Road vehicles” and IEC Technical committees, whose aim is to ensure an effective and professional development of standards for road vehicles and to avoid duplication in standardization, the ISO/TC 22/SC3 joint with IEC/TC 69 are involved in ISO/IEC 15118 “Vehicle to Grid communication interface (V2G CI)” standard that specifies the communication between battery electric vehicles (BEV) or plug-in hybrid electric vehicles (PHEV) and the Electric Vehicle Supply Equipment (EVSE, also known as charge spot). It covers the overall information exchange between all actors involved in the electrical energy exchange.

Concerning electrical installation of buildings, the LV installation shall be according the requirements of the IEC 60364 series of TC 64, Low-voltage electrical installations. The following standards are seen to be important:

- IEC 60364-7-722, Electrical installations of buildings - Part 7-722: Requirements for special installations or locations - Supply of Electrical Vehicle
- IEC/ NP 60364-7-760, Electrical installations of buildings – Part 7-760: Electrical vehicle
- IEC 60364-4-41, Low-voltage electrical installations – Part 4-41: Protection for safety –Protection against electric shock

Regarding the standardization of metering devices to quantify energy consumed in the charge of EV in DC fast recharging mode, currently, a DC energy metering device is not approved. Standards for electricity metering, tariff-and load control are under the responsibility of IEC TC 13 and are:

- IEC/TR 62051, Electricity metering - Data exchange for meter reading, tariff and load control
- IEC 62052, Electricity metering equipment (AC) - General requirements, tests and test conditions
- IEC 62053, Electricity metering equipment (AC) - Particular requirements
- IEC 62054, Electricity metering (AC) - Tariff and load control
- IEC 62056, Electricity metering data exchange for meter reading, tariff and load control
- IEC 62058, Electricity metering equipment (AC) - Acceptance inspection
- IEC/TR 62059, Electricity metering equipment - Dependability

Regarding the standardization of charging infrastructure there are different initiatives. On one hand, the Society of Automotive Engineers (SAE) have prepared the SAE J-1772 standard “Electric Vehicle and Plug-in Hybrid Electric Vehicle conductive charge coupler” that covers the general physical, electrical and performance requirements of the connector and the vehicle electrical plug. It also defines general system requirements, and personnel protection devices for the three levels of charging. Level 3 corresponds to DC fast charging. On the other hand, in Japan, the CHAdeMO association leads by the Tokyo Electric Power Company (TEPCO) and Japan Automobile Research Institute (JARI) have promoted the standardization of DC fast charging system. In Europe, fast charging initiatives are according to the definition of mode 4 done in the IEC 61851.

New items have been proposed from Japanese institutions to the IEC that are expected to be published for November 2012. Such proposals are the following

- IEC/TC69/PT61851-23: DC electric vehicle charging station.
- IEC/SC23H/PT62196-3: Dimensional interchangeability requirements for pin and contact-tube coupler for dedicated DC charging.
- IEC/TC69/PT61851-24: Control communication protocol between off-board DC charger and electric vehicle.

3 Infrastructure requirements

This section defines the improvements of the distribution system infrastructure to facilitate the EV charge.

The scenario worlds that have been defined in G4V project present different possibilities regarding the evolution of the power sector in Europe. Therefore, different worlds are defined in which different assumptions are valid.

The point of origin is our world as it is today with all established technologies and rules. Coming from this point, different developments concerning technology or regulatory frameworks are imaginable.

The Conservative World pursues a business as usual approach. Like in the last decades, changes in the energy sector need a lot of time. Therefore, integration of innovations into the system is quite difficult. The grid planning and control will be organized as today and no avoidable changes will happen.

The Pragmatic World operates a bit different. Innovations like a new technology or a new organisation of grid control are likely as long as these changes are reasonable. An example might be Italy where it was reasonable to install smart meters because it is profitable. In this world the countries might have differences in their installed technologies.

The third world is called Advanced World. It is assumed that nearly all technical solutions are possible and the situation for EVs is nearly optimal. The reason might be that the EU forces developments in the energy sector such as an installation of certain technologies even if the profitability is low.

Table 1. Overview about the main difference in the scenario worlds.

	Conservative World	Pragmatic World	Advanced World
Charging control	No	Yes, simple charging control	Yes, complex charging control
Prices	As today	Dynamic tariffs	No limitation
Regulation	Conservative	Some liberalization	Optimal situation for EVs
Services	Unidirectional, no services	Unidirectional, all services can be provided	Bidirectional, all services can be provided
Grid infrastructure	Conventional development	Smart grids	Advanced smart grids, virtual power plant etc.

3.1 *Definition of Technical solutions*

For charging electric vehicles, three basic types of energy transmission can be distinguished: conductive charging, inductive charging and electric batteries swapping.

The conductive charging (plug and cable) is probably the simplest solution available. It offers a few advantages over the other technologies, as charging stations are easy to install. Also, this technology is fairly cheap compared to the others and communication between car and grid for all kinds of purposes can be realized via the same cable that is used for energy transmission.

Conductive charging can be achieved by connecting the vehicle charger directly to the grid with an AC connection, where the on-board charger converts it to DC current to the batteries, or using a DC connection, where an external charger converts AC power from the grid, to the requested DC current by the vehicle. AC connections are cheaper to supply but are limited in power to the maximum vehicle on-board charger that can be fitted. DC connections can go up to higher power, as the off-board charger does not have that limitation, and is shared by different users. DC connections are however more expensive to the infrastructure supplier as they require the off-board charger.

Different type of charging station can be distinguished by different power ratings (according to CIVES classification):

- Slow charging: P < 7 kW
- Quick charging: 7 kW < P < 44 kW
- Fast charging: P > 44 kW

According to this classification, swapping stations have to be considered ultra-fast charging stations and inductive charging can be of any kind, depending on their power rating.

Another classification based on power level is the Eurelectric one, that can be summarize as follow in Table 2:

Table 2. Eurelectric classification of charging types.

Power nomination	Mains connection	Power in kW	Power in Amps
Normal power	1- phase AC connection	<3.7 kW	10-16 amps
Medium power	1- or - 3 phase AC connection	3.7 – 22 kW	16-32 amps
High power	3- phase AC connection	> 22 kW	>32 amps
High power	DC connection	>22 kW	>32 amps

Recharging stations can be also diversified in public and private, according to the place where a vehicle will be charged:

- Public station: recharging infrastructure for use in street, parking areas, public garages and place with access allowed to more persons; charge should be permitted only after customer identification that can be done in various ways (User Interface, Smart Card RFID, PLC, Cash Card). Some simple versions of public charge stations can have no customer identification (for example using direct cash payment).
- Private station: recharging infrastructure for use in private box; charge does not require customer identification.

3.2 *Analysis of Electrical impact of recharging stations*

In order to determine necessary requirements due to the introduction of EV within power systems, the first step is assessing the impact of the recharging process into the distribution network. Although EV will be charged in private facilities, mass production of EV capable of travelling longer distances results in a need for electric service stations that can satisfy the requirements for a significant amount of power provided at a time as short as possible.

The main impacts of recharging station are harmonics and network operation. Following sections deal with these issues.

3.2.1 Harmonics

The batteries of EV are chargeable DC power sources. Thus, batteries involve the use of power electronics converters for charging them from the AC distribution networks. Depending on the charging mode that is desired to be used for EV, such power electronics converters are placed whether on-board (modes 1, 2 and 3 defined at IEC 61851-1) and off-board (mode 4 defined at IEC 61851-1). The latter type permits fast charging by providing DC power while on-boards battery chargers are limited to slow and quick charge.

Power electronics converters are non-linear loads due to switching element, which is the main source of non-linearity. Non-linear loads create harmonics by drawing current in abrupt short pulses, rather than in a smooth sinusoidal manner. A harmonic is a component of a periodic wave having a frequency that is an integer multiple of the fundamental power line frequency of 50 Hz. Harmonics are the integer multiples of the fundamental frequency.

High levels of harmonic distortion can lead to problems in any facilities where harmonics appear, including distribution system. The main issues that must be considered due to harmonics in low-voltage networks are listed below.

- Overheating of elements of power systems. Harmonics increase RMS current and then, power losses are higher due to they are a function of the square RMS current and the frequencies (skin effect).
- Currents through neutral conductor. Single-phase power electronics converters can draw triple-n harmonics (a harmonic order that is a triple-n multiple of the fundamental) that are added arithmetically in the neutral conductor instead of summing zero as the rest of harmonics. In some cases, the amplitude of neutral current might exceed the amplitude of phase current and oversizing the neutral conductor is needed.
- Transformers. Harmonics increase both power losses and eddy currents losses, which overheat transformer windings. Thus, it is necessary to consider a *K-factor* when sizing transformers that supply non-linear loads.
- Synchronization of generators. Voltage harmonic distortion can cause multiple zero crossing of the current waveform, which affect the voltage regulator and controls of generator to be synchronized. Current harmonic distortion increase RMS current and oversizing the generator might be necessary.
- Capacitors banks. Harmonics increase heat in capacitors and reduce their life, and even might provoke their destruction: case of harmonic resonance between the capacitors and grid impedance.
- Fuses and circuit breakers. Harmonics can cause their false operation and trip.
- Meters. Harmonics can cause an error when recording measurement.

As it can be seen, the effects of harmonics vary from unwanted operation of equipment to a failure in equipment and can lead to power system inefficiency. Thus, it has been defined standards limits to harmonic pollution. The main standards are depicted following.

The standard IEC 61000-3-2 specifies limits for current harmonic emissions applicable to electrical and electronic equipment having an input current up to and including 16 A per phase and intended to be connected to public low-voltage distribution systems. Table 3 shows the values of the emission limits of currents for class A equipment.

Table 3. Emission limits of currents. Source: IEC 61000-3-2.

Harmonic order (n)	Maximum permissible harmonic current (A)	Harmonic order (n)	Maximum permissible harmonic current (A)
Odd harmonics		**Even harmonics**	
3	**2,30**	**2**	**1,08**
5	**1,14**	**4**	**0,43**
7	**0,77**	**6**	**0,30**
9	**0,40**	**8 ≤ n ≤ 40**	**0,23 8/n**
11	**0,33**		
13	**0,21**		
15 ≤ n ≤ 39	**0,15 15/n**		

The standard IEC 61000-3-12 defines the limits for harmonic currents produced by equipment connected to public low-voltage with input current exceeding 16 A and less than or equal to 75 A per phase. Table 4 shows the values of the emission limits of currents.

Table 4. Emission limits of currents. Source: IEC 61000-3-12.

Minimum R_{cc}	Individual Distortion Rate of Current D (%)				Harmonic Distortion factor of admissible current (%)	
	I5	**I7**	**I9**	**I11**	**THD**	**PWHD**
33	**10,7**	**7,2**	**3,1**	**2**	**13**	**22**
66	**14**	**9**	**5**	**3**	**16**	**25**
120	**19**	**12**	**7**	**4**	**22**	**28**
250	**31**	**20**	**12**	**7**	**37**	**38**
≥ 350	**40**	**25**	**15**	**10**	**48**	**46**

The standard EN 50160 *Voltage characteristics of electricity supplied by public distribution systems* defines the voltage characteristics of electricity supplied by European power networks. It defines the main voltage parameters and the permitted ranges of derivations in public low-voltage and medium-voltage networks at the customer's point of common coupling, PCC for 95 % of the time.

Table 5 shows the limits of voltage harmonics fixed at the standard 50160.

Table 5. Values of individual harmonic voltages at the supply terminals.

Odd harmonics				Even harmonics		Total Distortion Rate of Voltage
Not multiples of 3		Multiples of 3				
Order h	Relative voltage (%)	Order h	Relative voltage (%)	Order h	Relative voltage (%)	THD (%)
5	**6**	**3**	**5**	**2**	**2**	**< 8%**
7	**5**	**9**	**1,5**	**4**	**1**	
11	**3,5**	**15**	**0,5**	**6**	**0,5**	
13	**3**	**21**	**0,5**			
17	**2**					
19	**1,5**					
23	**1,5**					

On one hand, AC charging facilitates a slow and a quick charging process by means of on-board chargers up to 22 kW. Such equipment can be whether single-phase (up to 3,7 kW for slow charge) or three-phase (up to 22 kW for quick charge). Current through neutral conductor asks for special attention in AC charging due to single-phase devices.

On the other hand, DC charging permits a fast charging process by means of off-board charger consisting of a three-phase power electronics converter that allows direct access to the terminals of the battery placed in the EV. Such equipment has a rated power above 44 kW.

Moreover, harmonics depends on the equipment connected to the network and the network characteristics. Thus, the harmonics production during the recharging process should be analysed from existing experiences in order to assess the emission and verify the immunity. The analysis of DC charging is done next.

3.2.1.1 AC charging

During the AC charging process, also harmonics are generated. Obviously, the harmonics are not generated by the charge spot, they are created by the power electronic converters present on the car, in other words, they are produced by the on-board charger.

Focusing in a real AC test charging, a test done by ENDESA in the CRAVE project is shown, with special attention to the harmonics generation.

The test conditions were:

Battery technology:	Lithium-Ion
Battery capacity:	16 kWh

Type of charger:	Inside AC charger
Protection device:	Built into the hose
Rated charge voltage:	230 V
Rated charge current:	16 A

Start recording time:	9:09pm
Stop recording time:	3:01am
Time elapsed:	5 h 52 min
Initial SOC:	0%
Final SOC:	100%
Energy accepted during the charge process:	14,833.2 Wh
Ambient temperature:	17ºC

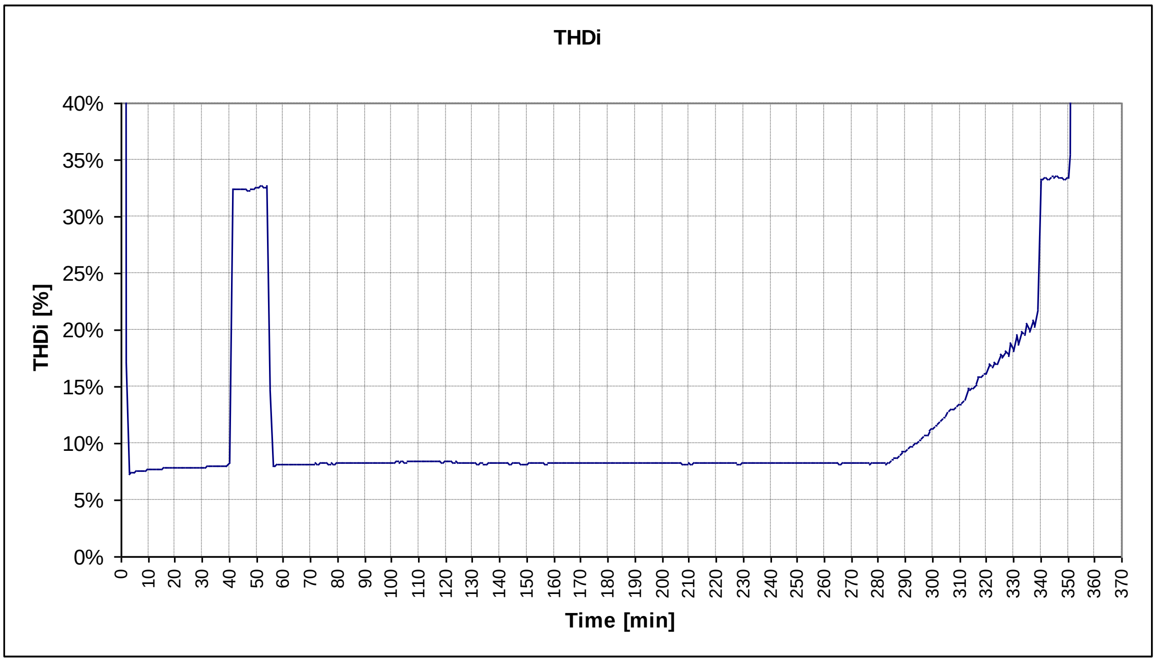

Figure 1. THDi of an AC charging. Source: CRAVE project (ENDESA)

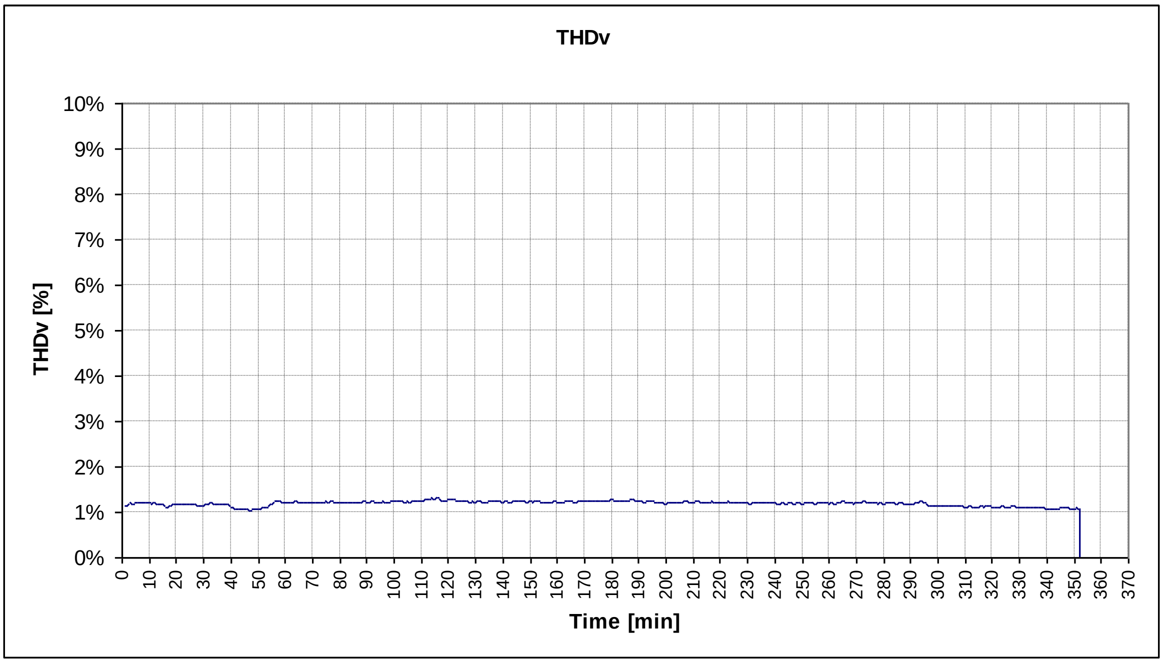

Figure 2. THDv of an AC charging. Source: CRAVE project (ENDESA)

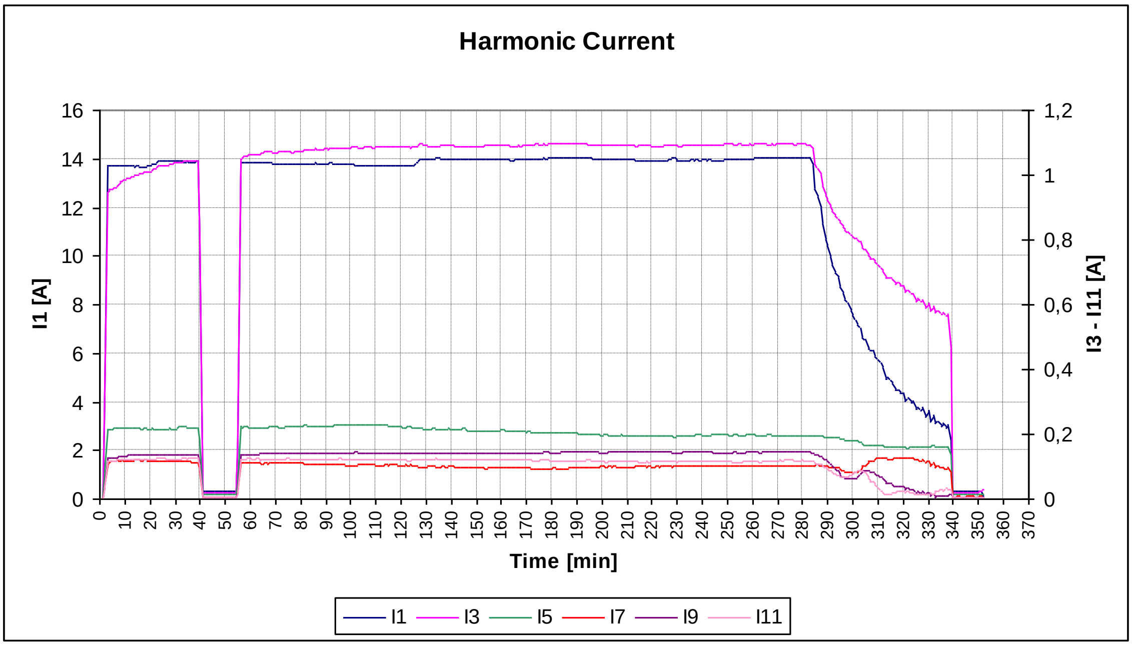

Figure 3. Harmonic current values of an AC charging. Source: CRAVE project (ENDESA)

The total harmonic distortion is always below the 8% except at the last stage, when it gets higher due to the diminution of the fundamental harmonic. The third harmonic is the predominant in the distortion and should be taken into account for the electrical installation designs. However, this component is easily avoided upstream using an adequate transformer connection. High order harmonics have reduced values, always bellow 300 milliamps. Therefore, it can be neglected in regular grids.

Since the power is consumed through a 1-phase connection, the aggregation of several vehicles in an inadequate way might become a strongly unbalanced load. For that reason the design for the different charge points wiring and the transformer connection will be very important. However, due to the random character of the charge points' occupation, it is not easy to assure the load balancing between phases.

As stated by J. Balcells [1], the energy supply of a huge amount of EVs in parking areas generates a serious problem for the supply system of such facilities. The main problems are generated in facilities where the charging is done by 1-phase chargers. That consumption involves a big amount of third harmonic, thus forcing to oversize the neutral conductors and the supply transformers to avoid very high peak currents and overheating of the supply system. The use of three phase charger for the vehicles charging through three phase rectifiers and the use of active filters at the PCC of such installations can avoid the above mentioned problems and improve the efficiency of the charging installations.

In order to reduce the problem of harmonics the on-board chargers of EV should comply with electromagnetic compatibility standards and therefore they should include harmonics reduction filters (IEC 61851-21 Ed.2.0). In addition, the AC recharging stations have to comply with all electromagnetic compatibility tests, i.e. emission testing (conducted according to IEC 61000-6-3) and immunity testing (conducted according to IEC 61000-6-1).

3.2.1.2 DC charging

Figure 4 shows the behaviour of voltage, current and power during a fast charging process of an EV. The data correspond to a 50 kW fast-charger device placed in an urban area and have been obtained from CRAVE project, supported by ENDESA. The time of the charge was about 26 minutes.

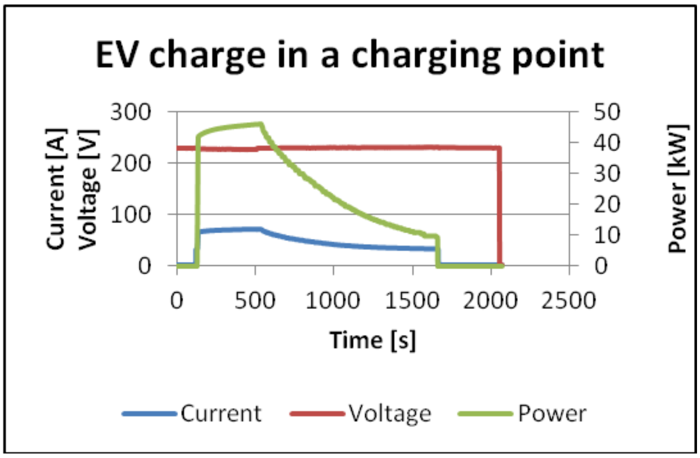

Figure 4. EV behaviour during a charge process. Source: CRAVE project (ENDESA)

Harmonics content during such process has been analysed with next results for current and voltage harmonics.

Regarding the current harmonics, the analysis examined the individual distortion rate of each harmonic and the total distortion rate. For a value of 33 of R_{cc}, the data show that the harmonic distortion varies for each current harmonic between 37% and 67% of the limit value. Regarding the total distortion rate, the results are about 53% of the limit value. Table 6 summaries current harmonics measured.

Table 6. Values of current drawing by DC charging point during EV charge. Source CRAVE project (ENDESA)

Current harmonics drawn by DC charging point during EV charge				
Individual Distortion Rate of Current D (%)				**Total Harmonic Distortion**
I5	**I7**	**I9**	**I11**	**THD**
3,95	**2,42**	**1,22**	**2,15**	**6,89**

Regarding the voltage harmonics, the analysis done also examined the individual distortion of each harmonic, which results vary between 3% and 30% of limit value.
Table 7 shows the values of voltage drawing by DC charging point during EV charge.

Table 7. Values of voltage drawing by DC charging point during EV charge. Source CRAVE project (ENDESA)

Voltage harmonics drawn by DC charging point during EV charge						
Odd harmonics				**Even harmonics**		**Total Harmonic Distortion**
Not multiples of 3		**Multiples of 3**				
Order h	**Relative voltage (%)**	**Order h**	**Relative voltage (%)**	**Order h**	**Relative voltage (%)**	**THD**
5	**0,55**	**3**	**0,17**	**2**	**0,15**	**0,97**
7	**0,38**	**9**	**0,29**	**4**	**0,07**	
11	**0,39**	**15**	**0,18**	**6**	**0,05**	
13	**0,30**	**21**	**0,12**			
17	**0,25**					
19	**0,35**					
23	**0,23**					

As the results of the analysis of the data obtained from the fast recharging of an EV confirm, the harmonics drawn during the process do not exceed the emission limits recommended by the standards.

3.2.2 Voltage fluctuations and flicker

EV charger shall be in compliance with the following two standards according to its rated current:

The standard IEC 61000-3-3 (Limits -Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection) specifies the limits that shall be applicable to voltage fluctuations and flicker at the supply terminals of the equipment under test, measured or calculated according to clause 4 under test conditions described in clause 6 and annex A of the same standard.

The standard IEC 61000-3-11 (Part 3-11: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤ 75 A and subject to conditional connection) specifies the limits that shall be applicable to voltage fluctuations and flicker at the supply terminals of the equipment under test, measured or calculated according to clause 4 under test conditions described in clause 6 of the same standard.

3.2.3 Network operation

Other important impacts that may appear due to the large-scale diffusion of electric vehicle on the distribution grid are the overload of power lines and the voltage excursions. It is feasible that EV charging process provoke in some networks an overload and/or voltage profile problems if these networks are already heavily loaded. These impacts are deeply studied in D5.1 and D5.3.

3.3 AC Recharging Infrastructure

3.3.1 Connection to the grid

The technical base for charging stations and their infrastructure is given by the standard IEC 61851-1 “Electric vehicle conductive charging system”.
This standard applies to all charging devices, inside and outside of electric vehicles, connected to standardized AC voltages up to 1000 V or DC voltages up to 1500 V. Electric vehicles for the purpose of this standard are all vehicles that derive their energy partly or completely from batteries within the vehicle, i.e. pure electric (EV) as well as plug in hybrid electric vehicles (PHEV).

This standard does not apply to overhead power line buses, rail vehicles, industrial transport vehicles as well as all vehicles that are not primarily used on roads.

According to this standard, there are four possible operation modes of charging and for all modes a residual current device in conjunction with an over-current protection device shall be required. The charging modes are:

Mode 1: the EV is connected to the AC supply network not exceeding 16A and not exceeding 250 V AC single-phase or 480 V AC three-phase utilizing standardized socket-outlets and utilizing the power and protective earth conductors.
Mode 2: the EV is connected to the AC supply network not exceeding 32A and not exceeding 250 V AC single-phase or 480 V AC three-phase utilizing standardized socket-outlets and utilizing the power and protective earth conductors together with a control pilot function.
Mode 3: the EV is connected to the AC supply network utilizing dedicated EV supply equipment which has a pilot function (conductor) leading all the way to the device continuously connected to the AC supply network.
Mode 4: the EV is connected to the AC supply network utilizing an off-board charger that delivers direct current and where the pilot function (conductor) has to lead all the way to the device continuously connected to the AC supply network.

The connection with control pilot function has to provide the following functions:

- verification that the vehicle is properly connected: the system should be able to determine that the connector is properly inserted in the vehicle inlet and properly connected to the charging station; vehicle movement by its own propulsion system shall be impossible as long as the vehicle is physically connected;
- continuous protective earth conductor continuity checking: equipment earth continuity between the charging station and the vehicle should be continuously verified;
- energization of the system: energization of the system should not be performed until the pilot function between charging station and electric vehicle has been established correctly;
- de-energization of the system: if the pilot function is interrupted, the power supply to the cable assembly should be interrupted but the control circuit may remain energized

Other additional functions should be provided as given below:

- selection of charging rate: an automatic means should be provided to ensure that the charging rate does not exceed the rated capacity of the AC supply network (mains), vehicle or battery capabilities;
- determination of ventilation requirements of the charging area: if additional ventilation is required during charging, charging should only be allowed if such ventilation is provided;
- detection/adjustment of the real time available load current of the supply equipment: means shall be provided to ensure that the charging rate shall not exceed the real time available load current of the charging station and its power supply;
- retaining/releasing of the coupling: a mechanical means shall be provided to retain/release the coupler;
- control of bi-directional power flow to and from the vehicle.

The connection of EV is supposed using cables and it may be carried out in different ways:

Case A: connection of an EV to the AC supply network utilizing a supply cable and plug permanently attached to the EV.

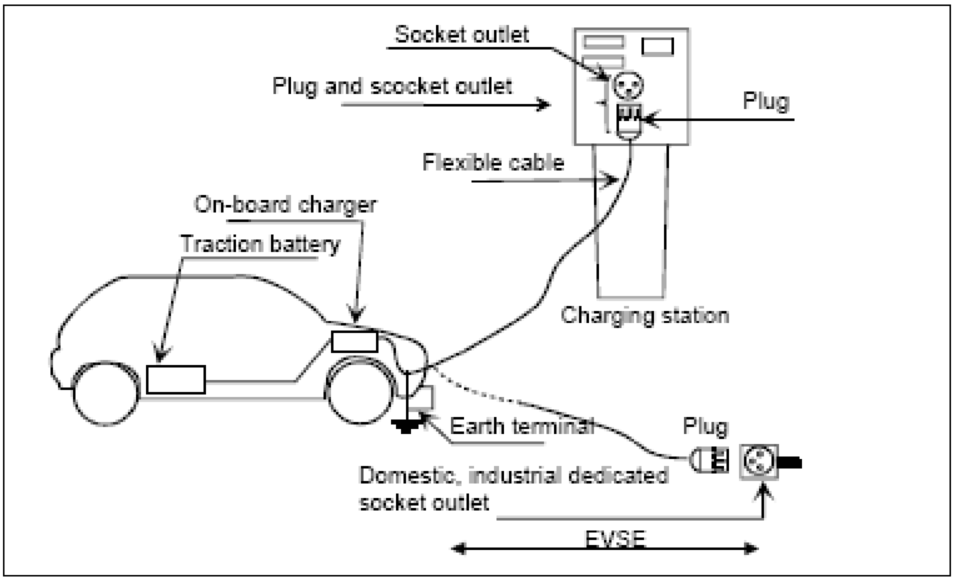

Figure 5. Case A of connection of an EV.

Case B: connection of an EV to the AC supply network utilizing a cable set which can be completely taken off.

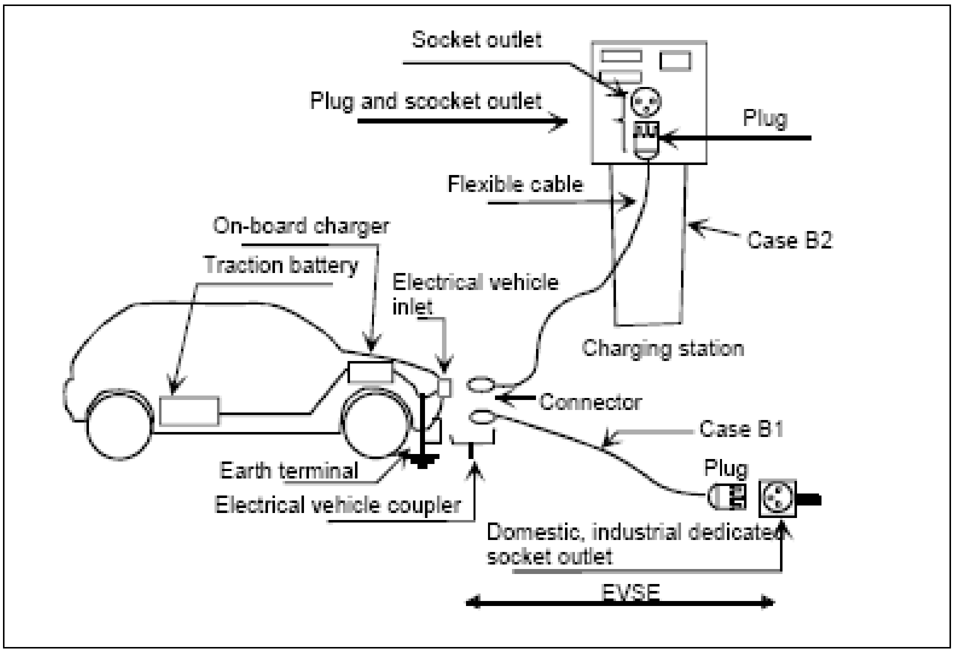

Figure 6. Case B of connection of an EV.

Case C: connection of an EV to the AC supply network utilizing a supply cable and vehicle connector permanently attached to the supply equipment.

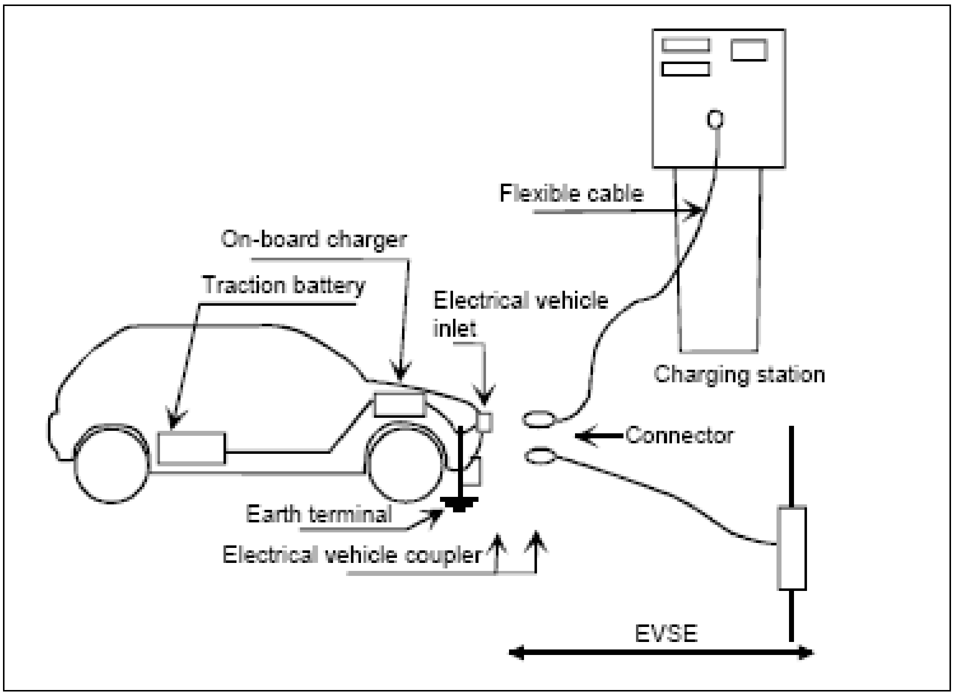

Figure 7. Case C of connection of an EV.

3.3.2 Protections

For safety reasons, the contact sequence during the connection process in mode 3, 4 and in mode 2 (at the vehicle side) shall be such that the earth connection is made first and the pilot connection is made last. The order of connection of the other contacts is not specified. During disconnection, the pilot connection shall be broken first and the earth connection shall be broken last.

For protection against electric shock all hazardous live parts shall not be accessible and all exposed conductive parts shall not become an hazardous live part under normal conditions (operation as intended use and in the absence of a fault), and under single-fault conditions. Anyway, protection against electric shock is provided by the application of appropriate measures for protection both in normal service and in case of a fault:

- protection in normal service (protection against direct contact or basic protection), is defined in 411.2 of IEC 60364-4-41
- protection in case of a fault (protection against indirect contact) is defined in 411.3 of IEC 60364-4-41

To avoid an undesirable load interruption, a device to prevent unintentional disconnection of the connector or the plug may be provided. Examples include mechanical latching of the connectors, trap door to the connector, etc.

As specified in IEC 61851-22 Ed 2, if required by national rules, an emergency disconnection device shall be installed to isolate the AC supply network (mains) from the AC electric vehicle charging station in case of risk of electric shock, fire or explosion. The disconnection device shall be provided with a means to prevent accidental operation.

3.3.3 Metering features

The energy supply involves the need of metering devices. The evolution of the metering devices has involved the implementation of electronics to bring new capabilities and functionalities which allow advanced functions and the direct connection to information systems of control centres.

This new features of metering devices have led to AMM (Automatic Meter Management) systems. The AMM is an expansion of a remote reading system that includes the possibility of performing technical measurements and functions and carrying out customer-oriented service via the system. The AMM concept is referred to a microprocessor-based automatic electricity meter reading system which provides cost-effective and reliable data transfer between metering devices and the electric utility control centre. The AMM system allows functions such as periodical measurements, communications, customer and vendor control services, consumption measurements and information about quality of electricity or meter self-diagnostic and enables a sensible and economically viable allocation of the resources from data collection to analysing data.

Thus, the point of charge features an electric meter to quantify the amount of electrical energy consumed during charging of the electrical vehicle. For example, in the DSO business model, in which charging points are installed, owned and operated by the DSO, also the electronic meter has to be installed, managed and operated by the local distribution company and then the meter can be integrated in the charging station.

3.3.4 Not Controlled Infrastructure

The **Conservative World** pursues a business as usual approach. In this scenario the grid planning and control is organized as today and the recharging infrastructure is not controlled. Smart meters are installed but have a very limited functionality.

3.3.4.1 Private

Private station is a recharging infrastructure for use in private parking places (garage), therefore charge doesn’t require customer identification and the infrastructure doesn’t required additional features beyond already described safety requirements. Other functionalities and requirements shall be considered optional to provide added value services, such as a display to inform the user about the state of the charge.

3.3.4.2 Public

Public station is a recharging infrastructure for use in street, public parking areas, public garages and other places with access allowed to more persons; therefore the access to the infrastructure should be restricted to the authorized users (i.e. clients of the charge service). This limitation is needed in order to enforce safety and security and in order to allow billing of the clients. In order to control the access to the service, it is needed to establish an authorization process that every client has to undertake before the charging service could start.
Such an authorization can be provide using a number of different solutions:

- Pure mechanical key: this method is very simple to implement and it has been proposed in some pilot project. Nevertheless, it is suitable only when the number of customers is very low.
- User interface: the user can be required to use a user interface on the charge infrastructure to insert a code (e.g. a pin) in order to authenticate himself.
- Smart card: this system requires the use of a smart card which stores some kind of user identification. The stored information can be a simple identifier (i.e. a unique contract id) or can also contain additional information, such as a credit for pre-paid contract. The use of the card can be combined with the user interface.
- Communication between the vehicle and the infrastructure: similar to smart card solution, but the information is stored inside the vehicle.
- Payment card: in this case the user can directly authenticate itself and pay using a payment card also without having a contract.

More details on the identification technologies are contained in *G4V- D4.1: Report on ID and charging architecture and recommendations*.

An appropriate user interface, such as a local display, is required to communicate the outcome of authorization. In addition it can be used to easily provide information about the recharging in progress: times, costs and other optional data such as CO2 not emitted and energy saving in comparison to use a traditional car.

The authentication and authorization procedure can be managed completely by the charging station itself, or can be delegated to an external system which contains the database of users and contracts. The former solution is simpler because does not require any form communication. Nevertheless it can prove less effective with a considerable number of customers and charging stations, because any modification to the customer’s database (e.g. adding or removing a customer) should be replicated to all the charging station. Therefore it is advisable to have a remote authorization system (single or distributed) and providing the charging station with a communication channel.

The same communication channel toward a Control System could be used to transmit data need to bill the clients for the use of the infrastructure. Without such a mechanism, the same data should be collected directly from charging stations implying high labour costs and delayed billing.

In addition, the communication with a Control System can be used in order to control the charging station by sending commands to it. For example it could be possible:

- to open and enable the switch on the station
- to lock and unlock the sockets,
- to stop and restart the charge

Those functionalities are particularly useful to handle remotely contingency situations. For example a customer who has lost his smart card can call an help desk to have access the infrastructure.

Finally, having a communication channel, would allow the charging station to communicate to a control system also information about quality of service and in particular possible interruption of furniture (with date and hour of interruption), malfunction and attempt of tampering.

The communication channel can be provided with different technologies (wired or wireless) and different levels of performance. More details on the topic are contained in *G4V- D4.3: Report on ICT requirements and recommendations*.

Hereafter a list of macro-requirements is provided together with possible implementations:

- Customer identification (RFID, P&C or Similar)
- Customer Interface: a user-friendly customer interface is required in order to help the client during the identification and authorization process. This interface can be implemented via a simple alphanumeric display or via a more complex display (e.g. touch screen). The right solution shall be a trade-off between cost and performances.
- For public infrastructure is highly suggested the implementation of communication channel toward a control system in order to provide the following functionalities:
    - Authorization: when the user requests to access the infrastructure, the request can be forwarded to a remote central system where users/contracts database is stored.
    - Remote Operations & Maintenance: having a direct communication to back office systems, it is possible to remotely monitor the infrastructure in order to detect immediately fault conditions. Moreover, it is possible to remotely control the station configure it and update its software
    - Billing: after the charge process has completed, it is possible to send metering data to the control system in order to bill the client.

    Note: even without a communication channel, it is still possible to implement a public infrastructure that provides a controlled access. Nevertheless, this could require more complex processes for authorization and billing, because on-site intervention should be required in order to update the access lists

- "Intelligent" control unit: this component shall control all the operations related to user identification and access to the infrastructure. Therefore, all the other devices (such as communication equipment and user interfaces) shall be connected to this control unit. In order to provide a more integrated solution, also the safety processes (such as the pilot circuit) can be controlled by the same unit.

3.3.5 Controlled Infrastructure

Controlled infrastructure applies to **Pragmatic World** and **Advanced World** and allows an external actor to remotely control in real time the charging process. This requirement implies that the charging stations are provided with a communication device able to receive with low latency requests from a Control Centre (centralized or distributed) potentially during the entire charge process. This requirement to have this communication mechanism is applicable to both private and public location, independently by other functionalities that could be provided through it (such as the one described in previous section). Nevertheless, different levels of service are applicable to the two different scenarios:

- Pragmatic World: charging stations are controlled by the DSO which can send signals to reduce charging power when congestions are detected in distribution grid. The minimal requirement is to have a mono-directional broadcast real time communication, although more advanced mechanism (bidirectional) can improve DSO capability to analyse in real time the response of the control actions.
- Advanced World: charging stations cooperates with the actors responsible for providing the aggregation function. In this case, multiple subjects can play this role, hence bidirectional communication is envisaged, because the different players shall know the amount of customers able to participate in aggregation service.

In addition using the communication device for implementing the charging strategies, it can be used to provide all the functionalities provided in previous section:

- Authorization: when the user requests to access the infrastructure, the request can be forwarded to a remote central system where users/contracts database is stored.
- Remote Operations & Maintenance: having a direct communication to back office systems, it is possible to remotely monitor the infrastructure in order to detect immediately fault conditions. Moreover, it is possible to remotely configure the infrastructure and update its software
- Billing: after the charge process has completed, it is possible to send metering data to the central system in order to bill the client.

The communication channel can be provided with different technologies (wired or wireless) and different levels of performance. More details on the topic are contained in *G4V- D4.3: Report on ICT requirements and recommendations*.

In addition to the communication between the charging station and a Control Centre, another communication channel with EV is required to make plans of the best charge profile basing on actual available power and best energy price.
All devices shall be connected to an intelligent control unit that has the management of all functionalities for recharging process and communication.

3.3.5.1 Private

In the controlled private infrastructure, the additional resources (communication channel and control unit) are mandatory in order to provide the control of charge process. Therefore is natural to extend their use also to support additional functionalities, as described before.

3.3.5.2 Public

The controlled public infrastructure shall provide the combination of all the already described features, therefore it is the most complete one. In any case, the additional costs are not expected to be far higher compared to other solutions, because most of the equipment is shared by different functionalities. More details about costs are provided in section 4.

3.4 DC Recharging Infrastructure

The DC recharging is considered as mode 4 of IEC 61851, that is, an external charger with DC output and power higher than 44 kW. Such equipment contains: the electrical connection to the network, the charger (AC-DC power electronics converter), the electricity meter, the communication modules needed for communicating with the EV and/or the supplier/aggregator and DSO, the HMI for interacting with the users, and the cable with the connector to be plugged in the EV.

According the standard IEC-61851-1, some of the most important general requirements of connection between the electric vehicle and the recharging point are:

- Control pilot function (mandatory and optional functions) supports the following functions:
    - Verify the correct connection of the EV.
    - Activate and deactivate the power system of the electric vehicle.
    - Constantly checks the integrity of the conductor.
    - Transmit information to the charging control.
    - Select the charging speed and additional information for the control of recharging.
- Additional protection required against electric shock.
- Minimum degree of mechanical protection in the charging station.

The IEC 61851-23 standard, that is currently under development, will describe the requirements of fast charging stations in DC, including power supply necessities. The standard IEC 61851-24 under development describes the communication between the vehicle and the off-board DC charging station. Nowadays, the CHAdeMO initiative is the more spread out option for DC charging. CHAdeMO association proposes a standard where the essential functions for the DC charger are: verification of charger and vehicle connection, interruption of power supply to the system, prevention of accidental start moving the vehicle, detection and protection of the DC ground fault, DC short circuit protection and vehicle relay.

Figure 8 shows expected power for the DC-fast charging units versus charging time considering. The area shown in the figure is limited by two curves. The lower curve is for a city electric vehicle and the upper curve is for of a sedan electric vehicle. As it can be seen, nowadays with current DC charger of 50 kW it is possible to charge 80% of the capacity of a city EV in about 15 minutes. In future, with DC charger in the range of 125 to 300 kW, this time will be reduced till 5 minutes[1]**.**

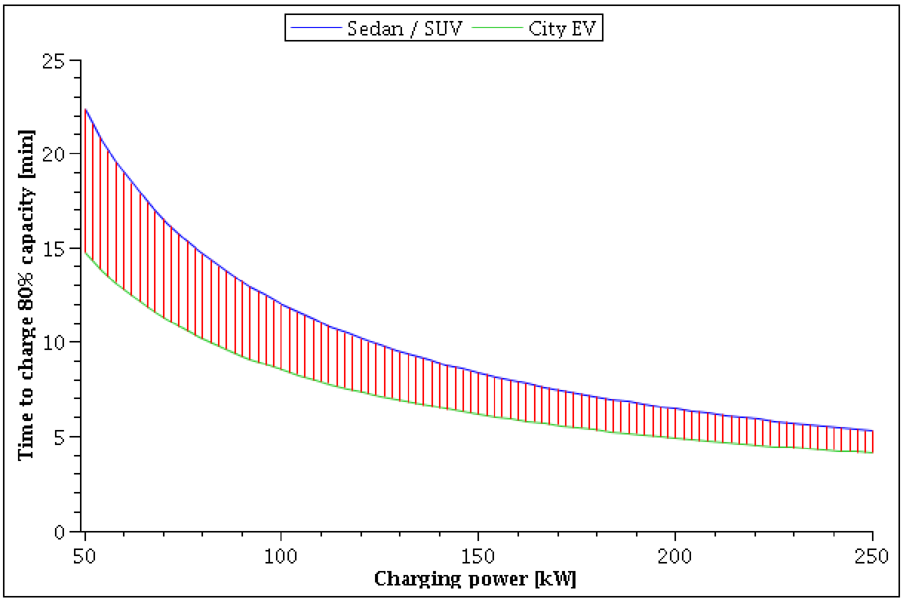

Figure 8. . Typical 80% charging time versus DC charger available power1.

The DC fast charging is performed by an external charger, which is connected to the network, and consists of a power electronics converter that converts AC to DC. From AC/DC converter two possible configurations of DC charging point can be considered as it is described next. Moreover, DC charging units can be placed together to form large charging station. In these places, such chargers can be combined with some small generation, like photovoltaics and wind turbines, and storage systems, like batteries and ultracapacitors in order to provide some support to the charging station and reducing its impact on the network.

Figure 9 depicts a configuration of DC charging station. One AC/DC converter feeds different DC/DC converters that provide power to charge electric vehicles. Here, between the network and AC/DC converter is installed an AC power meter to measure energy consumption during the charge. A DC power meter that measures the energy consumed during the charge of each EV connected to the specific charging point.

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[1] Aggeler, D.; Canales, F.; Zelaya-De La Parra, H.; Coccia, A.; Butcher, N.; Apeldoorn, O.; , "Ultra-fast DC-charge infrastructures for EV-mobility and future smart grids," Innovative Smart Grid Technologies Conference Europe (ISGT Europe), 2010 IEEE PES , vol., no., pp.1-8, 11-13 Oct. 2010

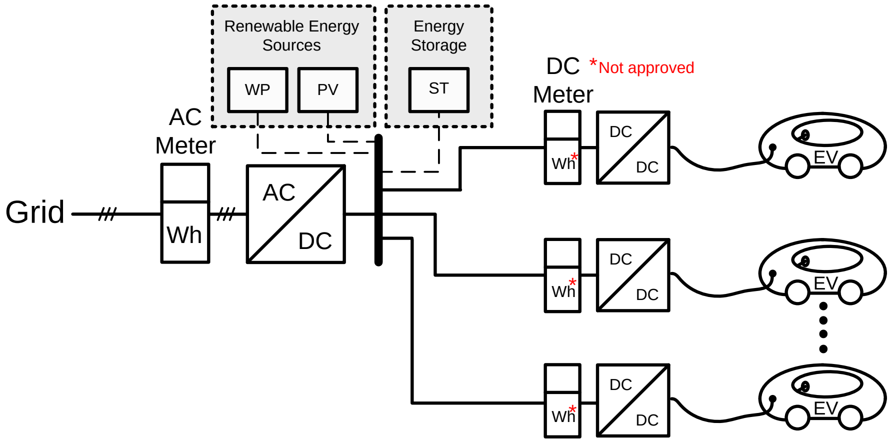

Figure 9. Multi-output of DC recharging station.

Figure 10 shows a second configuration. One AC/DC converter charges the battery of one EV. The energy consumed during the charging period is measured by an AC power meter installed in the AC side of each DC charging unit. Plus one upstream AC meter to record the power & energy supplied to the charging station

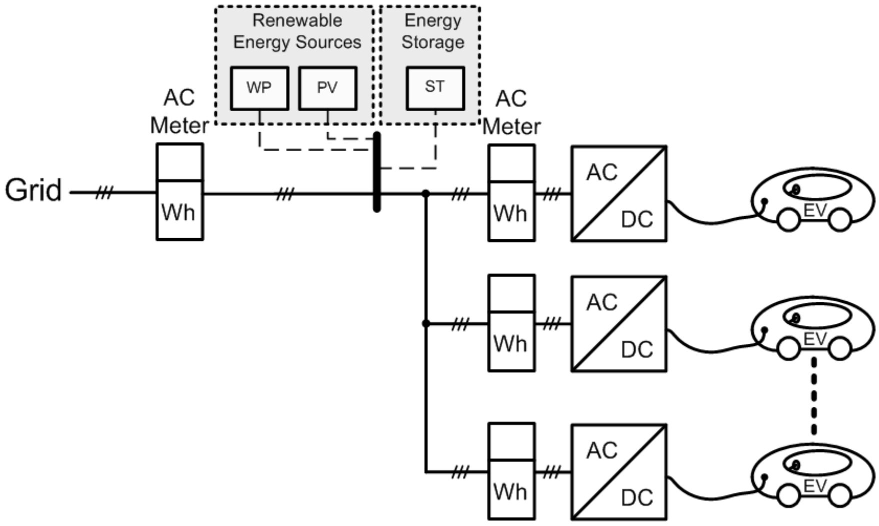

Figure 10. Single-output of DC fast recharging station.

3.4.1 Connection to the grid

The distribution grid consists of high voltage (HV), medium voltage (MV), and low voltage (LV) network installations, power lines and transformers, at which final customers are connected. In a typical structure of a distribution grid, HV is located up to the distribution HV/MV substations. MV/LV transformers supply the LV grids which are radial. EVs will be presumably connected to LV grid or to MV when several vehicles are charging at a dedicated fast charging stations.

The fast charge mode needs to coordinate and control the charging batteries to minimise the negative effects caused by EVs and enhance their integration into power systems. In addition to reduce the reinforcements needed in the network. The connection of a charging point to the network must take into consideration a range of concepts. Thus, recharging point for fast charge mode is affected by a number of rules and regulations.

The regulations that affect the installation of any charging point are the electrotechnical regulation of low voltage, European standards of reference in the electrotechnical regulation of low voltage and specific technical rules of electric energy supplier. This set of rules and regulations shall refer to performance criteria and location of facilities, protection and measurement equipment and construction details.

From the point of view of power transmission, the point of charge is required to take a series of measures. These measures are intended to maintain the level of disturbances emission, within the limits established in the operating procedures of the electrical system.

The recharging point of fast charge in DC connected to the network consists of power electronics equipment. This non-linear load connected to the network demands non-sinusoidal currents. These harmonic currents cause harmonic voltages at the point of connection. This is due to the short circuit impedance network.

In the analysis done in previous section, it was determined the amount of harmonics injected to the network during the fast charge, in direct current, of an electric vehicle. The results of this analysis are that the injected harmonic currents and voltages into the network didn't exceed the emission limits recommended by IEC 61000-3-12 and EN 50160.

In the future increasing share of nonlinear loads in the network, including charging of large amount of electric vehicles, can influence the level of harmonic distortion. In some cases the situation might require installation of active or passive filters to improve the power quality.

The point of charge, as any electrical installation connected to the grid should be properly protected. Protection against electric shock is provided by the implementation of appropriate measures for protection in normal service and in case of failure.

The protection against direct contact must consist of one or more modes of supply that under normal conditions prevents contact with hazardous live parts. Protection against indirect contact must consist of one or more modes of supply, such as additional insulation, protective shielding, automatic disconnection of supply, etc.

The point of charge features an electrical meter to quantify the amount of electrical energy consumed during charging of the electrical vehicle. Data measurement is collected by a meter for alternating or direct current depending of the configuration of the installation of the recharging point.

3.4.2 Protections

TC 69 Group of IEC is working to develop a specific standard for charging station in DC for the electric vehicles. The standard IEC-61851-1 establishes general requirements of conductive charging system of electric vehicle.

Mode 4 of DC charging establishes that the connection is indirect from the electric vehicle to AC network through an external charger where the conductor of control pilot is extended to the equipment permanently connected to the AC network. The circuit of control pilot which is located in the recharging point verifies the correct connection of the vehicle checks the integrity of the grounding conductor of the vehicle protection and activates the power system.

The need for controlling the start and the stop of the charge process is very important when DC fast charger is considered. An unexpected termination of charging or disconnection needs to be controlled to prevent arcing or electrical damage. Thus, the recharging point of the electric vehicles in DC fast charge mode should be adequately protected against electric shock, direct contact and fault isolation. The charger shall be equipped with measures to disconnect the charger from the network in a quick manner for internal electric short circuits and ground faults.

The system shall be designed so as to prevent users to approach the dangerous parts on the vehicle and charger. The system shall be designed so that a level of voltage that is dangerous to the human body shall not be appeared on the connector surfaces during normal connector removal action as well as when the connector fall situation due to an accident.

The charger shall be equipped by a detecting resistor of ground fault current located between the ground and main circuit in order to detect ground-fault on the DC charging circuit, external wiring, and vehicle. The grounding wire shall be connected to external ground.

The charger connector shall be electrically and mechanically locked so that it does not become disengaged during charging process. The lock mechanism shall possess sufficient mechanical strength and shall not be able to be broken by human power. The soundness of connector lock circuit shall be verified before charging.

3.4.3 Metering features

The stations of recharging points for DC fast charge are expected to be located mainly in large public or private areas. These stations are used to charge the electric vehicles in short periods of time. This energy transaction involves the need of metering devices according to the new necessities. The evolution of the metering devices has involved the implementation of electronics to bring new capabilities and functionalities which allow advanced functions and the direct connection to information systems of control centres.

This new features of metering devices have led to AMM devices. The AMM concept is referred to a microprocessor-based automatic electricity meter reading system which provides cost-effective and reliable data transfer between metering devices and the electric utility control centre. The AMM meter allow functions like

The AMM meter has the potential to allow functions such as periodical measurements; communications, customer and vendor control services, consumption measurements and information about quality of electricity or meter self-diagnostic.

Thus, the point of charge features an electric meter to quantify the amount of electrical energy consumed during charging of the electrical vehicle. There are different settings to collect data measurement of energy consumed during the charge in fast charge mode in DC. It is possible to have electric meters for DC and/or AC depending of the configuration of the charging station.

3.4.4 Scenarios

In DC fast charge mode, the conservative scenario is not considered, as in this scenario charging control is not present.

The performance of DC chargers, considered for fast charging process, should be controlled for coordinating the needs of the battery with the instantaneous power that the off-board DC charger must provide. Apart from this coordination between the external charger and the battery, the distribution system operator should supervise such process, above all, due to the large instantaneous power transfer that it requires. However, fast charging can be performed in all the scenarios considered in this project: conservative, pragmatic and advanced. The main characteristics of these scenarios are described in section 2.

In a private area, charging stations for the batteries of electric vehicles in a fast charging mode DC presumably are located in an industrial environment. Two possible options are considered in this industrial environment. One option is the recharging stations for electric vehicle fleets. The other option is the recharging stations available in the company, for the charge of electric vehicles of employees of that company. Due to the high power required the recharging points for the electric vehicle batteries in fast charge mode DC are not expected in a domestic environment.

It is expected that in a public area, the DC charging points for fast charging mode DC will be placed at recharging stations specially designed for this purpose.

3.5 Integration in different location of recharging devices

This section summarises the necessary requirements for the recharging devices to be installed. The recharging devices will be classified in two main groups: urban areas and private/indoor environment. Each sub-section will collect the possible requirements to integrate them in the grid.

The recharging stations are subject to state and local building and electrical codes (depending on the place they are installed). These codes ensure the safety, accessibility, and equipment maintenance concerns of electric vehicle equipment users, property managers, utilities, and maintenance workers.

These rules and regulations are divided into two categories which are electrical code requirements and building code requirements.

The aim of the electrical codes is to establish the technical conditions and guarantees to be met by electrical equipment, ie EV, connected to a power supply within the limits of low voltage, with the aim of:

- Preserve the safety of persons and property.
- Ensure the normal operation of such facilities, and prevent disruptions in other facilities.
- Contribute to the technical reliability and economic efficiency of the facilities.

The physical construction and placement of the EV recharging station are governed by building code requirements, and if so, by ordinances of each city. This code covers aspects as accessibility of the equipment, stall dimensions, building materials, and placement on the property.

European countries fulfil with the requirements of electrical infrastructure with their respective regulations. For example, in Spain the Low Voltage Electrotechnical Regulation (REBT) and the Technical Building Code (CTE) are mandatory.

Recharging devices installed in both urban/public and private/indoor areas must comply with standard IEC 61851-22. According to this standard, the charging station may have one or more socket-outlets/vehicle connectors and shall be connected to the electric vehicle so that in normal conditions of use the equipment operates to reduce the risk of fire, electric shock or injury to persons, either indoors or outdoors. Electric vehicle charging stations shall be so designed and constructed that in normal use their performance is reliable and minimises the risk of danger to the user or surroundings.

3.5.1 Urban/public areas

The electric vehicle charging station installed in urban/public areas must be designed to be used in non-weather protected locations, hence the minimum IP degrees for ingress of object and liquids shall be IP44 and for the protection against electric shock the IP degree of plug mated with socket outlet shall be IPXXD. Compliance is checked by test in accordance with IEC 60529.

Equipment intended for outdoor use shall be designed to operate in an environment with a minimum pollution degree 3 and overvoltage category III. The lowest part of the socket-outlet shall be located at a height between 0,4 m and 1,5 m above ground level.

The DC charging station body shall not be damaged by mechanical impact. A force of 500 N shall be applied for 5 min in the horizontal direction to the top of the DC charging station in each of the four directions or in the worst possible horizontal direction. There shall be neither deterioration of the charging station nor deformation at its summit greater than 50 mm during the load application and 10 mm after the load application.

The ambient temperature range during charging may be between –25 °C and +40 °C at a relative humidity of between 5% and 95%. The electric vehicle charging station shall be designed to operate at an atmospheric pressure between 860hPa and 1060 hPa.

The maximum permissible surface temperature of parts of the charging station which are hand grasped, at the maximum rated current and at an ambient temperature of 40 °C, shall be 50 °C for metal parts, 60 °C for non-metallic parts. For parts which may be touched but not grasped, maximum permissible surface temperature under the same conditions shall be: 60 °C for metal parts, 85 °C for non-metallic parts. (National codes may allow other temperatures)

To enclosures and external parts of recharging devices installed outdoors and which are constructed of synthetic materials or metals that are entirely coated by synthetic material should be test resistance to ultra-violet radiation and heat test under solar radiation.

For special environmental conditions the equipments should test, such as cold test for extreme cold climates, damp and salt mist test for marine and coastal environments and hot damp test for tropical climates.

In public areas recharging infrastructure can be Public Station Stand alone or Public Station Master/Slave.

- **Public Station Stand Alone** is a recharging station autonomous and independent with integrated meter, for use in street, parking areas, public garages and place with access allowed to more persons, therefore charge is permitted only after customer identification. Each station has own dedicated connection to power line and a local display. The recharging station can be dimensioned for single-phase supply and for three-phase supply.
- **Public Station Master/Slave** is a system of n poles connected to each other, of which one is Master and the other n-1 are Slave. Master station has the administration of the system. It has a system for user identification and with a local display for service massages and to choice pole. Slave stations are used only as power supply to socket and communicate with Master station transition information. Each Slave station must be univocally identified and has own dedicated connection to power line independent of the Master Station. The recharging station can be dimensioned for single-phase supply and for three-phase supply.

3.5.2 Private/indoor environment

For equipment designed to be exclusively used in weather protected locations the minimum IP degrees for ingress of object and liquids for plug mated with socket outlet shall be IP21 and for the protection against electric shock the IP degree shall be IPXXD.

Equipment intended for indoor use only shall be designed to operate in an environment with a minimum pollution degree 2 and overvoltage category II.

The ambient temperature range during charging may be between –5 °C and +40 °C and at a relative humidity of between 5% and 95%. The electric vehicle charging station shall be designed to operate at an atmospheric pressure between 860hPa and 1060 hPa.

The station shall bear the marking “indoor use only” or the equivalent, if intended for indoor use only. The charging station body shall not be damaged by mechanical impact and shall be designed to resist the effect of normal automotive solvents and fluids, vibration and shock, material flammability standards and other conditions appropriate to the application.

In private/indoor environment, a wide range of different models of recharging infrastructure can be used:.

- **Sockets module** is a small-size module to fix on wall and connected with a the house primary meter or to an additional meter dedicated to the charge of electric vehicle

- **Smart private station** is a charger station with integrated meter and additional electronic devices in order to provide additional services.

4 Costs

This section has the purpose to evaluate the costs of both AC and DC stations. Costs voices are forecast for the possible values in 2020 and beyond. For this reason, for every position a range of possible values have been provided. The ranges incorporate the uncertainty due to alternative technical solutions and different specific cases.

An assessment of AC station is analysed from costs of production, grid connection, installation and maintenance for different scenarios in different environments. In case of recharging stations in DC an estimated assessment of the costs of various types of configurations has been made. Finally, a comparison was made between both fast charging and slow charging modes.

Apart of the costs of the recharging stations, their deployment may require actions such as listed below in order to meet requirements of power and power quality at PCC, which cost of last items is assessed in other tasks of the project:

- Expansion of distribution system: dedicated line from existing MV/LV transformer, dedicated MV/LV transformer, dedicated MV line + MV/LV transformer.
- Update of distribution system (derating of elements): line, transformer, MV network.
- Storage systems: batteries, ultracapacitors, others
- Update protection system
- Improving power quality: passive/active filters
- Active voltage control: OLTC at MV/LV transformer, FACTS/FACDS
- Smart control: ICT in all devices connected to the distribution network, SCADA system at LV

4.1 AC Stations

In the following Table 8 the estimate of the asset cost for AC station is provided.

Table 8. Asset cost for AC station.

Environment	Production Cost (Conservative World)	Production Cost (Pragmatic & Advanced World)	Grid Connection Cost (installation costs and startup costs)	Maintenance
Private (for private garage)	**200-300 €**	**250-350 €**	**350-500 €**	**0 – 20 €/y**
Semi-public (indoor)	**250-350 €**	**300 – 400 €**	**500-1200 €**	**20 – 40 €/y**
Public environment (outdoor)	**1300-1600 €**	**1300-1600 €**	**2400 -3600 €**	**40 – 60 €/y**

The Production Cost includes all components costs such as contactor, protection, sockets, etc. For Public station the range of variability depends on power rate and, as it is possible to see, there isn’t difference between controlled and not controlled infrastructure. This one because with the same hardware of not controlled infrastructure is possible to implement different functionalities via software. The cost also depends on the type of charger (power). Due to vandalism, the maintenance cost could be higher for public charging poles.

The Grid Connection Cost is intended to group all the costs needed in order to ensure the proper installation and connection to the grid. It includes the cost for civil works, such as excavation and road surfacing, allowances required for the connection to the supply network and the set-up by expert staff. It is influenced by the voltage and proximity of the grid and according to the national regulation and the considered business model, part of these activities are performed by the DSO.

The large interval for semi-public is due to very different nature of possible construction works needed. For example running cable under a parking space pavement is much expensive that installing them along the wall of an indoor garage.

4.2 DC Stations

In the following Table 9 the estimate of the asset cost for DC station is provided.

Table 9. Asset cost for DC station.

Environment	**DC Charger (Conservative World)**	**DC Charger (Pragmatic & Advanced World)**	**Space EV plus charging point**	**Installation Cost (labour) + Grid connection**
Private (for fleets)	**10000-12000 €**	**10000-12000**	**1000-3000 €/m^2**	**2750 – 3250 €**
Public/Urban	**10000-12000**	**10000-12000**	**1000 -2000 €/m^2**	**2750 – 3250 €**

4.3 Comparison

An assessment of the costs for the different types of configurations of EV recharging stations in public area has been made. Four configurations are compared, two for DC charging and two for AC charging mode.

4.3.1 Fast charge stations in DC

4.3.1.1 Multi-Output of DC recharging station

In this type of station, there is only one charger for multiple outputs. In this case, it is considered two DC chargers and two 25 kW outputs per charger. This means that the station has 4 recharging points. Charging time for each vehicle is 15 minutes and, considering an utilization factor of 25%, an estimated number of electric vehicles that could charge their batteries for 24 hours is 96.

96 EVs are charged per day with an expected extra range achieved of 42 km more.

- Installation cost
    - Cost of DC charger: 20.000 €
        - Number of DC chargers: 2
        - €/Charger: 10.000 €
    - Cost of space required: 50.000 €
        - Number of recharging point: 4
        - Space required of recharging point plus EV: 12,5 m^2
        - €/m^2: 1.000 €
    - Cost of labour and grid connection: 12.000 €
        - Number or recharging points: 4
        - €/point: 3000 €
    - **Total cost of Installation: 82.000 €**
    - **Total energy charged for 24 hours: 600kWh**

4.3.1.2 Single-Output of DC recharging station

In this type of station, there is one charger for only one output. That is the current case with the CHAdeMO chargers already present on the market. In this case, it is considered two DC chargers and one 50 kW output per charger. This means that the station has 2 recharging points. Charging time for each vehicle is 15 minutes, assuming an utilization factor of 25%, an estimated number of electric vehicles that could charge their batteries for 24 hours is 48.

48 EVs are charged per day with an expected extra range achieved of 83 km more.

- Installation cost
    - Cost of DC charger: 20.000 €
        - Number of DC chargers: 2
        - €/Charger: 10.000 €
    - Cost of space required: 30.000 €
        - Number of recharging point: 2
        - Space required of recharging point plus EV: 15 m^2
        - €/m^2: 1.000 €
    - Cost of labour and grid connection: 6.000 €
        - Number or recharging points: 2
        - €/point: 3.000 €
    - **Total cost of Installation: 56.000 €**
    - **Total energy charged in 24 hours: 600kWh**

4.3.2 Slow charge station in AC

4.3.2.1 Recharging station with cost of space

In this type of station, there are 12 recharging points. In this case, it is considered that each point of charge supplies a power of 4 kW. Charging time for each vehicle is 8 hours and assuming a utilization factor of 50% the number of electric vehicles that could charge their batteries for 24 hours is 18.

18 EVs are charged per day with an the expected range achieved of 197 km

- Installation cost
    - Cost of recharging points: 18.000 €
        - Number of recharging points: 12
        - €/point: 1.500 €
    - Cost of space required: 120.000 €
        - Number of recharging point: 12
        - Space required of recharging point plus EV: 10 m^2
        - €/m^2: 1.000 €
    - Cost of labour and grid connection: 28800 €
        - Number or recharging points: 12
        - €/point: 2400 €
    - **Total cost of Installation: 166.800 €**
    - **Total energy consumption for 24 hours: 600kWh**

4.3.2.2 Recharging station without cost of space

Not in all scenarios cost of space is required: in the DSO business model, the space is provided free of charge by either the client of the municipality. Also in other cases, it shall not be taken into account: for example, a private garage that wants to offer charge service already covers the space costs with its traditional business (i.e. via parking fees)

In this type of station, there are 12 recharging points. In this case, it is considered that each point of charge supplies a power of 4 kW. Charging time for each vehicle is 8 hours and assuming a utilization factor of 50% the number of electric vehicles that could charge their batteries for 24 hours is 18.

18 EVs are charged per day with an the expected range achieved of 197 km

- Installation cost
    - Cost of recharging points: 18.000 €
        - Number of recharging points: 12
        - €/point: 1.500 €
    - Cost of labour and grid connection 28000 €
        - Number or recharging points: 12
        - €/point: 2400 €
    - **Total cost of Installation: 46.800 €**
    - **Total energy consumption for 24 hours: 600kWh**

4.3.3 Comparison of results

It has been assumed an energy consumption of 600 kWh for a period of 24 hours to calculate the various costs (installation, energy, energy per EV). This energy is the energy consumed during the recharging of the electric vehicles. The total number of EV that charge their batteries for 24 hours in each type of station, varies depending on the time required to charge the batteries as the energy supplied from each point of charge and on the utilization factor considered. Table 10 shows the difference in cost for each configuration of recharging station of EV.

Table 10. Comparison of costs in 2020 for each configuration

Configuration	**Fast charge in DC[2]**		**Slow charge in AC**	
	Multi-Output	**Single-Output**	**With Cost of Space**	**No Cost of Space**
Cost of installation (€)	82.000 €	56.000 €	166.800 €	46.800 €
Energy charged per facility per day (kWh)	600 kWh	600 kWh	600 kWh	600 kWh
Charging duration	15 minutes	15 minutes	8 hours	8 hours
Power rate	25 kW	50 kW	4 kW	4 kW
Range Achieved per EV[3]	42 km	83 km	197 km	197 km
Chargers per Facility	4 x 25kW	2 x 50kW	18 x 4W	18 x 4kW
Utilization Factor	25%	25%	50%	50%
Number of EVs charged per facility per day	96	48	18	18

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5 Conclusions

The basic requirements applicable to charging stations are related to functionalities connected to safety, since they ensure that the charging stations can be operated within proper safety conditions and reduce as much as

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[2] Including the cost of the space needed for the installation and to park the EVs (without space cost, total facility costs would be: multi-output 32.000€, Single output 26.000€)

[3] Average EV consumes 15 kWh per 100km.

possible dangers to people. Noticeably, such safety requirements have already been carefully addressed by standardization bodies and regulated in documents such as the IEC 61851 family.

On top of safety issues, additional requirements have been considered in order to provide additional functionalities, which are as well needed to foster the adoption of electric mobility. In particular, the most important functionalities for implementing the control strategies are:

- Control access to infrastructure in public and semi-public environment
- Control charge process in order to integrate EVs into the Smart Grid operational processes
- Remote maintenance functionalities
- Development of added value services based on ICT platforms.

It is important that also these requirements are addressed by standardization activities in order to facilitate their development and guaranteeing open access to the market, while allowing all the players to differentiate their offer in order to create a competitive and innovative market.

There are several different charging connectors available, each with comparable functionalities. This could be problematic as the EV owners expect to be able to charge their EV at any charging station. Hence it is desirable for the development of a unique market to have an only and standard connector. It is important that there is a merging of standards and charging technology so that charging infrastructure is common, customers are comfortable with the technology and manufacturing costs are reduced.

6 References

[1] Balcells, J.; García, J. Impact of plug-in electric vehicles on the supply grid. A: IEEE Vehicle Power and Propulsion Conference. "IEEE Vehicle Power and Propulsion Conference 2010". Lille: 2010, p. 1-4.

[2] ENDESA CRAVE project

[3] IEC 61851. Electric vehicle conductive charging system

7 Glossary

- **BEV:** Battery Electric Vehicle
- **PHEV:** Plug-in Hybrid Electric Vehicle
- **EVSE:** Electric Vehicle Supply Equipment
- **SAE:** Society of Automotive Engineers
- **TEPCO:** Tokyo Electric Power Company
- **JARI:** Japan Automobile Research Institute
- **RFID**: Radio-Frequency Identification
- **PLC**: Power Line Communications
- **Rsce:** Short Circuit Ratio
- **THD:** Total Harmonic Distortion
- **PWHD:** Partial Weighted Harmonic Distortion
- **PCC:** Point of Common Coupling
- **AMM:** Automatic Meter Management
- **DSO:** Distribution System Operator
- **ICT:** Information and communications technology
- **HMI:** Human Machine Interface
- **FACTS:** Flexible AC Transmission Systems
- **FACDS:** Flexible AC Distribution Systems
- **OLTC:** On-Load Tap-Changers
- **SCADA**: Supervisory Control And Data Acquisition
- **ID**: Identification

ANNEX A: Example of charging stations

ENEL E-MOBILITY PUBLIC STATION

General features:

Station for conductive charging of electric vehicle, with direct AC connection to the grid and with on-board charger that converts it to DC current to the batteries. It is for installation in street, parking areas, public garages and place with access allowed to more persons. Charge and payment take place automatically: the user must only connect the vehicle to the station with an appropriate connector.

Charge is permitted only after user identification made by Smart Card RFID, that requires only close proximity to an appropriate reader, or rather by PLC for last generation electric vehicle. These vehicles have a communication system to dialog with recharging station and, as well as they allow customer identification without use of Smart Card RFID, they can plan the best charge profile basing on actual available power and the best energy price.

When recharging process is completed, a central Control System acquires consumption data for billing.

Electrical characteristics:

Supply: Three-phase line 400Vac, 50Hz;

Socket-outlet SCAME	Socket-outlet MENNEKES
Single-phase: L, N, Earth + Pilot. Power Max: 3,3kW Current max: 16A	Three-phase: R, S, T, N, Earth + Pilot + Proximity Power Max: 25 kW Current max: 32A

Both sockets are equipped with:
- A device to avoid an undesirable load interruption and to prevent unintentional disconnection of the connector.
- A device to lock the socket during stand-by of station. The un-lock is allowed only after user identification by RFID Card.

It’s not possible simultaneous supply from both sockets.

Environmental conditions:

Ambient air temperature: -30°÷ +50°C;
Ambient humidity 5%÷95%;
Ambient air pressure: 860hPa÷1060hPa.

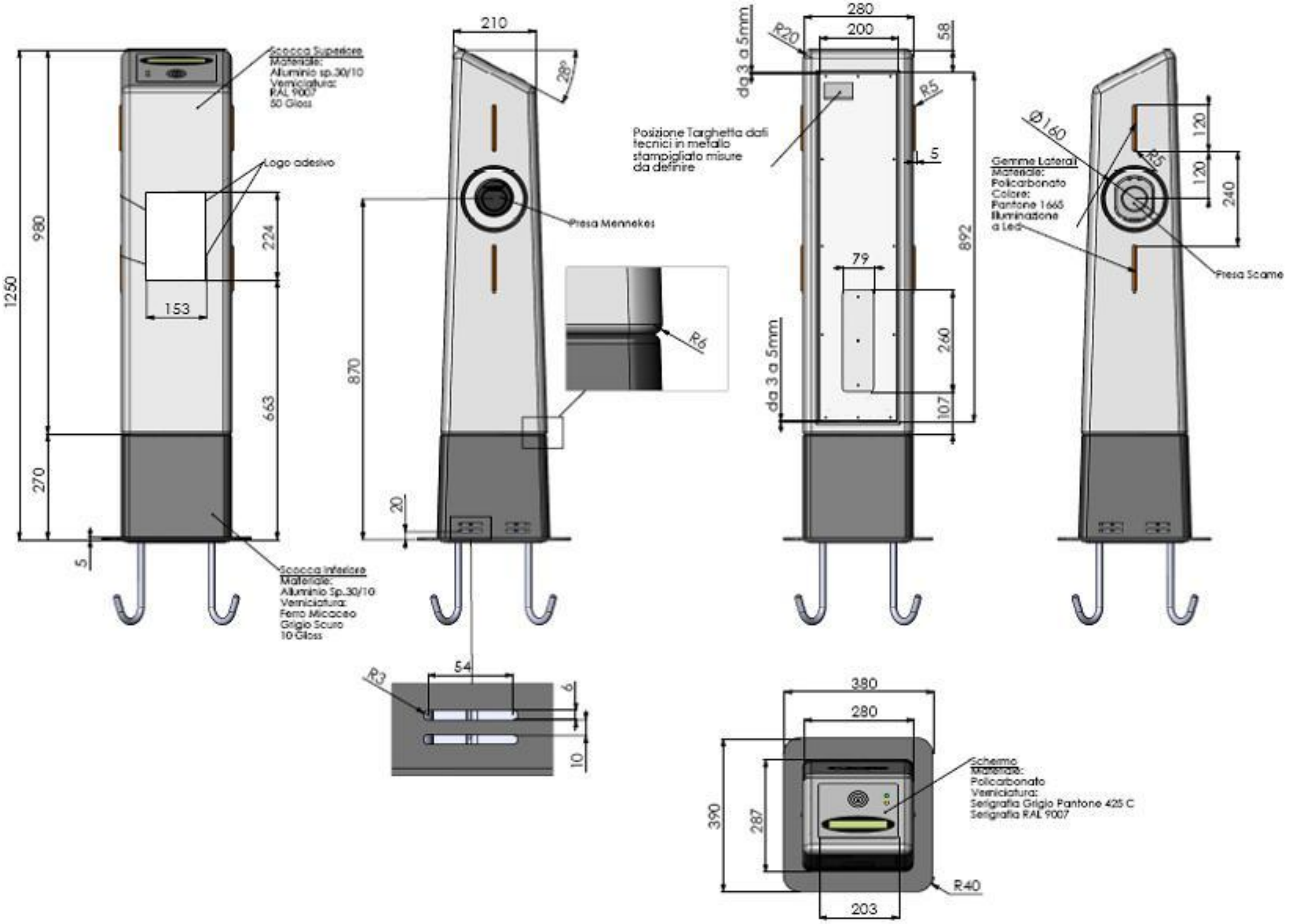
IP degree: IP44
Anti-tamper device
Flammability level: UL V-0;

Normative references:

IEC/CEI EN 61851-1: ricarica conduttiva dei veicoli elettrici – Aspetti generali;
IEC/CEI EN 61851-22: ricarica conduttiva – Stazioni di ricarica in c.a. per veicoli Elettrici

CEI R069-001 (CEI 69-10): Dispositivi di connessione in c.a. per la ricarica conduttiva dei veicoli elettrici
CEI 69-6: Foglio di unificazione di prese a spina per la connessione alla rete elettrica di veicoli elettrici stradali
CEI EN 60950-1: Apparecchiature per la tecnologia dell’informazione – Sicurezza – Parte 1 – Requisiti generali
CEI EN 610000-6-1: Compatibilità elettromagnetica (EMC) – Parte 6-1: Norme generiche – Immunità per gli ambienti residenziali, commerciali e dell’industria leggera
CEI EN 610000-6-3: Compatibilità elettromagnetica (EMC) – Parte 6-1: Norme generiche – Emissioni per gli ambienti residenziali, commerciali e dell’industria leggera

Dimensions:



1:16 Scale

ENEL E-MOBILITY HOME STATION

General features:

Station for conductive charging of electric vehicle, with direct AC connection to the grid and with on-board charger that converts it to DC current to the batteries. It is for installation in private garage. Charge and payment take place automatically: the user must only connect the vehicle to the station with an appropriate connector.

Station can be configured to allow user identification before recharging process. Identification can be made by Smart Card RFID, which requires only close proximity to an appropriate reader, or rather by PLC for last generation electric vehicle. These vehicles have a communication system to dialog with recharging station and, as well as, they allow customer identification without use of Smart Card RFID, they can plan the best charge profile basing on actual available power and the best energy price.

When recharging process is completed, a central Control System acquires consumption data for billing.

Electrical characteristics:

Supply: Single-phase 230Vac, 50Hz;

Socket-outlet SCAME	Socket-outlet MENNEKES
Single-phase: L, N, Earth + Pilot. Power Max: 3,3kW Current max: 16A	Three-phase: R, S, T, N, Earth + Pilot + Proximity Single-phase supply only on one phase and N Power Max: 25 kW Current max: 32A Lock system on the connector to avoid disconnection under load

It's not possible simultaneous supply from both sockets.

Environmental conditions:

Ambient air temperature: -30°÷ +50°C;
Ambient humidity 5%÷95%;
Ambient air pressure: 860hPa÷1060hPa.

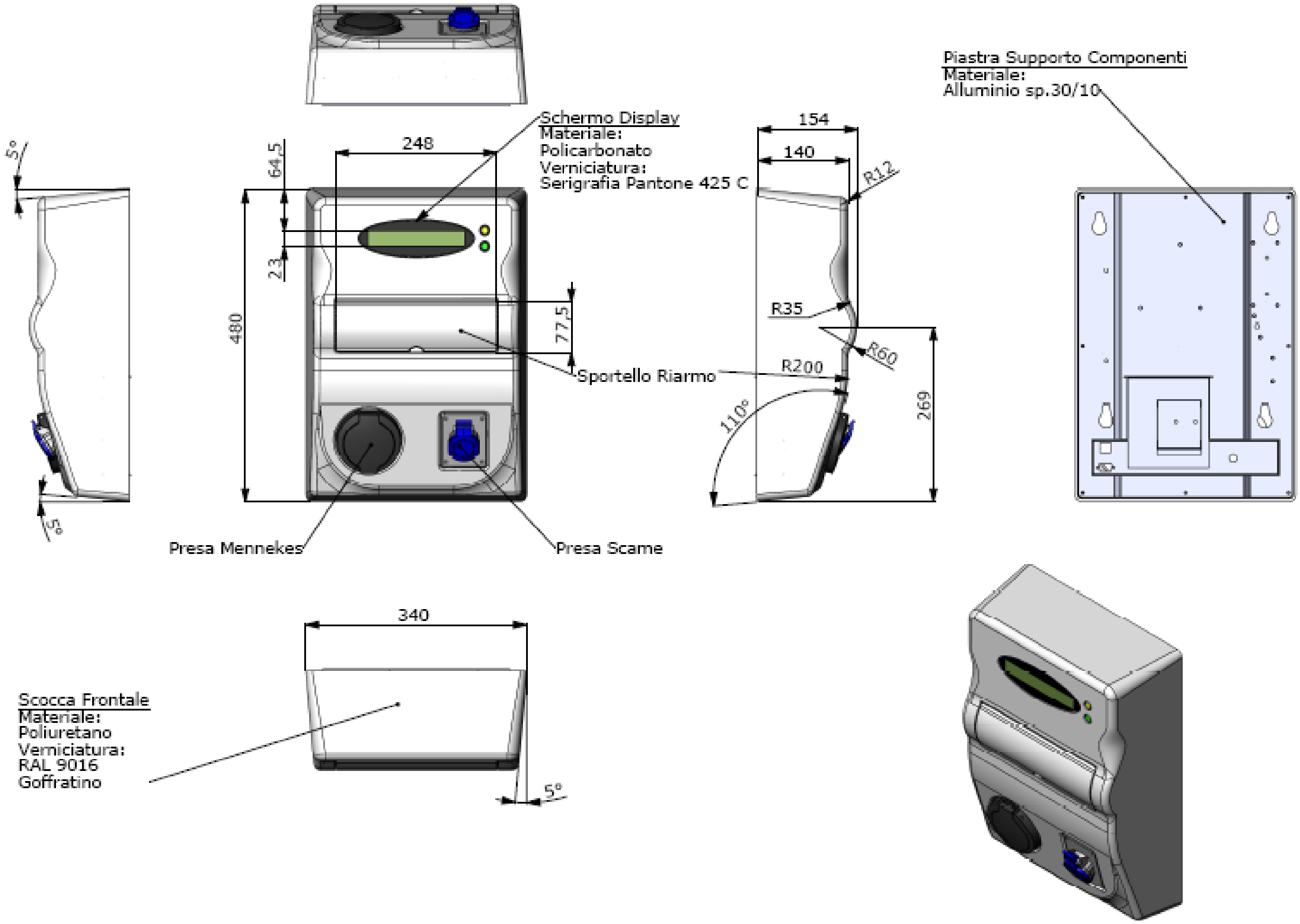
IP degree: IP44
Anti-tamper device
Flammability level: UL V-0;

Normative references:

IEC 61851 / CEI EN 61851-1: ricarica conduttiva dei veicoli elettrici – Aspetti generali;
IEC 61581/ CEI EN 61851-22: ricarica conduttiva – Stazioni di ricarica in c.a. per veicoli Elettrici
CEI R069-001 (CEI 69-10): Dispositivi di connessione in c.a. per la ricarica conduttiva dei veicoli elettrici
CEI 69-6: Foglio di unificazione di prese a spina per la connessione alla rete elettrica di veicoli elettrici stradali

CEI EN 60950-1: Apparecchiature per la tecnologia dell'informazione – Sicurezza – Parte 1 – Requisiti generali
CEI EN 610000-6-1: Compatibilità elettromagnetica (EMC) – Parte 6-1: Norme generiche – Immunità per gli ambienti residenziali, commerciali e dell'industria leggera
CEI EN 610000-6-3: Compatibilità elettromagnetica (EMC) – Parte 6-1: Norme generiche – Emissioni per gli ambienti residenziali, commerciali e dell'industria leggera

Dimensions:



1:16 Scale

ENDESA Fast Charger

General features:

Station for conductive charging of electric vehicle, with direct AC connection to the grid and with off-board charger that converts it to DC current. It is for installation in an urban public area.

This SGTE DC Rapid Charger of 500 VDC/125A is compatible with all electric vehicles using the CHAdeMO standard.

It meets the norms in force regarding to the pollution, the electromagnetic compatibility and has a filter that suppressed the harmonic waves sent in the power grid.

A first Fast Charge station, for public use, has been already installed in the City of Barcelona in April’11 by ENDESA.

Electrical characteristics:

Supply:

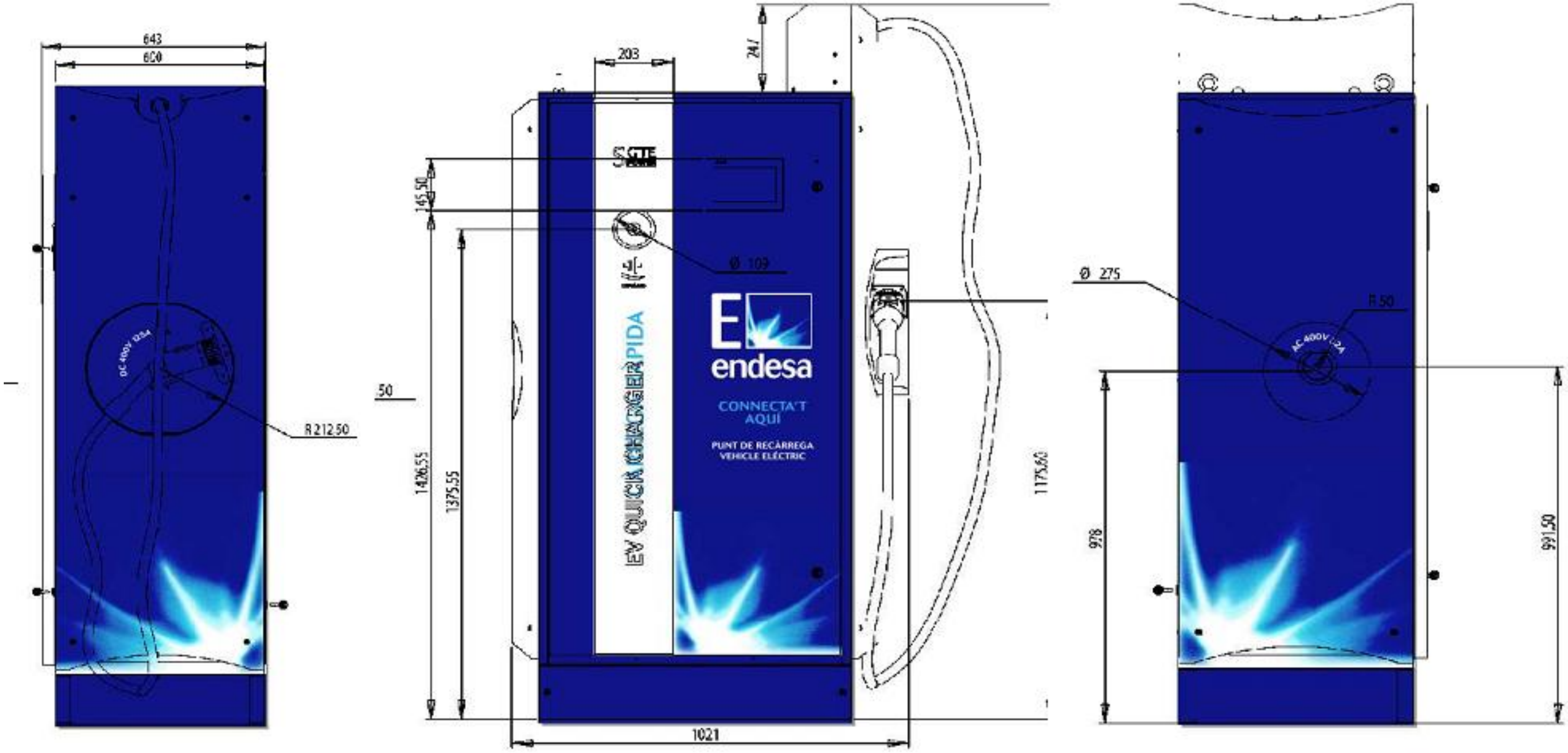
- Voltage: 400VAC 3-phase
- Frequency: 50Hz

DIMENSIONS AND WEIGHT

LxPxH (cm): 80 x 60 x 180
Poids (kg): 450
IP degree: IP 55

Figure 11. ENDESA fast charger.

Dimensions:


643
600
DC 400V 125A
R 212.50
203
247
145.50
Ø 109
50
1426.55
1375.55
EV QUICK CHARGER
RÀPIDA
endesa
CONNECTA'T AQUÍ
PUNT DE RECÀRREGA VEHICLE ELÈCTRIC
1175.60
1021
Ø 275
R 50
AC 400V 32A
978
991.50

FRENCH EXAMPLES

AC charging station

Main characteristics:

Mode 3: Specific socket on a dedicated circuit
Type 3 – single and three phase vehicle coupler and mains plug and socket-outlet with shutters - reflecting the EV Plug Alliance proposal

Figure 12. Public charging station

Fast charging station

Power :

- AC 43 kW (400V / 63A)
- DC 50 kW (500V / 125A) – CHAdeMO standard

Figure 13. Public fast charging station.

Reference : http://www.smartgrids-cre.fr/index.php?rubrique=dossiers&srub=vehicules&page=10 (2011/05/16)

Annex B: Evaluation of number of charging stations

The purpose of this annex is to provide an approach for evaluating the consistence of the charging infrastructure needed to ensure a satisfactory level of service to e-mobility clients. The output of the process are “multipliers” that provide the number of charging stations as a function of the number of EVs.

It should be noted that the proposed model aims to provide a simplified method useful to estimate the order of magnitude of the different types of charging station at regional or national level. For the actual localization of charging stations, different methods will be needed in order to identify the optimal locations and types of charging station, taking into account variables like the local mobility patterns.

There are different ways to evaluate the number of charging stations. In this annex the evaluation start taking into account the behaviours of the different types of client and the average number of charge operations performed during a week.

Evaluation of charging behaviours

EV’ owners are divided into two types, depending on the availability of a private place where they can park and charge their EVs.

The following assumption has been made:

- Two thirds of EVs owner have a private parking location such as a private garage or dedicated parking place in a condominium or at office.
- One third of customers does not have a private parking and must charge on the public infrastructure.

This proportion is, of course, different in different European Regions and especially in different locations (urban, sub-urban and rural). The survey provided by WP3 “*D3.3 How will EV users react to off-peak charging schemes and V2G services? - A survey of behavioral preferences in eight EU countries*” provides figures for different countries, which support this assumption.

Despite customers with private parking charge mainly at their dedicated place, they occasionally charge also at public places. It is assumed that these customers make six charges a week (86% of times) at their parking and they perform a charge a week (14%) at the public point.

Moreover it has been assumed that at home almost all the charge will be performed with Slow AC stations, while the public infrastructure is composed by a combination of Quick AC stations and Fast DC stations.

The public infrastructure can be used with different types of charge depending on:

- the type of charging station used (Quick AC or Fast DC)
- the capability of the EV: for example an EV able to charge only at 3kWor below cannot exploit all the potentiality of a Quick AC station.
- the preferences of the client: for example a client could decide to charge at reduced power in order to have discounted tariffs.

For the simulations in G4V, (especially the load flow simulations presented in D5.1 and D5.2) the following three types of charge have been considered.

Table 11. Characteristics of charge types

Type of charging	Current (A)	Voltage (V)	Phase (N°)	Power (kW)	Power factor	Power	Max km charged in 1h	Max km charged in10m
Slow AC	16	230	1	3,7	0,95	3	23	4
Quick AC	16	230	3	11,0	0,95	10	70	12
Fast DC	80	230	3	55,0			367	61

Note: It is assumed that the average EV consumes 15 kWh per 100km.

It is assumed that, in the public infrastructure, clients make slow, fast and quick charge as the following percentages.

Table 12. Percentage of charge in public infrastructure

Slow charge	30%
Quick charge	45%
Fast charge	25%

The following picture illustrates previous assumptions:

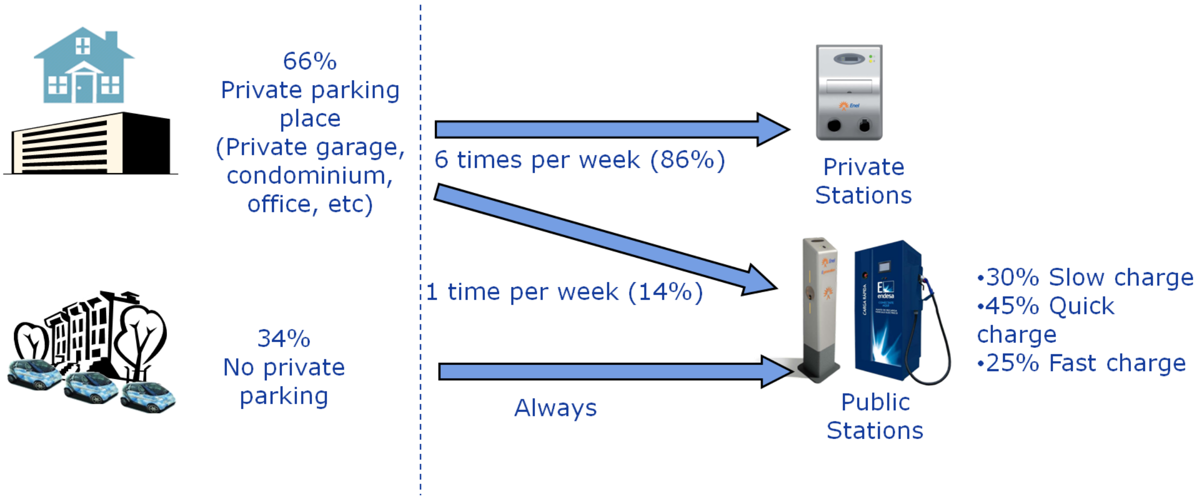


Figure 14. Percentage of charge in public and private infrastructure.

The overall behaviour of the customers is depicted in following diagram:

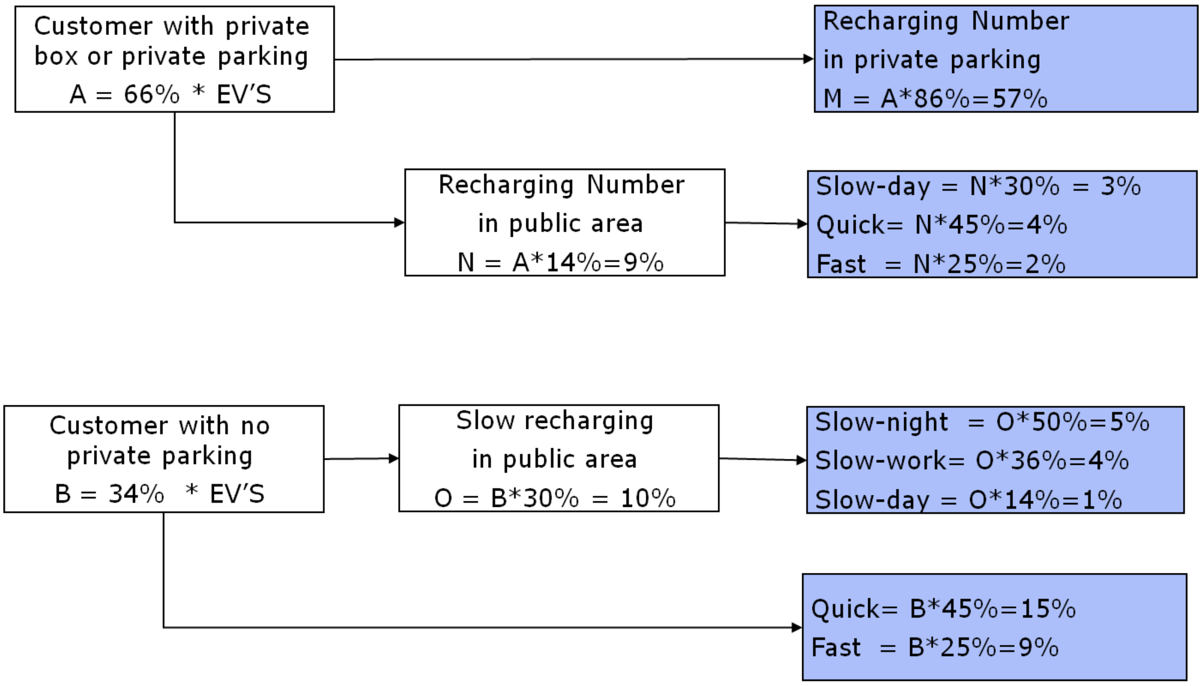


Figure 15. Number of charges per type.

Evaluation of the number of charging points in public location

For the calculation of number of recharging points needed in public location is assumed that, for each type of recharging, a charging point is engaged for the following average duration.

Table 13. Average charge duration (hours)

Slow-night recharging	13
Slow-work recharging	9
Slow-day recharging	3
Quick recharging	1
Fast recharging	0,25

In addition, a proper utilization factor (defined percentage of time when the station is actually in use) has been used. The utilization factor shall be less than 100% to ensure that the client has a high probability to find a free charging point when needed. This is a very important requirement, because, in case all the charging points in a given location are busy, it is not possible for an upcoming client to wait for one to get free. In fact, differently from what happens for gasoline stations, the average waiting time can be very long. For Fast DC station, the requirement can be relaxed, because the waiting time is reduced; nevertheless the case the client has to wait shall not be too frequent.

An indicative utilization factor can be calculated using queue theory and imposing very low probability to wait events. For example, assuming that both the arrival and the charge processes can be modelled as Markovian ones, the following results can be obtained:

- Location with 2 fast DC charging points
    - utilization factor 12.5% : Probability to wait is approximately 3% (10 times per year assuming a charge per day)
    - utilization factor 25 %: Probability to wait is approximately 10% (36 times per year assuming a charge per day)
- Location with 6 AC stations
    - utilization factor 25 %: Probability to wait is approximately 0,5%
    - utilization factor 50 %: Probability to wait is approximately 10%

Note that, with the same utilization factor, increasing the number charging points decrease the probability clients have to wait, hence DC stations shall have lower utilization factor compared to AC ones. For the calculation, the following assumptions have been used.

Table 14. Utilization factor of charging station

Slow recharging pole	25%
Quick recharging pole	25%
Fast recharging pole	12,5%

Multiplying the durations with the number of recharging and the corresponding utilization factor gives the following quantities.

Table 15. Number of charging points

Charging power (kW)	Total recharging (EV's %)		Total Charging port (EV's N)	
	Private	Public	Private	Public
3.7	57%	13%	0.66	
11		20%		0.22
55		10%		0.01

The number of charging points can be obtained multiplying the indexes by the number of electric vehicles. For example assuming 1 million EVs:

- Private charging points: 660.000
- Quick charging points: 220.000
- Fast charging points: 10.000