FABRIC

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

Verification methodologies

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LIST OF SELECTED ABBREVIATIONS

ABBREVIATION	DESCRIPTION
DSO	Distribution System Operator
EMC	Electromagnetic Compatibility
EMF	Electromagnetic field
HSE	Health, Safety and Environment
LV	Low Voltage
OEM	Original Equipment Manufacturer
WP	Work Package
WPT	Wireless Power Transfer

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EXECUTIVE SUMMARY

The objective of this deliverable is to propose a common testing methodology to verify in a laboratory environment that the FABRIC prototype charging solutions meet their specifications. The main focus of the tests is to verify charging efficiency under different operating conditions. Secondary requirements are to determine interference from the charging systems with the electrical grid, the temperature of the devices during operation, the generated EM field with respect to health effects, and the EMC with regards to the vehicles.

Tests will be performed at the nominal operating conditions of each charging prototype. Additionally, the effect of any misalignment between primary and secondary devices, of partial input power and of a moving secondary device will be analysed.

No standards currently exist with regards to verification and testing of dynamic wireless charging systems. Therefore, the planned tests, described in this document, are designed utilising the consortium's knowledge and expectations. It can be expected that the proposed methodology will have to be updated and fine-tuned during the actual tests, according to the characteristics of each charging prototype and the specifics of each laboratory environment. The findings and lessons learnt, as regards the detailed methodology, may be submitted to relevant standardisation working groups for their consideration.

It has to be stated that the laboratory testing equipment and testing environment is not fully representative of operational conditions, as the tests involve a number of prototype charging systems. However, the proposed verification tests provide a common basis for collecting comparable data, with regards to performance of the charging prototypes in a laboratory environment. These results will be compared later with data collected under real operational conditions.

1 INTRODUCTION

This deliverable is the first deliverable of WP3.7, Technological Verification, of FABRIC, entitled “Verification methodologies”. The objective of the work presented in this deliverable is the methodology and procedures to be followed, in order to test the FABRIC prototype charging solutions against their specifications.

Three different prototypes for wireless charging of electric vehicles are being developed in FABRIC (Saet, Polito and Vedecom). The prototypes have been designed so that power transfer takes place under different driving conditions, from urban to highway speeds. The verification results from a fourth prototype will be made available to FABRIC, to create a bigger basis for the feasibility studies in SP5. In more details, a prototype from the VICTORIA project which enables the static, stationary and dynamic wireless charging of an urban bus, will be verified using the methodology proposed in this document.

The verification tests in this Work Package will be conducted in a laboratory environment and will involve the bare prototypes, without them being installed in the vehicle or in the pavement. The verification of the charging prototypes in real operating conditions, when installed in the vehicle and in the pavement, will be conducted at the project test sites during WP4.6 of the FABRIC project. Therefore, parameters relevant to the installation of components or monitoring the interaction between components and pavement will be addressed in WP4.6 and are not considered in the present document, which only aims to verify the prototypes functioning at laboratory conditions.

The main aim of the tests within WP3.7 is to verify that the FABRIC prototype charging solutions meet the specifications regarding power transfer. There are further verification tests planned using the laboratory power test equipment, to verify the prototypes’ interference with the electricity grid, with the rest of the vehicle components and with the road, with regards to their dimensions and operating temperature. Since the prototypes will be “bare”, only some limited EMF and EMC measurements will be conducted, mainly to ensure the safety of personnel who will conduct the verification tests within WP4.6, and an initial check for vehicle compatibility.

Figure 1 shows the dependencies for WP3.7. The verification work is based on the specifications developed within WP3.4. The work will be also based on the design of the charging solutions, as described in WP3.6. The proposed methodology will be the basis for the verification tests to be conducted in WP3.7 and the analysis and recommendations work, which will be documented in D3.7.2 of the project.

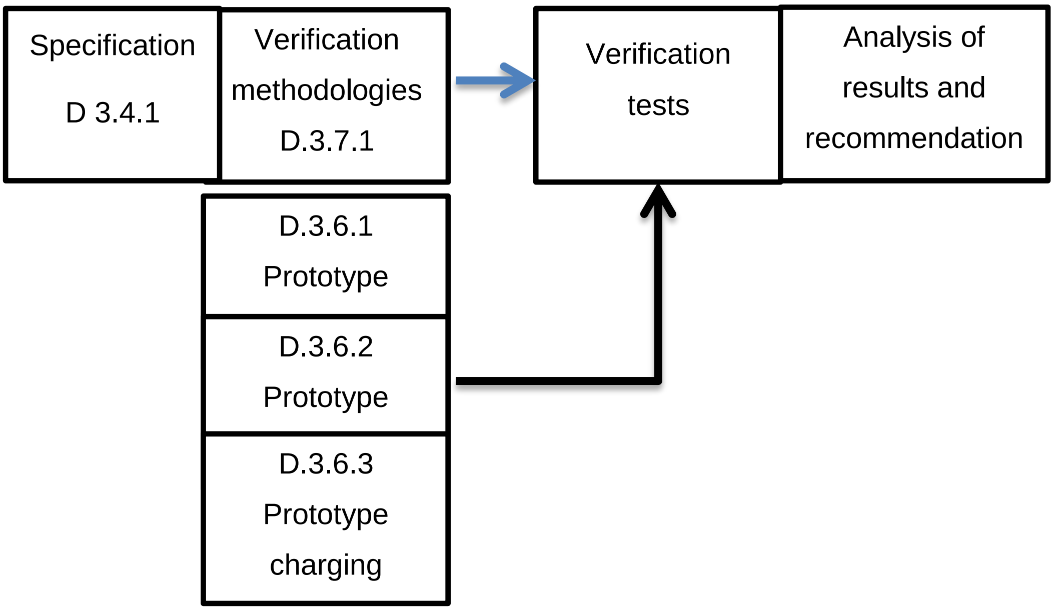


Figure 1: WP 3.7 technological verification dependencies

It must be noted, that some small adjustments were done in the verification methodology by Vedecom, due to the specificities of their prototype. Due to commercial sensitivity they are presented as a confidential annex to this deliverable.

2 METHODOLOGY

2.1 Objectives of tests

As explained, the purpose of the verification process is to ensure that the prototype design solutions meet the specifications as regards charging which have been described in Deliverable 3.4.1.

Figure 2 shows how technological verification process is implemented in the complete design and development process. The verification test results are compared with the specifications, in order to conclude whether the system under testing meets the requirements. If the system fails to meet the specifications, then recommendations will be fed back to the design and development phases, in order to improve the design and ensure that the final prototype meets the specifications. The purpose of the verification phase is, in fact, to verify the system against its specifications, while the validation phase is meant to test the system against the user needs and requirements.

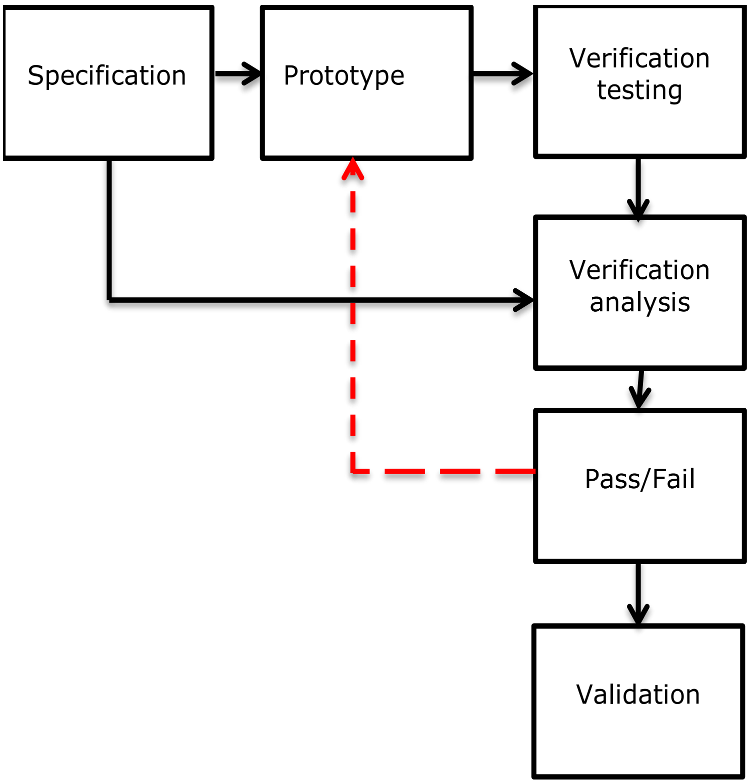


Figure 2: Verification methodology process

A main aim of the work in this WP is to develop a harmonised verification methodology that will be applicable and followed for all charging solution prototypes in FABRIC, so that the data sets from similar tests are comparable across the prototype solutions. It must be noted that to the consortium's knowledge there is no standard available as regards the testing and verification of non-static inductive charging systems. In May 2016, SAE TIR J2954 was approved for publication and it provides (among others guidance) for testing as regards static inductive charging. Given this rather pioneer technological area, the verification tests are currently designed according to the consortium's current views and expectations. It is probable that during the actual verification tests, the planned methodology may have to be adapted and fine-tuned, to better serve the objectives of the work, according to the specificities of each prototype and the limitations of a laboratory environment.

The experiences collected during the tests will lead to recommendations of how these tests should be carried out.

2.2 Categories of tests

The planned verification tests are split into the following main categories:

- **Power transfer system verification:** These tests focus on the wireless power transfer components, aiming to verify their performance in terms of nominal efficiency and impact of misalignments on their efficiency.
- **Grid interference verification:** These tests focus on studying the impact of the charging prototype operation on the total harmonic distortion, on the power factor (reactive power consumption) and on the voltage fluctuation. It has to be noted that the laboratory tests will involve only one charging system and will employ a power load and not a battery, so the results have to be considered with care. Even more so if active loads are employed as in this case, the effects on interference will be even higher. Still, these tests may provide a first overview of the expected impact.
- **Impact on road and vehicle verification:** These tests will record the size and weight of the components of the charging systems and will analyse their temperature during operation.
- **EMF verification:** These tests aim to get a first overview of the generated EM field and to ensure that there will be no risk for the operators during the completion of tests in WP4.6.

Additional, EMC verification tests are planned, aiming to give a first overview of the generated EM field and to ensure that there will be no risk for the car control system during the complete tests in WP4.6. The methodology and limited results will be delivered by the car manufacturer.

The tests proposed in the next chapters are a collection of tests that can be conducted with the FABRIC prototypes in a laboratory environment. All the proposed tests are described using a common template, providing the following information for each test:

- Purpose
- Target, i.e. the applicable specifications from D3.4.1 or from available standards, if any
- Tool requirements
- Ambient conditions
- Test procedure
- Measurements and calculated variables

2.3 Coordinate system

For a common reference, it is very important to define the coordinate system and point of origin utilized for testing and presentation of results.

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.

From this point of origin, the positive X direction is towards the rear of the vehicle, the positive Y direction is towards the left side of the vehicle, and the positive Z direction is up vertically towards the roof of the vehicle.

Therefore, the secondary coil is also chosen as the reference frame 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.

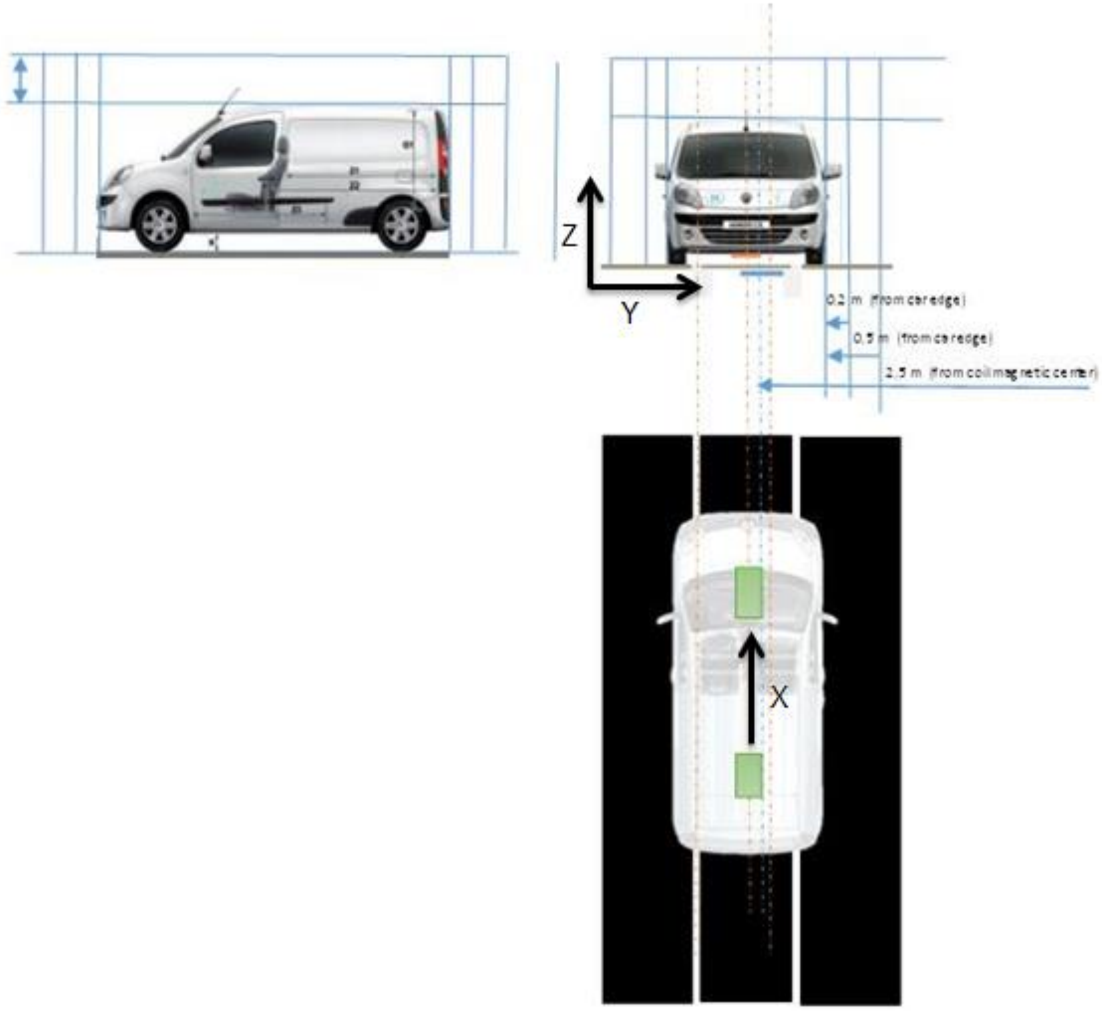


Figure 3: Coordinate system

2.4 Test conditions

The main aim of the verification tests within WP3.7 is to measure several key parameters 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.

For this, the majority of the envisaged tests will be conducted in **five** different **test conditions**. See Table 1 for verification tests.

A. **Nominal value of parameter at static charging:** Initially, the nominal value of each parameter, 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.

B. **Impact of misalignment:** Each parameter will be then measured during wireless power transfer while the primary and secondary devices are misaligned in the y axis. For this condition, the secondary coil will be moved in the y-axis at 50 mm intervals, until a maximum of 200 mm. In each test, the devices will be static at nominal air gap and at nominal power level.

C. **Impact of air gap:** Similarly, each parameter will be measured during wireless power transfer while the primary and secondary devices are not be in their nominal air gap. For this condition, the secondary coil will be moved in the z-axis, and measurements will be taken at +- 50 mm (up or down) for each y-axis misalignment. In each test, the devices will be static at ideal x-axis alignment and at nominal power level.

D. **Impact of power level:** The values of parameters will be measured during wireless power transfer at partial values of the nominal power level, for example at 60%. In this condition, the primary and secondary devices will be static, at ideal alignment conditions and at nominal air gap.

E. **Moving secondary:** The values of parameters will be measured during wireless power transfer, while the secondary is moving at a steady speed, with respect to the primary. Since the tests will be done in a laboratory environment, this movement will be at a low speed (very low speed 10 km/h), but will give an indication of what can be expected in real operating conditions. In this condition, the primary and secondary devices will be at ideal alignment, at nominal air gap and at nominal power level.

Table 1: Verification tests

Test ID	Z (vertical direction) (mm)	Y(Horizontal direction) (mm)
T.1.1	0	0
T.1.2.1	0	50
T.1.2.2	0	100
T.1.2.3	0	150
T.1.2.4	0	200
T.1.2.5	0	-50

T.1.2.6	0	-100
T.1.2.7	0	-150
T.1.2.8	0	-200
T.1.3.1	-50	0
T.1.3.1.1	-50	50
T.1.3.1.2	-50	100
T.1.3.1.3	-50	150
T.1.3.1.4	-50	200
T.1.3.2	50	0
T.1.3.2.1	50	50
T.1.3.2.2	50	100
T.1.3.2.3	50	150
T.1.3.2.4	50	200
T.1.4 (60% power)	0	0
T1.5 (secondary Moving)	0	0

In order to impose different misalignments and air gaps between the primary and secondary coil, a movable structure is required. In the Polito laboratory, where the Polito and Saet prototypes will be verified, the experimental setup shown in Figure 4 has been built. The structure is composed of a fixed part that emulates the ground pavement, and over which three primary/transmitting coils and a movable structure that emulates the vehicle are placed. The movable structure contains the receiving coil with the aluminium shield allowing the reproduction of different conditions of positioning at three directions. It also enables one to perform dynamic tests at very low speeds. This will help to predict the system efficiency in dynamic conditions and verify the automatic procedure of vehicle detection and transmitting coil activation; one of the major problems in dynamic wireless power transfer. It is obvious that differences will exist between laboratory testing and testing in the test sites. For

example, due to the steel vehicle chassis modifying the distribution of the electromagnetic field, the vehicle vibrations and uneven road conditions, all of which cannot be easily simulated in the laboratory. However, tests in a laboratory environment under known and repeatable conditions will provide comparable data, enabling evaluation of different WPT technologies.

Figure 4: Movable structure available in the POLITO laboratory

A similar test rig will be used by Qualcomm Halo Vedecom, enabling the secondary coil to move at a speed of up to 10 km/h.

In the VICTORIA project, laboratory tests will be carried out at CIRCE (Zaragoza) with a fully equipped bus, also enabling dynamic testing.

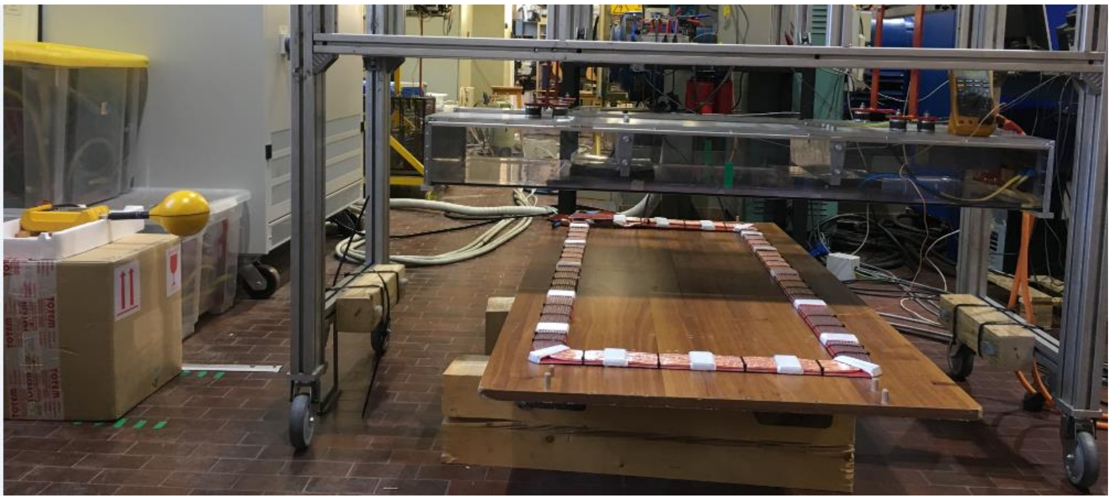


Figure 5: Polito Solution 200mm offset

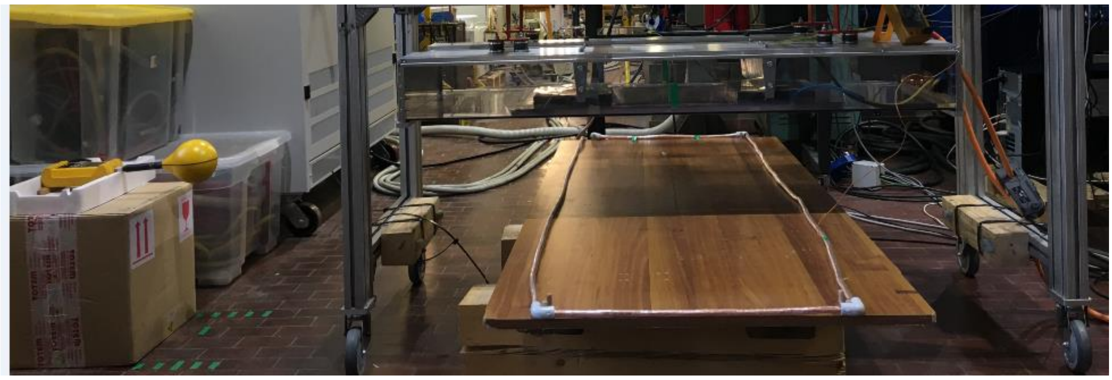


Figure 6: SAET solution

Figure 7: Laboratory test setup for CIRCE solution (VICTORIA)

Figure 8: Laboratory test setup within the bus while testing at CIRCE

2.5 Test procedure

For each test condition, data recording starts as soon as the power is on.

Data recording will continue for 400ms for test conditions A to D and for as long as the secondary is moving, for test condition E.

The duration of data recording for 400 ms is indicative. The prototypes have been designed to transfer energy while the vehicle is moving at around 80 km/h. Considering the size of the primary device this means that each coupling between primary and secondary devices will last around 0.01 to 0.1 s. Thus the test duration for conditions A to D has been set at the order of 400 ms.

The measured data will be stored at an adequate sampling frequency and the values of the required variables will be calculated.

Measurements whilst in the transient phase will be specifically analysed.

Each of the proposed tests will be repeated 3 times. The primary and secondary devices should be at ambient temperature before the start of each of the three tests.

All tests should be carried out in a designated test zone; namely there should be a safe distance between the tests and all personnel, which has been validated by EMF measurement and specialist engineers. Particular care should be taken with the metallic components around the power transfer equipment.

3 POWER TRANSFER

3.1 Test set-up

The main objective of these tests is to verify the efficiency of the power transfer at nominal conditions and to analyse how this will be affected by misalignments between the primary and secondary devices and by reduced input power. A further objective is to get an initial idea as to the impact secondary device movement has on the efficiency of the system.

Figure 3 presents the layout of a generic WPT system according to IEC 61980-1.

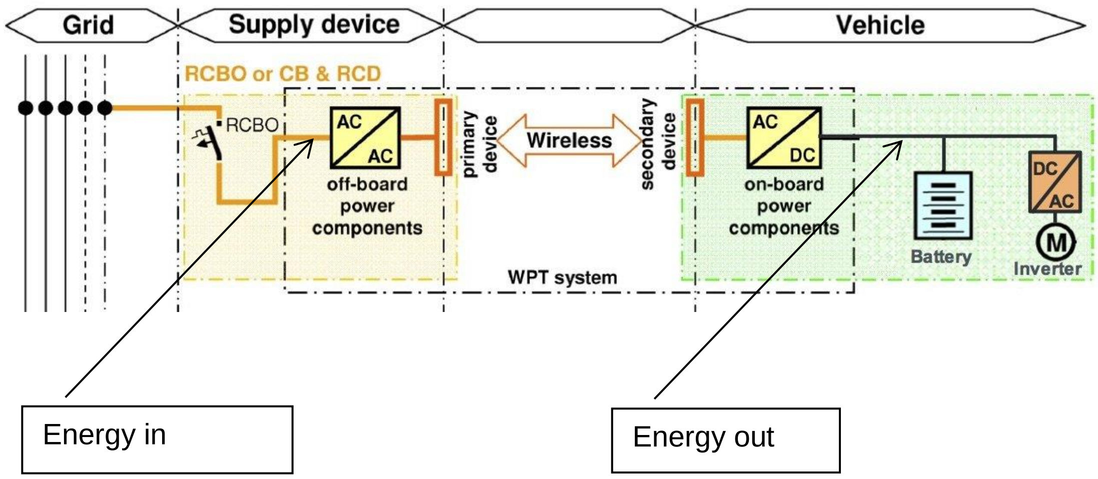


Figure 9: General WPT System to be considered (Source: IEC 61980-1), input power (Pin) and output power (Pout) are indicated.

The IEC 61980-1 standard defines the system efficiency as being calculated between the AC power supply, Energy $_{in}$ at grid connection point, and the DC vehicle side, Energy E_{out} at battery or other device. Additionally, the system efficiency may be measured as a DC-DC power conversion, considering that the AC grid will be converted in a DC voltage source, thus focusing on the efficiency of the wireless power transfer system itself and excluding the losses incurred in the commercial roadside AC-DC convertor, which may vary according to power size and cost. The nominal efficiency is calculated when the system is located in the optimum operating position (or nominal operating point) and it operates at nominal power.

The following figure shows a more detailed test bench layout, indicating locations where each variable measurement is needed to calculate the energy transfer efficiency. No detailed wiring diagram is provided at this stage, as all the testing

laboratories are quite different and with different equipment availability. The detailed test bench configurations, including a list of all equipment (brand, measuring limits, etc.) will be provided along with the test results in D3.7.2.

In one implementation the voltage was measured by using a Voltmeter and oscilloscope; the current was measured by using a transducer and the wave forms were recorded on an oscilloscope. All the data was monitored using a Gen7ta data acquisition system. The sampling rate was 2MHz and sampled current and voltage measurements were used to calculate the RMS value over a waveform.

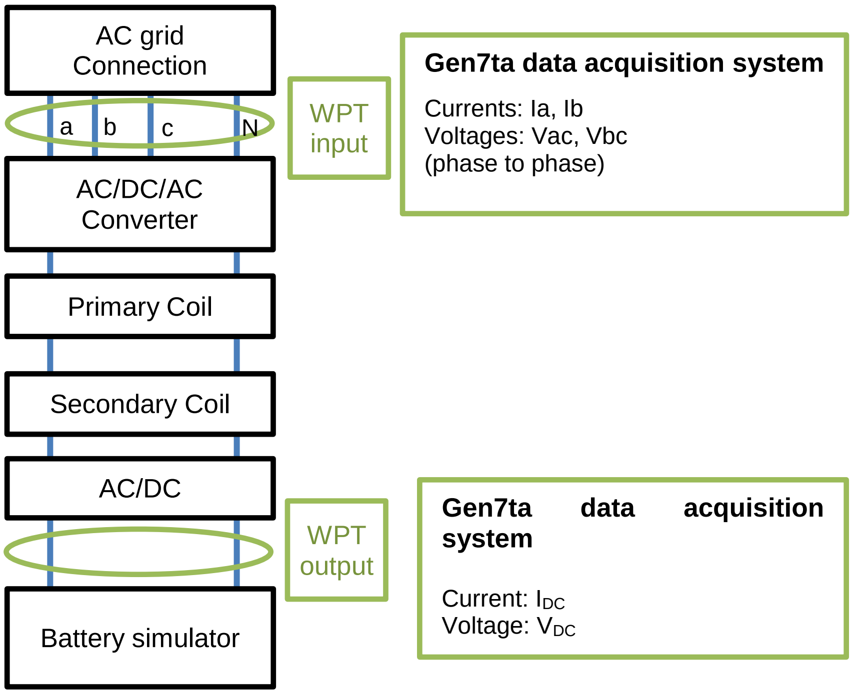


Figure 10: Test bench diagram for measuring energy transfer efficiency (Polito).

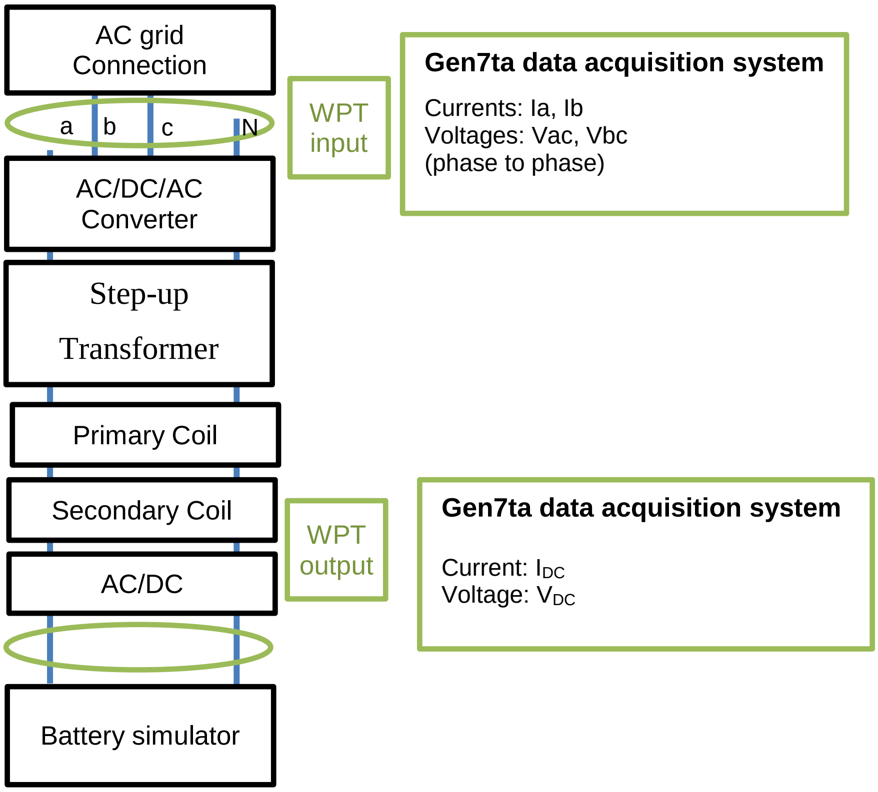
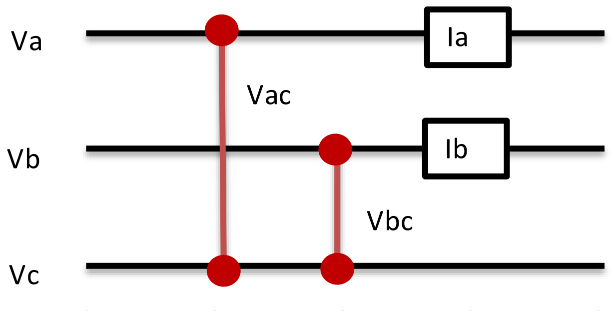


Figure 11: Test bench diagram for measuring energy transfer efficiency (Saet).

The other conditions for efficiency measurements are:

- AC grid should be able to provide required voltage and current at required frequency and phase
- Input power should be measured before power factor correction
- Output load voltage and power should be at specified value
- The system should be warmed up. The solution should be switched on and off several times
- The battery should not be fully charged (charge up to 70-80% because trickle charging towards the end of the charging will have an impact on power transfer rate from the charger)

3.2 Verification tests

Verification test name	**Energy transfer Efficiency**
Purpose	To calculate the systems nominal efficiency and the effects due to misalignments, due to movement of the secondary and due to variations in the input power level
Target	The nominal system efficiency should be at least 80%.
Tool requirements	Oscilloscope, voltmeter, transducer (OLEM IT 200-S Ultrastab) and Transient data recorder
Ambient conditions	Ambient room temperature (should be recorded)
Test procedure	• Align the primary and secondary device at x and y axes according to the test condition (A, B, D). • Switch on power at nominal value. • For test conditions A, B, D measure and record the input and output voltage, current (or power in case of wattmeter) for 400 ms. • For test condition E, initiate movement of the secondary, switch on power and measure and record until the end of the movement. In this case, record also the speed of the secondary and the duration of the movement. • Change the air-gap (condition C) and repeat A, B, D. • Each test has to be repeated three times. • Measure phase to phase voltage Vac and Vbc. And current Ia and Ib on the primary side. Measure Vdc and Idc at the AC/DC output of the secondary coil. • Calculate RMS voltage and current • Calculate the total power on the primary side by using Aron Connection method. • Calculate the power on the secondary coil DC output • Calculate nominal system Efficiency as follows: $$\eta = \frac{Pout}{Pin} \times 100$$ $\eta \;\; = efficiency;\ Pout = Power\ out;\ Pin = Power\ in$ • Aron connection is also known as the two wattmeter method. In this method two voltage and current measurements are used to calculate the three phase power; the third phase is used as a reference point for measurements on the first two phases. 

	$$P_{Total} = P_a + P_b$$ $$P_a = V_{ac} \times I_a \times \cos(\emptyset - 30)$$ $$Pb = V_{bc} \times I_b \times \cos(\emptyset + 30)$$ $$S_{Total} = S_a + S_b = (V_{ac} \times I_a) + (V_{bc} \times I_b$$ $$Q = \sqrt{3} \times (Pa - Pb)$$ $$S = \sqrt{P^2 + Q^2}$$ AC input power is referring to RMS values of a single phase (phase-to-neutral voltage and phase current), assuming a symmetric 3-phase system. The tests reports should clearly state if measurements were carried out in all three phases or in just one. In the case that measurements of all three phases are available, the final indicator (active power P) is the sum of the three, otherwise measured power should be multiplied by 3 (as provided in the formula). The phase shift φ is obtained directly from the oscilloscope

A comparison of results of these tests with those from tests in WP4.6 may highlight the effects on efficiency from vehicle vibrations, ambient temperature and uneven road conditions.

4 GRID INTERFERENCE

4.1 Test set-up

Since the laboratory testing within FABRIC will be limited in power, the aim of these tests will be to collect some data as regards the interference of the wireless transfer prototypes with the grid. It should be understood that laboratory measurements cannot precisely reproduce real-world conditions, as observed on the test track. For example, in the laboratory the converter will feed only one primary coil and the secondary load will not be a car battery. Nevertheless, the laboratory measurements will be an important reference for evaluation of results from the test tracks in WP4.6 and WP4.7.

A test bench diagram is shown in Figure 12. All measurements which will be used for the analysis of the system's grid interference will be taken at the grid connection point or "Point of Common Coupling" (PCC). Due to different availability of measurement equipment at the laboratories, several types of grid analysing tools are considered adequate for the planned tests. This diagram is very similar to the one presented in chapter 3 (energy transfer), and actually, the grid impact will be obtained with the same setup, but focussing on the PCC rather than on the efficiency of the energy transfer.

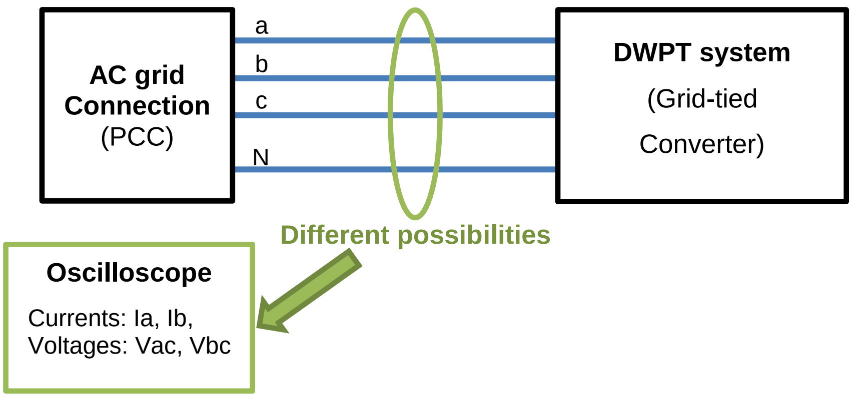


Figure 12: Test bench diagram for grid interference tests

Although each laboratory may have different set-ups, if possible, the grid connection point (PCC) should fulfil the standard requirements at the grid connection point (EN 50160 standard), i.e. the frequency should be within the established range of 50 Hz ±1% and voltage variations should not exceed ±10% of nominal voltage in normal operation conditions.

High-resolution measurements with an oscilloscope are the suggested option, as wave forms can be observed directly and high-frequency phenomena can be captured. Using an oscilloscope, waveforms of currents and voltages will be recorded which contain all information needed for the calculations. Another option is grid analysers, which are very common and can provide relevant power quality indicators. Finally, high-end wattmeters also may be useful, although they provide less information as, for example, voltage fluctuations cannot be measured.

The following grid variables need to be observed at high sampling: 3-phase voltages (3 channels) and 3-phase currents (3 channels). Otherwise, a high accuracy wattmeter should be used.

During actual tests, the methodology below will be updated according to the specificities of each prototype and each laboratory.

4.2 Verification tests

The following test will be conducted for all five test conditions (A, B, C, D).

Verification test name	**Total Harmonic Distortion (THD)**
Purpose	To ensure that the power transfer equipment does not exceed the harmonic limits.
Target	According to EN 50160 and IEC 61000-3-4, the THD should be less than 8% at maximum voltage.
Tool requirements	Oscilloscope
Ambient test conditions	Ambient room temperature (should be recorded)
Test procedure	• Align the primary and secondary device at x and y axes according to the test condition (A, B, C, D). • Switch on power. • For test conditions A, B, C, D, keep recording for 400 ms after power on. • Measure and record voltage and current wave forms. • Use Fast Fourier Transform (FFT) function to calculate the harmonics. • The harmonic distortion during the transient phase is also analysed. • THD will be calculated as follows: $THD_I = 100\,\frac{I_H}{I_F} \quad THD_V = 100\,\frac{V_H}{V_F}$ where: I current, V voltage, subscript H: RMS value of total harmonics, subscript F: RMS value of fundamental component. • Total harmonics will be calculated as follows: $I_H = \sqrt{I_2 + I_3 + \cdots + I_n}$ $V_H = \sqrt{V_2 + V_3 + \cdots + V_n}$ where: I_n, V_n: RMS value of value of the harmonic n, as recorded by the measuring tool. All THD definitions used are referring to a single phase. As the feeding transformer is a 3-phase system, the reports should clearly state if measurements were carried out in all three phases or in just one. In the case that measurements of all three phases are available, the final indicator (THD_I) will be expressed as the mean value of the three.

It must be noted that the current legislation for harmonic distortion is very permissive. Local Distribution System Operators might have stricter requirements or if a dedicated medium voltage grid is considered, requirements might even be relaxed. The standards (EN 50160, IEC61000-3-4) are an important orientation, but might not be the only criterion to be taken into account when thinking of large-scale implementation.

The following test will be conducted for all five test conditions, A to D.

Verification test name	**Power Factor**
Purpose	To quantify the reactive power consumption of the grid-tied converter relative to nominal power and partial nominal power.
Target	Unity Power Factor (no reactive power consumption)
Tool requirements	Oscilloscope or high accuracy wattmeter
Ambient conditions	Ambient room temperature (should be recorded)
Test procedure	• Align the primary and secondary device at x and y axes according to the test condition (A, B, C, D). • Switch on power. • For test conditions A, B, C, D, keep recording for 400 ms after power on. • From the measurements, average power factor is calculated during the entire power transfer interval. • The Power Factor is calculated as follows: $$PF = \frac{P}{S} = \frac{P}{\sqrt{P^2 + Q^2}} = cos\ \varphi$$ Where, P is active power (kW), S is apparent power (kVA), Q is reactive power (kvar) and φ is the phase angle between current and voltage. If wave forms are available, the harmonic distortion can be included in the PF calculation, using total harmonic distortion of the current THD_I, as follows: $$PF = \frac{1}{\sqrt{1 + THD_I^2}} cos\ \varphi$$ If an oscilloscope is used, the Power Factor is obtained by measuring the time difference between current and voltage.

The following test is designed in order to quantify possible short-time changes in voltage, which might imply safety issues if, for example, the power supply is interrupted due to excessive voltage drop.

This test will be conducted at least for one test condition (A). This test procedure is not a separate test by itself, but the calculations may be done using measurements collected during the THD or Power Factor tests. Particularly, if an oscilloscope is used in the THD test, the voltage fluctuations can then be derived.

Verification test name	**Voltage fluctuations**
Purpose	To verify possible voltage fluctuations due to fast variations of power absorbed by the DWPT system.
Target	Voltage fluctuations within permitted limits (EN 50160: Rapid voltage changes +/- 5%)
Tool requirements	Oscilloscope or grid analyser
Ambient conditions	Ambient room temperature (should be recorded)
Test procedure	• Align the primary and secondary device at x and y axes according to the test condition A. • Switch on power (nominal power) for 400 ms and switch off

	again. • Measure and record voltage with available equipment including at voltage before and after the power transfer event. • For this test, also measurements from the THD or Power Factor tests can be used, if oscilloscopes or grid analysers were employed. • From the measurements, RMS values of voltage are obtained. • The voltage fluctuation is calculated as follows: $$\Delta V = 100\% \frac{\frac{1}{N_{\text{off}}} \sum V_{\text{off}}}{\min(V_{\text{on}})}$$ where V_{off} is RMS voltage and N_{off} is the number of data points registered while the WPT is switched off and $\min(V_{\text{on}})$ is the minimum voltage recorded while WPT is switched on. The test report should clearly state if measurements were carried out in all three phases or in just one. In the case that measurements of all three phases are available, the final indicator (ΔV) should be presented for each phase.

It is considered that the worst-case scenario for this test, namely the most severe event during the WPT operation, is the on-off switching of the system (impulse signal). A single charge event might last at most 1 s if the vehicle moves slowly, so the impulse will always be fast. From the grid-side point of view, it is not relevant if the vehicle is moving or not. Also, the misalignment and air-gap are not so important parameters for this test, as they mainly impact the energy flow to the vehicle rather than the power absorbed by the grid. If there occurs some power fluctuation during the charging period, for example due to a bump on the road, the impulse will never be greater than this occurring during the on-off switching, so the test covers the worst case scenario, as explained. This statement assumes that the system control algorithms will prevent the system from absorbing higher power from the grid than its design value; otherwise the whole WPT system could be at risk.

In summary, the proposed impulse signal for this test will study the maximum possible voltage variations that can be induced by the WPT system. It is worth mentioning that preliminary simulations of the test site grid connections (see Deliverable 4.4.1) revealed that, given the low power levels at the test sites, no major voltage fluctuations are expected. In fact, the test sites were designed exactly with this objective. Also, the impact of power variations on the grid voltage is highly site-specific, as it depends on the grid impedance at the connection point. For example, if

there is a long low-voltage cable from the grid transformer to the WPT power converter, large voltage drops might be experienced by the WPT system, but they will not be experienced by other clients who are connected to that transformer via other lines. Another example would be that the low-voltage transformer is situated at the end of a long medium-voltage line (weak grid conditions). In this case, power variations will result in minimal voltage fluctuations for all clients which are connected to the transformer, as the voltage drop happens in the feeding medium-voltage line.

5 IMPACT ON ROAD AND ON VEHICLE

These tests will measure the size and operational temperature of the prototypes. It must be noted that the final products will be rather different than the prototypes. However, the tests below will provide a first indication about the measured parameters.

Verification test name	**Primary and secondary equipment size**
Purpose	Measure the size of the equipment installed at the road and in the vehicle.
Target	The FABRIC specifications for the road equipment are: Saet Spa: 1.5x0.5 m (LxW) single turn winding Vedecom: 2x0.8 m (LxW) Polito: 100x0.5 m (LxW)
Tool requirements	Length measuring equipment
Ambient conditions	Ambient room temperature (should be recorded)
Test procedure	• Measure the outer dimensions of the primary and secondary devices. • This test can be done in a static condition.

Verification test name	**Primary and secondary equipment weight**
Purpose	Measure the weight of the equipment installed at the road and in the vehicle, to verify the impact on the vehicle weight and on the road structure.
Target	The presence of any sub-surface equipment within the road structure should not exceed the weight of the road material that it is replacing. The system should not significantly alter the vehicle weight, as this will alter vehicle dynamics and will increase fuel consumption.
Tool requirements	Weight measurement equipment
Ambient conditions	Ambient room temperature (should be recorded)
Test procedure	• Measure the weight of the ground embedded and the in-vehicle power transfer equipment. Predict the weight of the material that will be replaced by the ground power transfer equipment. • This test can be done in a static condition.

Verification test name	**Operating Temperature after a fixed time of operation**
Purpose	Measure the temperature of the primary and secondary device at the outer surface of the power transfer module during the power transfer event during a fixed time.
Target	The operating temperature of the system must not affect the design temperature of the surrounding materials at the road and of the vehicle components.
Tool requirements	Data logger. Multi-meter with thermocouple
Ambient conditions	Ambient room temperature (should be recorded)
Test procedure	• This test can be conducted in all five of the test conditions. • Switch power on. • For test condition E, initiate movement of the secondary. • Measure and record temperature at outer surface of primary and secondary device. • For each of the test conditions, A to D, record temperature after 400ms. • For condition E record the temperature until the end of the movement of the secondary. In this case, record also the speed of the secondary and the duration of the movement.

It must be noted, that since the primary modules will not be coated by the road surface layer and the secondary ones will not be in the vehicle, there will be flow of thermal energy to the open air. Therefore, the results of the previous tests will not be indicative of what will really happen in real operating conditions. Still, they may give a first indication of what to expect in real life.

6 EMF AND HSE CONCERNS

6.1 Test set-up

IEC 62980-1 describes an EMF measurement procedure for static WPT which will also be the reference for dynamic measurements. No standard for WPT exists at the present time. However, if any standards or working drafts become available, they will be considered in FABRIC work. The final methodology used at the test sites within WP4.6 and WP4.7 will be used as an input to any relevant standardisation task forces.

Figure 6 presents the different protection areas according to IEC 61980-1, namely:

1) Area of operation (reserved for operation of the device)
2) Transition area (between areas 1 and 3)
3) Public area (area around the chassis silhouette of the vehicle – see below)
4) Vehicle interior (vehicle cabin)

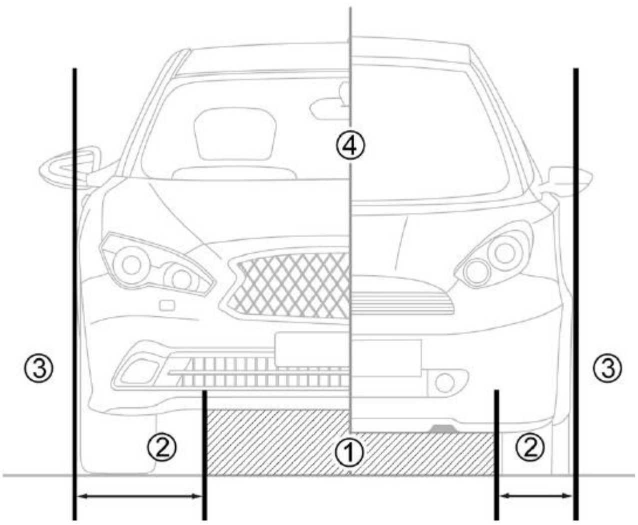


Figure 13: Areas of protection (Source: IEC 61980-1)

It must be noted that the tests in WP3.7 will involve only the charging prototypes, which will not yet be installed in the vehicle. The presence of the vehicle, shield, and ground will change the fields around the system in real operating conditions. Therefore, deviations are expected between the results of WP3.7 and tests with the fully integrated systems in WP4.6 and WP.7. Still, EMF measurements conducted within WP3.7, will be necessary in order to safeguard the safety of personnel conducting the tests in this WP and in the rest WPs of the project.

The tests will be conducted using the set up as described in section 2.4. A safety zone should be defined around the prototype test benches, based on values by the International Commission on Non-Ionizing Radiation Protection (ICNIRP 2010).

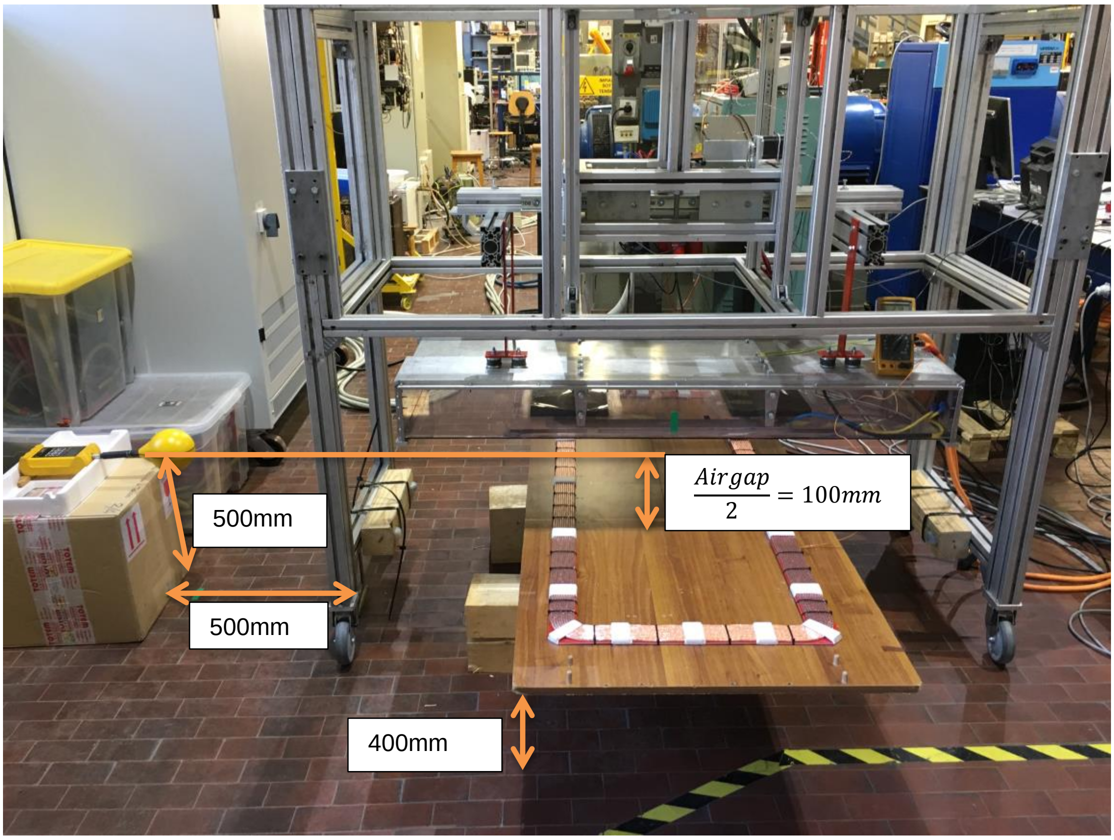


Figure 14: EMF test setup

6.2 Verification tests

The following tests are indicative; the detailed procedure will be defined during conduction of the actual tests.

Verification test name	**EMF**
Purpose	Estimation of the EMF intensity at selected positions
Target	The maximum recorded value should be below 27 μT.

Tool requirements	Field probe according to IEC 62311, for example Narda ELT-400 (1Hz-400kHz).
Ambient conditions	Ambient room temperature (should be recorded)
Test procedure	• Switch power on. • For test condition E, initiate movement of the secondary. • For each of the five test conditions, A to E, scan with the field-probe according to IEC 62311 (100 cm^2 coil area) at the horizontal plane passing from the point (x=0, z = minus half of the nominal air gap) until y = vehicle width + 50 cm. • Continue measurements and recordings until 400ms for conditions A to D or until end of movement for condition E. In condition E, record the speed of the secondary and the duration of the movement. • Record the waveform on oscilloscope. • The ELT-400's scale is 32uT/800mV; this scale is set to achieve the highest accuracy. • The test methodology is derived from ICNIRP 1998,2003 and 2010. • The guidelines suggest the use of weighted peak method for pulsed magnetic fields. • Weighted peak method is equivalent to the application of an high-pass filter to the measured waveforms of magnetic flux density along the three axes. The compliance is measured by calculating the exposure index. • The solution is compliant if the exposure index is below 1. • The fundamental frequency of the solutions is greater than 10kHz, therefore the exposure index can be evaluated according to the formula: $$EI = \frac{\sqrt{B_{x,pk}^2+B_{y,pk}^2+B_{z,pk}^2}}{\sqrt{2}B_{lim}}$$ • Blim is the limit equal to 27uT and Bx,pk, By,pk, Bz,pk are the peaks of the magnetic flux density along each axis
Health and Safety	Test needs to be executed in an isolated zone

As regards EMC, it must be noted that EMC measurements are only meaningful when the components are installed in the vehicle. Such tests will be done in WP4.6. A number of internal tests according to OEMs specifications can be envisioned in WP3.7, to anticipate the possible risks in WP4.6.

7 CONCLUSIONS

This deliverable presents the current consortium plans as regards the verification tests to be performed with the charging prototypes in a laboratory environment. The main objective is to verify the charging efficiency under several test conditions. Secondary objectives are to get an initial impression of the interference of the charging systems with the electricity grid, about the temperature of the devices during operation, about the generated EM field in respect to health effects, and about EMC as regards the vehicles.

No standards currently exist for verification and testing of dynamic wireless charging systems. Therefore, the planned tests, described in the present document, are designed according to the consortium’s knowledge and expectations. Due to the nature of the prototypes, IPR and confidentiality issues have been taken into account in the description of the tests. It is to be expected that the methodology will undergo updating and fine-tuning during conduction of the tests, according to the characteristics of each charging prototype and the specificities of each laboratory environment. The findings and lessons learnt, as regards the methodology, may be submitted to relevant standardisation working groups for their consideration.

It has to be mentioned that the laboratory testing equipment and environment is not fully representative of the charging systems operating in real conditions, even more because the tests will involve prototype charging systems. Still, the proposed verification tests may provide a common basis for collecting comparable data about the performance of the charging prototypes in laboratory environment, which may be later compared with data collected in real operational conditions.

APPENDIX

A1. Equipment-Italian test site

IT-200-S Ultratab. Current Transducer	
Three phase autotransformer (40KVA)	

Gen7ta data acquisition system Transient Data Recorder	
MCTS Signaltec. Current transducer	
Narda ELT-400. Magnetic field Probe	

Battery Simulator	

LeCroy. Oscilloscope	

A2. Equipment – VICTORIA test site

Grid Analyser Dranetz PX5-XFAST	
Oscilloscope Tektronix MSO 3014	
Current Probe FLUKE i1000s Voltage Probe HAMEG Instruments HZ115	 
Magnetic field Probe Narda ELT