FABRIC

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

FABRIC Test Scenarios

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LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
AC	Alternating Current
ANPR	Automatice Number Plate Recognition
DMS	Distribution Management System
DSO	Distribution System Operator
EM	Electro-Magnetic radiation
EMF	Electro-magnetic Field
EMI	Electro-magnetic Interference
ETC	Electronic Toll Collection
EV	Electric Vehicle
GIS	Geographic Information System
HV	High Voltage
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ICT	Information and Communications Technology
LCV	Light Commercial Vehicle
LGV	Large Goods Vehicle
LV	Low Voltage
MV	Medium Voltage
OPF	Optimum Power Flow algorithm
SCADA	Supervisory Control And Data Acquisition
SOC	State of Charge
VMS	Variable Message Sign

REVISION CHART AND HISTORY LOG

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EXECUTIVE SUMMARY

The purpose of this task is to develop Test Scenarios to test the power transfer unit, communications system and integration between all the operators in the FABRIC project. The results from this task will feed into integration of vehicles and test sites, validation and verification of the charging solutions.

The objective of these Test Scenarios is to test the system in “normal use” as well as scenarios where the systems are pushed to their limits to determine maximum operation parameters or uncover any anomalies which do not appear during normal operation.

The Test Scenarios are based on the outputs from the Use Cases defined in a previous deliverable. The Use Cases are stories describing how a system will be used in real life situations.

For each Test Scenario, one or more Test Cases have been developed. Subsequently possible tests, with parameters/metrics that tests should measure or calculate for validation of the solutions, are presented.

The Test Scenarios are divided into three power transfer modes:

- **Static**, where a vehicle is “parked” and will remain so for the foreseeable future.
- **Stationary** (also called opportunistic charging), where a vehicle is stopped for a short time and takes the opportunity to top up the battery charge. This is the typical case of a vehicle stopped at traffic lights, intersections etc.
- **Dynamic**, where the vehicle battery is charged while the vehicle is moving.

In addition, separate scenarios which test the Information and Communications Technology (ICT) elements of FABRIC have been developed.

As different vehicle types have different charging and power requirements, for each of the three power transfer modes, we have considered three vehicle types:

- **Car**: The car is classified as a private passenger vehicle with a maximum mass below 3.5 tonnes;
- **Light Commercial Vehicle (LCV)**: The light commercial vehicle is classified as a commercial vehicle with maximum mass below 3.5 tonnes;
- **Large Goods Vehicle (LGV):** The large goods vehicle is classified as a vehicle with maximum mass above 3.5 tonnes, including buses.

For the stationary and dynamic charging modes, a number of operating scenarios relating to driving conditions have been defined, and these conditions, together with the vehicle types, form the Test Scenarios.

Combining relevant power transfer modes, vehicle types and operating modes, the following Test Scenarios have been defined:

- Static charging mode, on charge point in a car
- Static charging mode, on charge point in a light commercial vehicle
- Static charging mode, on charge point in a large goods vehicle
- Stationary charging mode on a highway in a car
- Stationary charging mode on a highway in a light commercial vehicle
- Stationary charging mode, on the highway in a large goods vehicle.
- Stationary, on urban road, power request from a car
- Stationary, on urban road, power request from a light commercial vehicle
- Stationary, on urban road, power request from a large goods vehicle
- Stationary, dedicated charging location in urban environment, power request from a car
- Stationary, dedicated charging location in urban environment, power request from a light commercial vehicle
- Stationary, dedicated charging location in urban environment, power request from a large goods vehicle
- Dynamic charging mode, highway start-stop in a car
- Dynamic charging mode, highway start-stop in a light commercial vehicle
- Dynamic charging mode, highway start-stop in a large goods vehicle
- Dynamic charging mode, highway congestion in a car
- Dynamic charging mode, highway congestion in a light commercial vehicle
- Dynamic charging mode, highway congestion in a large goods vehicle
- Dynamic charging mode, highway free flow in a car
- Dynamic charging mode, highway free flow in a light commercial vehicle
- Dynamic charging mode, highway free flow in a large goods vehicle
- Dynamic charging mode, urban local in a car
- Dynamic charging mode, urban local in a light commercial vehicle
- Dynamic charging mode, urban local in a large goods vehicle

In addition, the following Information and Communications Technology (ICT) test scenarios have been defined:

- Booking and Reservation, including scheduled and unscheduled availability
- Tariff modulation
- EV identification
- Operator messaging
- Power Transfer Management, including

- Load balancing in static mode
- Load balancing in stationary and dynamic situations.

For each scenario, one or more Test Cases have been defined. Test cases are specific instances of a Test Scenario where a single aspect of the Test Scenario is varied. A Test Scenario can consist of a number of Test Cases, and each Test Case may require a number of tests to evaluate the system. Individual tests measure specific aspects of the charging performance and other characteristics of the integrated system.

The variables considered in Test Cases will be related to the different parts of the charging system, including the grid, the vehicle, the charging infrastructure, the road and the ICT system. The variables to be considered include grid availability, costs, vehicle speeds, material used in roads, alignment etc.

Finally a set of tests has been identified in order to test the response of the systems to the various scenarios. Each test will measure a single quantity; for example, power transferred, efficiency, temperature etc. The tests which have been identified should be considered preliminary and will be subject to change as the project progresses.

1. INTRODUCTION

This report is a deliverable for work package 4, describing task 4.3.2 which will define the Test Scenarios for the charging solutions in the FABRIC Project. The Test Scenarios will be based on tests for ICT, EV back office, charging infrastructure, grid and the road operator. The results from this task will feed into integration of vehicles and test sites, validation and verification of the charging solutions.

The purpose of this task is to develop Test Scenarios to test the power transfer unit, communications system and integration between all the operators. The Test Scenarios will be based on the outputs from the use cases defined in task 4.3.1.

The use cases are stories describing how a system will be used in real life situations. The Test Scenarios will be formed from various Test Cases, testing the system parameters or behaviour. The objective of these Test Scenarios is to test the system in “normal use” as well as scenarios where the systems are pushed to their limits to determine maximum operation parameters or uncover any anomalies which do not appear during normal operation.

This report will define Test Scenarios for both test sites in Italy and France.

The power transfer scenarios are divided into three modes:

- Static, where a vehicle is “parked” and will remain so for the foreseeable future
- Stationary (also called opportunistic charging), where a vehicle is stopped for a short time and takes the opportunity to top up the battery charge. This is the typical case of a vehicle stopped at traffic lights, intersections etc.
- Dynamic, where the vehicle battery is charged while the vehicle is moving

In addition to the three power transfer modes, scenarios are required to test the ICT elements of FABRIC which are independent of charging modes, for example registration onto the system.

The Test Scenarios also include the driving environment and the type of vehicle under investigation and are developed to test the system under various Test Cases. Each Test Case investigates the system by varying a single parameter that could have an influence on system behaviour; furthermore, Test Scenarios are as flexible as possible, allowing other modes of charging to be incorporated at a later stage.

The tests will be carried out as whole systems to observe the effects of variables in Test Cases on the module under investigation and the whole system as an integrated unit.

The method of measuring or calculating the test parameters and the test procedures are outside

the scope of this deliverable. However, outputs from this task will be used in common validation methodology (WP4.7) and they will form the requirements to make the site suitable for the execution of the tests required.

2. STRUCTURE OF THE REPORT

The report describes the Test Scenario, rationale, Test Cases and possible tests that can be performed. Figure 1 shows the test hierarchy, which shows the Test Scenarios derived from use cases.

The use cases from task 4.3.1 will be used to develop Test Scenarios for communication and power transfer sub-systems. For each Test Scenario, one or more Test Cases will be developed, and subsequently the actual tests which will be run. The task 4.3.2 aims to develop Test Scenarios, possible Test Cases for each scenario and possible test parameters/metrics that tests should measure or calculate for validation of the solutions.

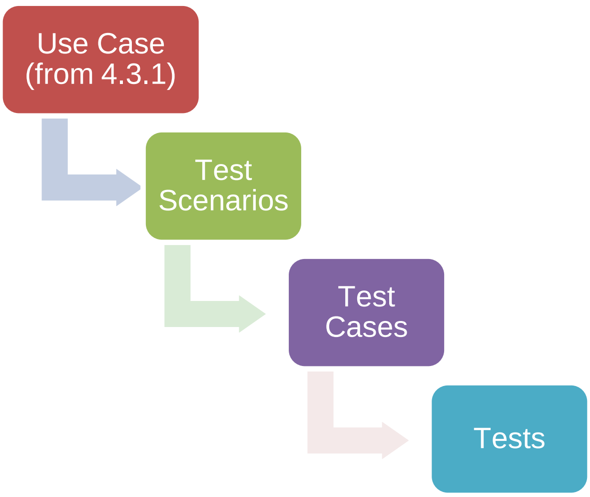

Figure 1: Test Scenario layout

Figure 2 shows the information flow diagram for deliverable 4.3.2. As shown from the diagram, this deliverable will compile input from use cases along with contributions from the grid, charging solutions providers, and ICT solution providers, as well as the test sites to ensure that the sites are able to support the proposed Test Scenarios.

The grid operators will contribute to test definitions, grid requirements and test metric/parameters regarding reliability and availability of power supply. Distribution System Operator (DSO) input

will help to develop scenarios under various grid power supply demand conditions. The charging solution providers will contribute to Test Scenarios regarding power transfer between the infrastructure, vehicle and DSO. This will include Test Scenarios for power transfer, vehicle alignment assistance and load balancing.

The operators of the test sites will ensure the Test Scenarios that are developed can be performed on their site. They will contribute to availability of test equipment, test site plans and the possibility of performing the Test Scenarios.

The ICT solution providers will contribute to communications Test Scenarios, which will include bookings, chargers, guidance, EV recognition, information exchange between subsystems and payment.

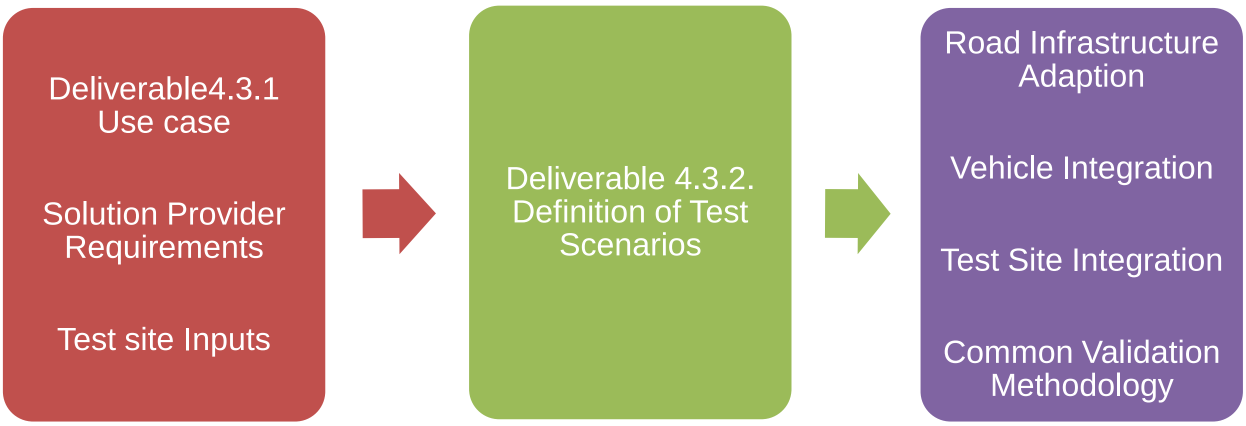

Figure 2: Structure of deliverable 4.3.2

The rest of this report includes an overview of test scenarios, followed by the definition of the test scenarios defined. The subsequent test cases and tests which will be required to evaluate system performance in these test scenarios are then described. The test scenarios are then presented in tabular form for ease of reference, followed finally by the conclusions.

3. TEST SCENARIO OVERVIEW

The Test Scenarios will be identified by considering real life situations as identified in the use cases from which the Test Scenarios will be developed. The aim is to ensure that all the devices and services involved in the charging process operate as intended and within their specified limits. Each Test Scenario will concentrate on a specific mode, driving condition, vehicle type and ICT.

Figure 3 shows the relationship between the Test Scenarios, Test Cases and tests.

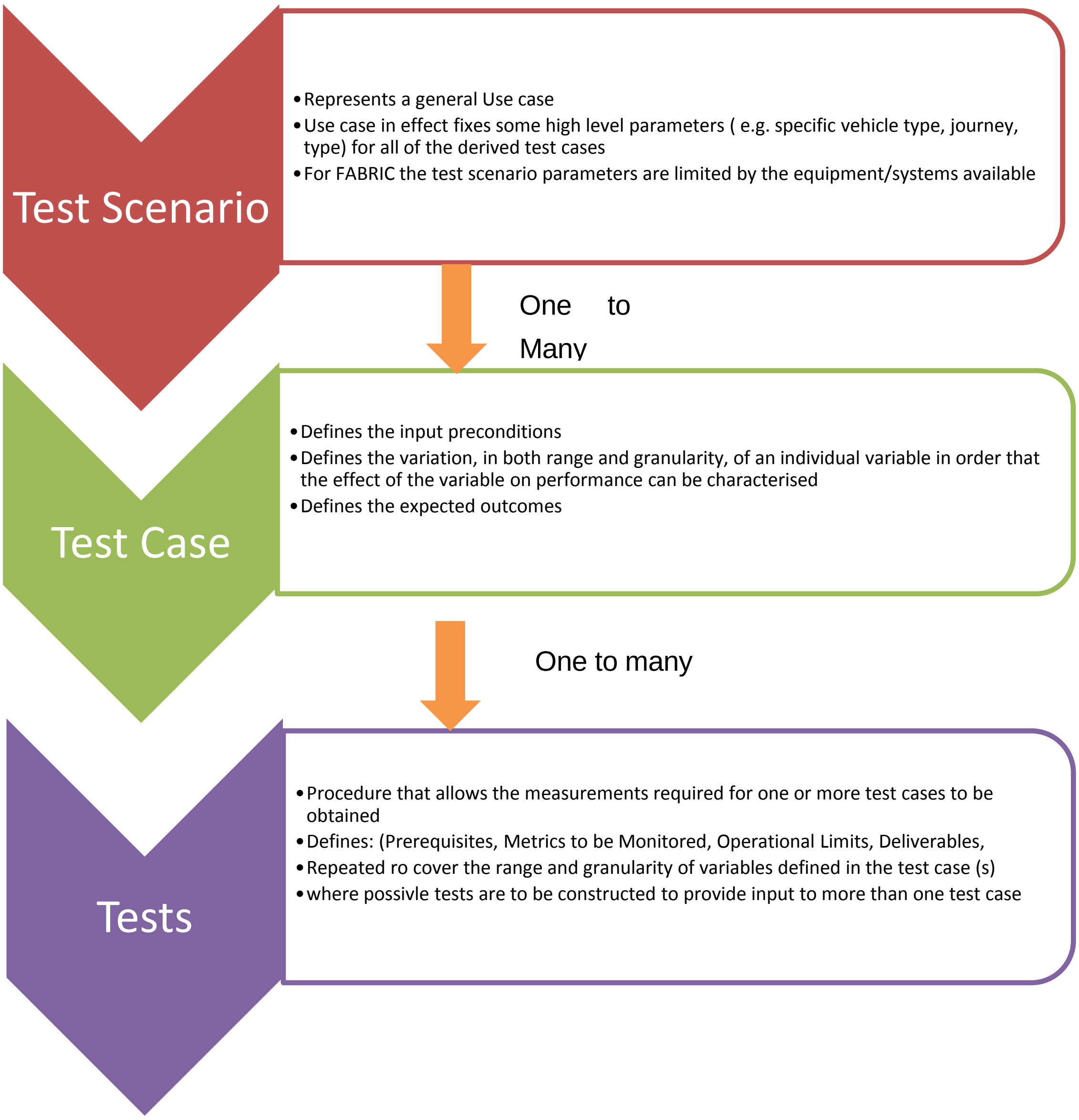

Figure 3: FABRIC testing overview

A Test Scenario represents a general use case: the scenario fixes a variable parameter such as power transfer mode, speed or vehicle type. A Test Scenario can have multiple numbers of factors that can affect the results; in these cases the Test Scenario will be divided into further Test Scenarios by varying a single determinant at a time. For example, maintaining driving condition but varying the vehicle type one at the time. Examples of Test Scenarios would be:

Scenario C.1.1: Dynamic charging of car on a highway in stop-start driving conditions

Scenario C.3.1: Dynamic charging of a car on a highway in free-flow driving conditions

For each Test Scenario, one or more Test Cases will be derived. A Test Case will define the input preconditions, variation and expected outcome. The Test Cases will be formed for each Test Scenario to investigate the behaviour of the systems' response to variations in the grid supply, ICT parameters, vehicle behaviour, and power transfer infrastructure type and pavement characteristics. Examples of Test Cases may be (relating to the Test Scenario example above):

Case 1: Alignment: Receiving coil is perfectly aligned on charging coil;

Case 2: Alignment: Receiving coil is laterally misaligned to charging coil.

For each Test Case, one or more tests will be performed to understand the effect of the Test Case on the charging performance. Typical tests will include the amount of energy transferred, transfer efficiency etc. Some tests will be simple pass/fail tests where the success or failure of a particular action is being measured; for example "has the user succeeded in logging onto the system?"

4. TEST SCENARIO DEFINITIONS

The Test Scenarios have been developed from the use case deliverable and intended use scenarios. In Deliverable 43.1 Use Cases, 8 demonstrable and 5 feasible use cases are identified. Only the Demonstrable use cases are considered for testing. The use cases provide the backgrounds against which the test scenarios are developed. Note though that use cases 2 (driver login) and 3 (user account management) are no longer considered core to FABRIC and will therefore not be tested.

The FABRIC mobility platform acts as central communication link between all subsystems. The system is responsible to reserve bookings, ensure supply of power, notify users and establish communication link between subsystems.

The Test Scenarios section is defined under three power transfer modes related to the type of power transfer (Static, Stationary and Dynamic), and one section related to ICT functions which are independent of the type of power transfer.

For each transfer mode, we define different scenarios based on vehicle type and driving condition. We define 3 vehicle types:

- **Car:** The vehicle classified as a private passenger vehicle with a maximum mass below 3.5 tonnes.
- **Light Commercial Vehicle (LCV):** The light commercial vehicle is classified as a commercial vehicle with maximum mass below 3.5 tonnes
- **Large Goods Vehicle (LGV):** The large goods vehicle is classified as a vehicle with maximum mass above 3.5 tonnes.

Buses are considered a special case of LGVs so will not be considered separately in this project. The LGV category covers a very wide range of vehicles, and buses fall into this wide definition. It is accepted that buses, particularly those serving urban routes, have different usage patterns to other LGVs, they are similar enough from an energy transfer perspective to be considered together. On longer routes, (extra-urban and motorway), there is little difference between usage patterns of buses and other LGVs.

The difference between the three considered types of vehicles will be mainly their maximum charging power levels, which may require different charging infrastructure.

Another aspect that must be kept in mind is that each vehicle may have its own secondary coil design. A direct conclusion for viability is that solutions should be highly standardised. Nevertheless for the proposed test scenarios, this means that each vehicle type comes with a

dedicated solution for primary and secondary coils.

Independently from the vehicle type, the speed of the vehicle is one of the main factors that can affect the amount of energy transferred from the primary coil/loop to the vehicle when it is in dynamic mode.

The energy transferred to the vehicle is higher when the time over the charging unit is longer, so potentially lower speeds are better for dynamic power transfer. However, this will compromise journey times.

The driving conditions are only relevant to the Dynamic power transfer mode.

4.1 Static Power Transfer 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 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.

Figure 4 shows the Test Scenarios for static mode which are:

- Test Scenario A.1.1: Static, on charge point, car
- Test Scenario A.1.2 : Static, on charge point, light commercial vehicle
- Test Scenario A.1.3: Static, on charge point, large goods vehicle

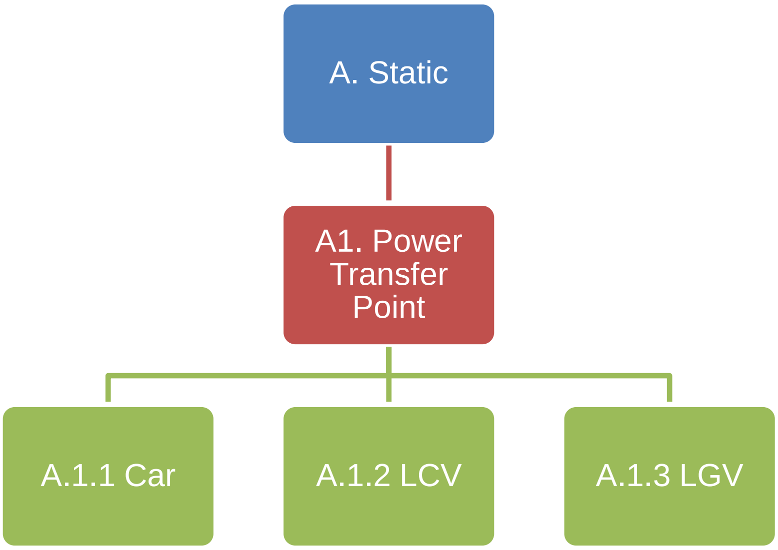

Figure 4: Static Test Scenario

4.2 Stationary Power Transfer 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 is 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.

Figure 5 shows the Test Scenarios for stationary power transfer mode. The Test Scenarios in stationary power transfer are divided into three categories:

B1. Stationary Highway: This Test Scenario is the stationary charging scenario when the vehicle is in stationary mode in the motorway. This is not classified as dynamic start-stop in the highway scenario (see below) even though it is closely related. The two scenarios are kept separate as stationary charging is assumed to terminate as soon as the vehicle moves, while in dynamic charging the system must cope with moving vehicles.

B2. Stationary Urban on road: This is the stationary case when the vehicle uses the power transfer infrastructure embedded in the road; the approach speed tends to be low.

B3. Stationary Urban dedicated: This case indicate stationary mode of charging in separated sections in the urban areas, such as taxi ranks, bus stops etc.

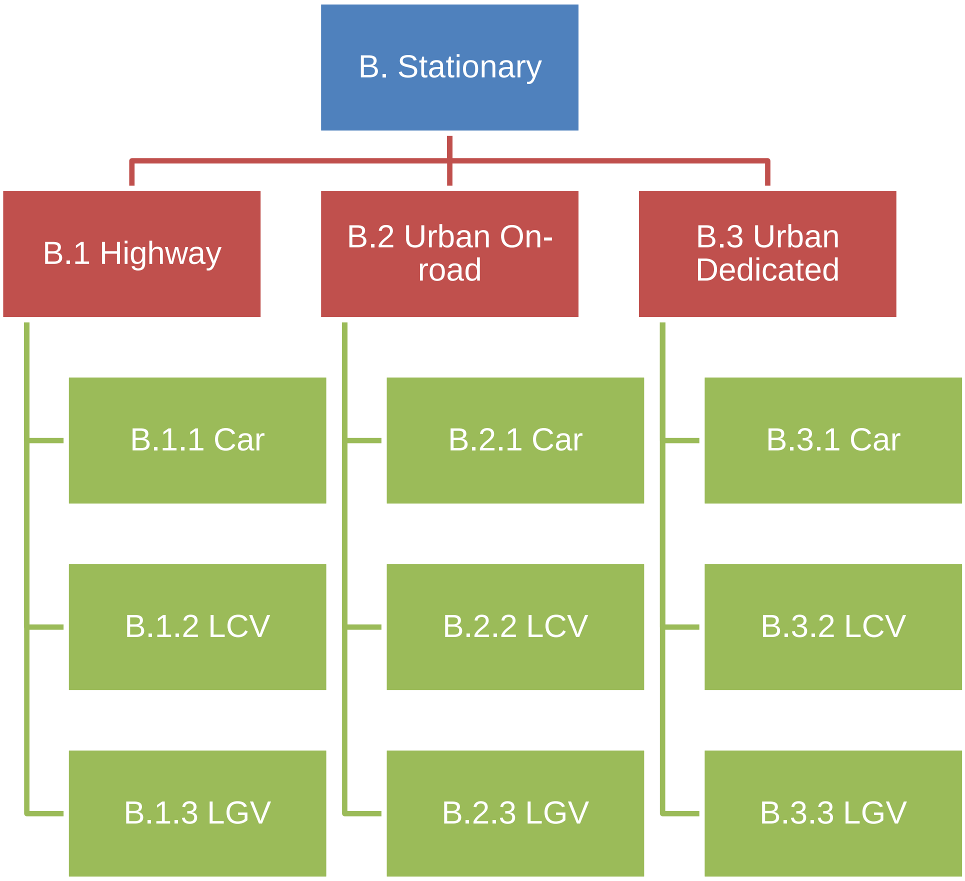

Figure 5: Stationary charging Test Scenarios

Nine Test Scenarios have been identified for the Stationary case, namely;

- B.1.1 Stationary charging mode on a highway in a car
- B.1.2 Stationary charging mode on a highway in a light commercial vehicle
- B.1.3 Stationary charging mode, on the highway in a large goods vehicle.
- B.2.1: Stationary, on urban road, power request from a car
- B.2.2: Stationary, on urban road, power request from a light commercial vehicle
- B.2.3: Stationary, on urban road, power request from a large goods vehicle
- B.3.1: Stationary, dedicated charging location in urban environment, power request from a car
- B.3.2: Stationary, dedicated charging location in urban environment, power request from a light commercial vehicle
- B.3.3: Stationary, dedicated charging location in urban environment, power request from a large goods vehicle.

4.3 Dynamic Power Transfer 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(s), 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 number of variables which will affect the power transfer, such as:

- Alignment
- Speed of the vehicle
- Coupling duration
- Number of vehicles
- 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 (only a few

seconds). 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 has 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;

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

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

Hence:

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

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).

Therefore 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.

This complexity of dynamic systems leads to multi-layer Test Scenarios to analyse numerous possibilities. Figure 6 shows the Test Scenarios under dynamic mode, including the driving environment which is based on speed of the vehicle and the type of the vehicle.

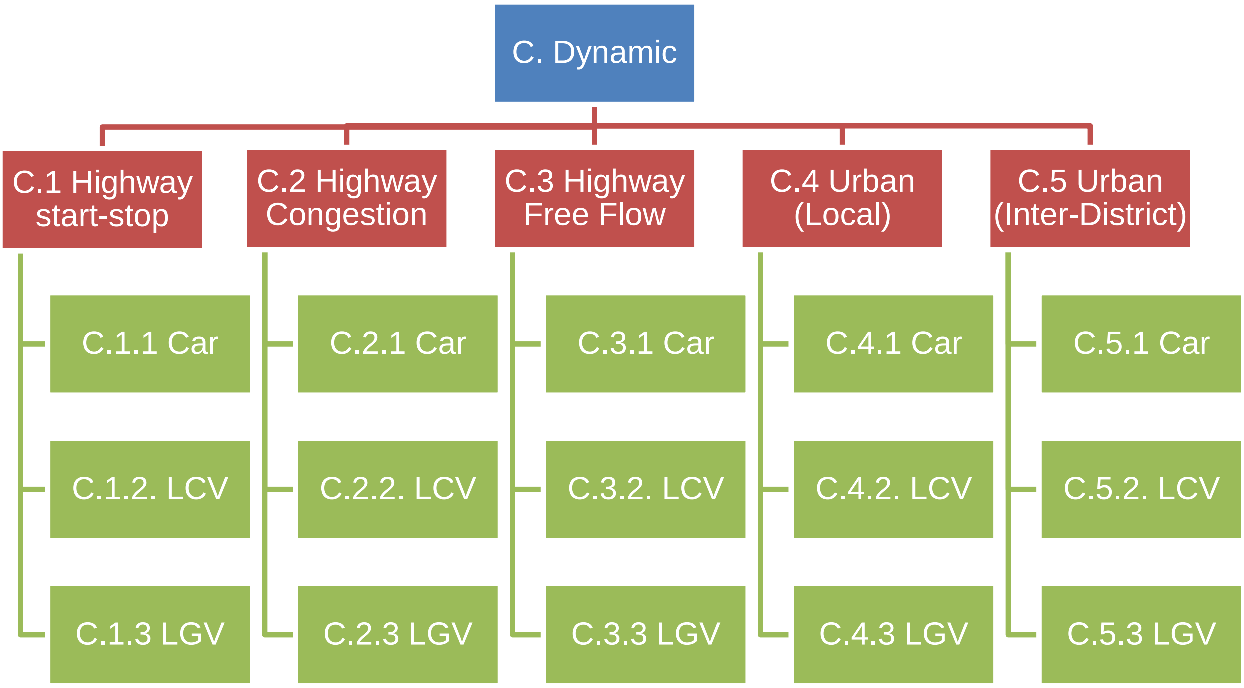

Figure 6: Test Scenarios under dynamic mode

The Test Scenarios in dynamic power transfer mode are divided into five categories:

C1. Dynamic Highway Stop-start: Stop-start case is when the vehicle is moving at a range of low speeds, possibly stand still, in the motorway. The speed of the vehicle can range from 0 km/h up to 30 km/h. the rationale is to simulate a situation when there is heavy traffic due to an obstruction.

C2. Dynamic Highway Congestion: This scenario will model the environment when the vehicle moves at lower speeds than the normally anticipated speed. In the highway case the speed can range between 30 – 80 km/h.

C3. Dynamic Highway Free flow: This is the ideal scenario when the vehicle is attempting to collect energy from the power transfer infrastructure at free flow highway speeds. In the highway environment free flow speed is expected to be 120 km/h for cars in light commercial vehicles and 85 km/h - 100 km/h for heavy commercial vehicles

C4. Dynamic Urban Local: Urban local environment represents congested inner city drive conditions where the speeds are usually around 15 km/h. The speed of the vehicle rarely reaches 50 km/h, which can be considered as free flow speed in urban area. Note that this scenario

includes very variable traffic speeds, including significant acceleration and deceleration, so may require a wide range of test cases.

C5. Dynamic Urban Inter-district: Urban inter-district drive conditions represent the driving conditions in outer city between built up urban areas. The speeds of the vehicles in this area can be between 50 km/h to 80 km/h depending on the type of the road. From a charging perspective, this is very similar to scenario C2; hence it is proposed that this scenario is not included in the tests.

15 Test Scenarios have been identified, namely:

- C.1.1: Dynamic, highway start-stop, car
- C.1.2: Dynamic, highway start-stop, light commercial vehicle
- C.1.3: Dynamic, highway start-stop, large goods vehicle
- C.2.1: Dynamic, highway congestion, car
- C.2.2: Dynamic, highway congestion, light commercial vehicle
- C.2.3: Dynamic, highway congestion, large goods vehicle
- C.3.1: Dynamic, highway free flow, car
- C.3.2: Dynamic, highway free flow, light commercial vehicle
- C.3.3: Dynamic, highway free flow, large goods vehicle
- C.4.1: Dynamic, urban local, car
- C.4.2: Dynamic, urban local, light commercial vehicle
- C.4.3: Dynamic, urban local, large goods vehicle
- ~~C.5.1: Dynamic, inter-district, congestion, car~~
- ~~C.5.2: Dynamic, inter-district, light commercial vehicle~~
- ~~C.5.3: Dynamic, inter-district, large goods vehicle~~

C5 test scenarios have been left here as a placeholder in case it becomes apparent that a separate inter-urban scenario is required, so only the first 12 scenarios are considered further.

4.4 ICT

The ICT Test Scenarios concentrate on cases where the subsystems operation is independent from vehicle type or driving environment. These are usually back office processes taking place before the driver plans a route or exchange of information between EV, FABRIC mobility platform, grid and the road operator.

The Test Scenarios for the ICT sub-system are shown in Figure 7: the ICT Test Scenario is divided in six main groups, a Test Scenario for each subsystem. These are:

D1. User: ICT aspects which affect the system user.

D2. Grid: ICT aspects which are relevant to the grid.

D3. Energy Retailer: ICT aspects which are relevant to the energy retailer.

D4. Road Operator: ICT aspects which are relevant to the road operator

D5. Operations: ICT aspects which are relevant to the day to day operation of the system, mainly from the operative perspective.

D6. Power Transfer Infrastructure Operator: ICT aspects which are relevant to the operator i.e. the power transfer infrastructure.

There are 9 Test Scenarios for the ICT back office;

- ~~D.1.1 User registration~~
- ~~D.1.2 User login~~
- ~~D.1.3 User account management~~
- D.2.1 Booking and Reservation, including scheduled and unscheduled availability
- D.3.1 Tariff modulation
- D.4.1 EV identification
- ~~D.5.1 Operator login~~
- D.5.2 Operator messaging
- D.6.1 Power transfer management, including
    - Load balancing in static mode
    - Load balancing in stationary and dynamic.

Test scenarios D.1.1, D.1.2, D.1.3 and D.5.1 are not considered relevant to the operation of FABRIC and hence will not be developed in this work package. They are kept here as place holder to indicate that in a production system they will be required.

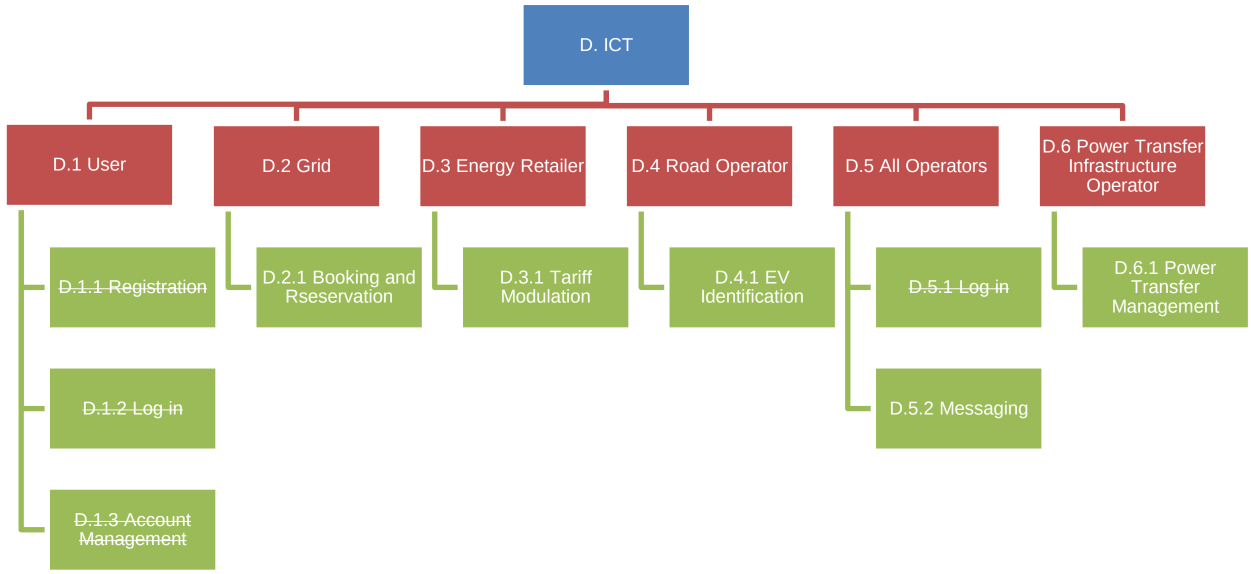

Figure 7: ICT Test Scenario

Each Test Scenario aims to establish a connection to exchange information between responsible parties. Therefore the tests for these scenarios will be based mainly on pass/fail criteria as well as the speed of information processing and exchange.

5. TEST CASES

Test Cases are specific instances of a Test Scenario where a single aspect of the Test Scenario is varied. A Test Scenario can consist of a number of Test Cases, and each Test Case may require a number of tests to evaluate the system. Individual tests measure specific aspects of charging performance and other characteristics of the integrated system. As the metrics required to assess different Test Cases may, in many instances, be identical (e.g. efficiency of power transfer is measured in many different Test Cases), the same tests may be used to implement many Test Cases.

Figure 8 shows the Test Cases applicable for Test Scenarios. These Test Cases are generic in that they may apply to more than one Test Scenario. The Test Cases can be grouped under each sub-system, similar to the ICT Test Scenarios. In this case the Test Cases are grouped under grid, ICT, vehicle, charging infrastructure and the pavement.

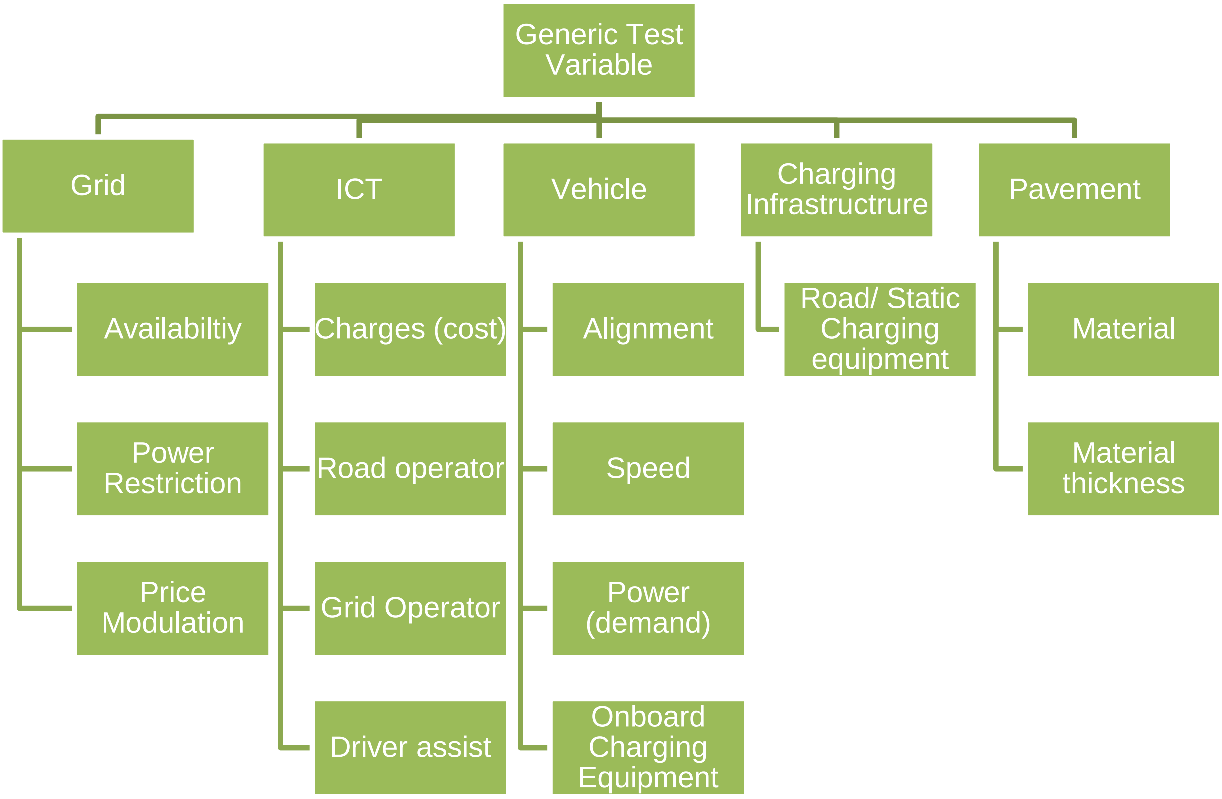

Figure 8: FABRIC generic Test Cases

5.1 Grid

The power Grid's distribution system will be loaded due to concurrent charging sessions across multiple lanes of the charging infrastructure. The test cases will test how the constellation of charging solutions attached to a distribution substation comply with nominal ratings that ensure the reliable and safe functionality of charging systems without detrimental effects on the distribution grid.

Availability

It is expected that multiple charging stations attached to the same distribution system can operate concurrently at the nominal transfer power rate. The overall objective of availability is the ability to supply continuous voltage across feeder terminals. In order to ensure grid availability, the following conditions must be avoided:

- Out of range mains voltage
- Mains loss

The following test cases are proposed:

- Reduced mains voltage: A temporal voltage sag can be produced, similar to wind turbine testing
- Mains loss: Main supply switched off/on

Power system design must be performed in such a way that the probability of these two situations is minimized.

These criteria assess the ability to minimize the unavailability rate of the system due to the employment of availability increase techniques such as:

- **Redundancy:** using looped or meshed grid topologies instead of radial ones.
- **Component level reliability:** allowing quick response if a grid fault occurs ensuring isolation of the fault, looking for an alternative way to feed the largest possible number of loads.
- **Employment of availability technologies and techniques:** using D-FACTS (Flexible AC transmission systems for distributed grids) or storage systems, for example, that helps the distribution grid to act in case of malfunction without disconnection, or in some cases can allow isolated operation.

Power restrictions:

Local power restrictions may apply due to local installation restrictions. Such limitations are taken

into account by the charging infrastructure operator and are reflected in maximum charging power levels. The maximum power charging limit must be equal to the installation's local limit even if the following cases occur:

- The vehicle's maximum charging rate is higher than the local installation's limit
- The maximum power of the charging profile that has occurred due to EV demand modulation as defined in the subsequent paragraph is greater than the local installation limit.

The most interesting feature of the FABRIC system from the point of view of the distribution system operator (DSO) is the ability to reduce at any time the allowed power limit. These temporal modifications are the main objective of the proposed test cases. As described in deliverable D43.1, there will be foreseen and unforeseen events.

Foreseen events will reduce available charging power in a controlled way. For the test case, this means that all charging tests will be done at a reduced maximum charging power limit. The charging infrastructure agrees with the EV charging power according to the standard protocol, with the only difference that the maximum power will be lower.

Unforeseen events require typically very fast (real-time) modifications of the power limit in order to safeguard system stability. In this case, it is possible that during the charging process, power is reduced. This test case applies for static/stationary charge or in dynamic charge when a large number of ground coils are used. In this case, power could be modified from one coil to the next if a sudden change is required by a grid contingency.

The following test cases are proposed:

- Reference cases: operation at nominal (installed) power
    - EV demands more power than available (controlled)
    - Charging profile resulting from demand modulation (see Load Balancing Control) modulation as defined in the subsequent paragraph is greater than the local installation limit
- Foreseen event: Maximum charging power is reduced in a controlled way
    - Test of proper communication with DSO module
- Unforeseen event: Maximum charging power is reduced in real-time
    - Test of power modulation during the charging process

Tariff Modulation

The objective of market based demand modulation is to shift loads in time (during the day) in

order to avoid foreseen grid congestions or to make better use of local distributed renewable generation. Unforeseen events cannot be managed with tariff signals, because of the time the driver needs to react.

Tests at the demo sites cannot capture the behaviour of EV owners who might opt for charging at another hour of the day, because there is a special offer. Therefore, load shifts over the day, induced by tariff modulation cannot be measured. Nevertheless, tariff limits can be implemented in the on-board module of the EV which causes rejection of charging if the price of energy is too high.

The corresponding ICT module is developed and integrated in the FABRIC platform. During the tests, proper functioning of the information flow from the retailer to the FABRIC platform and from there to the driver can be demonstrated.

The following test cases are proposed:

- Low tariff:
    - The retailer module communicates a low tariff to FABRIC
    - The EV module accepts tariff and charges
- Increased tariff:
    - Offered tariff is above the acceptable limit established by the EV
    - The EV module rejects tariff offer and does not charge

5.2 ICT

Fees (cost):

The Test Cases for this Test Scenario are:

- Standard case: tariff is calculated for the user depending on the amount charged, the date/time and special conditions applicable to the users
- Scheduled (on-time) charging: a bonus is applied to the standard case based on the booking request
- Scheduled (late arrival) charging: the bonus is not applied to the standard case based on the booking request because of late arrival
- Overall high-demand charging: the tariff calculation takes into account a high-demand scenarios of many users

Road operator:

The installation of the charging and ICT equipment will take place in a hostile environment when installed on a real road network; however, the test sites do not provide a sufficiently realistic environment to evaluate the effect of large numbers and varieties of vehicles, so no test cases are envisaged for this scenario.

Driver assist:

Driver assist test cases can only be defined for the static and stationary cases at this time. The definition of what can be achieved for driver assistance in the dynamic case will be defined in WP3, and until this is complete development of test cases will not be possible.

The Test Cases for this Test Scenario are:

- Driver follows the assistance procedures with high accuracy
- Driver follows the assistance procedures with low accuracy
- Driver does not follow the assistance procedures
- Driver cancels the charging process

5.3 The vehicle

Test Cases relating to the vehicle fall into three categories, namely Alignment, Power Demand and On-board Equipment. These are described below.

Alignment: The alignment cases will test vehicle misalignment conditions. The alignment of the vehicle with the charging infrastructure can, in the static case, be assisted by the power transfer unit and controlled by the user. Therefore it forms a good Test Case to develop series of tests to analyse the system. In the case where the solution provided does not include alignment sensing, the test cases will still be valid (possibly more so, as misalignment is more likely to occur) to measure the effect of misalignment. The Test Cases for this Test Scenario are:

- Perfectly aligned
- Lateral misalignment
- Longitudinal misalignment
- Rotational misalignment
- Angular misalignment

The perfectly aligned Test Case assumes the alignment assist is active and the aim of the test is to analyse the power transfer infrastructure when the primary and secondary coils are coupled perfectly to maximise power transfer. This Test Case will act as a reference to other Test Cases, and it will be used to compare the impact of the variations on the power transfer. The Test Case

will measure parameters such as the power transfer efficiency, energy transferred and EM exposure. This Test Case is applicable for static, stationary and dynamic power transfer modes.

The lateral misalignment Test Case will test for the vehicles when its position is misaligned by *x* metres to the side when compared to perfect alignment. This Test Case aims to analyse the transfer efficiency, EM exposure and effect of misalignment on operation of the equipment. This Test Case is applicable for static, stationary and dynamic modes; however, special measures may have to be taken to ensure that the vehicle misalignment is constant throughout the tests.

The longitudinal misalignment aims to test the system when the coupling is offset in front to back direction. This Test Case is applicable for static and stationary power transfer modes only.

The rotational Test Case is the set up when the vehicle is rotated at an angle; this Test Case is specially aimed at static chargers. It may not be possible for the driver to park on the primary coil in a straight line, so this Test Case will park the vehicle on the chargers at an angle and observe the system behaviour. This Test Case is applicable for static and stationary power transfer mode.

The angular misalignment Test Case will test for the system when the ground module and the pickup coil in not parallel; this can be caused by uneven road or different tyre pressures. This Test Case is applicable for static and stationary power transfer mode.

Speed: The speed of the vehicle is one of the main factors that can affect the amount of energy transferred from the primary coil/loop to the vehicle when it is in dynamic mode. The energy transferred to the vehicle is higher when the time over the charging unit is longer and, although lower speeds are ideal for dynamic power transfer, this may not be desirable as it will increase the duration of a journey.

Within each of the scenarios identified, a range of speeds is defined. The use cases will define a range of speeds at which tests will be undertaken within the speed range specified.

- Highway Stop Start case is when the vehicle is moving at very low speeds possibly stand-still on the motorway. The speed of the vehicle can range from 0 km/h up to 30 km/h.
- Highway Congestion case will model the environment when the vehicle moves at lower speeds than normally anticipated. The speed can range between 30 km/h - 80 km/h.
- Highway free flow speed is the expected cruising speed of the vehicle without any obstruction. In the highway environment free flow speed is expected to be 120 km/h for cars and light commercial vehicles and 85 km/h - 100 km/h for medium/heavy goods vehicles.
- Urban local environment represent congested inner city driving conditions where the speeds are usually around 15km/h. The speed of the vehicle rarely reaches 50 km/h,

which can be considered as free flow speed in urban area.

- Urban Inter-district drive represents the drive conditions in the outer city. The speeds of vehicles in this area can be between 50 km/h and 80 km/h depending on the type of the road.

Power (demand): When a vehicle is attempting to draw power from the infrastructure, there will often be a mismatch between what the vehicle wishes to draw, and what the infrastructure is willing (or able) to supply. We assume that the infrastructure has specified that rate at which energy can be transferred and we will call this the agreed power transfer rate as this may be less than the maximum possible power that the infrastructure can supply for operational reasons.

Test Cases can then be created for variable vehicle power demands.

The proposed Test Cases are:

- Vehicle attempts to draw 50% of agreed power transfer rate
- Vehicle attempts to draw 100% of agreed power transfer rate
- Vehicle attempts to draw 150% of agreed power transfer rate.
  This may have two sub-test cases:
  - Vehicle attempts to draw 150% of agreed power, where this is still within the maximum power capability of the infrastructure
  - Vehicle attempts to draw 150% of the maximum power capability

Power (supply): In this case the pick-up coil rate is held at a specified value but the power available from the primary coil is varied. The test cases for the charging infrastructure are:

- Primary provides 50% of demanded power
- Primary provides 100% of demanded power
- Primary provides 150% of demanded power

5.4 Charging Infrastructure

The on-board and infrastructure power transfer equipment will be supplied by a number of different providers. It is important that the on-board equipment and infrastructure equipment is fully interoperable. The Test Cases will test how each on-board equipment operates with each of the infrastructure providers.

The issue of interoperability is being addressed in SP 3 of FABRIC, and until then test cases for interoperability cannot be finalised. Hence the test cases identified in this section are high-level and subject to revision, once SP3 has reported. SP3 will cover issues of compatibility with respect

to frequency, field intensity and distribution, as well as how the control elements will be addressed.

It is envisaged that the following test cases are covered:

- Communications:
  - Is each vehicle able to establish a communications link with the infrastructure?
  - Can a charging session be established, with full exchange of credentials?
- Power transfer tests:
  - Is power successfully transferred at the negotiated rate?
  - Are fault conditions handled correctly?
  - How is power transfer affected by misalignment?

5.5 Pavement

It is expected that the majority of in-road static and stationary charging equipment will be designed not to be covered by pavement material. However in the case of dynamic charging equipment, it is likely that the in-road equipment (primary charging coils or pads) will need to be covered by pavement material for safety reasons. This Test Case will measure the sensitivity to variations in the road covering type and thickness.

At this stage it is not clear whether these tests will be possible on the test track environments as changing the covering will entail removing the installation which will in turn be costly or even destroy the in-road equipment. This means that each test case will require a new installation which is likely to be prohibitively expensive. Alternative to the test track environments will need to be considered, for example laboratory test installations, simulation etc.

The following test cases have been identified:

Material: This Test Case concentrates on the type and composition of the material used between the primary and secondary coil. The materials that can be tested are:

- Asphalt pavement
- Concrete pavement
- Other road material (if applicable).

Material thickness: The purpose of the thickness Test Case is to study the effect of thickness of the pavement surface between the primary and secondary coils on power transfer rate. It is assumed that each supplier will have an optimum thickness for the covering layer. It is possible that this optimum thickness will not be achievable, either because of local regulations on

pavement thickness, or due to variability at installation time.

These variations are:

- 50% of the optimum pavement thickness
- 75% of the optimum pavement thickness
- 100% of the optimum pavement thickness
- 125% of the optimum pavement thickness.

Considering the different material types, the test cases are as shown in the following matrix:

	Asphalt pavement	**Concrete pavement**	**other**
50% of opt. thickness			
75% of opt. thickness			
100% of opt. thickness			
125% of opt. thickness			

This Test Case will not be applicable where the charging infrastructure is not intended to be covered by a pavement layer.

In addition to the covering layer, the effects on the rest of the road infrastructure need to be considered for example:

- **Defects:** measure the length and width of any cracking generated by the installation
- **Effects on other roadside equipment:** does the installation affect previously existing equipment, for example optical fibre, VMS, traffic signals etc.?

As the test track environment does not constitute a realistic traffic environment (the distribution and volume of traffic will not approach that experience on real roads), these tests will need to be considered only in a future on-road installation.

6. TESTS

The tests are the measurements which need to be taken to evaluate the Test Cases in each of the Test Scenarios, specifying what needs to be measured and how it will be measured. The required accuracy of the measurement may vary for different Test Cases, as will the pass/fail values (if appropriate).

Note that this definition of tests to be performed must be considered preliminary as the full capabilities and limitations of the test sites are still to be finalised.

Table 1 shows the list of test metrics that needs to be measured for all the Test Scenarios. The measurements are divided into five groups:

6.1 Back office ICT

This covers the communications between the various charging entities and the FABRIC back office. This includes user registration, status information and billing.

The back office ICT tests relate to those functions required for the charging process to proceed. Administrative processes such as user account generation are not covered.

6.2 Road operator

Tests in this section will evaluate the interface between the road operator and the FABRIC system.

6.3 Grid

The covers the measurements which must be performed in order to assess the test cases previously mentioned.

Availability

The **cumulative unavailability metric** defines the amount of time during which the system is not capable of delivering power.

Power restriction

The **maximum installation power** metric defines the power that the charging infrastructure can draw from the grid. This value is set by the DSO and takes into account the installed power of the charging infrastructure as a global maximum.

The **actual demand metric** defines the actual power drawn from the grid for EV charging.

These metrics should be measured in real time in order to ensure that no overloads occur during the charging process.

Tariff Modulation

The **energy tariff signal** defines the cost of energy at a given point in time.

The **maximum acceptable tariff limit** is the cost of energy accepted by the EV.

6.3 Environment

These are the test metrics and parameters that need to be measured to ensure reliability of the tests. The parameters such as ambient temperature could have an effect on power transfer. These background environmental metrics can be recorded in real time in regular interval or a single measurement prior to testing.

6.3 Power transfer systems (EV and power transfer unit)

The tests for the vehicle and the power transfer infrastructure can be combined under a single heading of power transfer system. The purpose of these tests is to analyse the behaviour of power transfer between the primary coil embedded in the road and the secondary coil on the vehicle. The tests for power transfer system will measure the power, energy, efficiency etc. in real time.

Table 1: Test measurements for the subsystems

Test Metric	unit	Description	Power transfer mode
Back office ICT			
FABRIC registration user interface		Users ability to use the system	None, ICT task
Communication EV back office- FABRIC platform		Successful communication link between the vehicle and FABRIC. The user sends registration details and FABRIC receive information correctly.	All
FABRIC platform to store information into the database		The user details shall be stored in the database. The fail criteria are that the vehicle receives data, but the information cannot be accessed.	All
FABRIC to EV backend communication		FABRIC shall send a message regarding success/failure of registration	All
Notification display		The notification from the FABRIC shall be displayed on FABRIC user management interface	All
Request to charge		User request to charge, enter information on route, ETA, estimated SOC, power transfer capacity	All
FABRIC process		FABRIC to process request, if charger available, if power equipment suitable, if power available from the grid. These values shall be compared against FABRIC database.	All
FABRIC notification		EV to receive notification if charge request is accepted or rejected.	All
User charge termination		User terminate charge	Static, Stationary
Road Operator			

Test Metric	unit	Description	Power transfer mode
Vehicle Recognition (ANPR)		ANPR camera recognises the number plate as the vehicle approaches charging point	Static, Stationary
Vehicle Recognition (Electronic)		Vehicle is identified from the communications interface	All
Establish communication link between road operator and FABRIC platform		The vehicle identity is relayed from road operator to the FABRIC platform	All
FABRIC platform vehicle recognition		The FABRIC platform receives the data from the road operator and searches the database for matching EV. The FABRIC shall search whether the vehicle is registered, and if user pre-booked.	All
Time delay		Time delay between EV entering recognition zone and FABRIC approving vehicle ID	All
FABRIC notification		FABRIC to send message to the EV to approve or reject the charging.	All
Grid			
cumulative unavailability time	h	Time during which the charging installation cannot deliver power.	All
maximum installation power	W	Maximum power a single charging installation can draw from the grid. This value is set by the DSO.	All
actual demand	W	Actual power a single charging installation is actually drawing from the grid.	All
Grid Failure		Response of the system to complete failure of the grid supply (simulate by switching off grid supply)	All
Energy price	€	The cost of energy at a given point in time.	All
Tariff limit	€	Acceptable tariff limit from the EV	All

Test Metric	unit	Description	Power transfer mode
Communication link between Grid and FABRIC platform		The grid to notify FABRIC platform on power availability at regular intervals. Interval to be determined with formal test definition.	All
FABRIC to receive Notification		The message shall contain relevant information; FABRIC shall compare the available power against demand from the vehicles at that given time.	All
Grid Voltage	V	Monitor the voltage from at the grid transformer which supplies power to the power transfer modules	All
Frequency	Hz	Monitor frequency	All
Power Factor	p.u.	Monitor power factor, at the grid transformer	All
Current	A	Three phase current at the grid transformer	All
THD Voltage	%	Total voltage distortion at the grid transformer	All
Time delay	ms	Time delay between user termination action and power cut-off from the primary	All
Environment			
Temperature	ºC	Ambient temperature during power transfer	All
Road Surface Thickness	m	Thickness of the road surface covering the charging coils/pads	All (as appropriate)
Road Material		Asphalt, Concrete, Other	All
Power Transfer			
Alignment	m	Misalignment of the vehicle from centre point. In x, y, rotational and angular	Static, Stationary, Dynamic
Speed	m/s	The speed of the vehicle at all times	Dynamic
Power transfer rate between primary and secondary	W	Transfer of power from charging infrastructure to the vehicle	Static, Stationary, Dynamic

Test Metric	unit	Description	Power transfer mode
Power supply rate from the grid	W	Supply of power from the grid to the power transfer unit	Static, Stationary, Dynamic
Efficiency between primary and the secondary	%	Power transfer efficiency between charging infrastructure and the vehicle	Static, Stationary, Dynamic
Efficiency from grid to the secondary	%	Power transfer efficiency from the grid transformer to the vehicle secondary	Static, Stationary, Dynamic
Vehicle coupling time	s	Time it takes for vehicle to be recognised to primary and secondary vehicle to couple	Stationary, Dynamic
Energy transferred	J	Energy transferred per coupling	Static, Stationary, Dynamic
Coupling time	s	Total time energy transfer occurs	Static, Stationary, Dynamic
Start charge location	m	Location of the secondary coil with respect to the primary when charging begins	Static, Stationary, Dynamic
End charge location	m	Location of the secondary coil with respect to the primary when charging ends (should be the same for static and stationary)	Static, Stationary, Dynamic
Energy collected by the traction and the battery per charger	J per charger	Amount of energy transferred to the vehicle traction or the battery during primary and secondary coupling	Dynamic
Air gap	m	The air gap at all times during power transfer	Static, Stationary, Dynamic
EM exposure	T	EM exposure measured according to the ICNIRP guidelines	Static, Stationary, Dynamic
Harmonics	%	Harmonics on the charging infrastructure prior, during and after charging.	Static, Stationary, Dynamic
EMF, EMI	V/m	Whether EMF and EMI have any effect on the vehicle electronics	Static, Stationary, Dynamic
Ventilation	ºC	Ventilation activation/deactivation depending on battery and equipment temperature	Static, Stationary, Dynamic

Test Metric	unit	Description	Power transfer mode
Coil temperature	ºC	Coil temperature, both primary and secondary	Static, Stationary, Dynamic
Battery Temperature	ºC	Battery temperature	Static, Stationary, Dynamic
Battery SOC	%	Battery state of charge during charging	Static, Stationary, Dynamic
Traction power demand on the vehicle	W	Vehicle power requirement under different test conditions	Dynamic

7. TEST SCENARIO TABLES

7.1 Static Power Transfer

The tables below show the test scenarios for static power transfer.

In all cases, the test cases are the same, namely:

Grid:

Availability

- No specific test. The cumulative unavailability metric is monitored for all tests.

Power restriction

- Reference cases: operation at nominal (installed) power
- Foreseen event: Maximum charging power is reduced in a controlled way
- Unforeseen event: Maximum charging power is reduced in real-time

Tariff Modulation

- Low Tariff: EV module accepts tariff and charges
- High Tariff: EV module rejects tariff and does not charge

ICT:

Cost

- Standard case
- Scheduled (on-time) charging
- Scheduled (late arrival) charging
- Overall high-demand charging

Driver assist

- Driver follows the assistance procedures with high accuracy
- Driver follows the assistance procedures with low accuracy
- Driver does not follow the assistance procedures
- Driver cancels the charging process

EV identification

- Valid credentials, positive identification
- Invalid credentials/no credentials, negative identification
- Hard conditions to retrieve credentials (dirty condition of plate)

Vehicle:

- Alignment
- Power demand
- On-board charging equipment

Charging infrastructure:

- Road-side/static charging equipment

Pavement:

- Material
- Material thickness

Test Scenario: Static, charge point in a car	
Scenario code:	A.1.1
Use Cases:	1.5, 1.6, 1.8, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	EV, DSO, charging infrastructure, road operator, FABRIC platform
Rationale	To test the system under static parking conditions. This scenario will simulate the power transfer conditions for the car under low power transfer rate over a long charging period.
Description	The car will arrive at the charging spot and the testing will begin when the user books a charging spot and the tests will end when the user completes the transaction.

Test Scenario: Static, charge point in a LCV	
Scenario code:	A.1.2
Use Cases:	1.5, 1.6, 1.8, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	EV, DSO, charging infrastructure, road operator, FABRIC platform
Rationale	To test the system under static parking conditions. This scenario will simulate the power transfer conditions for the car under low power transfer conditions over a long charging period
Description	The car will arrive at the charging spot and testing will begin when the user books a charging spot and the tests will end when the user completes the transaction.

Test Scenario: Static charging point in LGV	
Scenario code:	A.1.3
Use Cases:	1.5, 1.6, 1.8, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	EV, DSO, charging infrastructure, road operator, FABRIC platform
Rationale	To test the system under static parking conditions. This scenario will simulate the power transfer conditions for the car with a low power transfer rate over a long charging period
Description	The car will arrive at the charging spot and the testing will begin when the user books a charging spot and the tests will end when the user complete the transaction.

7.2 Stationary power transfer mode

The tables below show the test scenarios for stationary power transfer.

In all cases, the test cases are the same as for static power transfer.

Test Scenario Stationary charging, on highway with car	
Scenario code:	B.1.1
Use Cases:	1.5, 1.6, 1.9, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	Road operator, DSO, FABRIC platform, power transfer unit, EV
Rationale	To test the system operation and integration under stationary charging mode, where the vehicle is static during the charging but the power transfer rate is high and duration of the power transfer is short.
Description	The tests will include booking a spot, approach, alignment, power transfer and communications between subsystems. The test can be at a road side parking space, a taxi rank or power transfer units on a road near traffic lights.

Test Scenario Stationary charging, on highway with LCV	
Scenario code:	B.1.2
Use Cases:	1.5, 1.6, 1.9, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	Road operator, DSO, FABRIC platform, power transfer unit, EV
Rationale	To test the system operation and integration under stationary charging mode, where the vehicle is static during the charging but the power transfer rate is high and the duration of power transfer is short.

Description	The tests will include booking a spot, approach, alignment, power transfer and communications between subsystems. The test can be at a road side parking space, a taxi rank or power transfer units on a road near traffic lights.

Test Scenario Stationary charging, on highway with LGV	
Scenario code:	B.1.3
Use Cases:	1.5, 1.6, 1.9, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	Road operator, DSO, FABRIC platform, power transfer unit, EV
Rationale	To test the system operation and integration under stationary charging mode, where the vehicle is static during charging but the power transfer rate is high and the duration of power transfer is short.
Description	The tests will include booking a spot, approach, alignment, power transfer and communications between subsystems. The test can be at a road side parking space, a taxi rank or power transfer units on a road near traffic lights.

Test Scenario Stationary charging, car on road	
Scenario code:	B.2.1
Use Cases:	1.5, 1.6, 1.9, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	Road operator, DSO, FABRIC platform, power transfer unit, EV
Rationale	To test the system operation and integration under stationary charging mode, where the vehicle is static during the charging but the power transfer rate is high and the duration of power transfer is short.

Description	The tests will include booking a spot, approach, alignment, power transfer and communications between subsystems. The test can be at a road side parking space, a taxi rank or power transfer units on a road near traffic lights.

Test Scenario: Stationary charging, LCV on road	
Scenario code:	B.2.2
Use Cases:	1.5, 1.6, 1.9, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	Road operator, DSO, FABRIC platform, power transfer unit, EV
Rationale	To test the system operation and integration under stationary charging mode, where the vehicle is static during the charging but the power transfer rate is high and the duration of power transfer is short.
Description	The tests will include booking a spot, approach, alignment, power transfer and communications between subsystems. The test can be on a road near traffic lights, junctions or statistically congested areas.

Test Scenario Stationary charging, LGV on road	
Scenario code:	B.2.3
Use Cases:	1.5, 1.6, 1.9, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	Road operator, DSO, FABRIC platform, power transfer unit, EV
Rationale	To test the system operation and integration under stationary charging mode, where the vehicle is static during the charging but the power transfer rate is high and the duration of power transfer is short.
Description	The tests will include booking a spot, approach, alignment, power transfer

	and communications between subsystems. The test can be at a road side parking space, a taxi rank or power transfer units on a road near traffic lights.

Test Scenario: Stationary charging, car on dedicated urban area	
Scenario code:	B.3.1
Use Cases:	1.5, 1.6, 1.9, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	Grid, FABRIC platform,, Vehicle & power transfer module, road operator
Rationale	To test the charging situation where chargers are in dedicated areas such as taxi ranks, motorway parking spots, bus stops etc.
Description	This Test Scenario concentrates on the situation where a user chooses to park the vehicle on the rapid chargers to boost the capacity of the battery in a short time. Example scenarios are: the bus stops at the bus stop for 10 minutes or a taxi stops at the taxi rank until he/she picks up a next customer.

Test Scenario: Stationary charging, LCV vehicle on dedicated urban area	
Scenario code:	B.3.2
Use Cases:	1.5, 1.6, 1.9, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	Grid, FABRIC platform, Vehicle & power transfer module, road operator
Rationale	To test the charging situation where chargers are in dedicated areas such as taxi ranks, motorway parking spots, bus stops etc.
Description	This Test Scenario concentrates on the scenario where user chooses to park the vehicle on the rapid chargers to boost the capacity of the battery

	in short time. Example scenarios are: the bus stops at the bus stop for 10 minutes or a taxi stops at the taxi rank until he/she pick up a next customer.

Test Scenario: Stationary charging, LGV on dedicated urban area	
Scenario code:	B.3.3
Use Cases:	1.5, 1.6, 1.9, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	Grid, FABRIC platform, Vehicle & power transfer module, road operator
Rationale	To test the charging situation where chargers are in dedicated areas such as taxi ranks, motorway parking spots, bus stops etc.
Description	This Test Scenario concentrates on the scenario where user chooses to park the vehicle on the rapid chargers to boost the capacity of the battery in short time. Example scenarios are; the bus stops at the bus stop for 10 minutes or a taxi stops at the taxi rank until he/she pick up a next customer.

7.3 Dynamic Power Transfer Mode

The tables below show the test scenarios for dynamic power transfer.

In all cases, the test cases are the same, namely:

Grid:

Availability

- No specific test. The cumulative unavailability metric is monitored for all tests.

Power restriction

- Reference cases: operation at nominal (installed) power
- Foreseen event: Maximum charging power is reduced in a controlled way
- Unforeseen event: Maximum charging power is reduced in real-time

Tariff Modulation

- Low Tariff: EV module accepts tariff and charges
- High Tariff: EV module rejects tariff and does not charge

ICT:

Cost

- Standard case
- Scheduled (on-time) charging
- Scheduled (late arrival) charging
- Overall high-demand charging

Driver assist – these test cases require additional definition as driver assisstance for dynamic charging is currently undefined

- Driver follows the assistance procedures with high accuracy
- Driver follows the assistance procedures with low accuracy
- Driver does not follow the assistance procedures
- Driver cancels the charging process

EV identification

- Valid credentials, positive identification
- Invalid credentials/no credentials, negative identification
- Hard conditions to retrieve credentials (dirty condition of plate)

Vehicle:

- Alignment
- Power demand
- On-board charging equipment

Charging infrastructure:

- Road-side/static charging equipment

Pavement:

- Material
- Material thickness

Test Scenario: Dynamic charging, car on highway start-stop traffic	
Scenario code:	C.1.1
Use Cases:	1.5, 1.10, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	Grid, FABRIC platform, Vehicle & power transfer module, road operator
Rationale	The dynamic chargers in the highway may have operational tolerance concerning the speed of the vehicle. This Test Scenario will test the vehicle under start-stop traffic conditions in the highways where expected speed in free flow is 120km/h.
Description	This Test Scenario aims to test the system under the conditions where the speed of vehicle is very low compared to the normal expected traffic flow. In low speed conditions the time spent on each charger may be longer or, depending on the length of a segment, two vehicles can be on one segment at the same time. These changes may have an effect on operation of the system.

Test Scenario: Dynamic charging, LCV on highway start-stop traffic	
Scenario code:	C.1.2
Use Cases:	1.5, 1.10, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	Grid, FABRIC platform, Vehicle & power transfer module, road operator
Rationale	The dynamic chargers in the highway may have operational tolerance concerning the speed of the vehicle. This Test Scenario will test the vehicle under start-stop traffic conditions in the highways where expected speed in free flow is 120km/h.
Description	This Test Scenario aims to test the system under the conditions where the speed of vehicle is very low compared to the normal expected traffic flow.

	In low speed conditions the time spent on each charger may be longer or, depending on the length of a segment, two vehicles can be on one segment at the same time. These changes may have an effect on operation of the system.

Test Scenario: Dynamic charging, LGV on highway start-stop traffic	
Scenario code:	C.1.3
Use Cases:	1.5, 1.10, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	Grid, FABRIC platform, Vehicle & power transfer module, road operator
Rationale	The dynamic chargers in the highway may have operational tolerance concerning the speed of the vehicle. This Test Scenario will test the vehicle under start-stop traffic conditions in the highways where expected speed in free flow is 120 km/h.
Description	This Test Scenario aims to test the system under the conditions where the speed of vehicle is very low compared to the normal expected traffic flow. In low speed conditions the time spent on each charger may be longer or, depending on the length of a segment, two vehicles can be on one segment at the same time. These changes may have an effect on operation of the system.

Test Scenario: Dynamic charging, car on highway congested traffic	
Scenario code:	C.2.1
Use Cases:	1.5, 1.10, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Rationale	The dynamic chargers in the highway may have operational tolerance concerning the speed of the vehicle. This Test Scenario will test the

	vehicle under start-stop traffic conditions in the highways where expected speed in free flow is 120 km/h.
Description	This Test Scenario aims to test the system under the conditions where the speed of vehicle is very low compared to the normal expected traffic flow. In low speed conditions the time spent on each charger may be longer or, depending on the length of a segment, two vehicles can be on one segment at the same time. These changes may have an effect on operation of the system.

Test Scenario Dynamic charging, LCV on highway congested traffic	
Scenario code:	C.2.2
Use Cases:	1.5, 1.10, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Rationale	The dynamic chargers in the highway may have operational tolerance concerning the speed of the vehicle. This Test Scenario will test the vehicle under start-stop traffic conditions in the highways where expected speed in free flow is 120 km/h.
Description	This Test Scenario aims to test the system under the conditions where the speed of vehicle is very low compared to the normal expected traffic flow. In low speed conditions the time spent on each charger may be longer or, depending on the length of a segment, two vehicles can be on one segment at the same time. These changes may have an effect on operation of the system.

Test Scenario: Dynamic charging, LGV on highway congested traffic	
Scenario code:	C.2.3
Use Cases:	1.5, 1.10, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2

Test site	Italy, France
Rationale	The dynamic chargers in the highway may have operational tolerance concerning the speed of the vehicle. This Test Scenario will test the vehicle under start-stop traffic conditions in the highways where expected speed in free flow is 120 km/h.
Description	This Test Scenario aims to test the system under the conditions where the speed of vehicle is very low compared to the normal expected traffic flow. In low speed conditions the time spent on each charger may be longer or, depending on the length of a segment, two vehicles can be on one segment at the same time. These changes may have an effect on operation of the system.

Test Scenario: Dynamic charging, car on highway in free flow	
Scenario code:	C.3.1
Use Cases:	1.5, 1.10, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Rationale	The dynamic chargers in the highway may have operational tolerance concerning the speed of the vehicle. This Test Scenario will test the vehicle under free-flow traffic conditions up to 120 km/h. This is the expected driving environment for a vehicle in the highway; therefore these results should be base figures for analysis of the system.
Description	This Test Scenario aims to test the system under free flow conditions. This is the expected driving conditions for the highway; therefore, the system should be designed to operate in these conditions.

Test Scenario Dynamic charging, LCV on highway in free flow	
Scenario code:	C3.2
Use Cases:	1.5, 1.10, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Rationale	The dynamic chargers in the highway may have operational tolerance concerning the speed of the vehicle. This Test Scenario will test the vehicle under free-flow traffic conditions up to 120 km/h. This is the expected driving environment for a vehicle in the highway; therefore these results should be base figures for analysis of the system.
Description	This Test Scenario aims to test the system under free flow conditions. This is the expected driving conditions for the highway; therefore, the system should be designed to operate in these conditions.

Test Scenario: Dynamic charging, LGV on highway in free flow	
Scenario code:	C.3.3
Use Cases:	1.5, 1.10, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Rationale	The dynamic chargers in the highway may have operational tolerance concerning the speed of the vehicle. This Test Scenario will test the vehicle under free-flow traffic conditions up to 120 km/h. This is the expected driving environment for a vehicle in the highway; therefore these results should be base figures for analysis of the system.
Description	This Test Scenario aims to test the system under free flow conditions. This is the expected driving conditions for the highway; therefore, the system should be designed to operate in these conditions.

Test Scenario Dynamic charging, car in local urban driving	
Scenario code:	C.4.1
Use Cases:	1.5, 1.10, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Rationale	This Test Scenario concentrates on dynamic charging in built up urban areas. In this scenario the environment is complex including greater human activity when compared with highway scenarios.
Description	This Test Scenario will test the vehicle in the low speed local driving environment. The tests will be used to study the use of the power transfer module in built up areas and the effect it has on: health and safety, operations, traffic, grid and air quality.

Test Scenario Dynamic charging, LCV in local urban driving	
Scenario code:	C.4.2
Use Cases:	1.5, 1.10, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Rationale	This Test Scenario concentrates on dynamic charging in built up urban areas. In this scenario the environment is complex including greater human activity when compared with highway scenarios.
Description	This Test Scenario will test the vehicle in the low speed local driving environment. The tests will be used to study the use of the power transfer module in built up areas and the effect it has on: health and safety, operations, traffic, grid and air quality.

Test Scenario Dynamic charging, LGV in local urban driving	
Scenario code:	C.4.3
Use Cases:	1.5, 1.10, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Rationale	This Test Scenario concentrates on dynamic charging in built up urban areas. In this scenario the environment is complex including greater human activity when compared with highway scenarios.
Description	This Test Scenario will test the vehicle in the low speed local driving environment. The tests will be used to study the use of the power transfer module in built up areas and the effect it has on: health and safety, operations, traffic, grid and air quality.

Test Scenario: Dynamic charging, the car in inter-district driving environment	
Scenario code:	C.5.1
Use Cases:	1.5, 1.10, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Rationale	This Test Scenario concentrates on dynamic charging on roads between urban areas. In this scenario the environment is complex with greater human activity when compared against highway scenarios but the speed of the vehicle is relatively high.
Description	This Test Scenario will test the vehicle at higher speeds in the local driving environment. The tests will be used to study the use of the power transfer module between built up areas and the affect it has on the health and safety, operation, traffic, grid and the air quality.

Test Scenario : Dynamic charging, the LCV in inter-district driving environment	
Scenario code:	C.5.2
Use Cases:	1.5, 1.10, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	Grid, FABRIC platform, Vehicle & power transfer module, road operator
Rationale	This Test Scenario concentrates on dynamic charging on roads between urban areas. In this scenario the environment is complex with greater human activity when compared against highway scenarios but the speed of the vehicle is relatively high.
Description	This Test Scenario will test the vehicle at higher speeds in the local driving environment. The tests will be used to study the use of the power transfer module between built up areas and the affect it has on the health and safety, operation, traffic, grid and the air quality.

Test Scenario: Dynamic charging, the LGV in inter-district driving environment	
Scenario code:	C.5.3
Use Cases:	1.5, 1.10, 2.1, 3.1, 4.2, 4.3, 4.4, 6.1, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	Grid, FABRIC platform, Vehicle & power transfer module, road operator
Rationale	This Test Scenario concentrates on dynamic charging on roads between urban areas. In this scenario the environment is complex with greater human activity when compared against highway scenarios but the speed of the vehicle is relatively high.
Description	This Test Scenario will test the vehicle at higher speeds in the local driving environment. The tests will be used to study the use of the power transfer module between built up areas and the affect it has on the health and safety, operation, traffic, grid and the air quality.

7.4 ICT Test Scenarios

NOTE: Test scenarios D.1.1, D.1.2, D.1.3 and D.5.1 have not been developed as they are very general to any system specification and do not provide specific cases for the context of FABRIC

Test Scenario: Booking and reservation	
Scenario code:	D.2.1
Use Cases:	1.4, 1.5, 1.7, 4.2, 4.4, 5.2, 8.1
Test site	Italy, France
Affected Subsystem	FABRIC DSO Interface FABRIC electric mobility system
Rationale	The user must be able to reserve a time and/or location when he/she expects to be able to make use of the charging system
Description	This Test Scenario considers requirements to reserve a charging slot with the charging system. It must also consider how to deal with both scheduled and unscheduled availability. In the case of scheduled maintenance works, the road operator should be able to inform FABRIC in advance. This will help FABRIC manage prebookings and re-planning of journeys. The Scenario anticipates an incident which results in road closure. The road operator is expected to inform FABRIC within a very short time and regularly update on the status of the road. In return, FABRIC should take necessary actions to minimise inconveniences to the EV users. The reason for road closure should be selected by the road operator and this information should be displayed on users' EV and FABRIC platforms. The FABRIC platform will update the availability of chargers from the database, and if necessary the EV driver can be re-routed.
Test Cases	There is currently not enough information available to develop test cases

Test Scenario: Energy retailer, the tariff modulation	
Scenario code:	D.3.1
Use Cases:	3.1, 8.1
Test site	Italy, France
Affected Subsystem	Energy retailer to FABRIC interface FABRIC charging cost management module
Rationale	The Test Scenario analyses how fluctuation in rates is handled when applying a dynamic tariff model to take profit from the changing conditions in demand, supply, etc.
Description	As the energy retailer is applying the cost of the power supplied, it is important to describe the impact on EV charging and schedules
Test Cases	Rate changes while EVs are charging Rate changes while EVs are scheduled with a fixed tariff Rate changes while an EV is charging and it manually cancels the charging

Test Scenario: Road operator EV identification	
Scenario code:	D.4.1
Use Cases:	4.2, 4.3
Test site	Italy, France
Affected Subsystem	Road Operator Interface FABRIC electric mobility platform EV back-end

	Charging infrastructure operator
Rationale	This Test Scenario aims to monitor the vehicle accessing the charging infrastructure and correctly identify it. Different identification technologies available such as Automatic Number Plate Recognition (ANPR) and Tag and Beacon systems as used in Electronic Toll Collection (ETC) technologies. These technologies will be used independently or combined for testing
Description	The procedure of vehicle identification has several phases: 1) vehicle detection 2) capture of vehicle credentials 3) validation of the correctness of the credentials 4) authorization. Several external conditions may affect this procedure: speed, weather conditions, vehicle conditions (such as dirtiness of the plate or low battery in the ETC). The purpose of this scenario is to make sure that the charging infrastructure is available to the correct vehicle.
Test Cases	- Valid credentials, positive identification - Invalid credentials/no credentials, negative identification - Hard conditions to retrieve credentials (dirty condition of plate)

Test Scenario: All operators, messaging	
Scenario code:	D.5.2
Use Cases:	1.4, 1.5, 1.6, 1.7, 2.1, 3.1, 4.1, 4.2, 4.3, 4.4, 6.1, 8.1
Test site	Italy, France
Affected Subsystem	All
Rationale	The purpose of the Test Scenario is to ensure a message is delivered from one party to the other correctly in an acceptable amount of time.

Description	The operator will select a message and send to the FABRIC platform to be distributed to the drivers. The messages can be pre-defined messages or custom message. If the message is delivered and the operator receives a delivery report, the Test Scenario is successful. However if the message is not received by the FABRIC platform, the Test Scenario can be considered as fail.
Test Cases	Message delivered successfully Operator cannot connect to the FABRIC platform

Test Scenario: Power Transfer Management	
Scenario code:	D.6.1
Use Cases:	2.1, 4.3, 4.4, 7.1, 7.2
Test site	Italy, France
Affected Subsystem	FABRIC on-board unit Charging infrastructure operator FABRIC Electric Mobility platform EV backend FABRIC DSO interface
Rationale	This Test Scenario considers the process to decide the power transfer assigned to an EV that it is going to be charged taking into consideration a number of parameters.
Description	During normal operation of the charging infrastructure, it is necessary to assign correct charging conditions to a specific EV based on several parameters related to the vehicle (such as battery capacity, current power, level, charging speed) but also taking into consideration the schedule of the EV as well as the current power supply. This test scenario must also consider load balancing requirements. This scenario may require testing with dummy loads and simulation due to the difficulty in undertaking a

	realistic test in a test track environment.
Test Cases	Performance during normal conditions with an occupation of more than 50% of infrastructure capacity Performance during normal conditions with full occupation of infrastructure capacity but limited power supply Reduction in power transferred during charging: occupation of less than 50% of infrastructure capacity Reduction in power transferred during charging: occupation of more than 50% of infrastructure capacity Reduction in power transferred during charging: full occupation of infrastructure capacity Reduction in power transferred during charging: full occupation of infrastructure capacity and scheduled EV

8. CONCLUSIONS

This report has created a number of Test Scenarios which are designed to be used in future phases of this project to form the basis of the test and evaluation of the FABRIC solutions.

The scenarios are derived from the Use Cases developed in a previous deliverable in the FABRIC project.

The Test Scenarios are divided into three power transfer modes:

- **Static**, where a vehicle is "parked" and will remain so for the foreseeable future.
- **Stationary** (also called opportunistic charging), where a vehicle is stopped for a short time and takes the opportunity to top up the battery charge. This is the typical case of a vehicle stopped at traffic lights, intersections etc.
- **Dynamic**, where the vehicle battery is charged while the vehicle is moving.

In addition, separate scenarios which test the ICT elements of FABRIC have been developed.

As different vehicle types have different charging and power requirements, for each of the three power transfer modes, we have considered three vehicle types:

- **Car**: The car is classified as a private passenger vehicle with a maximum mass below 3.5 tonnes;
- **Light Commercial Vehicle (LCV)**: The light commercial vehicle is classified as a commercial vehicle with maximum mass below 3.5 tonnes;
- **Large Goods Vehicle (LGV):** The large goods vehicle is classified as a vehicle with maximum mass above 3.5 tonnes.

For the stationary and dynamic charging modes, a number of operating scenarios relating to driving conditions have been defined, and these conditions, together with the vehicle types, form the Test Scenarios.

Combining relevant power transfer modes, vehicle types and operating modes, 24 Test Scenarios have been defined. In addition, five Information and Communications Technology (ICT) test scenarios have been defined.

For each scenario, one or more Test Cases have been defined. Test cases are specific instances of a Test Scenario where a single aspect of the Test Scenario is varied. A Test Scenario can consist of a number of Test Cases, and each Test Case may require a number of tests to evaluate the system. Individual tests measure specific aspects of the charging performance and other characteristics of the integrated system.

Finally a set of tests has been identified in order to test the response of the systems to the various scenarios. Each test will measure a single quantity; for example, power transferred, efficiency, temperature etc. The tests which have been identified should be considered preliminary and will be subject to change as the project progresses.

It is expected that the test scenarios will form the basis of the FABRIC evaluation tasks. The test cases and tests presented in this report will need to be developed into a definitive test suite in subsequent phases of this project.

BIBLIOGRAPHY

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