FABRIC

Feasibility analysis and development of on-road charging solutions for future electric vehicles

# FABRIC Validation methodology

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# LIST OF ABBREVIATIONS

| ABBREVIATION | DESCRIPTION |
|---|---|
| DoW | Description of Work |
| DSO | Distribution System Operator |
| DWPT | Dynamic Wireless Power Transfer |
| Dx.x.x | Deliverable x.x.x |
| eCo-FEV | efficient Cooperative infrastructure for Fully Electric Vehicles |
| EM | Electro-Magnetic |
| EMF | Electromagnetic field |
| EV | Electric Vehicle |
| ICT | Information and Communication Technologies |
| IPxx | International Protection Marking, IEC standard 60529 |
| LBC | Load Balancing Controller |
| LKS | Lane Keeping System |
| PCC | Point of Common Coupling |
| SoC | State of Charge |
| SP | Sub Project |
| V2I | Vehicle to Infrastructure |
| V2G | Vehicle to Grid |

# REVISION CHART AND HISTORY LOG

| REV | DATE | REASON |
|---|---|---|
| 1 | 24.02.16 | First draft (ICCS). Circulation of draft to partners. |
| 2 | 09.03.16 | Input by CIRCE on grid impact validation tests. |
| 3 | 17.03.16 | Input from CRF on system validation. |
| 4 | 28.03.16 | Input from TRL on data collection templates. Circulation of draft to partners. |
| 5 | 06.04.16 | Update of methodology section (ICCS). Integration of input from SP5. |
| 6 | 08.04.16 | Input by CIRCE on data collection templates. |
| 7 | 17.06.16 | Common tests for efficiency and EMF emissions measurement. Submitted for Peer Review. |
| 8 | 24.06.16 | Updating of EMC and EMF testing sections with input from VEDECOM. |
| 9 | 18.10.16 | Updated after the review meeting |

# EXECUTIVE SUMMARY

FABRIC Deliverable D4.7.1 provides the methodology for validation testing on a system level. This testing will take place after all ICT and hardware components become available and integrated in a functional system. The aim of the validation is to ensure that the produced systems (at the Italian and French test sites) operate within the specified requirements and provide the expected functionalities.

Initially the methodology for the design of the validation plan is described. Due to the complex nature of FABRIC, which also includes a feasibility analysis for the deployment potential of wireless power transfer technologies, an extended group of project experts was formed and it contributed and reviewed the validation plans. This was done in order to ensure that the necessary data for the evaluation of the system and the conduct of the feasibility analysis will be collected during the tests.

The validation plans focus on assessing the functionality of the developed systems, their efficiency, and their impact on the grid and the road (taking into account that these are prototypes and not representative of industrial level implementations). Due to this, the document is also organized in this manner. Initially the processes for validating the physical aspects of the delivered systems are defined. This includes geometric characteristics on a component level (e.g. charging pad) as well as on system level to make sure that the system is installed as required.

The second step is the definition of the parameters that need to be measured during the tests. These include both the data necessary for the evaluation of the systems but also environmental and situational data that will allow potentially the extraction of meaningful conclusions on the robustness of the tested systems to various operating conditions.

The main objective of FABRIC tests is the evaluation of the charging solutions developed by VEDECOM, POLITO and SAET, thus the main effort is put towards defining testing protocols and drafting the templates for test data collection in a standardized manner which will allow the comparison of the different charging solutions. The templates are similar to the ones used in WP37 for the verification of the components in a lab environment prior to their installation at the test sites but extended to take into account the overall charging system and the environmental parameters at the test sites.

Finally, as a secondary objective, validation of ICT functionalities is planned at the document's last chapter. The ICT in FABRIC is limited to modules that enable the proper operation of the charging solutions, since extended electromobility functionalities such as infrastructure booking and payment are developed and tested in other projects.

In order to ensure the highest validity of the test results published in FABRIC documents, a common functional principle is agreed between directly involved partners (CRF/POLITO/VEDE/CIRCE/ICCS), as follows:

Given the prototypic status of the three wireless charging systems to be tested, the novelty of the technology and the lack of standards regarding dynamic charging testing the test protocols, measurement tools and devices proposed in the present document should be considered preliminary and might be subject to changes and evolutions during the actual implementation of the systems at the two test sites (as commonly agreed by the Italian and French test site/OEM partners).

It is important that testing methods and results are reviewed and consolidated in a consensual way by the directly involved partners (CRF/POLITO/VEDE/CIRCE/ICCS) to minimize misinterpretation risks and ensure suitable credibility for further research, development and dissemination of results. The compilation of a set of testing methodologies and protocols focused on dynamic charging is a very complex and iterative task which requires the hands-on interaction with the prototypes and infrastructure, rather than a theoretical study based on prototype specifications. The result can potentially be very beneficial as input to the standardization bodies that are currently finalizing some aspects of static charging (SAE TIR J2954) but haven't investigated dynamic charging due to the embryonic stage of the technology (IEEE has launched only recently a pre-standardization committee focused on dynamic charging which will work in conjunction with SAE TIR J2954).

To this end, dedicated telephone conferences or workshops will be held when test results are available. Methods and results will be presented by VEDE or POLITO/CRF and results presentation agreed between CRF/POLITO/VEDE/CIRCE/ICCS.

All modifications regarding the proposed methodology in this deliverable (D4.7.1) will be clearly identified and justified within D4.7.2, where results are presented.

# 1 INTRODUCTION

FABRIC Deliverable D4.7.1 provides the methodology for validation testing on a system level. This testing will take place after all ICT and hardware components become available and integrated in a functional system. The aim of the validation is to ensure that the produced systems (at the Italian and French test sites) operate within the specified requirements and provide the expected functionalities.

FABRIC is a complex system that entails both novel hardware that enables wireless charging of EVs on the go and the necessary ICT for the communication of the EV with the infrastructure. Even though the systems developed are different the high-level goal is common: to dynamically charge an EV at various speeds and test the feasibility of this technology and forward the measured data to FABRIC SP5 for further analysis regarding the sustainability of wireless dynamic charging in a large-scale deployment scenario.

To this end, FABRIC's main focus is on the development of the required hardware and the road and grid infrastructures. ICT is a secondary objective due to the fact that many European R&D projects have developed and currently improve V2I ICT, especially for EVs. A prime example is the eCoFEV project, whose outcome FABRIC will utilize for the Italian test site system via knowledge transfer of common partners (HITACHI Europe ltd – eCoFEV coordinator, TUB, CRF and POLITO). The ICT in this case is already validated within eCoFEV, and only some additional functionalities (such as the load balancing implementation) will be tested within FABRIC. The eCoFEV ICT infrastructure already implements functionalities such as identity management, booking and payment procedures so it can be considered adequate for a real-world deployment of a system that incorporates FABRIC's dynamic wireless charging technologies.

On the other hand, at the French test site only critical ICT functionalities will be implemented, such as lane alignment to optimize power transfer efficiency and V2G communications. This however will allow the collection of the necessary data during the tests for the assessment of technology feasibility, efficiency and comparison with the Italian counterpart. In addition, at the French site emphasis will be given to the EMF emissions measurement with the development of specialized, custom measuring equipment. This will give additional information not available at the Italian site.

This document formulates the guidelines to exploit the two separate approaches in a way that allows more extensive testing and collection of versatile data and removes the resources waste risk due to unnecessary redundancy while making sure that the critical data needed for comparison purposes and the feasibility studies in SP5 are collected at both test sites in a standardized manner.

These guidelines specify the parameters to be measured and the testing procedures for the collection of the data. It is important to keep in mind that the methodological framework described in this document contains operating modes and values that might require adaptations given the prototype nature of the tested equipment, the experimental research characteristics of the FABRIC project and the complexity of some physical aspects (EMF, EMC in particular). An important outcome of the project could be to actually provide refined test methods and levels which could be of use in future standardization works.

# 2 METHODOLOGY

FABRIC Project employs the systems engineering approach for ITS as guidance for its development and testing. The FABRIC system is an artefact that consists of hardware and software components or modules that pursue a common goal that cannot be achieved by each of them separately. Each component of the system and its behaviour are tightly connected to the other components.

Therefore, the systems engineering approach is suitable, which implies the traceability of specifications from customer requirements through production, operation and disposal, passing through test and maintenance phases. In this sense it integrates all specialty groups forming a structured development process ("top-down" approach).

Considering the commonly used "V" Model in this approach, depicted in Figure 1, WP47 is mainly concerned with the System Validation phase. Figure 1 also depicts the input deliverables and the information flow within the project that lead to the creation of the present document.

The V-model describes accurately enough the life cycle of FABRIC system development. The left side represents the system decomposition and requirements definition, followed by product and process design; while the right side represents system production, integration and verification.

Following this whole process, the evaluation will start with the unit testing of low-level individual components of the FABRIC ICT and hardware modules defined in D2.2.1 and D3.2.1. The unit testing should verify the internal functionality of each component and that they meet the design specifications and requirements (D2.4.1 and D3.4.1).

Once the individual components are verified, they are integrated to form the subsystems specified in the high-level design, which will then be evaluated in the subsystem verification phase in order to confirm that all interfaces have been correctly implemented and all requirements have been satisfied for each subsystem (D2.6.2 and D3.7.2).

The system verification phase (D4.6.2) is concerned with the evaluation of the system as a whole, ensuring that the system behaves as expected, taking the use cases defined in D2.2.1 (ICT functionalities) and D4.3.2 (test scenarios) as the main input.

Once the FABRIC system is verified for its error-free design and operation, the last phase of the evaluation, system validation (D4.7.2) ensures that the system is effective, for the given performance metrics, in meeting the intended purpose and needs defined at the beginning of the project. The main objective of the present document D4.7.1 is to establish these performance metrics and the testing protocols to validate the functionality of the system and measure its performance.

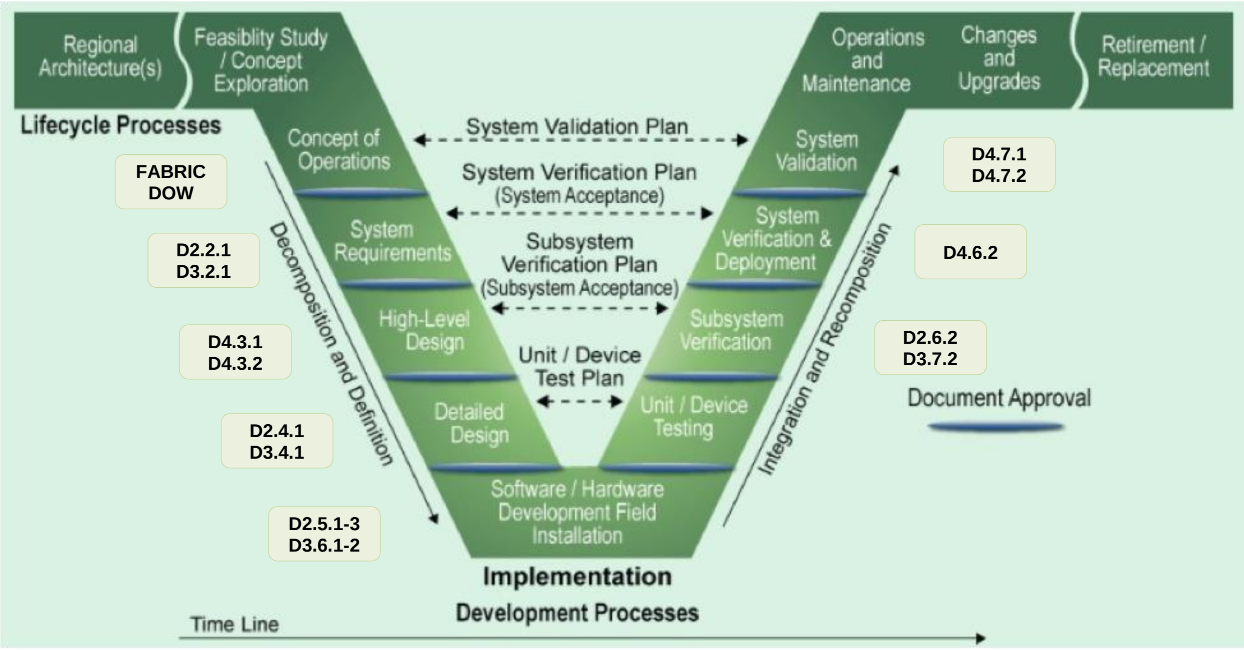


**Figure 1: The Systems Engineering "V" Model.**

As explained in the introductory chapter FABRIC's two different approaches in dynamic wireless charging makes the validation planning task challenging, since a common measurements denominator has to be achieved to allow comparisons between the developed systems within FABRIC and to make sure that the experimental data collected are suitable for large-scale deployment feasibility studies.

Towards this goal, initially, a "validation" working group was formed consisting of FABRIC partners who are involved in the development, testing and feasibility analysis. This group was led by ICCS and its members were the following:

- ICCS: Project coordinator, SP4 leader, WP47 leader and D4.7.1 responsible.
- VEDECOM: The producer of the Qualcomm Halo-based DWPT system and responsible for the French test site and vehicles.
- CRF: Provider of the vehicle for the Italian test site.
- POLITO: The producer of one of the two DWPT systems for the Italian test site.
- SAET: The producer of one of the two DWPT systems for the Italian test site.
- TECNOSITAF: The Italian test site operator.
- KTH: FABRIC SP5 leader ensuring that the necessary data for the SP5 feasibility studies are being collected during the tests.
- TRL: FABRIC SP3 leader and the main author of FABRIC D4.3.2 which described early in the project the test scenarios based on the use cases and requirements.

- VOLVO: The developer of "Solution 4" as stated in the FABRIC DoW which will provide consultation and data for charging systems comparison.
- SCANIA: The developer of "Solution 5" as stated in the FABRIC DoW which will provide consultation and data for charging systems comparison.
- CIRCE: Responsible for the technical validation of vehicles and integrated test sites.

The objectives of the working group were the following:

- To specify the **critical** parameters that need to be measured during the tests at both test sites in order to allow comparisons.
- To specify the testing procedures in a standardized manner that will be followed strictly at both test sites to ensure compatibility of results.
- To identify which test results are useful input for the feasibility studies in SP5 and include them in the testing protocols.
- To specify secondary parameters that will be measured separately at the test sites using custom equipment and procedures and will provide added value by covering a larger testing premise.
- To produce the data collection templates for use at the test sites during testing.

In order to produce this document input from D4.3.2 "Test scenarios" was used in order to make sure that the final system tests are close to the ones foreseen at the beginning of the project before the hardware and ICT modules became available. Due to the fact that these test scenarios were drafted very early in the project, the validation plans took into account the ICT functionalities specified in D2.2.1 and 2.6.1 as well as the SP5 requirements regarding metrics that would enable the conduct of feasibility studies for large-scale deployment.

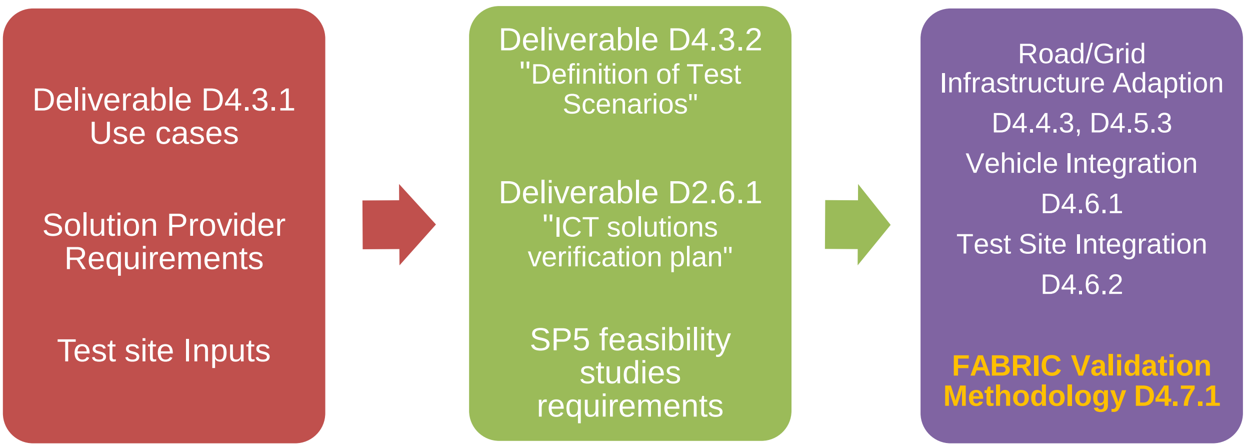


**Figure 2: Project information flow leading to D4.7.1 creation.**

FABRIC is a complex system that comprises ICT as well as hardware prototypes for two different test sites, two different vehicles involving several hardware OEMs. Validation is thus equally complex so the decomposing process of the system shown below is followed in order to guarantee that the system works as planned partially and as a whole.

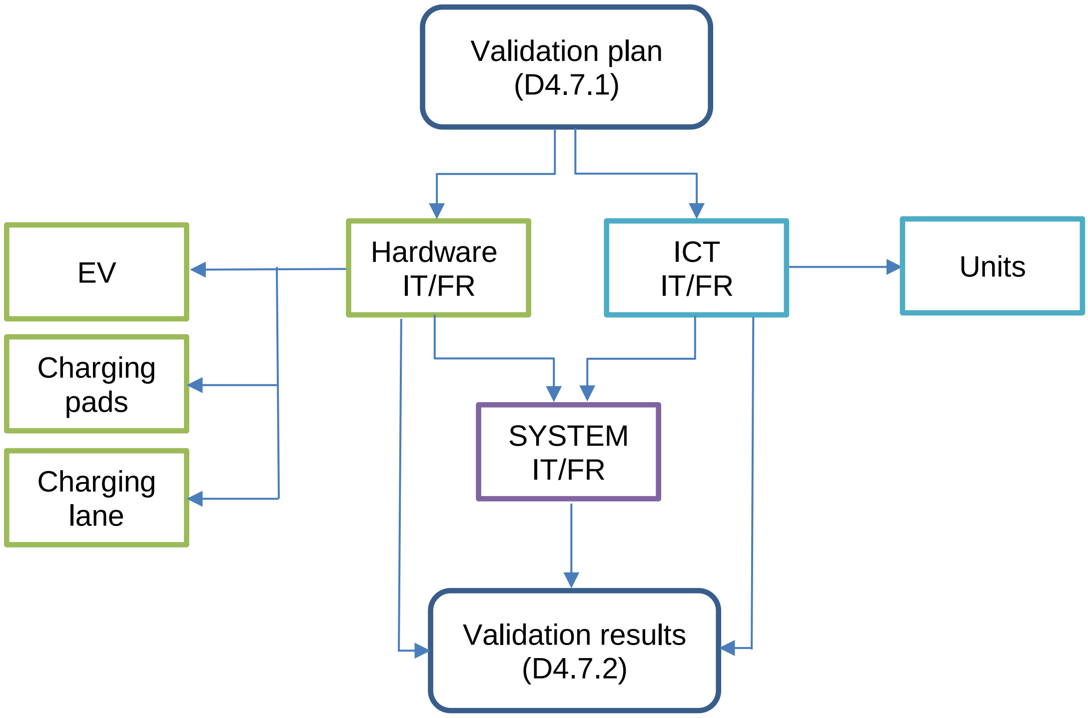


**Figure 3: System decomposition for the creation of the validation plans.**

- Application of “Co-validation” principle of test methods and test results:

In order to ensure the highest validity of the test results published in FABRIC documents, a common functional principle is agreed between directly involved partners (CRF/POLITO/VEDE/CIRCE/ICCS), as follows:

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To this end, dedicated telephone conferences or workshops will be held when test results are available. Methods and results will be presented by VEDE or POLITO/CRF and results presentation agreed between CRF/POLITO/VEDE/CIRCE/ICCS.

All modifications regarding the proposed methodology in this deliverable (D4.7.1) will be clearly identified and justified within D4.7.2, where results are presented.

# 3 HARDWARE VALIDATION

The validation of the hardware delivered by the solution providers will include physical and functional testing to ensure compliance with the specifications on component and system-wide levels.

## 3.1 Physical validation

A visual inspection will take place to detect anomalies of the equipment and deviations from the designs. Afterwards the following parameters will be inspected upon delivery and integration at the test sites:

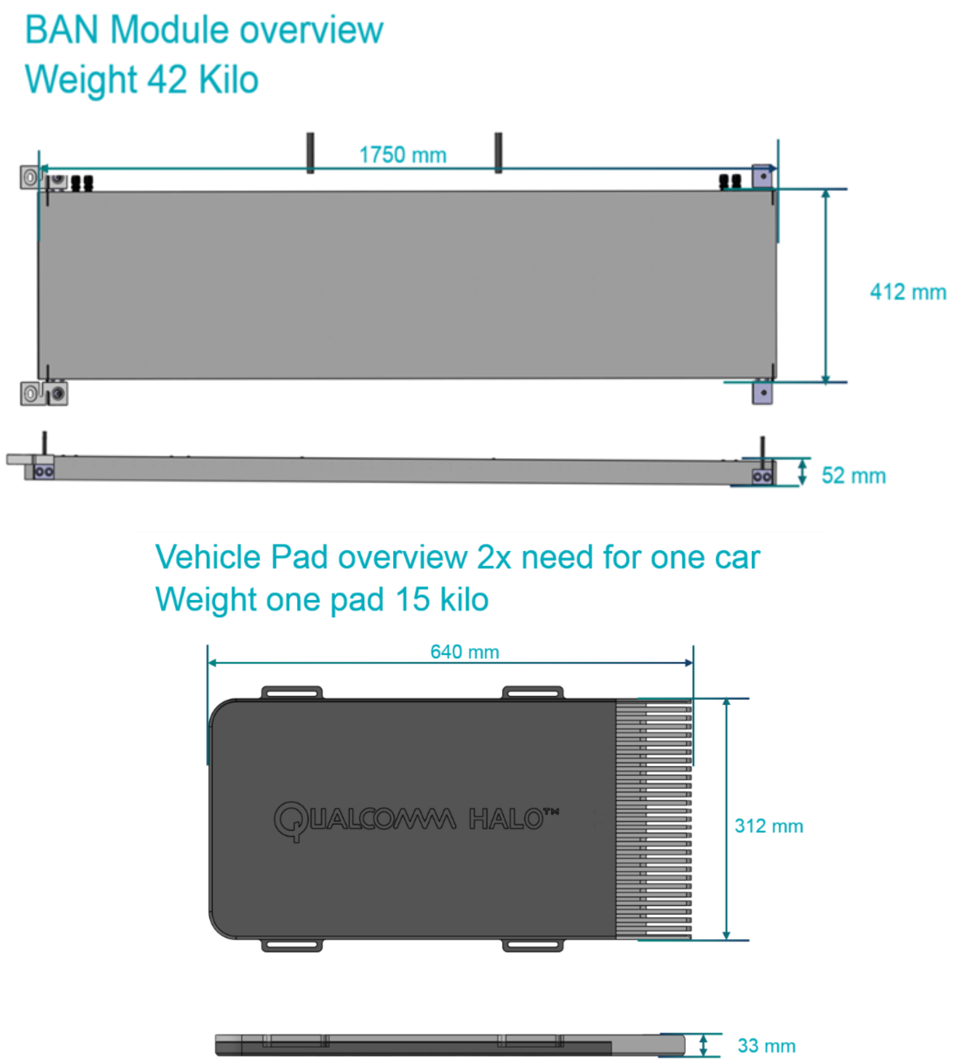



Figure 4: Geometric characteristics to be validated for charging pads.

**Table 1: Physical validation parameters regarding the on-road charging pads equipment.**

| | Solution 1 - VEDE | Solution 2 - POLITO | Solution 3 - SAET | Deviation from specifications | Comments |
|---|---|---|---|---|---|
| Geometric features | | | | | |
| Length (mm) | | | | | |
| Width (mm) | | | | | |
| Height (mm) | | | | | |
| Weight (kg) | | | | | |
| Water resistance | | | | | |
| Standard compliance (e.g. IPX6) | | | | | |

**Table 2: Physical validation parameters regarding the vehicle charging pads equipment.**

| | Renault - VEDE | IVECO - CRF | Deviation from specifications | Comments |
|---|---|---|---|---|
| Geometric features | | | | |
| Length (mm) | | | | |
| Width (mm) | | | | |
| Height (mm) | | | | |
| Weight (kg) | | | | |
| Water resistance | | | | |
| Standard compliance (e.g. IPX6) | | | | |
| Shielding | | | | |
| Visual inspection | | | | |

- System-wide physical validation

**Table 3: System-wide physical validation parameters regarding test sites' specifications.**

| | | **Charging lane length** | **Number of pads** | **Deviation from plans/comments** |
|---|---|---|---|---|
| *Italian test site* | POLITO system | | | |
| | SAET system | | | |
| *French test site* | VEDE system | | | |

## 3.2 Functional validation

The hardware functional validation is split in two parts:

- The first part aims to validate the basic functionality of the hardware, to ensure that the equipment is connected and operational as intended in the design phase.
- The second part aims at measuring the efficiency of the prototypes and collect the data necessary for the feasibility studies (chapter 5). Secondary data will also be collected, utilizing custom equipment and measurement procedures.

### 3.2.1 Modular functional validation

Critical components should first be identified to validate that they are connected and function properly prior to the testing of the system as a whole. The following check list will be used to validate the basic functionality of the hardware. Due to confidentiality restrictions the modules and tests cannot be included in this public version but are available to the EC upon request.

**Table 4: Functional validation tests template for modules.**

| Module | Action/Test | Description | Result |
|---|---|---|---|
| | | | Pass/Fail |
| | | | |
| | | | |

# 4 ICT VALIDATION

The objective of ICT validation is to make sure that the ICT “units” developed within FABRIC and delivered/installed at the test sites function properly under field testing conditions. A “unit” is considered an ensemble of ICT components that performs one or more high-level functionalities at a system level. According to the DoW the FABRIC ICT Units to be tested are:

- On-Board Unit (OBU) (T2.5.1 in the DoW)
- Lane Keeping System (T2.5.2 in the DoW)
- Load Balancing system (LBS) (T2.5.3 in the DoW)

Unit testing applies only to the software / hardware components that are implemented or modified in the scope of FABRIC, omitting off-the-shelf components and those which have been already validated in other projects. The OBU, load balancing system and lane keeping system will specify and execute their individual component tests. An example unit test template is provided in the following table.

In addition, tests will be conducted for FABRIC electromobility services backend and charging infrastructure backend which are adaptations of the ICT backends that were produced in eCo-FEV project and are available only for the Italian site. This is considered added-value since FABRIC’s technological objective is the development of the hardware for the wireless dynamic charging of EVs and the ICT that is necessary for the testing of these hardware modules and the maximization of efficiency. The backend validation tests are included in Annex I.

**Table 5: Example Unit Test Template**

| Test Case Id | Test site(s) : Italy/France/Both | Test Case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Both | | | PASS | |
| 2 | Italy | | | FAIL | |
| 3 | France | | | | |

## 4.1 On-Board Unit ICT

The goal of the On-Board Unit (OBU) developed in FABRIC T2.5.1 is provide the necessary feedback to the drivers in order to guide them through the charging process and to optimize the charging efficiency. The OBU ICT includes the HMI application and hardware which receives input from the Lane Keeping System and displays the information and corrective actions to the driver during the charging process to optimize the alignment between the primary and secondary charging pads.

| Test case Id | Test site(s): Italy/ France /both | Test case goal and description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1. | both | Road image display on the user interface | The user interface should display the image of the road | | |
| 2. | both | Vehicle lane coloration on the user interface | The user interface should colour the vehicle lane on the road image | | |
| 3. | both | Lane mark coloration on the user interface | The user interface should colour the lane mark on the road image | | |
| 4. | both | Driver guidance | The user interface should display a message to assist the driver to align the charging coil of the vehicle with the charging coil of the road | | |

Due to the different implementations at the two test sites, the HMIs will be different but serve the same objectives as stated above. The expected result is shown at the following figures.

In Figure 5, the blue lines indicate the borders of the charging lane while the yellow line indicates the axis along which the charging pads are installed. The green arrow informs the driver of the necessary corrective action to reduce misalignment.

In Figure 6 the driver will be informed about the status of the system and the charging power requested. Information will be provided incrementally as the vehicle enters the charging zone, during the charging and when exiting the charging zone. The coloured band located at the bottom of the screen informs the driver of the misalignment with the infrastructure charging pads axis in real time.

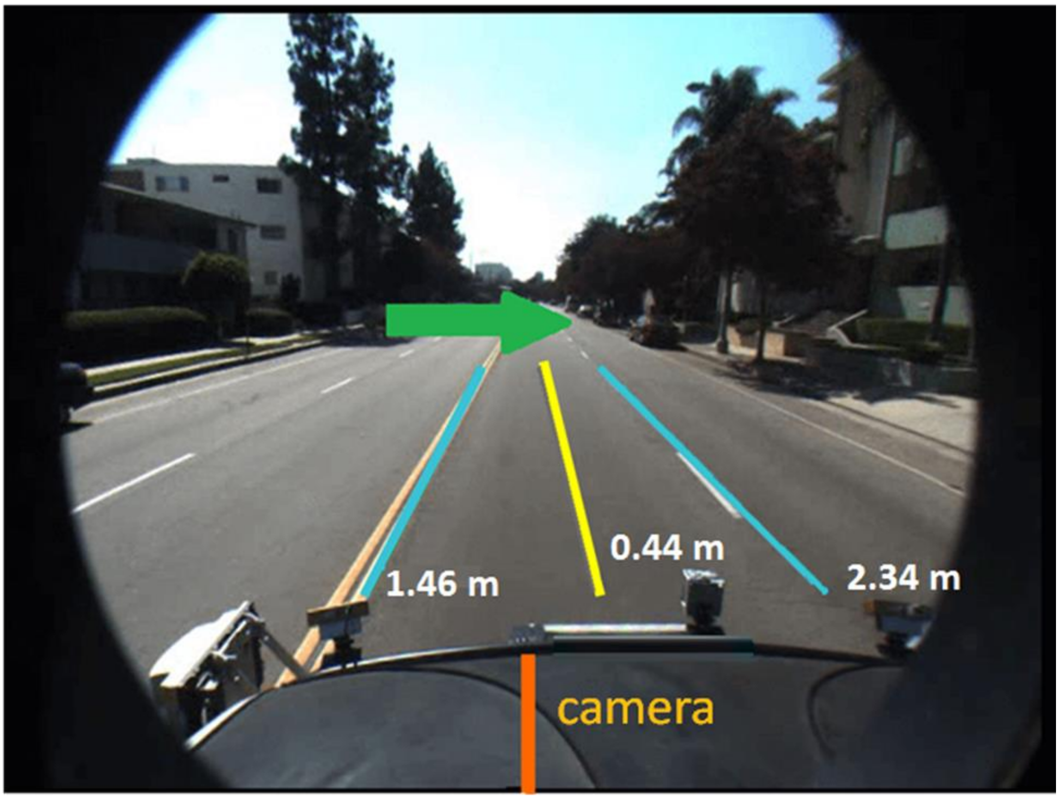



Figure 5: HMI lane alignment concept for the Italian OBU.

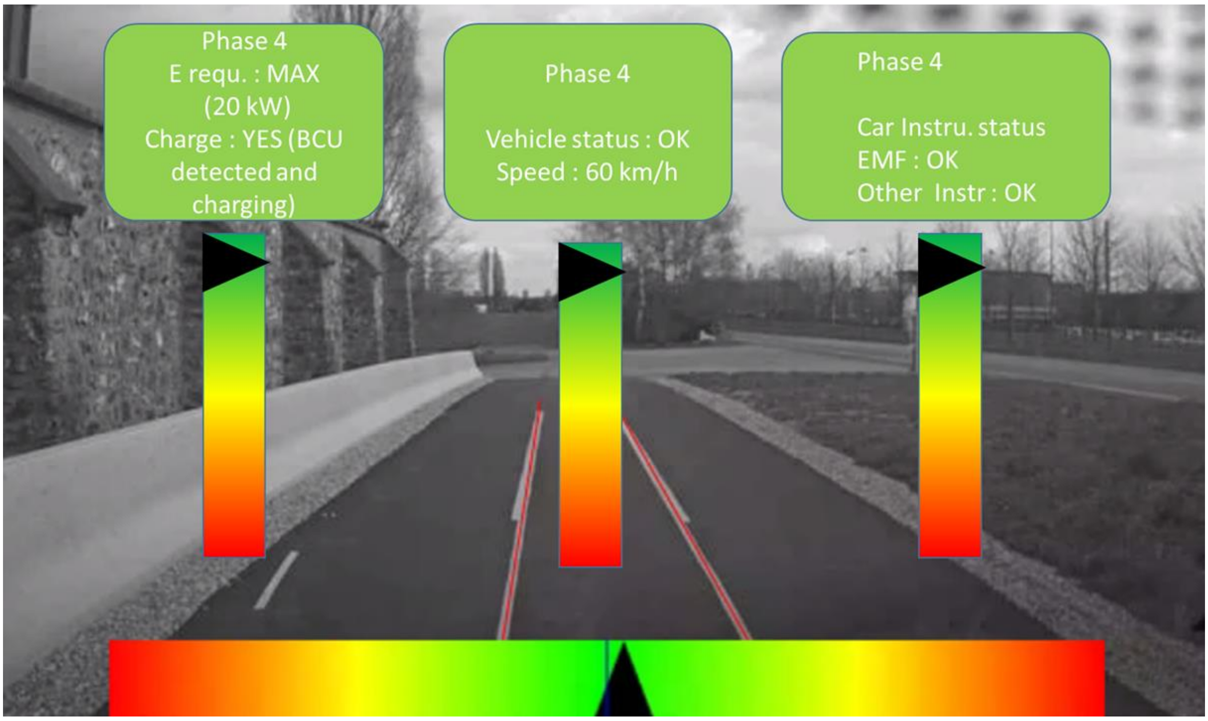



Figure 6: HMI concept for the French OBU.

## 4.2 Load Balancing ICT

Load balancing aims at keeping the equilibrium between grid supply and demand taking into account many parameters relevant to the EV BMS, charging infrastructure operating characteristics, grid stability, power quality and user preferences. It is essential in order to ensure that net capacity and grid-connection transformer limits will not be violated. Moreover, it ensures that highly unpredictable energy sources can be integrated (wind, solar) by shaping the overall demand due to charging operations to match the available supply.

The following figure shows the architecture of the load balancing application and depicts the main components of the system.

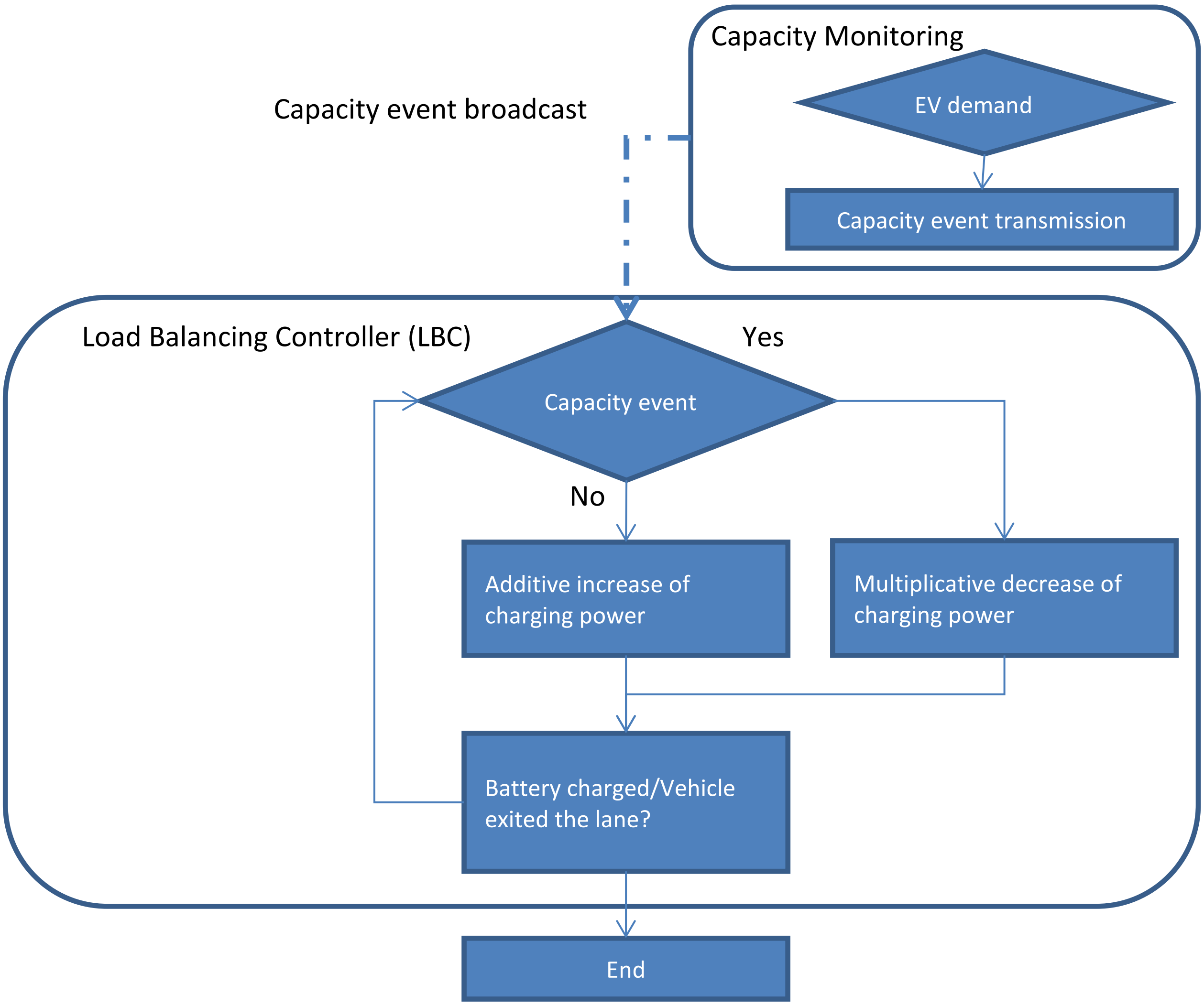



Figure 7 Architecture of the load balancing application.

**Table 6: LBC infrastructure tests.**

| Test case Id | Test site(s): Italy/ France /both | Test case goal and description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Both | The Load Balancing Controller (LBC) receives the capacity event broadcast through the communication medium installed on site. | Reception of an object/message, indicating that the overall power transfer capacity of the system has been reached. The object/message is received through the communications interface installed on the Italian/French test site. | | |
| 2 | Both | The Load Balancing Controller controls the power to be transmitted from the primary side to the secondary side of the vehicle through the communication medium available on site. | A setpoint indicating the power to be transferred from the primary to the secondary coil is sent from the load balancing controller to the charging procedure controller installed at the Italian/French test site. | | |
| 3 | Both | The Load Balancing Controller decreases the charging power rate once a capacity event is issued by the capacity monitoring module | The Load Balancing Controller transmits a power setpoint, which indicates a reduction of the power to be transferred, from the primary to the secondary coil | | |
| 4 | Both | The Load Balancing Controller increases the charging power rate if a capacity event is not issued and the maximum charging rate negotiated between the vehicle and infrastructure has not reached its maximum value. | The Load Balancing controller increases the power transfer setpoint up to the nominal charging rate, as long as a congestion event is not received from the capacity module, through the communication medium installed at the Italian/ French test site. | | |
| 5 | Both | The Load Balancing Controller correctly receives a notification of a vehicle exiting the dedicated charging zone through the communication medium available on site. | The Load Balancing Controller receives an object/message indicating, a vehicle exits from the dedicated charging zone. This message is received from the charging procedure control module installed at the Italian/ French test site. | | |

**Table 7: Load monitoring tests.**

| Test case Id | Test sites: Italy / France/ both | Test case goal and description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Both | The load monitoring module receives information about the current demand of the system through the respective interface installed on site | Correct reception of an object/message that represents the overall load of the system over the respective Italian/French test site communications medium. | | |
| 2 | Both | The load monitoring module receives a threshold indicating the maximum power to be transmitted by the charging infrastructure to vehicles. This threshold is correctly received through the hosted web service interface from external entities such as DSO/Energy retailers, through the communications medium installed on site | Reception of an object/message that demonstrates the setpoint of power that can be transmitted by the infrastructure to vehicles through the web hosting environment for the Italian/French test site. | | |
| 3 | Both | The load monitoring module issues a capacity event broadcast if the overall load exceeds the overall power capacity of the grid. The broadcast is disseminated through the communication medium installed on site | Transmission of an object/message indicating that the maximum power transfer capacity of the system has been reached. The transmission is done through the communication medium installed at the Italian/ French site. | | |

Table 8: Load balancing vehicle controller tests.

| Test case Id | Test site(s): Italy/ France /both | Test case goal and description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Both | The vehicle can correctly receive the congestion signal from the load balancing controller through the communication medium available on site | The Load Balancing Vehicle controller correctly receives the set-point indicating the power transfer rate, through the communication medium installed at the Italian/French test site. | | |
| 2 | Both | The Load Balancing Vehicle Controller can check the battery status and accept charging at a given charging power according to the set points indicated by the charging infrastructure | The Load Balancing Vehicle Controller sets the actual charging transfer power according to the power setpoint received, and the battery status. | | |

## 4.3 Lane Keeping ICT

The Lane Keeping System (LKS) runs on a PC connected to a camera. The camera is installed inside the vehicle near the windshield mirror and transmits the image of the road to the LKS in real time. After installing the camera inside the vehicle, we calculate the camera extrinsic and intrinsic parameters using calibration software. The camera extrinsic parameters are the pitch angle, yaw angle, and height above ground. The camera intrinsic parameters are the focal length and optical centre. The camera's parameters are used by the LKS to detect the lane mark and calculate the lateral distance between the camera and the lane mark. The value of the lateral distance is displayed on an Android Tablet which is connected to the PC using Bluetooth.

**Table 9: LKS validation tests.**

| Test case Id | Test sites: Italy / France/ both | Test case goal and description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1. | both | Lane Marking Extraction | Lane marking extracted | | |
| 2. | both | Calculation of the lateral distance between the vehicle and the marking lane | The lateral distance estimation error should be less than 5 centimetres | | |
| 3. | both | Latency | Latency should be below 0.2 seconds | | |
| 4. | both | Lane Detection in curved road | The user interface should colour the lane mark detected in a curved road | | Depending on the test track. |
| 5. | both | Lane detection in straight road | The user interface should colour the lane mark detected in a straight road | | |
| 6. | both | Lane detection in shadowed road | The user interface should colour the lane mark detected in a shadowed road | | |
| 7. | both | Lane detection in good illumination | The user interface should colour the lane detected in a good illumination | | |
| 8. | both | Lane detection in poor illumination | The user interface should colour the lane detected in a poor illumination | | |

# 5 SYSTEM VALIDATION

## 5.1 Overview

This phase involves the validation of the good operation of the system as a whole and the collection of the testing data. As mentioned previously, test data are classified as primary, which should be collected in the same way at both test sites in order to allow the extraction of conclusions based on comparison, and secondary which are data collected via custom procedures and measuring equipment at each of the test sites.

The data will be collected so as to cover the three charging modes as defined in D4.3.2, namely static, stationary and dynamic.

### 5.1.1 Static charging mode

Static charging occurs when the vehicle is parked; it is the common charging scenario for the vehicles to be charged at home, work or in car parks. Typically, the driver will not be present in the vehicle during static charging. The power is provided by a Static Charge Point. The power transfer rate for static transfer may be lower as the vehicle will have a longer time to charge up to full State of Charge (SOC). This mode covers both wired and wireless charging, though in this project we are only concerned with wireless charging so the wired case will not be considered.

Alignment is the main variable factor that can affect system performance in static power transfer. The Test Scenarios for static charging systems will aim to maximise the efficiency of the system and, at the same time, minimise the Electro-Magnetic radiation (EM) exposure as the vehicle can be in a publicly accessible location.

During static charging the chargers typically transfer power at lower rates for longer time periods. Therefore, the DSO aspects can be integrated to test for load balancing and control in various DSO demand Test Scenarios.

It can be assumed during the static charging that the driver cannot be expected to be present in the vehicle, so the communication with the vehicle should consider the possibility of no response from the user.

### 5.1.2 Stationary charging mode

Stationary charging occurs when the vehicle is stopped for a short amount of time along the route to transfer power at high rate. The common use of stationary chargers can be at bus stops, taxi ranks, motorway start-stop traffic and possibly at traffic lights. The driver typically stays in the vehicle during power transfer, although this is not necessary (e.g. taxi ranks).

Stationary charging is similar to the static charging scenarios but due to the shorter charging time there are some significant differences. In the stationary case the charge period is expected to be shorter and thus power transfer rates should be sensibly higher, in order to charge with a reasonable amount of energy. To give an example, if recharged at 3.7 kW, in 30 seconds, only 0.03 kWh are transferred. In order to obtain 1 kWh in 1 minute, a transfer power of 60 kW would be required (ignoring losses).

Another important factor that could affect the power transfer is the alignment of the vehicle. As one cannot expect the driver to align the vehicle as carefully as in the static case, tolerance to misalignment is more important in the stationary case than in the static case.

The power transfer unit reservation and communication delay time are also one of the important factors, as the driver has very limited time. As a consequence, identification procedures may need to be different.

Finally, the user may be in the vehicle during charging. Therefore, additional health and safety aspects should be considered to ensure health and safety of the driver as well as surroundings.

### 5.1.3 Dynamic charging mode

The dynamic charging is the most complex integration between the grid, power transfer unit, vehicle and the FABRIC mobility platform. The power transfer rate should be very high because the time spent over the charging infrastructure can be very short, depending on the vehicle speed. In addition to use the received power to charge the vehicle batteries (as in the static and stationary modes), in the dynamic mode the received power can also (or alternatively) be used to directly power the vehicle's motor, thus reducing the losses associated with charging and discharging the battery. The common Test Scenario for this mode is to drive from A to B and ensure the vehicle does not run out of power. The dynamic scenario will be tested under various driving environments and with several vehicle types.

There are a number of variables which will affect the power transfer, such as:

- Alignment
- Speed of the vehicle
- Coupling duration
- Air gap
- Availability of power from the grid.

The alignment and the speed are variable factors, which are mainly affected by driver behaviour. The coupling duration is the interval between recognition of the vehicle and the time it takes to couple the primary and secondary coil. This is one of the important factors that will affect power

transfer in the dynamic mode, as the time spent on the actual chargers is very short (possibly only a fraction of a second). Therefore, the system has to ensure that the infrastructure and the vehicle are optimised to transfer power for the greatest possible time per power transfer unit. Finally, the availability of power from the grid becomes crucial, due to the high transfer power rates. Keep in mind that at 360 kW, in 1 second just 0.1 kWh are transferred to the vehicle. In the case of direct powering of the vehicle motors, it is crucial that the power supply will not be interrupted.

The Test Scenario for dynamic power transfer will include the speed of the vehicle as well as power supplied to the power transfer unit, as both of these factors have an effect on the energy transferred to the vehicle. The power supply from the DSO will affect the transfer rate, whereas the speed of the vehicle will affect the energy transferred. The relationship can be explained by the power formula stated below:

$$Energy = Power \times time \quad (1)$$

$$Time = \frac{Distance}{Speed} \quad (2)$$

Hence:

$$Energy = \frac{Power \times Distance}{Speed} \quad (3)$$

Equation 3 shows that the energy transferred is proportional to the power transfer rate and the length of the coil/loop but inversely proportional to the speed of the vehicle. Also, other technical aspects could be considered; for example, power transfer conditions if two or more vehicles are over the primary coil (dependent on primary coil size).

In order to analyse the power transfer parameters/metrics in the dynamic mode, the factors that will affect power and energy should be considered together.

The system efficiency will be measured with two approaches:

1- Global efficiency calculation: the average global efficiency defined by the ratio between Energy delivered to the battery + HV vehicle circuit and the Energy supplied from the grid (more suited for static/stationary)

2 - Time based efficiency (ex every 100 ms): same as global efficiency principle, calculation will be done at a higher rate in order to have an instantaneous efficiency estimation (more suited for dynamic).

### 5.1.4 Primary data collection

The primary data to be collected at both the Italian and French test sites following the same procedures are the following:

**Table 10: Primary data to be collected/measured before the tests of the system.**

| Parameter (unit) | Description | Comment |
|---|---|---|
| **Test identification data (code, description etc. according to the templates)** | | |
| **ENVIRONMENT** | | |
| **Date** | Date and time logging of the test. | |
| **Temperature (ºC)** | Ambient temperature during power transfer. | |
| **Weather conditions** | Weather conditions during the testing that may have some effect to the results. | Rainy, sunny, etc. |
| **GRID** | | |
| **Grid Voltage (V)** | Monitor the voltage at the grid transformer which supplies the power transfer modules. | |
| **Frequency (Hz)** | Monitor frequency. | |
| **Power factor (p.u.)** | Monitor power factor, at the grid transformer. | |
| **Current (A)** | Three-phase current at the grid transformer. | |
| **THD Voltage (%)** | Total voltage distortion at the grid transformer. | |
| **Time delay (ms)** | Time delay between user termination action and power cut-off from the primary. | |
| **ROAD** | | |
| **Road Surface Thickness (mm)** | Thickness of the road surface covering the charging coils/pads. | |
| **Road Material** | Asphalt, Concrete, Other. | |

**Table 11: Primary data to be collected/measured during the tests of the system.**

| Parameter (unit) | Description | Comment |
|---|---|---|
| **Vehicle** | | |
| **Air gap (mm)** | The air gap at all times during power transfer. | |
| **Misalignment (mm)** | Continuous misalignment measurement of the vehicle from centre point. In x, y, rotational and angular. | |
| **Speed (m/s)** | The speed of the vehicle at all times. | |
| **Vehicle coupling time (ms)** | Time it takes for vehicle to be recognised to primary and secondary vehicle to couple. | |
| **Coupling time (ms)** | Total time energy transfer occurs. | |
| **Battery Temperature (ºC)** | Battery temperature | |
| **Battery SOC** | Battery state of charge during charging | |
| **EMF, EMI (V/m)** | Measure whether EMF and EMI have any effect on the vehicle electronics. | |
| **Energy transfer** | | |
| **Power supply rate from the grid (W)** | Supply of power from the grid to the power transfer unit. | |
| **Power transfer rate between primary and secondary (W)** | Transfer of power from charging infrastructure to the vehicle. | |
| **Efficiency between primary and the secondary (%)** | Power transfer efficiency between charging infrastructure and the vehicle. | |
| **Efficiency from grid to the secondary (%)** | Power transfer efficiency from the grid transformer to the vehicle secondary. | |
| **Energy transferred (Wh)** | Energy transferred per coupling. | |
| **Energy collected by the traction and the battery per charger (Wh)** | Amount of energy transferred to the vehicle traction or the battery during primary and secondary coupling. | |
| **Environment and infrastructure** | | |
| **EM exposure (T)** | EM exposure measured according to the ICNIRP guidelines. | |
| **Harmonics (%)** | Harmonics on the charging infrastructure prior, during and after charging. | |
| **Coil temperature (ºC)** | Coil temperature, both primary and secondary. | |

In order to collect the data, the following template will be used during testing which provides the means to define each testing procedure in a unique and standardized manner for all test sites. The template describes the purpose of the tests, test set up, and expected outcome based on the specification and the results. In addition, the opportunities where multiple validation tests can be carried out at the same time are identified. Table 14 represents a generic approach; where results can be recorded in a few lines, this should be included in the table, otherwise they can be included in an appendix and referenced from within the table.

**Table 12: Validation template**

| | |
|---|---|
| Validation test No | Unique test ID |
| Validation test name | Name of the test |
| Date | date of the test |
| Test team | Names and organisations. |
| Purpose | Purpose of carrying out the test; what is the test and why it is being carried out |
| Parameter(s) measured | The parameters from Tables 5 and 6 that will be measured during the test. |
| Target (standard; requirements etc.) | What is the reference standard; requirement; specification that the tests should be based on. |
| System under test | Name of the system; subsystem or component |
| Tool requirements | What tools, equipment, test rig set up is required/used |
| Test conditions (ambient temp, surface etc.) | What the environmental conditions such as temperature; incline; noise; number of repeats etc., are |
| Test methodology | Step by step guides on how to carry out the test. |
| Health and Safety | Identification of hazards and safety considerations |
| Expected outcome | What the expected result in order to consider the test a success is |
| Results | What the results of test are |
| Number of repeats | How many times the test has been repeated |
| Limitations | What the limitations of test are |
| Comments | Any additional comments |

For the primary data collection testing protocols are defined in the following sections.

## 5.2 System efficiency estimation tests

The current standardization converging task forces (SAE J2954 – ISO 19363) have started to define some test principles regarding the measurement efficiency of static wireless systems. These principles are based on global energy measurements (from the vehicle adapter to the vehicle control panel). These principles have been taken into account in the protocols proposed below.

### 5.2.1 Test 1.1: Static charging mode

Static charging is considered in accordance with the definitions listed earlier in this chapter; if a static charging spot is not foreseen in the test site area, the test can anyway be performed on the dynamic charging track on a primary pad, realising a sub-case of dynamic charging for vehicle speed v=0 m/s.

Among the previously defined parameters, the tuneable ones to be considered in this test are listed below, together with the discrete values identified for each one of them.

- Airgap: two levels were initially identified (15 cm for French system and 25 cm for Italian systems) but may be adapted after the integration of the systems.
- Power level: One or two levels identified (the maximum power level is one of them).
- Misalignment: x and/or y axes (at least 3 misalignment conditions within the operating range, including 2 extreme positions)
- Vehicle speed: fixed value (0 m/s).

The parameters that need to be measured in order to evaluate the efficiency of the energy transfer in static charging mode are:

- Power supply delivered from the grid
- Efficiency between primary and secondary if possible (not possible at VEDECOM: VEDECOM will provide efficiency between grid AC and DC output of the WPT charging system (which is connected to the HV car network)

All electrical data from the grid and electrical data from the output of the WPT car system will be measured with a real-time data acquisition system at the car level and ground level.

The demonstrator vehicle shall be positioned on the charging spot, measuring the misalignment on x and y axes. The airgap shall be adjusted by appropriate means (vehicle suspensions control or car loading) according to the aforementioned levels. Assuming the data logging devices to be active from the start-up of the charging process, all the other parameters will be monitored and gathered continuously during the test. The test starts when asking to start the charging of the battery with a predefined power level, and it could end for one of the following reasons:

- Fault
- User defined stop
- Target battery SOC achieved (e.g. 90%).

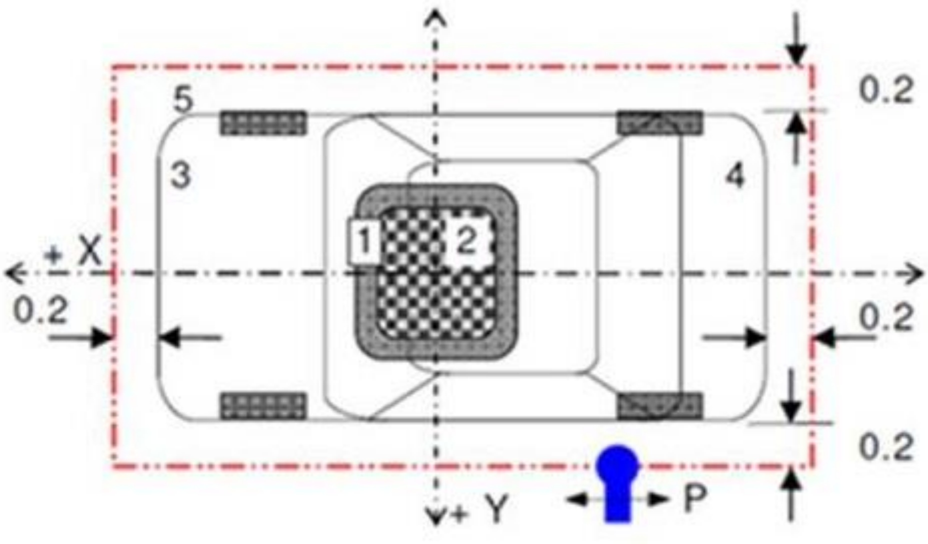



**Figure 8: ISO coordinates system.**

The point of origin is defined to be at the geometric centre of the secondary coil and at the bottom plane of the enclosure housing the secondary coil. This geometric centre of the secondary coil is not necessarily in the centre of the housing that encloses the secondary coil. For the French test site implementation which utilizes two secondary coils, the point pf origin is considered the centre of the front coil.

From this point of origin, the positive X direction is towards the front of the vehicle, the positive Y direction is towards the left side (driver's side) of the vehicle, and the positive Z direction is up vertically towards the roof of the vehicle, which is in agreement with the ISO 19363 coordinates system. Therefore, the secondary coil is chosen also as the frame of reference for testing when compared to the primary coil. This is important when evaluating the EM field strength at a location at a fixed distance from the secondary coil; therefore, it is an appropriate origin for the coordinate system test measurements and reporting.

The main aim of the tests is to estimate several key variables at nominal operating conditions of the charging prototype. Apart from the nominal conditions, the effect of misalignments between primary and secondary device, of partial input power and of moving secondary will be analysed.

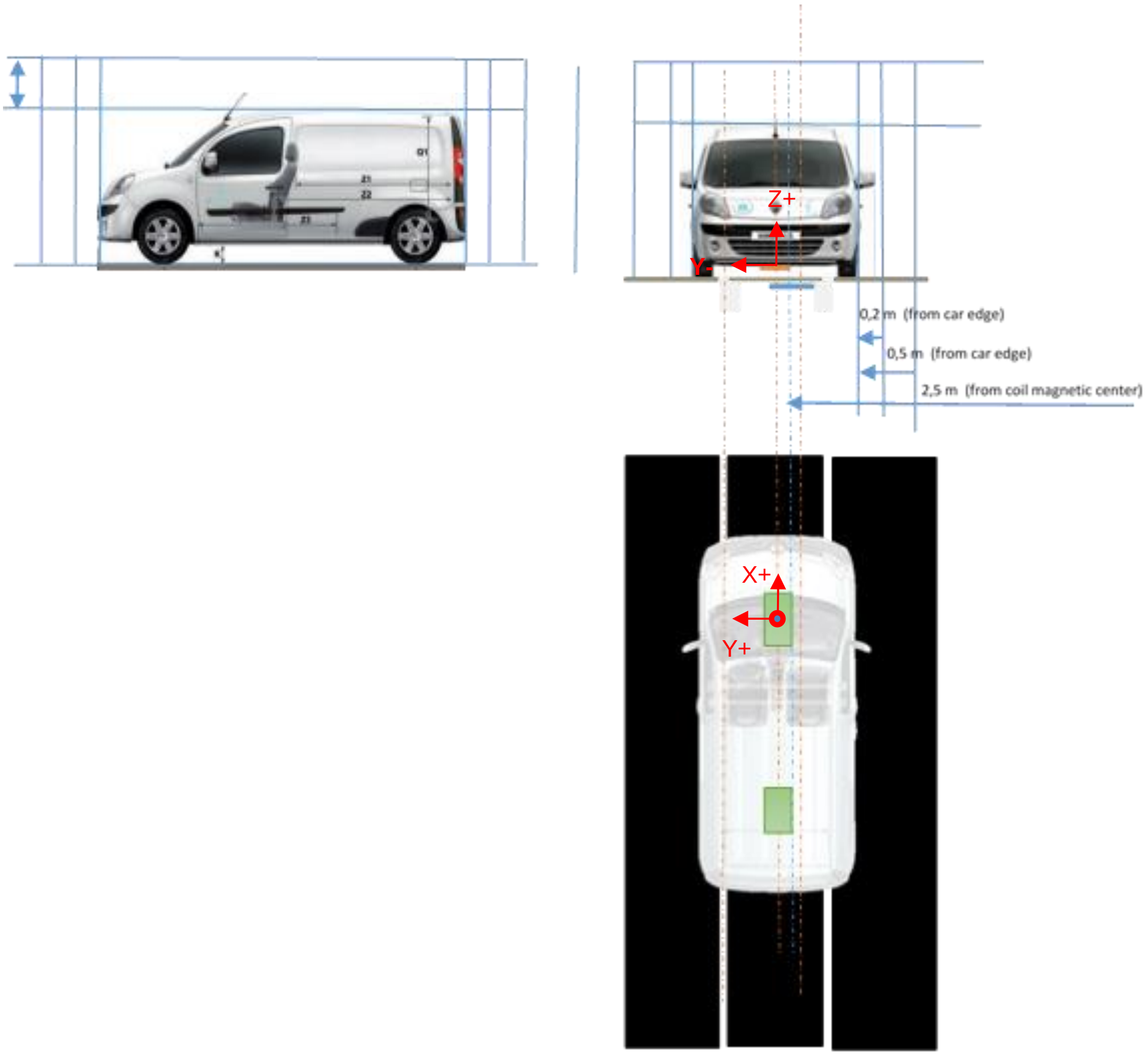



Figure 9: Coordinates system for the French implementation.

For this, the majority of the envisaged tests might be conducted in different **test conditions**.

A. **Nominal value at static charging:** Initially, the nominal value of each variable, for example efficiency, will be measured. In this condition, the primary and secondary devices will be static, at ideal alignment conditions, at their nominal air gap and at nominal power level for static charging scenario (estimated to be 6.6kW).

B. **Impact of misalignment:** Each variable will be then measured during wireless power transfer while the primary and secondary devices are misaligned in the x and y axis. For this condition, the vehicle will be moved in the y-axis in appropriate intervals (50 mm in static), until a maximum of +-200 mm (or until the operating range in the case of the

QUALCOMM pads). In each test, the devices will be static at nominal air gap and at nominal power level for static charging scenario.

C. **Impact of air gap:** Similarly, each variable will be measured during wireless power transfer while the primary and secondary devices will not be in their nominal air gap. For this condition, the Vehicle air gap will be changed (if technically possible), and measurements should be taken. In each test, the devices will be static at ideal alignment and at the maximum allowable power level which will be defined by technical and safety standards restrictions. This power level is estimated to be around 7kW.

The following templates can be used for the collection of test data:

**Table 13: Energy transfer efficiency estimation template – Static charging**

| Validation test name | **Energy transfer efficiency in static conditions** |
|---|---|
| Purpose | To calculate the system nominal efficiency and the effects due to misalignments, due secondary/vehicle position and due to variations in the input power level. |
| Target | The nominal system efficiency should be 80% and it should not be affected until a 20 cm offset in the x and y axis. |
| Tool requirements | Will be specified in test reports.<br>A data logger should be used to continuously record voltage and current with an adequate sampling frequency. |
| Ambient conditions | Measured ambient temperature. |
| Test procedure | Align the primary and the vehicle/secondary device at x and y axes according to the test condition (A, B, C).<br>Switch on power.<br>For test conditions A, B, C, measure and record the input and output voltage, current and transfer frequency.<br>Calculate the momentary Power, mean Power, Energy in, Energy out, and nominal system efficiency, as follows:<br>$Power = \ V \times I$<br>Energy = integral of Power over total time of transfer<br>$Efficiency = \frac{Eout}{Ein} \times 100$<br>Results for each of the three iterations and the average of all three iterations will be provided. |

### 5.2.2 Test 1.2: Stationary charging mode

Stationary charging is considered in accordance with the definitions listed earlier in this chapter; The test can be performed on the dynamic charging track on a primary pad, realising a sub-case of dynamic charging for vehicle speed v < 5 km/h. Stationary charging occurs when the vehicle is stopped for a short amount of time along the route to transfer power at high rate.

The tuneable parameters to be considered in this test are the same as for the static case. The difference will reside that $P_{max}$ will be used, and that there will be limiting conditions, i.e.:

- Overheating of the on-board component
- EMF values become too high
- A test duration should be fixed (for example 5 min)

The parameters that need to be measured in order to evaluate the efficiency of the energy transfer in stationary charging mode are:

- Power supply rate from the grid
- Power transfer rate between primary and secondary
- Power supply rate in the battery
- Power supply rate to the traction drive (inverter + e-motor)

Different **test conditions** could be considered for this use case:

D. **Nominal values at stationary charging:**
   a. In this condition, the vehicle will be stopped and charged for a short time at nominal power which simulates charging at traffic lights, junctions etc.
   b. The test will be expanded to include movement at very low speed 5 km/h at their nominal air gap and at nominal power level. This will simulate the charging at taxi queues scenario.

E. **Impact of misalignment at stationary charging:** Each variable will be then measured during wireless power transfer while vehicle is moving at very low speed 5 km/h and the driver, will with the help of the Lane keeping system, should try to maintain a given misalignment (50 mm intervals until max +-200 mm) in the y-axis, at their nominal air gap and at nominal power level. The nominal power level will the maximum operating power (around 20kW), restricted by technical (e.g. severe heating of the components due to elongated charging pad operation) or safety standards limitations (e.g. high EMF emissions inside the cabin).

F. **Impact of air gap at stationary charging:** Similarly, each variable will be measured during wireless power transfer while the primary and secondary devices will not be in their

nominal air gap. For this condition, the vehicle air gap will be changed (if technically feasible), and measurements should be taken. In each test, the vehicle will be maintained at the ideal alignment conditions and at nominal power level.

For stationary charging when the vehicle is stopped the template for static charging may be used. The following template will be used for the collection of test data for the case of low speed movement:

**Table 14: Energy transfer efficiency estimation template - Stationary charging**

| Verification test name | **Energy transfer efficiency in stationary conditions** |
|---|---|
| Purpose | To calculate the system nominal efficiency and the effects due to misalignments, due secondary/vehicle position |
| Target | The nominal system efficiency should be 80% and it should not be affected until a 20 cm offset in the x and y axis (target) |
| Tool requirements | Appropriate transducers to measure voltage and current.<br>A data logger should be used to continuously record voltage and current with an adequate sampling frequency. |
| Ambient conditions | (temperature, weather conditions etc) |
| Test procedure | Vehicle is moving at very low speed 5 km/h and the driver, with the help of the Lane keeping system, should maintain a misalignment in y axis according to the test condition (D,E,F).<br>Switch on power at nominal value.<br>For test conditions D, E, F, measure and record the input and output voltage, current and transfer frequency.<br>Calculate the momentary Power, mean Power, Energy in, Energy out, and nominal system efficiency, as follows:<br>$Power = V \times I$<br>Energy = integral of Power over total time of transfer<br>$Efficiency = \frac{Eout}{Ein} \times 100$<br>Results for each of the three iterations and the average of all three iterations will be provided. |

### 5.2.3 Test 1.2: Dynamic charging mode

Dynamic charging is considered in accordance with the definitions listed earlier in this chapter.

Among the previously defined parameters, the tuneable ones to be considered in this test are listed below, together with the discrete values identified for each one of them.

- Airgap: two levels identified (15cm French vehicle / 25cm Italian vehicle) – For CRF vehicle that features adaptable suspensions airgap could be modified.
- Power level: Maximum power rating.
- Misalignment: y axes (+- 100 mm and +- 300 mm) (TBC if possible to keep 100 mm). VEDECOM/QUALCOMM system stops transferring energy when misalignment is >200mm as a safety measure.
- Vehicle speed: different speed values (i.e. v=10 km/h, 30 km/h, 50 km/h, 70 km/h or alternatively similar speed levels agreed between test sites).

The parameters that need to be measured in order to evaluate the efficiency of the energy transfer in dynamic charging mode are:

- Power supply rate from the grid
- Power transfer rate between primary and secondary
- Power supply rate in the battery
- Power supply rate to the traction drive (inverter+e-motor)

Different test conditions could be considered for this use case:

G. **<u>Nominal values at dynamic charging:</u>** In this condition, vehicle is moving at different speed values and the driver, will with the help of the Lane keeping system, should try to maintain the ideal alignment conditions, at their nominal air gap and at nominal power level.

H. **<u>Impact of misalignment at dynamic charging:</u>** Each variable will be then measured during wireless power transfer while vehicle is moving at different vehicle speed values and the driver, will with the help of the Lane keeping system, should try to maintain a given misalignment (50mm intervals until max +-200 mm) in the y-axis, at their nominal air gap and at nominal power level.

I. **<u>Impact of air gap at dynamic charging:</u>** Similarly, each variable will be measured during wireless power transfer while the primary and secondary devices will not be in their nominal air gap. For this condition, the vehicle air gap will be changed (if applicable), and measurements should be taken. The vehicle will be maintained at the ideal alignment

conditions and at nominal power level (see stationary charging mode on how the nominal power level will be specified).

The following templates will be used for the collection of test data:

**Table 15: Energy transfer efficiency estimation template - Dynamic charging**

| Verification test name | **Energy transfer efficiency in dynamic conditions** |
|---|---|
| Purpose | To calculate the system nominal efficiency and the effects due to misalignments, due secondary/vehicle position and due to variations in the input power level. |
| Target | The nominal system efficiency should be 80% and it should not be affected until a 20 cm offset in the x and y axis. |
| Tool requirements | Will be defined in test results report.<br>Indicatively: multi-meter or/and power quality meter to measure voltage and current.<br>A data logger should be used to continuously record voltage and current with an adequate sampling frequency. |
| Ambient conditions | (Temperature, weather conditions, etc) |
| Test procedure | Vehicle is moving at different vehicle speeds and the driver, with the help of the Lane keeping system, should maintain a misalignment in y axis according to the test condition (G, H, I).<br>Switch on power at nominal value.<br>For test conditions G, H, I, measure and record the input and output voltage, current and transfer frequency.<br>Calculate the momentary Power, mean Power, Energy in, Energy out, and nominal system efficiency, as follows:<br>$Power = V \times I$<br>Energy = integral of Power over total time of transfer<br>$Efficiency = \frac{Eout}{Ein} \times 100$<br>Results for each of the three iterations and the average of all three iterations will be provided. |

The testing procedure defined above will be repeated without the assistance of the LKS in order to compare efficiency results and in that way measure the effect that LKS has.

### 5.3 EMC and EMF emissions safety tests

Safety is of paramount importance, especially when testing novel technologies such as dynamic wireless charging. Tests will be done in order to ensure the safety of the test drivers and the participants in the vicinity of the systems, both on-board and off-board.

#### 5.3.1 EMC tests

Complete standardized laboratory EMC tests are not relevant nor scheduled in the verification/validations phases of the charging system, given their prototype nature. However, at the final validation level, two types of approaches will ensure the integrated systems are compatible from EMC point of view:

- OEMs have their own EMC specifications (confidential) based on regulation on bandwidth. For the French test case, Qualcomm has been informed of such specifications, and evaluated the risks of its solution taking measures in order to comply with these specifications. In addition, in order to check the impact of conducted emissions, some specific measurements directly on select points of the electrical car network can be done (in French test site).
- The more practical testing of validating the system's EMC is to operate the car and charging system at increasing power levels until the maximum level, for an extended period of time and observe whether there is any functional failure or hazardous effect on the vehicle's systems.

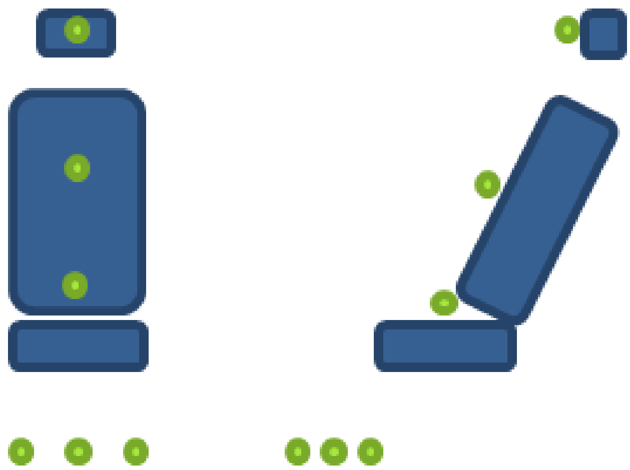
#### 5.3.2 EMF exposure measurement

The task force ISO 19363 has defined some guidelines regarding the protection against the EM effects of wireless charging systems. The safety levels required refer to:

- ICNIRP recommendations (1998 and 2010 versions)
- ISO 14117 (pacemakers reference levels)

The current work document (2016) contains test principles which have been adapted to the needs of the FABRIC.

| | |
|---|---|
| Validation test No | Unique test ID |
| Validation test name | Intra vehicle magnetic field exposure preliminary checks |
| Date | |

| | |
|---|---|
| Test team | |
| Purpose | To test for magnetic exposure on general public inside the vehicle. The exposure should be below guidelines published by ICNRP and ISO 14117 in order to ensure public health and safety is not compromised. |
| Parameter(s) measured | EM field (B) |
| Target (standard; requirements etc.) | ICNRP 1998/2010<br>ISO 14117 |
| System under test | Vehicle with integrated power transfer system |
| Tool requirements | Equipment to measure the magnetic field: possibly Narda EHP 50 F (1-400 kHz probe). |
| Test conditions | (ambient temp, etc) |
| Test methodology | Successively: In static – then stationary – then dynamic (10 km/h) – conditions.<br>For two vehicle/coil positions (aligned, and worst case predicted by simulation:<br>1- Set power by adapted increments (up to 20 kW)<br>2- Measure B field at selected points (probe 1-400 kHz Probe) – (Priority low points)<br><br>3- Check repeatability (2/3- case) on few selected cases to assess robustness of measurements.<br>4- Compare with simulation results to ensure validity of generalizations based on simulations. |

<table>
<tr><td></td><td>5- Compare Levels with ICNIRP (1998, 2010 values) and ISO 14117.</td></tr>
<tr><td>Health and Safety</td><td>Assess safe test zone</td></tr>
<tr><td>Expected outcome</td><td>Assessment that vehicle interior is safe for tests according to local regulation (which will refer to the relevant ICNIRP version) or own HSE provisions.</td></tr>
<tr><td></td><td>
<table>
<tr><td>Veh / coil position</td><td colspan="4">Nominal</td><td colspan="4">Worst case</td></tr>
<tr><td>Power (kW)</td><td>5</td><td>10</td><td>15</td><td>20</td><td>5</td><td>10</td><td>15</td><td>20</td></tr>
<tr><td>Point ID</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Driver seat (6 points)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Pass seat (6)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Rear right seat (6)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Rear middle seat (6)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Rear left seat (6)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Other points in vehicle (TBD)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>
</td></tr>
<tr><td>Number of repeats</td><td>As many as necessary to ensure validity of measurements.</td></tr>
<tr><td>Limitation</td><td></td></tr>
<tr><td>Comment</td><td>These tests shall be carried out as the first ones in the global validation plan of the car with integrated charging system as they are needed for HSE considerations.<br><br>Additional points to be studied following simulation investigations<br><br>Additional characterization of the EM environment will be performed in the French test site (complete spectrum analysis with Active Magnetic antenna and spectrum analyser)</td></tr>
</table>

For the needs of safety zone assessment, specific control planes have to be defined. The following zones have been considered (it is judged not necessary at this stage to test above the car), however the zones may be reconsidered as the project moves closer to the testing phase, in order to address possible technical or other limitations that may be revealed after the full integration of the system:

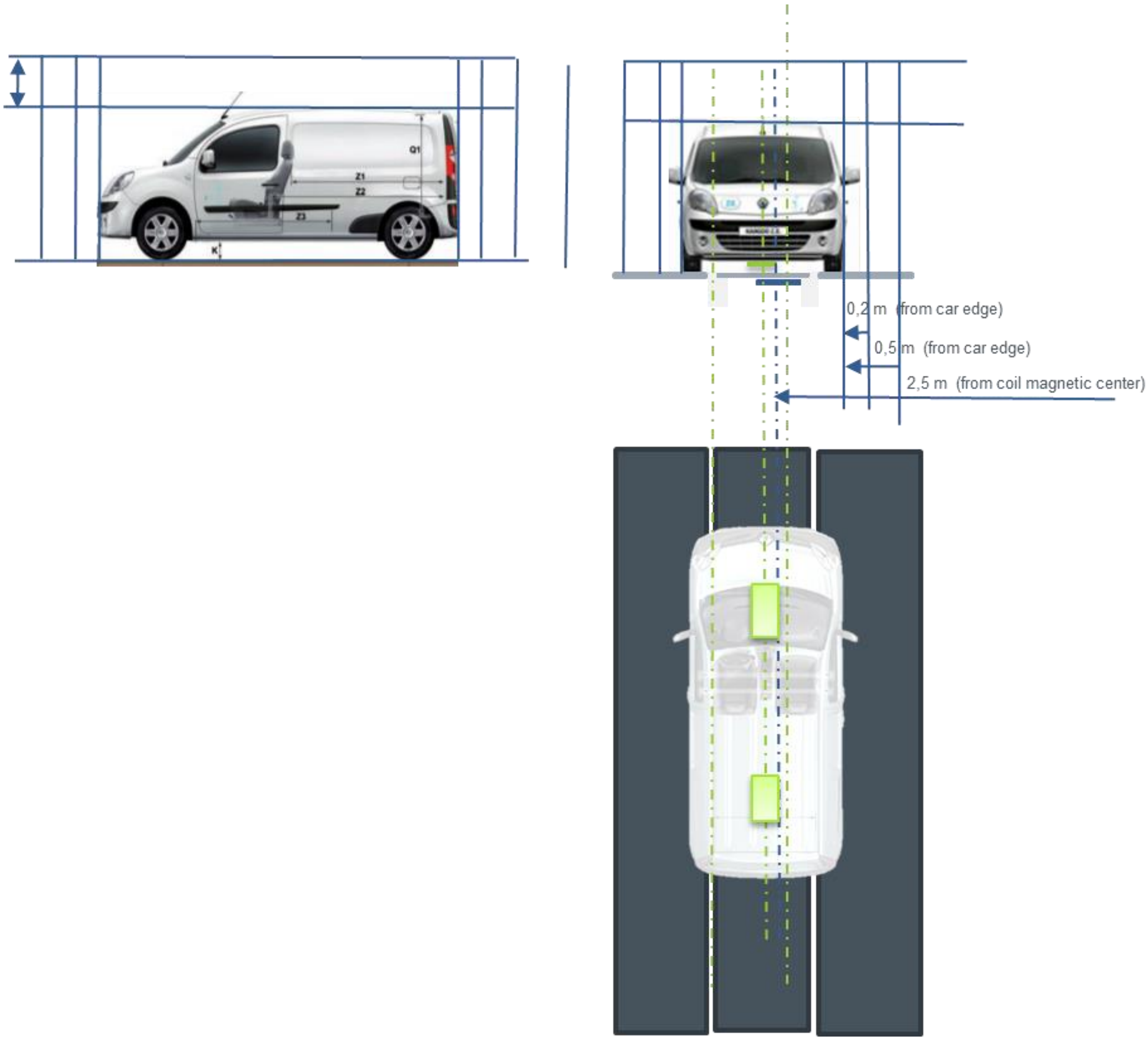



**Figure 10: Safety zones preliminary specification.**

**Table 16: EMF emissions measurement around the vehicle**

| | |
|---|---|
| Validation test No | Unique test ID |
| Validation test name | EMF emissions measurement around the vehicle |
| Date | |
| Test team | |
| Purpose | To measure the potential magnetic exposure on general public outside the vehicle. |

| | |
|---|---|
| | To define safety zones outside the vehicle. |
| Parameter(s) measured | EM field (B) |
| Target (standard; requirements etc.) | The exposure should be below guidelines published by ICNRP 1998/2010 and ISO 14117 in order to ensure that public health and safety are not compromised. |
| System under test | Vehicle with integrated power transfer system, test track. |
| Tool requirements | Equipment to measure the magnetic field: possibly Narda EHP 50 F (1-400 kHz probe). |
| Test conditions | (ambient temp, weather conditions, testing environment etc) |
| Test methodology | In worst case Vehicle/coil position (TBD)<br>**In static charging conditions:**<br>1- Set Power level to maximum power transfer capacity in case it was cleared in the previous test for the vehicle interior regarding HSE concerns or the maximum power that is compatible with HSE regulations as was defined during the measurements inside the vehicle.<br>2- Perform Static exploration: find worst case zone by control plane<br>- at 0,2 m (from car edge) (4 control planes; #9 points by control plane)<br>- if values at 0,2 m are greater than ICNIRP 1998<br>- Repeat Same procedure at 0,5 m (from car edge)<br>- if values at 0,5 m are greater than ICNIRP 1998<br>- Repeat same procedure at 2,5 m (from primary coil magnetic centre)<br>**In stationary charging conditions:** repeat same procedure as in static charging.<br>A “safe static-stationary zone” around the vehicle can be then established for these two charging scenarios.<br>**In dynamic charging conditions:**<br>1- Mount the probe on the car at locations corresponding to the boundaries of the “safe zone”.<br>2- Check whether the static/stationary safe zone is also safe during dynamic charging. |

<table>
<tr><td></td><td>3- Evaluate consistency/repeatability (by test repetition or other appropriate way that will be determined).<br>4- Evaluate simulations based on real testing measurements.<br>5- Verify that decay of B field at levels below 1998 ICNIRP values is effective at least 2.5m away from the primary coil centre (in Y direction).<br><br>Note: the test in dynamic conditions should be repeated at different speeds.</td></tr>
<tr><td>Health and Safety</td><td>Assess safe test zone for static/stationary/dynamic charging scenarios.</td></tr>
<tr><td>Expected outcome</td><td>Assessment that extra vehicle environment is safe for tests according to local regulation (which will refer to the relevant ICNIRP version) or own HSE provisions.</td></tr>
<tr><td></td><td>
<table>
<tr><td>Power Level</td><td colspan="6">Max HSE compliant<br>(from preliminary intra-vehicle checks)</td></tr>
<tr><td>Test cond</td><td colspan="6">Extra vehicle static exploration</td></tr>
<tr><td>Speed</td><td colspan="6">0 - …</td></tr>
<tr><td>Veh / coil position</td><td colspan="3">Nominal</td><td colspan="3">Worst case</td></tr>
<tr><td>Distance to car edge (or other reference depending on simulation case studies)</td><td>0,2</td><td>0,5</td><td>2,5</td><td>0,2</td><td>0,5</td><td>2,5</td></tr>
<tr><td>Control plane (1 - XZ driver side )</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td></tr>
<tr><td>Control plane (2 - XZ passenger side)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td></tr>
<tr><td>Control plane (3 - YZ Front)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td></tr>
<tr><td>Control plane (4 - YZ rear)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td><td>Worst case zone / Max level (T)</td></tr>
</table>
Same type of template shall be used for stationary and dynamic test at different speeds.</td></tr>
<tr><td>Number of repeats</td><td>As many as necessary to ensure valid measurements.</td></tr>
<tr><td>Limitation</td><td>HSE standards, local constraints</td></tr>
<tr><td>Comment</td><td>Additional points to be studied following simulation investigations.</td></tr>
</table>

## 5.4 Grid impact estimation tests

For grid impact estimation, there will be two specific tests (according to D4.3.2) and in addition, sensing of grid parameters during ALL tests where power transfer is involved.

### 5.4.1 Test 3.1: Grid parameter sensing at PCC

The configuration of grid impact measurements is very similar to the one established for technological verification on component level (WP37) and of integrated test sites (WP46). It is foreseen to install the measurement equipment directly at the power transformer terminals (LV side) or at the input terminals of the grid-tied AC-DC converter.

The main difference at the test sites is that oscilloscopes will only be available for a limited period of time (not for all tests). Therefore, a simple test is defined using wattmeters (in order to monitor power drawn from the grid) and an advanced test is defined assuming availability of oscilloscopes which opens the possibility to analyse more parameters, such as THD, frequency and voltage fluctuations, validating results from laboratory tests (WP37).

**Simple power supply quality assessment:**

At the PCC, wattmeters will be available at the test sites, which enable registration of input power drawn from the grid for all conducted tests. The following parameters will be measured with this device:

- Active power consumption
- Reactive power consumption

From these measurements, the power factor can be calculated. This calculation might be even incorporated in the device.

**Advanced power supply quality assessment:**

Wattmeters are calibrated for grid frequency (i.e. 50 Hz at the test sites) and therefore will not measure possible contributions from higher harmonic components. Therefore, both test sites will be equipped at least temporarily with oscilloscopes in order to monitor high-frequency phenomena at the PCC during the dynamic power transfer process. During these advanced tests, the following grid variables will be observed at high sampling rate:

- 3-phase voltage (3 channels)
- 3-phase current (3 channels)

From the oscillograms of voltage and current, the following parameters for grid impact can be derived:

- Active power consumption
- Reactive power consumption (including contributions from harmonics)
- THD (current and voltage)
- Voltage stability (fluctuations at PCC during tests)
- Frequency

**Table 17: Power supply quality assessment template (simple).**

| | |
|---|---|
| Validation test No | Unique test ID |
| Validation test name | Input power |
| Date | |
| Test team | |
| Purpose | Test for input power in order to ensure that the prototype output meets specification. |
| Parameter(s) measured | |
| Target (standard; requirements etc.) | Unity power factor and active power according to specifications |
| System under test | Grid-tied AC-DC converter (supply to primary power transfer coil/rail) |
| Tool requirements | Wattmeter (active/reactive power) for all tests. |
| Test conditions (ambient temp, surface etc.) | Ambient temperature, normal operating conditions |
| Test methodology | Use test rig to align the primary and secondary coil with a specified air gap.<br>Measure active and reactive power at the AC input on the primary side. Power factor will be calculated from these measurements. |
| Health and Safety | Valid for ALL tests: Test to be carried out in the test zone, safe distance away from all the personnel. Take extra care with the metallic components around the power transfer equipment. |
| Expected outcome | CRF=25 kW<br>Vedecom= 25 kW |
| Results | CRF=<br>Vedecom= |
| Number of repeats | 3- Ensure the coils are at ambient temperature before commencing a test |
| Limitation | |
| Comment | Input power should be measured at the point where the equipment is connected to the grid. |

Table 18: Power supply quality assessment template (advanced).

| | |
|---|---|
| Validation test No | Unique test ID |
| Validation test name | Advanced Input Power |
| Date | |
| Test team | |
| Purpose | Detailed characterisation of wave forms of input current and voltage for detailed analysis of THD, power factor and voltage/frequency fluctuations |
| Parameter(s) measured | Instantaneous AC Current and Voltage |
| Target (standard; requirements etc.) | Unity power factor, Active power according to specifications, nominal voltage and frequency, THD below 8%.<br>Grid: EN 50160<br>Equipment: IEC 61980-1, IEC61000 |
| System under test | Grid-tied AC-DC converter (supply to primary power transfer coil/rail) |
| Tool requirements | Oscilloscope |
| Test conditions (ambient temp, surface etc) | Ambient temperature, normal operating conditions |
| Test methodology | Use test rig to align the primary and secondary coil with a specified air gap.<br>Measure current and voltage at the AC input on the primary side with an Oscilloscope for a number of tests (still to be defined). Nominal and non-nominal conditions are desirable (misalignment, reduced power transfer, etc.).<br>Based on the oscillograms, system parameters such as power factor, THD and frequency are calculated.<br>Possible fluctuations of frequency and voltage are documented. |
| Health and Safety | Valid for ALL tests: Test to be carried out in the test zone, safe distance away from all the personnel. Take extra care with the metallic components around the power transfer equipment. |
| Expected outcome | THD and power factor should be in line with system specifications and coherent with results from simple |

| | |
|---|---|
| | power supply assessment. No voltage or frequency fluctuations are expected. |
| Results | CRF=<br>Vedecom= |
| Number of repeats | 3- Ensure the coils are at ambient temperature before commencing a test |
| Limitation | Oscilloscopes will only be available for some selected tests. A special test series should be selected to be carried out with this advanced equipment in place. |
| Comment | As the equipment is connected to the public grid, it is not expected that the power drawn by the WPT equipment might have any sensible impact on network voltage or frequency.<br>The equipment might be affected by voltage or frequency fluctuations coming from the grid. Therefore, both will be monitored here.<br>In the unlikely case that large fluctuations are observed, this will be documented in order to identify possible effects on the equipment. Also, additional teste might be necessary in this case, to make sure that test conditions are acceptable.<br>Current legislation for harmonic distortion is very permissive. Local DSOs might have stricter requirements or if a dedicated MV grid is considered, requirements might even be relaxed. The standards (EN 50160, IEC61000) are an important orientation, but might not be the only criterion to be taken into account thinking of a large-scale implementation (-> WP5). |

**Table 19: Dynamic behaviour assessment template.**

| | |
|---|---|
| Validation test No | Unique test ID |
| Validation test name | Dynamic behaviour |
| Date | |
| Test team | |
| Purpose | To validate dynamic behaviour of the whole system under abrupt speed variations of the vehicle (acceleration and braking on the test track) |
| Parameter(s) measured | |
| Target (standard; requirements etc.) | Grid: EN 50160<br>Equipment: IEC 61980-1 (→ IEC 61000-3-11) |
| System under test | Power transfer system as a whole |
| Tool requirements | Oscilloscope |
| Test conditions (ambient temp, surface etc) | Ambient temperature, normal operating conditions |
| Test methodology | The vehicle will accelerate and brake on the test track and all electrical parameters (Voltage, current, frequency, THD, input power) will be monitored. |
| Health and Safety | See "Input power" test |
| Expected outcome | Possible transient effects (power transfer fluctuations) |
| Results | |
| Number of repeats | At least one acceleration and one braking test is needed (desirable 3) |
| Limitation | |
| Comment | Within the consortium, no previous experience is available regarding dynamic behaviour of the WPT system. Due to the high frequencies (> 20 kHz) of the coupling field, no major effects are expected, but this thesis has to be confirmed in practice.<br>Tests will be conducted under advanced power supply quality assessment conditions (see above). |

### 5.4.2 Test 3.2: Power modulation

This test is for validation of power modulation functionality of the WPT system. For all tests, grid parameters are monitored, although here the main objective is to validate the functionality of ICT modules with impact of power transfer (DSO module and load balancing system). The test comprises the following 4 test runs:

1. Reference: Power transfer at nominal power
2. EV demands 120% of nominal power (test if system limits to 100%)
3. DSO module reduces power to 80% (test if power is actually reduced to 80%)
4. Load balancing control reduces from 100% to 80% during charging process

The first test is for validation of normal power transfer, in order to establish a reference.

The second test introduces a failure from EV side, demanding more power than available from the WPT system. This might be also a normal situation, as charger and vehicle should establish a negotiation prior to the charging process (similar to static charging). At the end, it will be verified if the system handles correctly this situation and 100% power is provided.

The third test validates the functionality of the DSO module, which is to reduce maximum available power from the WPT system if needed. In this case, a limitation to 80% is proposed for the test. In this case, it is a foreseen action and the EV should be informed about this limited power transfer BEFORE the power transfer is started (eventually, giving an option to the driver to abort the whole charging procedure).

Finally, the fourth test will validate the load balancing module, which should be able to change transfer power DURING the power transfer process. This emulates an unforeseen event (emergency).

**Table 20: Power modulation reference test template.**

| | |
|---|---|
| Validation test No | Unique test ID |
| Validation test name | Power modulation reference test |
| Date | |
| Test team | |
| Purpose | To create a reference of normal functionality of the system |
| Parameter(s) measured | |
| Target (standard; requirements etc.) | WPT system requirements |
| System under test | FABRIC Power management |
| Tool requirements | Oscilloscope (power measurements) and data acquisition from power management module |
| Test conditions (ambient temp, surface etc) | Ambient temperature, normal operating conditions |
| Test methodology | Test run with all parameters at standard |
| Health and Safety | See "Input power" test |
| Expected outcome | All systems work properly and 100% of power is transferred |
| Results | |
| Number of repeats | 1 (to be repeated if anything fails) |
| Limitation | |
| Comment | |

**Table 21: Vehicle excess power demand test template.**

| | |
|---|---|
| Validation test No | Unique test ID |
| Validation test name | Vehicle excess power demand |
| Date | |
| Test team | |
| Purpose | To validate that the WPT system still provides 100% of available power, even if the vehicle demands more |
| Parameter(s) measured | |
| Target (standard; requirements etc.) | WPT system requirements |
| System under test | FABRIC Power management |
| Tool requirements | Oscilloscope (power measurements) and data acquisition from power management module |
| Test conditions (ambient temp, surface etc) | Ambient temperature, normal operating conditions |
| Test methodology | Test run with the vehicle demanding 120% of nominal power of the WPT system |
| Health and Safety | See "Input power" test |
| Expected outcome | All systems work properly and 100% of power is transferred. Possible notification to the driver. |
| Results | |
| Number of repeats | 1 (to be repeated if anything fails) |
| Limitation | |
| Comment | |

**Table 22: Foreseen event: Power reduction from DSO module test template.**

| | |
|---|---|
| Validation test No | Unique test ID |
| Validation test name | DSO power reduction |
| Date | |
| Test team | |
| Purpose | To validate proper reduction of transferred power if the DSO module requires a reduction |
| Parameter(s) measured | |
| Target (standard; requirements etc.) | |
| System under test | DSO module |
| Tool requirements | Oscilloscope (power measurements) and data acquisition from power management module |
| Test conditions (ambient temp, surface etc) | Ambient temperature, normal operating conditions |
| Test methodology | Test run with DSO set point at 80% of nominal power |
| Health and Safety | See “Input power” test |
| Expected outcome | All systems work properly and 80% of power is transferred. The driver is notified in advance and given the option to abort the whole power transfer process. |
| Results | |
| Number of repeats | 1 (to be repeated if anything fails) |
| Limitation | |
| Comment | |

**Table 23: Unforeseen event: Power modulation while charging test template.**

| | |
|---|---|
| Validation test No | Unique test ID |
| Validation test name | Power modulation while charging |
| Date | |
| Test team | |
| Purpose | To demonstrate the capability of the WPT system to change transferred power dynamically |
| Parameter(s) measured | |
| Target (standard; requirements etc.) | |
| System under test | Load Balancing System |
| Tool requirements | Oscilloscope (power measurements) and data acquisition from power management module |
| Test conditions (ambient temp, surface etc) | Ambient temperature, normal operating conditions |
| Test methodology | Test run with a defined power profile (to be specified) |
| Health and Safety | See "Input power" test |
| Expected outcome | All systems work properly and power transfer changes during the charging process |
| Results | |
| Number of repeats | 1 (to be repeated if anything fails) |
| Limitation | |
| Comment | Several profiles might be considered:<br>• Step change<br>• Impulse change<br>• Ramping (up and down) |

## 5.5 Road impact estimation tests

Below are the templates for the collection of test data in order to estimate whether there is noticeable impact on the road/pavement and whether this could limit the functionality of the e-roads. These tests however cannot be considered representative of the technology and the future deployment implementations due to the construction process which was aimed primarily at enabling tests during the FABRIC project lifetime, rather than a long-term operation in real traffic conditions.

In that way, the implementation at the Satory site which incorporates a cement trench for hosting the charging pads, with removable covers to make access during the tests easier is not expected to be realized in realistic deployment conditions thus the road tests cannot provide useful information for feasibility studies but rather a hint on the behaviour of the specific e-road layers under stress. More useful results can be obtained by the Italian e-road which will embed the pads under a layer of asphalt. These results cannot be generalized as well due to the specific experimental construction process and the traffic pattern during the tests which is not representative of normal traffic and the durability of the e-road against time and weather cannot be validated in the long term due to the limited duration of the tests (and the project), however this initial data could be useful for further studies and implementations, especially if problems are detected during this time-limited study.

After the delivery of the e-road in Italy the road will be validated for:

- the type of asphalt used (gradation, bitumen, voids etc),
- asphalt temperatures during laying,
- technique and uniformity of compaction/installation procedures,
- road materials incorporated (unbound materials, asphalt or other).

The above should be found to be consistent with the confidential road construction specifications reported in D4.5.3.

**Table 24: Installation size impact to the road template.**

| | |
|---|---|
| Validation test No | Unique test ID |
| Validation test name | Primary side equipment size |
| Date | |
| Test team | Polito, Saet, Vedecom |

| | |
|---|---|
| Purpose | Measure the size of the equipment installed in the road, the required air gaps, cabling and space around it. What is essential to know is the boundaries of the solution and the stiffness of those boundaries. |
| Parameter(s) measured | |
| Target (standard; requirements etc.) | In the UK SROH 1.8.1 |
| System under test | Primary power transfer unit |
| Tool requirements | Installation drawings |
| Test conditions (ambient temp, surface etc) | |
| Test methodology | Use the drawing the determine the dimensions of the primary side in-road equipment |
| Health and Safety | |
| Expected outcome | Any apparatus that has an external diameter greater than 20mm will not be permitted in the road unless special circumstances exist |
| Results | Saet Spa:<br>Vedecom:<br>Polito: |
| Number of repeats | 1 |
| Limitation | It is very likely that the ground embedded power transfer equipment diameters are greater than 20mm; with that said power transfer equipment can be considered as special circumstances as they are very new technologies and current standards possibly have not considered possibility of installing power transfer equipment's in the ground when it was drafted |
| Comment | |

Table 25: Installation weight impact to the road template.

| | |
|---|---|
| Validation test No | Unique test ID |
| Validation test name | Primary side equipment weight |

| | |
|---|---|
| Date | |
| Test team | Polito, Saet, Vedecom |
| Purpose | Measure the weight of the equipment installed in the road. In order make sure the weight of the power transfer system does not have a negative impact on the road structure. |
| Parameter(s) measured | |
| Target (standard; requirements etc.) | FABRIC specification |
| System under test | Primary power transfer unit |
| Tool requirements | weight measurement equipment |
| Test conditions (ambient temp, surface etc) | |
| Test methodology | Measure the weight of the ground embedded power transfer equipment. Predict the weight to of the material that is being replaced by the ground power transfer equipment. |
| Health and Safety | |
| Expected outcome | The presence of any sub-surface equipment within the road structure should not exceed the weight of the road material that it is replacing, or indeed be significantly lighter |
| Results | |
| Number of repeats | 1 |
| Limitation | |
| Comment | |

**Table 26: Installation's operating temperature impact to the road template.**

| | |
|---|---|
| Validation test No | Unique test ID |
| Validation test name | Operating Temperature |
| Date | |
| Test team | |

| | |
|---|---|
| Purpose | The operating temperature of the equipment is important because if the temperature of the surrounding pavement significantly increases due to the energy emitted from the equipment, this may affect the performance of the bound layers of the road structure under traffic, and lead to possible deformation and long-term damage to the road structure |
| Parameter(s) measured | |
| Target (standard; requirements etc.) | FABRIC specification |
| System under test | Primary power transfer unit |
| Tool requirements | Data logger, thermal camera |
| Test conditions (ambient temp, surface etc) | Thermometer; resistance meter |
| Test methodology | Measure the temperature of the road surface and outer module of the power transfer module during the power transfer event and if possible measure the temperature of the coil.<br><br>It is possible to measure the temperature of the coil by measuring the resistance across the coil and using the temperature and resistance constant value to calculate the coil temperature. The measurements of the coil temperature will be useful to understand whether coil insulation is capable of providing insulation when the system is operating at the limits. |
| Health and Safety | |
| Expected outcome | The operating temperature of the system must not affect the design temperature of the surrounding road materials |
| Results | |
| Number of repeats | 3 |
| Limitation | Some of the systems may not be covered by the road surface layer; in that case only measure the temperature at the outer module. However, not being able to cover the power transfer equipment with the road surface layer may result in easy escape to any heat that is |

| | |
|---|---|
| | generated by the power transfer equipment as it is in direct contact with the open air; some form of insulation material can be used to simulate the road surface. |
| Comment | |

**Table 27: Installation's impact to skid resistance template.**

| | |
|---|---|
| Validation test No | Unique test ID |
| Validation test name | Skid Resistance |
| Date | |
| Test team | |
| Purpose | To ensure that the installed systems do not become an accident risk. |
| Parameter(s) measured | |
| Target (standard; requirements etc.) | FABRIC specification |
| System under test | Primary power transfer unit |
| Tool requirements | |
| Test conditions (ambient temp, surface etc) | |
| Test methodology | |
| Health and Safety | |
| Expected outcome | Should be same as road surface it is replacing for buried equipment. A surface with a skid resistance lower than that of the surrounding road surface, should be avoided. |
| Results | |
| Number of repeats | 1 |

| | |
|---|---|
| Limitation | |
| Comment | |

Table 28: E-road robustness under braking conditions assessment template.

| | |
|---|---|
| Validation test No | Unique test ID |
| Validation test name | Road robustness |
| Date | |
| Test team | |
| Purpose | To assess the robustness of the constructed e-road under vehicle braking conditions at various speeds |
| Parameter(s) measured | |
| Target (standard; requirements etc.) | FABRIC specification |
| System under test | Primary power transfer unit |
| Tool requirements | Visual inspection |
| Test conditions (ambient temp, surface etc) | |
| Test methodology | Vehicle accelerates to the specific speed and then brakes abruptly on top of a road segment that has charging pads embedded. |
| Health and Safety | |
| Expected outcome | Pavement to withstand the forces exerted from braking. No visual indications of rutting, cracking or other abnormalities. |

<table>
<tr><td>Results</td><td>
<table>
<tr><td></td><td colspan="2">Road integrity after braking (pass/fail)</td></tr>
<tr><td>Vehicle speed (km/h)</td><td>SAET</td><td>POLITO</td></tr>
<tr><td>20</td><td></td><td></td></tr>
<tr><td>30</td><td></td><td></td></tr>
<tr><td>50</td><td></td><td></td></tr>
<tr><td>60</td><td></td><td></td></tr>
<tr><td>80</td><td></td><td></td></tr>
</table>
</td></tr>
<tr><td>Number of repeats</td><td>1</td></tr>
<tr><td>Limitations</td><td>The speed that the vehicle can reach due to the length of the testing track and safety concerns.<br>The weight of the vehicle.</td></tr>
<tr><td>Comment</td><td></td></tr>
</table>

In addition, the temperature and weather conditions should be monitored after the delivery of the roads with coils embedded. This monitoring should allow correlation of environmental conditions with potential pavement abnormalities that may appear (e.g. cracking, debonding) and provide information relevant to the robustness of the selected materials and embedding procedure, under normal environmental conditions.

**Table 29: Installation's operating temperature impact to the road template.**

| | |
|---|---|
| Validation test No | Unique test ID |
| Validation test name | Environmental conditions monitoring |
| Date | |
| Test team | |
| Purpose | The ambient temperature and environmental conditions (snow, ice etc) may affect the performance of the bound layers of the road structure under traffic or not, and lead |

| | |
|---|---|
| | to possible deformation and long-term damage to the road structure. The conditions should be monitored for extended time in order to correlate with potential deformations in order to assess the robustness of the pavement to the elements. |
| Parameter(s) measured | Minimum and maximum temperatures, weather phenomena (rain, snow, icing etc) |
| Target (standard; requirements etc.) | |
| System under test | Pavement |
| Tool requirements | Data logger, thermal camera or thermometer |
| Test conditions (ambient temp, surface etc) | |
| Test methodology | Measure the ambient temperature and temperature of the road surface at regular intervals during the day. Make manual note of weather conditions and phenomena. Create a log in order to be able to track back conditions that may have led to pavement deterioration |
| Health and Safety | |
| Expected outcome | The ambient temperature and weather conditions must not affect the integrity of the e-road pavement. |
| Results | |
| Number of repeats | Multiple daily measurements right after the delivery of the e-road. |
| Limitation | |
| Comment | |

# 6 CONCLUSIONS

In this document the common validation methodology to be used in both FABRIC test sites is defined. The aim is to collect test data in a harmonized and standardized manner to allow analysis and comparisons in Task 4.7.3 “Data analysis and validation of the integrated system”. All system stakeholders were included in the process of specifying the performance indicators necessary for the validation and efficiency assessment of the FABRIC system. The definition of data to be collected took into account SP5 requirements to enable the extraction of conclusions for a feasibility study related to large-scale wireless dynamic charging deployment.

The critical parameters that will allow consistent system efficiency measurement were first identified. The tests that were designed by charging solution providers and site operators ensure that the data will be collected in a standardized manner, using the same equipment so as to allow for system comparisons regardless of the differences of the charging solutions and their supporting ICT.

FABRIC’s main R&D focus is on the creation of prototypes for the wireless dynamic charging of EVs, their evaluation in terms of efficiency and safety and, based on the testing results, on estimating the potential that wireless dynamic charging technology has towards large-scale deployment. EV supporting ICT development plays secondary role because it is investigated thoroughly in other EC funded projects and the allocated to ICT resources in FABRIC are very limited. FABRIC ICT development is limited to functions that enable the efficient operation of the charging prototypes, namely load balancing and communication with the grid, optimal alignment with the charging lane and in-vehicle ICT for controlling and monitoring the charging. For the Italian test site, the ICT infrastructure of eCoFEV was utilized and enhanced to support FABRIC. This back-office infrastructure provides functionalities such as identity management, booking, navigation and other ICT functionalities that are essential in case FABRIC is to be commercially deployed. For ICT the validation was in general limited to assuring the correct operation of the various ICT modules rather than measuring performance indicators in detail. However, for the modules developed in FABRIC specific tests were drafted to collect information about the crucial parameters that affect the charging efficiency on a system level.

In order to ensure the highest validity of the test results published in FABRIC documents, a co-validation procedure has been agreed between directly involved partners (CRF/POLITO/VEDE/CIRCE/ICCS). This means that testing methods and results will be reviewed and consolidated in a consensual way amongst involved partners to minimize misinterpretation risks and ensure suitable credibility for further research, development and dissemination of results. Possible modifications of test procedures regarding the proposed

methodology in this deliverable (D4.7.1) will be clearly identified and justified within D4.7.2, where results are presented. Resulting test procedures have the potential to be valuable input for standardization of DWPT, which is still not defined.

# REFERENCES

1. FABRIC Description of Work
2. M. Emre et. al. FABRIC D4.3.2 “FABRIC Test Scenarios”, 2014
3. V-model https://en.wikipedia.org/wiki/V-Model

# 7 ANNEX I – ITALIAN SITE ICT BACKEND VALIDATION

The following paragraphs describe the validation tests for the ICT services supported by the backend at the Italian site. This backend was largely developed in eCo-FEV project to support electromobility services and it was inherited by FABRIC via the common partners (one of them the coordinator of eCo-FEV) with the permission of eCo-FEV consortium and more specifically the partners that developed the corresponding systems.

The backend has been tested in eCo-FEV and the procedures below will take place in order to validate the proper operation of the systems during FABRIC tests. FABRIC is focused on the development of charging technologies (hardware) for dynamic wireless charging and the estimation of their efficiency and safety in order to assess the feasibility of these technologies for large scale deployment, and due to the reduced funding for ICT deployment both test sites have implemented only the services needed for the operation of the hardware i.e. the lane keeping system, the HMIs and the charging management services. The ICT electromobility services at the Italian site supported by the existing backend were considered “nice to have” for future commercial deployment but not essential for the objectives of FABRIC thus they were not replicated at the French test site.

Below are the validation tests for the functionalities of the ICT backend at the Italian test site.

## 7.1 FABRIC Backend

The Backend is envisioned as the gateway between FABRIC and the EV. It will handle all communications with the EV and the end-users and in that way reduce the load for the core FABRIC electric mobility platform.

The following lab and field test description is based on the deliverable D400.1 [5] of the eCo-FEV project. Essentially, the most relevant tests have been selected to be performed also in FABRIC.

### 7.1.1 EV info retrieval

| Test case Id | Test sites: Italy / France/ both | Test case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Italy | Decode EVR message | EVR message is successfully received and decoded | | |
| 2 | Italy | EVR message rate | Receiving rate of EVR reception is identical of EVR transmission | | |

### 7.1.2 Notification Support

| Test case Id | Test sites: Italy / France/ both | Test case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Italy | Encode notification (NOT) message | Notification message is successfully encoded and transmitted | | |
| 2 | Italy | Notification (NOT) message content | Notification message includes required content for receiving vehicle to inform FABRIC users, including notification type, relevant position and time, targeted destination EV. | | |
| 3 | Italy | Notification (NOT) request | The module is able to process request from any Backend component and informs the processing result | | |

### 7.1.3 Charging Infrastructure Info Retrieval

| Test case Id | Test sites: Italy / France/ both | Test case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Italy | Decode CIR status message | Received CIR status message is correctly decoded | | |
| 2 | Italy | Encode CIR info retrieval request message | Backend sends request to charging operator to retrieve CIR info | | |
| 3 | Italy | CIR info retrieval request | The module is able to process request from any Backend component and informs the processing result | | |

### 7.1.4 Field test of the Data Management modules and interfaces

The Data Management module includes the components and databases to store and manage the various data that are necessary for the applications and their components.

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#### *7.1.4.1 User info management*

| Test case Id | Test sites: Italy / France/ both | Test case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Italy | User info access request | The module is able to process user info access request and provides response, if the requesting party is confirmed to be authorised to access the user info database | | |
| 2 | Italy | User info data base update | The module is able to update the user info database | | |

#### *7.1.4.2 Charging Infrastructure Info management*

| Test case Id | Test sites: Italy / France/ both | Test case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Italy | CIR info access | The module is able to process CIR info access request and provides response | | |
| 2 | Italy | CIR info push | The module is able to push the CIR info to requesting component when an update of the | | |

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|---|---|---|---|---|---|
| | | | requesting data is detected | | |
| 3 | Italy | CIR info database update | The module is able to update the CIR info database when received by Backend | | |
| 4 | Italy | Location referencing | The module should convert the location referencing data of the received CIR info message to a location referencing data (i.e. openStreetMap) compliant to the usage of Backend applications | | |

#### 7.1.4.3 Vehicle info management

| Test case Id | Test sites: Italy / France/ both | Test case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Italy | Vehicle info access request | The module is able to process vehicle info access request and provides response, if the requesting party is confirmed to be authorised to access the vehicle info database | | |
| 2 | Italy | Vehicle info data base update | The module is able to update the vehicle info database | | |

### 7.1.4.4 Probe management

| Test case Id | Test sites: Italy / France/ both | Test case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Italy | Probe info access | The module is able to process *probe* info access request and provides response | | |
| 2 | Italy | Probe info push | The module is able to push the p*robe* info to requesting component when an update of the requesting data is detected | | |
| 3 | Italy | Probe info database update | The module is able to update the probe info database when received by Backend | | |
| 4 | Italy | Location referencing | The module should convert the location referencing data of the received VRM to a location referencing data (i.e. openStreetMap) compliant to the usage of Backend applications | | |

### 7.1.5 Field test of the Utilities modules and interfaces

The Utilities module includes utilities and components that support the operation of the high-level applications.

#### *7.1.5.1 Authentication*

| Test case Id | Test sites: Italy / France/ both | Test case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 2 | Italy | User ID acquisition | The module receives request from user to access to an application, then sends request to ask for user ID information. | | |
| 3 | Italy | Check the validity of openID provider | The openID provider as included in user ID is recognised by the requesting application | | |
| 4 | Italy | Redirect user to ID provider | Send information to user in order to redirect him/her to openID provider for authentication | | |
| 5 | Italy | Trust verification | Backend negotiates the trust level with ID providers for a given user | | |
| 6 | Italy | Authentication token verification | Backend verifies the authentication token provided by user for user authentication | | |
| 7 | Italy | Authentication response | Backend provides verification result to user as authentication response | | |
| 8 | Italy | Temp token request | The module sends request to acquire a temp token when requested by an application. | | |

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|---|---|---|---|---|---|
| 9 | Italy | Authorization request | The module sends authorization request to user for authorization to access to user data | | |
| 10 | Italy | Access token request | The module sends request to acquire an access token when requested by an application, after receiving confirmation from user. | | |

#### *7.1.5.2 ID provider and rights management*

| Test case Id | Test sites: Italy / France/ both | Test case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Italy | ID provider | The module provides functionalities and interfaces as defined in openID protocol | | |
| 2 | Italy | User data access management | The module provides functionalities and interfaces as defined in Oauth protocol | | |

### 7.1.6 Field test of the Application modules and interfaces

The Application module includes the high-level applications for the FABRIC Electric Mobility Platform.

#### *7.1.6.1 Event notification*

| Test case Id | Test sites: Italy / France/ both | Test case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Italy | Notification request and response | The module is able to receive user requests for | | |

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|---|---|---|---|---|---|
| | | | notification and sends response to user | | |
| 2 | Italy | Notification message trigger | The module sends notification request and notification content to notification support module | | |
| 3 | Italy | Authentication | The module sends requests to authentication module for authentication. | | |
| 4 | Italy | Event relevance check | The module is able to verify if a detected event is relevant for a user. | | |

#### 7.1.6.2 Booking and cancellation

| Test case Id | Test sites: Italy / France/ both | Test case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Italy | Booking request and response | The module is able to receive user requests for charging station booking and sends response to user | | |
| 2 | Italy | Booking schedule result message | The module sends *booking schedule result* notification to requesting user. | | |
| 3 | Italy | Cancellation result message | The module sends cancellation result notification to requesting user. | | |
| 4 | Italy | Authentication | The module sends requests to authentication module for user authentication. | | |
| 5 | Italy | Booking request | The module is able to send booking request to CI operator and receives response from CI operator. | | |

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|---|---|---|---|---|---|
| 6 | Italy | Booking cancellation request | The module is able to send booking cancellation request to CI operator and receives response from CI operator. | | |

## 7.2 Charging Infrastructure

The charging infrastructure is mainly divided into two cooperating components (or subsystems): the C/S CU of EVSE and the EVSE Operator.

The EVSE Operator subsystem is the backend for the charging infrastructure. It communicates with a set of C/S CUs, for gathering and monitoring status information, and also triggering some actions, such as booking. It implements the Server-side of the AAA for the charging process. On the other hand, it communicates with the Backend for reporting the status of the charging facilities (monitoring) and providing accounting information.

Besides the AAA, booking and monitoring functionalities the C/S CU for CWD includes retrieving the EV's plate number from an Automatic Plate Number Recognition (ANPR) camera on one hand and, using the CAN Bus for communication with the EV the rest of the EVSE components on the other hand.

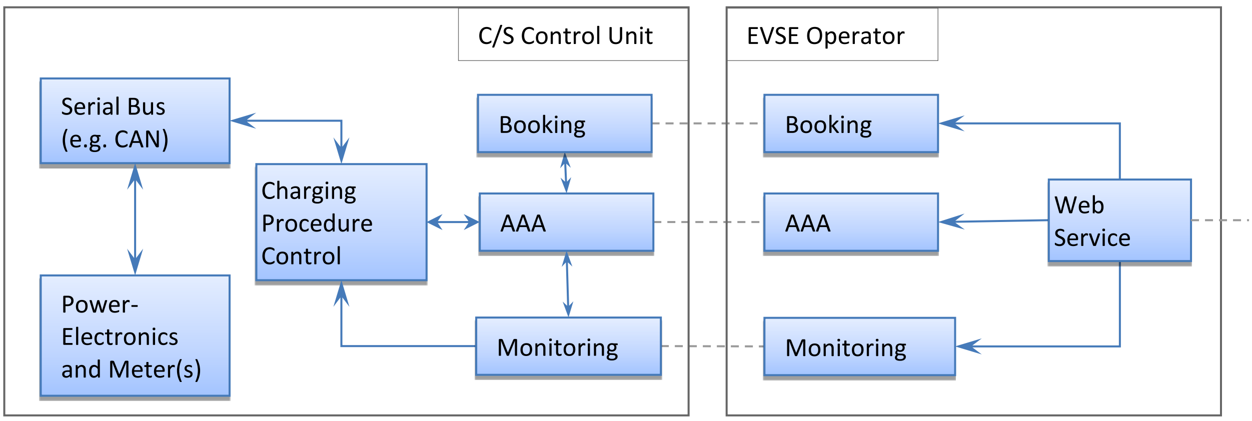


Figure 11: Charging Infrastructure components, spanning over the C/S CU and EVSE Operator entities.

### 7.2.1 AAA Module and Interfaces

The AAA functionality is realised jointly by the two corresponding entities on the C/S CU and EVSE Operator components. Hence, the tests need to ensure that each of those two entities performs the expected tasks properly, and that the interactions between them also fulfil the required functionality. Furthermore, the AAA component interacts with other components within the Charging Infrastructure subsystem, such as Charging Procedure Control (CPC) and Monitoring. These interactions also need to be covered in the subsystem testing.

| Test Case Id | Test sites: Italy / France/ both | Test Case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Italy | C/S CU_AAA ID acquisition | Right ID of EV can be acquired at the AAA frontend | | |
| 2 | Italy | C/S CU_AAA authentication request | Make sure that the interaction between the two AAA components result in either success or rejection, in case the ID is authorised or not, respectively. | | |
| 3 | Italy | EVSE_Operator_AAA authentication response | Make sure that the interaction between the two AAA components result in either success or rejection, in case the ID is authorised or not, respectively. | | |
| 4 | Italy | EVSE_Operator_AAA Accounting | Actually, charged energy in kWh can be determined and retained at EVSE-Operator | | |

### 7.2.2 Booking Module and Interfaces

The *Booking* component is also realised on the two entities, similar to the AAA component; a booking request arriving at the EVSE-Operator's Webservice Component will be routed to the respective Charge point where the CS/CU would lock this charge point for the respective EV ID.

| Test Case Id | Test sites: Italy / France/ both | Test Case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Italy | Booking routing | Booking request (or cancellation) is routed to the respective C/S CU | | |
| 2 | Italy | Booking execution | The C/S CU locks the charge point for the respective EV ID | | |
| 3 | Italy | Booking timeout | The C/S CU cancels the booking in case the EV does not show up at the respective charge point after a given timeout | | |

### 7.2.3 Monitoring Module and Interfaces

The Monitoring Component at each charging station sends status information to the monitoring component at the EVSE-Operator, which in its turn makes this information available to other subsystems using the Web-service component.

| Test Case Id | Test sites: Italy / France/ both | Test Case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Italy | AAA Status | CS/CU sends the AAA status to the EVSE-operator including the logged (charging) in EV ID and their meter values | | |
| 2 | Italy | CPC Status | The CS/CU sends the CPC status to the EVSE operator including the power at which the EV is | | |

| | | | | | |
|---|---|---|---|---|---|
| | | | charging, the internal status of the CPC state, and eventually the electrical failures in case they occur (CB, RCD …) | | |
| 3 | Italy | Booking status | The monitoring component retains the information of the bookings and booking cancellations | | |

### 7.2.4 Charging Procedure Control and Interfaces

The Charging procedure control is implemented on the CS/CU.

| Test Case Id | Test sites: Italy / France/ both | Test Case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Italy | CAN communication to the PE (Road) | Send and receive CAN messages to and from the PE (Road) | | |
| 2 | Italy | CAN communication to the PE (On Board) | Send and receive CAN messages to and from the PE (On Board) | | |
| 3 | Italy | CAN communication to the VMU | Send and receive CAN messages to and from the VMU | | |
| 4 | Italy | ANPR data acquisition | Acquire the plate number from the ANPR camera | | |
| 5 | Italy | Sending monitoring information | Monitoring information available upon request | | |
| 6 | Italy | AAA communication | FADIUS implementation on the C/S CU sends authentication request and accounting messages | | |
| 7 | Italy | State Machine validation | Stand-alone validation of the State Machine | | |

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|---|---|---|---|---|---|
| | | | according to the specification | | |

### 7.2.5 Web Service Module and Interfaces

The Web service module is implemented at the EVSE Operator. Its main responsibility is to provide the Backend with information about the charging infrastructure, after gathering these from the different C/S CUs. It mainly retrieves the information of the EVSE-Operator Components and implements the external interface with the Backend.

| Test Case Id | Test sites: Italy / France/ both | Test Case Description | Expected Result | Actual Result | Remarks |
|---|---|---|---|---|---|
| 1 | Italy | Information retrieval from the EVSE-Operator Component | Necessary Information available at the EVSE-operator components are represented at the web service component | | |
| 2 | Italy | Interface with the Backend | Web service implementation for pushing the status changes of any charge point to the Backend | | |