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Executive summary

For the evaluation of the reference and the demonstrator battery systems and vehicle, in this report, representative use cases have been selected and corresponding test case scenarios have been derived. The scenarios are related to the state-of-charge of the battery, ambient conditions and vehicle speed profiles. Based on this, a complete test matrix has been created, describing the necessary tests or simulations to be performed on different levels for components testing (WP2), virtual validation and bench tests (WP3) and vehicle tests (WP6).

Attainment of the objectives and explanation of deviations

The objectives related to this deliverable have been achieved in full, with delay of 2,5 months (M11 instead of M8) due to two main reasons: 1) the battery cell selection process took more time than initially planned, in order to retrieve the cell data from suppliers; 2) it took more time than expected to agree with other partners about the test matrix and to check the availability of the required test facilities at each involved partner's premise. Such a delay does not affect the other tasks of the project, since the outputs of this deliverable will only be necessary for the testing activities, which will not start before M13.

Introduction

In this project, the focus is on two aspects:

1. Charging a battery at rates of at least 3C and up to a maximum of 6C. This is already above the normal limits for present-day electric vehicles.
2. Development of a novel thermal management system that thanks to a properly calibrated strategy will be able to remove excess heat generated in the battery pack during fast charging as well as guarantee the thermal comfort inside the cabin in all the weather conditions.

The first requirement will reduce the charging time needed for the electric vehicle, thereby reducing consumer anxiety for the uptake of electric vehicles while the later will help prolong battery life and reduce degradation by keeping the battery temperature in the sweet spot of 25 to 35°C.

The innovations on the components for the battery pack will increase the efficiency of the system in comparison with a state-of-the-art indirect heat-pump system, during extreme use cases, namely: battery preconditioning as well as cabin heating in winter; battery cooling both during fast charging and while cruising in summer.

Considering the above two requirements, the use cases and test cases have been designed for safety and functional check of the battery pack as well as thermal system capabilities and performance both for cabin and battery requirements. The testing activity will be designed at the component level for all the components involved in the thermal management architecture as well as at vehicle level. The battery requires a specific chapter where the safety aspect is deeply investigated.

1 Thermal system components testing

According to the thermal architecture proposed (Figure 1), a bench test activity to validate the thermal performance @different fluids flow rates has to be done on these components:

- Outer heat exchanger
- Low-temperature radiator
- Water cooled condenser
- Cold storage device

Also, the pressure drops have to be taken into account and measured in order to size properly the coolant pumps and the radiator fans as well as the electric A/C compressor, which has to be characterized at different speeds to validate the thermal performance and to help the control strategy calibration.

CFD analysis, as well as thermal simulations, are required and they will help to check the component sizing before the physical tests.

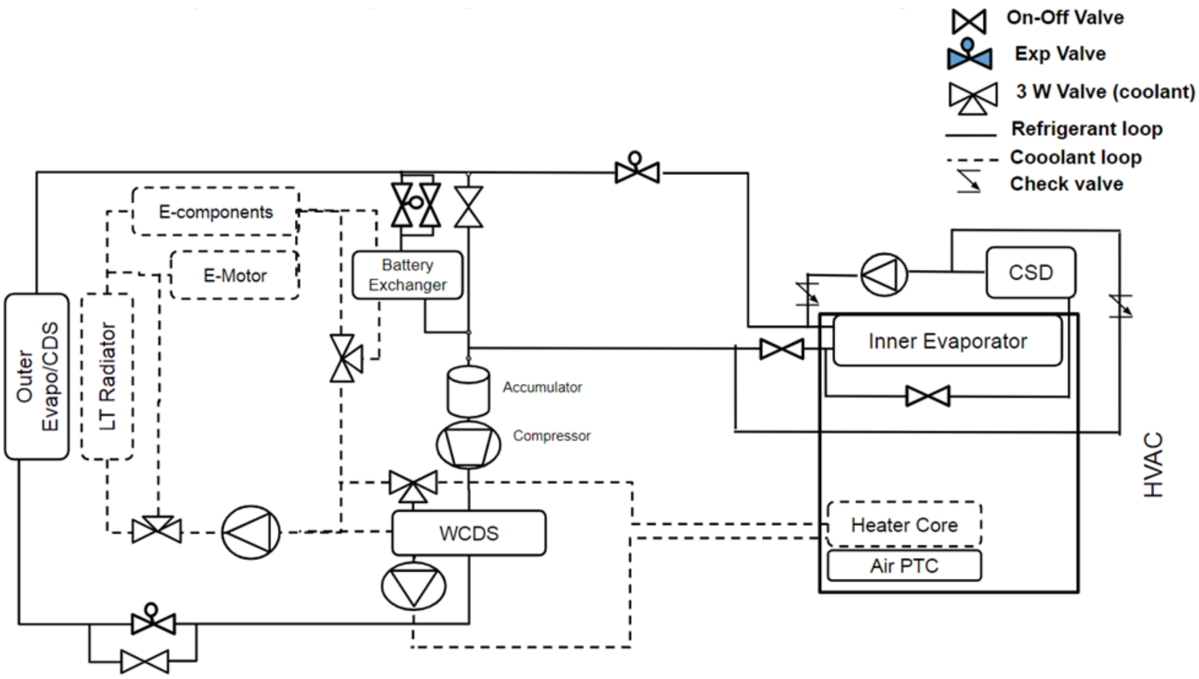

Figure 1. Indirect architecture (w/LT RAD) complete with PT loop

Durability tests are not required at the prototype level since the demo vehicle will be used to validate the thermal architecture solution. Further development steps need to include also affordability and durability tests.

Figure 2. Example of a heat exchanger under test

2 Battery pack bench testing

The tests to be performed have the objective to ensure a safe demonstration of vehicle application. Based on the demonstrator level and the small number of build systems, the test according to the UN 38.3 for transportation are not foreseen. Furthermore, due to the demonstrator level, no homologation or lifetime endurance tests are foreseen. Electromagnetic compatibility tests are expected to be done at the component level.

Other tests to be performed are the following:

- Cell tests
- Functional tests at the system level
- Vehicle testing
    - Validation on a rolling bench
    - test track

CRF and the other experts in the SELFIE consortium delivered different test lists and inputs to cover thermal, electrical and mechanical test requirements to validate the battery system on lab level, as explained in the following sub-chapters.

2.1 Performance tests

Performance tests measure electrical values like capacity, dynamic power capability, the ohmic resistance, the open-circuit voltage (OCV) and power capability of the device under test (DUT) during electrical and thermal load.

For the electrically propelled road vehicles, ISO 12405 (1) is a standard test specification for lithium-ion traction battery packs and systems. This specification ensures that a battery pack or system is able to meet the specific needs of the automobile industry. It consists of three parts. Part I is for high power application (hybrid vehicle) and Part II is for high-energy application (BEV and PHEV). Part III describes tests for safety performance requirements. ISO 12405 determines the essential characteristics of performance, reliability and abuse of lithium-ion battery packs and systems.

For the SELFIE project vehicle application the following performance tests are demanded (Table 1):

Table 1: Performance tests

#	Standard	Sub clause	purpose	Criteria for performance assessment and validation
1.	ISO 12405-1	7.3.2 Pulse power characterisation profile	Peak Discharge Power (2 s) – BoL (Beginning of Life	Adherence to predefined conditions (current/voltage) with an expected voltage response
2.			Peak Discharge Power (10 s) - BoL	
3.			Peak Charge Power (2 s) - BoL	
4.			Peak Charge Power (10 s) - BoL	
5.			Max. Current in Charge (10 s pulse)	Predefined from cell supplier and adherence to voltage limits
6.	ISO 12405-2	7.1 Energy and capacity at room temperature	Nominal energy - BoL	Nominal energy achieved after predefined (1) C-rate charge discharge cycle for 3 cycles on cell level
7.			Usable energy - BoL	Usable energy achieved after predefined (1) C-rate charge discharge cycle for 3 cycles on system level with predetermined depth of discharge
8.			Nominal voltage	Static voltage check at predefined rated nominal voltage on system level OCV at TBD SOC
9.			Voltage range – Full performance	Adherence to minimum and maximum system voltage for capacity test between 0% and 100% State of charge (SOC) window
10.			Continuous discharge - BoL	Adherence to predefined conditions (Current/Voltage/Temperature) with an expected voltage response
11.			Continuous charge - BoL	Adherence to predefined conditions (Current/Voltage/Temperature) with an expected voltage response
12.			Continuous charge - Plug-in charging	Adherence to predefined conditions (Current/Voltage/Temperature) with an expected voltage response

2.2 Mechanical tests

2.2.1 Vibration

Vibration tests on lab level simulate dynamic mechanical loads during operation and check the DUT for malfunctions and breakage. The main failures that shall be identified are breakage and loss of electrical contact. The mechanical load can be a specific OEM profile or one defined by a Standard like ISO 12405 or ECE R100 [2]. Vibration tests can differ in:

- Load frequencies
- Load magnitudes
- Load direction (uniaxial, multiaxial).

For the SELFIE project vehicles application **one** of the following vibration tests is demanded (Table 2):

Table 2: Vibration tests

#	Standard	Sub clause	purpose	Criteria for performance assessment and validation
1.	ISO 12405	White noise vibration with defined Power spectral density (PSD) profile (5-200 Hz)	Check for malfunctions and breakage	No breakage or loss of electrical contact
2.	ECE R100	Vibration with sinusoidal sweep (7-50 Hz)	Check for malfunctions and breakage	No breakage or loss of electrical contact

2.2.2 Shock

Checks the safety of the DUT under inertia forces introduced by driving over a curbstone at high speed or at accidents. The failure mode is mechanical damage due to the resulting high accelerations. Introduced is a dynamic force load (Table 3).

Table 3: Shock tests

#	Standard	Sub clause	purpose	Criteria for performance assessment and validation
1.	CRF Standard for driving permission on test rig	+/-3g in x-dir. +/-3g in y-dir. +/-3g in z-dir. Duration of rated mechanical stress: 25ms, 10 tests for each direction (uniaxial)	Crash pulse	no rupture/damaging of any parts of the battery, as externally as internally
2.	ISO 12405 -3	50 g, half- sine, 6ms, 10 shocks in x,y,z		No failure

2.2.3 Crash Test

This test checks the mechanical resistance of the housing structure. It evaluates the performance of the battery under contact loads that might be experienced in vehicle crash conditions. Introduced is a quasi-static force load (Table 4).

Table 4: Crash test

#	Standard	purpose	Criteria for performance assessment and validation	test sequence
1.	ECE R 100	Mechanical housing resistance	No failure	100 DaN / 1 dm**2

2.3 Safety tests

Safety tests validate the performance of the battery in case of misuse or malfunction of the vehicle or battery system. In addition, the functionality of safety strategies is verified. Based on performed Failure Mode and Effects Analysis (FMEA) and CRF specifications following safety tests are demanded (see Table 5):

Table 5: Safety tests

#	purpose	Test rig Category :	Criteria for performance assessment and validation	test sequence
1.	High Voltage Interlock Loop (HVIL) with contactors closed	Electrical	The HVIL fault be set in less than 100ms and remains set up to next key off-key-on. Contactors must be opened within 100ms from HVIL opening and remains opened up to next key off-key-on.	Close contactors After 5s open the HVIL After 10s close again the HVIL
2.	HVIL with contactors opened	Electrical	The HVIL fault be set in less than 100ms and remains set up to next key off-key-on. Contactors shall remain opened up to next key off-key-on.	Close contactors After 5s open the HVIL circuit After 10s close again the HVIL circuit
3.	Loss of Isolation (LOI) Detection	Electrical	R = 1Mohm The signal Insulation_kohm should report the correct measure with max ±10% accuracy. The Isolation Warning and Isolation Fault should remain clear.	Close contactors After 5s apply 1Mohm between HV+ and 12V GND (Ground) After 10s remove the 1Mohm resistor
4.	LOI Detection	Electrical	R = 1Mohm The signal Insulation_kohm should report the correct measure with max ±10% accuracy. The Isolation Warning and Isolation Fault should remain clear.	After 10s apply 1Mohm between HV- and 12V GND After 10s remove the 1Mohm resistor
5.	LOI Detection	Electrical	R = 500kohm The signal Insulation_kohm should report the correct measure with max ±10% accuracy. The Isolation Warning should be set in less than 5s and remains set up to next key off-key-on.	After 10s apply 500 kohm between HV+ and 12V GND After 10s remove the 500 kohm resistor Open contactors

6.	LOI Detection	Electrical	R = 500kohm The signal Insulation_kohm should report the correct measure with max ±10% accuracy. The Isolation Warning should be set in less than 5s and remains set up to next key off-key-on.	Close contactors After 5s apply 500 kohm between HV- and 12V GND After 10s remove the 500 kohm resistor Open contactors
7.	LOI Detection	Electrical	R = 100kohm The signal Insulation_kohm should report the correct measure with max ±10% accuracy. The Isolation Warning and Isolation Fault should be set in less than 5s and remains set up to next key off-key-on. Contactors must be opened within 100ms from LOI detection and remains opened up to next key off-key-on.	Close contactors After 5s apply 100 kohm between HV+ and 12V GND After 10s remove the 100 kohm resistor
8.	LOI Detection	Electrical	R = 100kohm The signal Insulation_kohm should report the correct measure with max ±10% accuracy. The Isolation Warning and Isolation Fault should be set in less than 5s and remains set up to next key off-key-on.	Close contactors After 5s apply 100 kohm between HV- and 12V GND After 10s remove the 100 kohm resistor
9.	Verification of Over-voltage protection	Electrical	Contactors must be opened within 100ms from LOI detection and remains opened up to next key off-key-on.	Reduce the max cell overvoltage limit below the actual most charged cell voltage
10.	Verification of Under-voltage protection	Electrical	The undervoltage fault must be set in less than 100ms and remains set up to next key off-key-on. Contactors must be opened within 100ms from undervoltage detection and remains opened up to next key off-key-on.	Increase the min cell undervoltage limit above the actual most discharged cell voltage
11.	Verification of Over-temperature protection	Electrical	The Overtemperature fault must be set in less than 100ms and remains set up to next key off-key-on. Contactors must be opened within 100ms from overtemperature detection and remains opened up to next key off-key-on	Reduce the max cell temperature limit below the actual most hot cell temperature

12.	Verification of Material corrosion	Thermal	Test with water&glycole No leakage during the corrosion test and during the post-test leakage test.	ASTM G85A3
13.	Verification of Material erosion	Thermal	Test with water&glycole No leakage during the corrosion test and during the post-test leakage test.	Fluid Mixture: 50/50 water/Paraflu/CCI, 100 mg/L chloride, 100 mg/L sulfate Coolant tube velocity: 2.5 +/- 0.1 m/sec Temperature: 105°C +/- 3°C Pressure: 2 bar ± 0.19 bar at radiator inlet Test duration: 300 hours
14.	Verification of coolant leakage	Thermal	Test pass if no variation of the pressure is measured.	Using nitrogen gas, put in pressure the cooling circuit with at least 15bar (relative pressure) in case of refrigerant and 3.5bar in case of coolant. The cooling circuit should be located in a temperature controlled area in order to avoid pressure variation due temperature variation. Close the inlet and outlet and monitor the pressure for 8 hours.
15.	Verification of overpressure	Thermal	Test @max pressure Test pass if no variation of the pressure is measured.	Using nitrogen gas, put in pressure the cooling circuit with at least 25bar (relative pressure) in case of refrigerant or 8bar in case of coolant. Close the inlet and outlet and monitor the pressure for 10 minutes

16.	Cell Temperature monitoring	Electrical, Thermal	Open Main contactors within TBD ms. The system shall monitor the temperature of the cells to prevent Overtemperature of cells.	Flooding of coolant circuit with coolant media with increasing temperature. Or drain/charge current from/to battery with coolant circuit empty or coolant pump switched off **Covered/identical with safety test No.11 "Verification of Over-temperature protection"**
17.	Cell Temperature monitoring plausibility	Electrical, Thermal	Open Main contactors within TBD ms. The System shall detect failures in cell temperature monitoring that can lead to a non-detected cell overtemperature event.	Depends on implementation. Test TBD. Can be done on component level.
18.	Cell Voltage monitoring	Electrical	Open Main contactors within TBD ms. The system shall monitor the voltage of the cells to prevent over- or undervoltage of cells.	Overcharge battery (Quality management (QM)thresholds disabled or change of parameters via service) Underdischarge battery (QM thresholds disabled or change of parameters via service) **Covered/identical with safety test No.9-10 "Verification of voltage protection"**
19.	Cell Voltage monitoring, - Diagnosis	Electrical	Open Main contactors within TBD ms. The System shall detect failures in cell voltage monitoring that can lead to a non-detected over- or undervoltage event.	Depends on implementation. Test TBD. Can be done on component level.
20.	Overcurrent protection, Fuse Shutoff	Electrical	Break HV current path The system shall break the HV current path within the battery in case of an external low impedance short circuit. Main contactors shall be kept close in case that the short circuit current is above the strategic switching point in the I-t (current over time in [A] and [s]) curve.	Application of external short circuit to HV Battery (Resistance according ECE R100)

21.	System Current monitoring, Overcurrent monitoring	Electrical	Open Main contactors within TBD ms The system shall detect currents exceeding the I-t current carry capability of all components in the HV current path to avoid damage to the components. In case that certain currents cannot be repeatedly damaged, counters shall be set.	Application of external short circuit with high impedance to HV Battery Current profile application on battery according defined important points in the I-t curve (e.g. max. carry current of contactors)
22.	System Current monitoring, Overcurrent monitoring - plausibility	Electrical	Open Main contactors within TBD ms The system shall determine a qualifier of the system current measurement based on the received current measurement values with respect to their measurement tolerances	Depends on implementation. Test TBD. Can be done on component level.
23.	HV person protection Isolation monitoring	Electrical	Provide warning message to vehicle Prevent activation of HV Power supply The system shall detect isolation faults between HV and LV potentials	Initiation of HV insulation fault on both HV+ and HV- after main contactors have been closed Initiation of HV insulation fault on both HV+ and HV- before precharging **Covered/identical with safety test No.3-8 “LOI Detection”**
24.	HV person protection, HVIL	Electrical	Open Main contactors within TBD ms Reporting of Open HVIL to complete vehicle The system shall open main contactors in case that HV connections are opened, where access to HV live parts is possible	Actuation of switches in the HVIL loop (at zero Current to avoid damage of contactors) **Covered/identical with safety test No.1 “HVIL with contactors closed”**
25.	HV person protection, MSD	Electrical	Open Main contactors within TBD ms The system shall open main contactors in case service disconnect switches are opened (pack internal or part of integration environment depending on concept)	Actuation of MSD (at zero current to avoid damage of contactors and measure HV potential on dedicated MSD measurement pins. Should be tested on system level.
26.	Contactor Diagnosis Weld check diagnosis	Electrical	Prohibit activation of HV power supply (closing of main contactors The system shall detect permanent connections in the HV shutoff paths after deactivation and prior to activation	Test TBD. Should be done on component level.

27.	Contactor Diagnosis Damage Counter of main contactors	Electrical	Prohibit activation of HV power supply (closing of main contactors The system shall set and accumulate damage counters for the main contactors, in case that the contactors are opened in a non-zero-current condition	Test TBD. Should be done on component level.
28.	Contactor Diagnosis plausibility of System voltages	Electrical	Open Main contactors within TBD ms The system shall monitor the plausibility of the HV potential differences within the battery. In case that measurements of HV potentials against LV ground are available, the plausibility should use at them in plausibility criteria to avoid dangerous effects of common cause failure in HV-based measurement.	Test TBD. Should be done on component level.
29.	Contactor Diagnosis Default damage counter	Electrical	Prohibit activation of HV power supply (closing of main contactors) To ensure a correct increase of damage counters in case of toggling KL30 supply, a default damage counter shall be set upon start up and shall be lowered only in case of correct shutdown.	Test TBD. Should be done on component level.
30.	Signal protection E2E Protection	Electrical	Open Main contactors within TBD ms The system shall monitor safety related communication paths, which respect to update, order and content of sent and received messages.	Test TBD. Should be done on component level.
31.	Crash Shutoff	Electrical	Open Main contactors within TBD ms. The system shall monitor external interfaces for a crash input.	Simulate external crash signal and check if main contactors have opened.
32.	Verify shutoff mechanisms.	Electrical	overcurrent test with currents exceeding the max charge/discharge current	The overcurrent limited, which cause minor damage of the main contactors The values for this current should be aligned with the manufacturers of the contactors

2.4 Functional tests

Functional tests check the normal operating performance of the battery management system (BMS). Following tests on main BMS functions are listed for the SELFIE battery system:

- Balancing
- State-of-charge (SOC) estimation
- Current and power limits.

Typically, each cell in a battery pack have different capacities and the cell with the lowest capacity influences the other cells. The balancing function improves, by transferring energy from or to individual cells, the available capacity of a battery. The SOC (0% = empty, 100% = full) estimation is one of the most important functions in a BMS. SOC cannot be measured directly, but it can be estimated from direct measurement variables. Limitation on the maximum power is essential to protect lithium-ion batteries from overcharge/discharge and overheating.

It is recommended that these tests will be performed before mechanical or performance tests (Table 6).

Table 6: Functional tests

#	purpose	Test rig Category	Criteria for performance assessment and validation	test sequence
1.	Balancing	Electrical	High unbalancing level (DSOC > 5% between most charged and most discharged cell) The balancing system should start the balancing procedure in the preferred way as during charging as during normal mode. The balancing system should be able to recover 1%/hour of the unbalancing level	Discharge one single cell by 6% of SOC Power up the Battery Management System (BMS)
2.	Balancing	Electrical	Low unbalancing level (DSOC <= 5% between most charged and most discharged cell) The balancing system should start the balancing procedure in the preferred way during charging. The balancing system should be able to recover 1%/hour of the unbalancing level.	Close contactors Connect battery to charger and enable the charger mode
3.	SOC estimation	Electrical	Test with constant&pulse load In post-processing, recalculate the SOC profile during the test from the integral calculation of the current and using the initial SOC get from OCV. The integral calculation should be divided by the real measured battery capacity, not the nominal one. Eventually, re-arrange the SOC calculation to the SOC range defined in the BMS. Report the comparison of the calculated SOC profile with the value supplied by BMS.	Make sure the battery is fully balanced Relax the battery for at least 12hours Place a calibrated and high accuracy current sensor along the positive or negative connection Measure the battery OCV with a calibrated and high accuracy voltage sense, then calculate the initial SOC using the OCV Close contactors After 5s apply the current profile 'SOC

			The maximum error should be lower than 5%.	pulse current' defined in 'Profiles' sheet in order to bring the battery from max SOC (i.e. 100%) to min SOC (ie 0%)
4.	SOC estimation	Electrical	Test with constant & pulse load In post-processing, recalculate the SOC profile during the test from the integral Calculation of the current and using the initial SOC get from OCV. The integral calculation should be divided by the real measured battery capacity, not the nominal one. Eventually, re-arrange the SOC calculation to the SOC range defined in the BMS. Report the comparison of the calculated SOC profile with the value supplied by BMS. The maximum error should be lower than 5%.	Make sure the battery is fully balanced Relax the battery for at least 12hours Place a calibrated and high accuracy current sensor along the positive or negative connection Measure the battery OCV with a calibrated and high accuracy voltage sense, then calculate the initial SOC using the OCV Close contactors After 5s apply the current profile 'SOC pulse current' defined in 'Profiles' sheet in order to bring the battery from min SOC (ie 0%) to max SOC (ie 100%).
5.	SOC estimation	Electrical	Test with constant & pulse load In post-processing, recalculate the SOC profile during the test from the integral calculation of the current and using the initial SOC get from OCV. The integral calculation should be divided by the real measured battery capacity, not the nominal one. Eventually, re-arrange the SOC calculation to the SOC range defined in the BMS. Report the comparison of the calculated SOC profile with the value supplied by BMS. The maximum error should be lower than 5%.	Make sure the battery is fully balanced Relax the battery for at least 12hours Place a calibrated and high accuracy current sensor along the positive or negative connection Measure the battery OCV with a calibrated and high accuracy voltage sense, then calculate the initial SOC using the OCV Close contactors After 5s apply the current profile 'SOC pulse current' defined in 'Profiles' sheet in order to bring the battery from min SOC (ie 0%) to max SOC (ie 100%).

6.	SOC estimation	Electrical	Test with driving load In post-processing, recalculate the SOC profile during the test from the integral calculation of the current and using the initial SOC get from OCV. The integral calculation should be divided by the real measured battery capacity, not the nominal one. Eventually, re-arrange the SOC calculation to the SOC range defined in the BMS. Report the comparison of the calculated SOC profile with the value supplied by BMS. The maximum error should be lower than 5%.	Make sure the battery is fully balanced Charge/discharge the battery up to 50% SOC Relax the battery for at least 12hours Place a calibrated and high accuracy current sensor along the positive or negative connection Measure the battery OCV with a calibrated and high accuracy voltage sense, then calculate the initial SOC using the OCV Close contactors After 5s apply the current profile 'SOC profile current' defined in 'Profiles' sheet Repeat the current profile for 3 consecutive times
7.	Current/Power limits	Electrical	Pulse test The expected result should be a current limitation similar to the example shown in 'Limits profile current' defined in 'Profiles' sheet.	Fully charge the battery up to >90% Make sure the battery is fully balanced Apply a pulse current of MAX(-300Amps, Max_Discharge_Current) for 60s Relax the battery for 5minutes Repeat the pulse & wait sequence until SOC of the battery is <10%
8.	Current/Power limits	Electrical	Pulse test The expected result should be a current limitation similar to the example shown in 'Limits profile current' defined in 'Profiles' sheet.	Fully discharge the battery up to <10% Make sure the battery is fully balanced Apply a pulse current of MIN(300Amps, Max_Charge_Current) for 60s Relax the battery for 5minutes Repeat the pulse & wait sequence until SOC of the battery is <10%

3 Thermal system performance on vehicle

For the evaluation of the reference and the demonstrator battery systems and vehicle, representative use cases have been selected and corresponding test case both stationary and transitory scenarios derived. The scenarios take into account the SOC of the battery, the ambient conditions, vehicle speed profiles, etc.

Based on this, a complete test matrix has been created (Table 7).

Figure 3 shows the vehicle speed profile to be used for the tests involving to the Worldwide Harmonised Light Vehicles Test Procedure (WLTP).

3.1 Stationary test cases

Table 7 – Thermal tests matrix

USE CASES validation of technology / function	Vehicle Speed [km/h]	SOC [%]	Ambient Temp [°C]	Relative Humidity [%] (Dew Point)	Temp. Battery [°C]	Temp. Cabin [°C]	Solar Radiation [W/m²]	Thermal Storage SOC [%]	Charg. Station (power level) [0; 150 kW]	Check Points
Battery Preconditioning	0 km/h	100	-10°C	19%(-29°C)	-10°C	N.A.	0	100	N.A.	Preconditioning time needed to reach battery in range temperature will be evaluated
Cabin Cooling Energy Demand	See WLTP speed Profile (Figure 3)	100	+35°C	60%(26°C)	+35°C	+35°C	1100	100	N.A.	kW/h spent @ EOC will be checked
Cabin Heating Energy Demand	See WLTP speed Profile (Figure 3)	100	-10°C	19%(-29°C)	-10°C	-10°C	0	N.A.	N.A.	kW/h spent @ EOC will be checked
Cabin Cooling Performance	See paragraph 4.2.2	100	+43°C	60%(26°C)	+43°C	+43°C	900	100	N.A.	Head Level Temperature = 22°C @ 10'
Cabin Heating Performance	See paragraph 4.2.1	N.A	-10°C	19%(-29°C)	-10°C	-10°C	0	N.A.	N.A.	Floor Level Temperature = 45°C @ 12' Mean Cabin Temperature = 22°C @ 22'
Fast Charging Battery Cooling	0 km/h	0	+35°C	N.A.	+22°C	+22°C	700-1100	100	150	Battery temperature in range during the charging procedure
Fast Charging Battery & Cabin cooling	0 km/h	0	+35°C	N.A.	+22°C	+22°C	700-1100	100	150	Cabin always in target (22°C) during the charge Fast Charging Time respected
Battery & Cabin Cooling Cooling/Heating while Cruising	Cruise @ constant speed 100 km/h	100	0°C +35°C	19%(-21°C) 50%(16.2°C)	0°C +35°C	0°C +35°C	700-1100	100 N.A.	N.A.	700 km cocered in max +1,5h wrt. ICE version

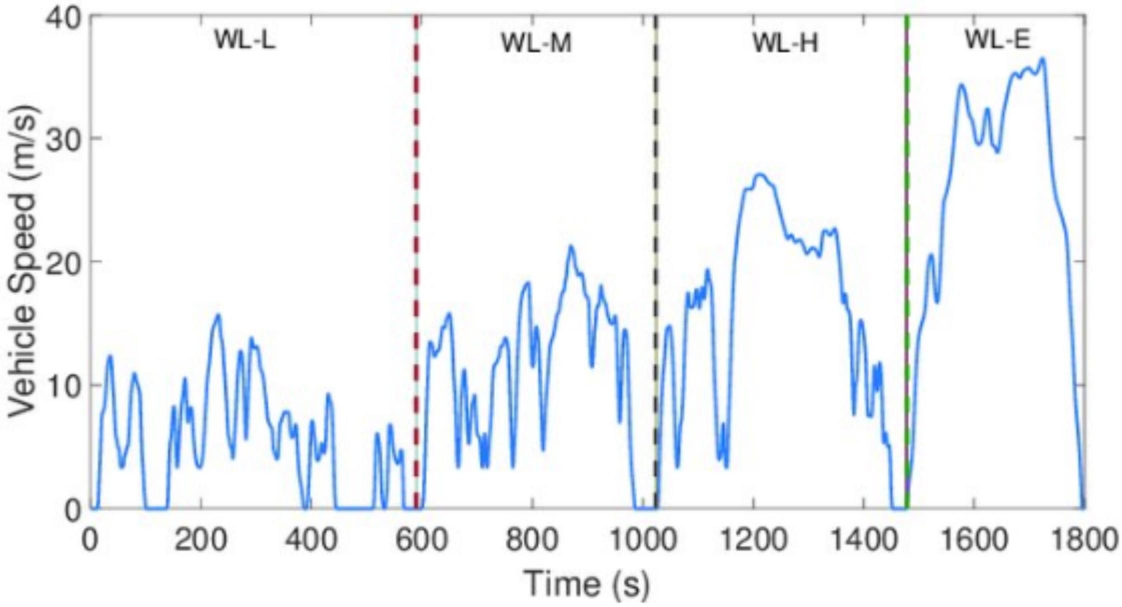

Figure 3. WLTP speed profile

3.2 Transitory test cases

For cabin cooling and heating use cases, the reference is a standard procedure, which is a reference for the performance assessment of the vehicle air conditioning systems.

The two different procedures are:

- Cabin warm-up
- Cabin cool down

4.2.1 Warm-up (Cabin Heating Performance)

This test is useful for evaluating the cabin heating performance. It is performed in a climatic wind tunnel (CWT) where the vehicle needs to be pre-conditioned at -10°C with its engine compartment hood raised to cold soak until engine coolant and lubricant are stabilized within the test temperature range for at least 2h.

For xHEV vehicles, preconditioning has to be applied also to the high-voltage. The soaking has to be maintained until the battery minimum cell temperature has reached the test temperature. The battery has to be fully charged and the charge must be done in parallel to soaking but only for the first 3 hours. Once at 100%, the vehicle must be unplugged and continue soaking for another 9 hours (see Figure 4).

	HOURS											
Temperature	1	2	3	4	5	6	7	8	9	10	11	12
-20F to 32F	High Voltage Charge + Soak			SOAK ONLY								

Figure 4. Battery soaking procedure valid from -28°C up to 0°C

For electric vehicles, the vehicle speed profile has to be followed to guarantee the wind speed on the front-end assuring the expected radiator performance.

In Figure 5 the different test phases are detailed:

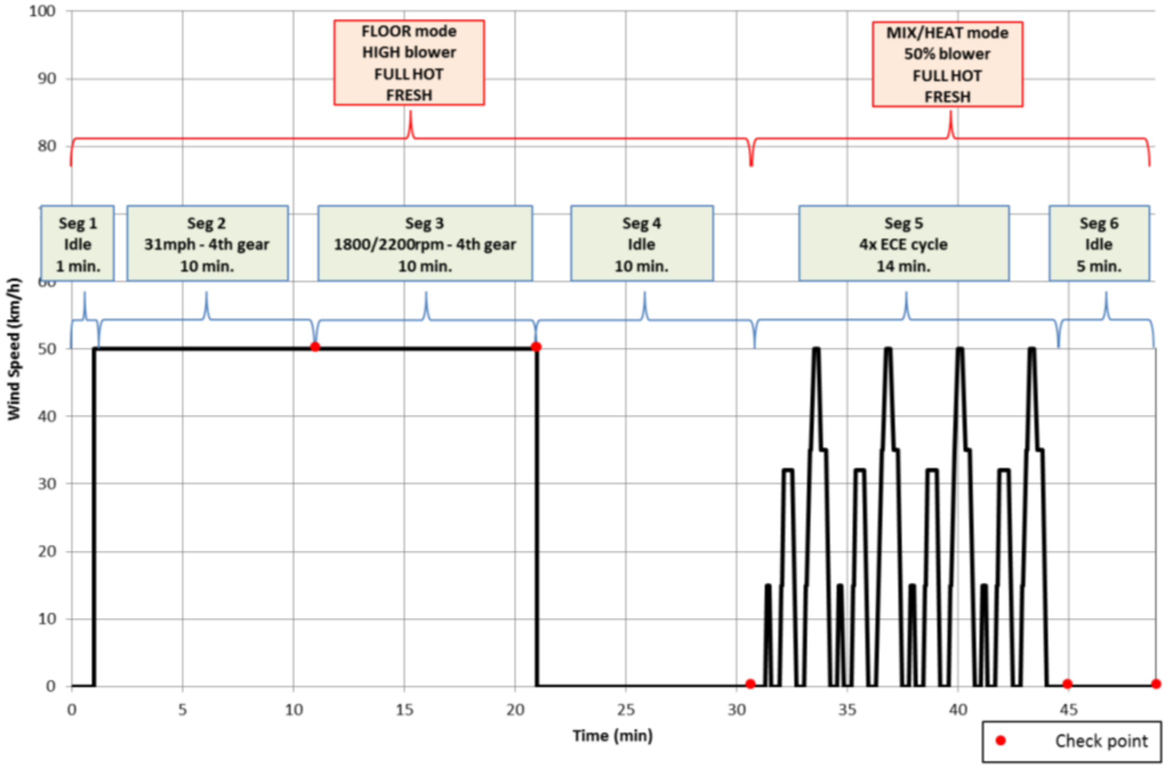

Figure 5. Warm-up speed profile and phases

The HVAC has to be configured with two different set-ups in terms of distribution, blower speed, set-point and recirculation flap position. The test segment 2 and 3 (referring to the gray boxes in Figure 5) have to be considered as only one because of the electric compressor which is not belt driven therefore not linked with the engine rpm.

The checkpoints are the temperature gates monitored for the performance evaluation.

The target values are:

- The temperature at floor outlet level higher than 45°C after 12’
- Mean cabin temperature at 22°C after 22’

The others checkpoints (red dots in Figure 5) are only placed to monitor the system behaviour and there is no specific target for system approval.

4.2.2 Cool down (Cabin cooling Performance)

This test requires a climatic wind tunnel and vehicle preconditioning as the previous one. In detail, the preconditioning phase requires to respect the following set-up:

The A/C unit controls have to be configured as described below:

- Recirculation
- Air distribution to the dashboard outlets (VENT)
- Max cold (LO displayed on HVAC ECU for automatic versions)
- A/C fan to OFF (For manual and automatic systems)
- Open-air outlets on dashboard and rear console, directing them at the heads of the dummies.

From the control room, the following environmental conditions in the climatic wind tunnel has to be respected:

- Temperature 43 °C ± 1
- Wind 7 to 8 km/h
- RH 30%.

The vehicle needs to be stabilized respecting this procedure:

- open the doors of the vehicle;
- ventilate with sunlight lamps off;

When the mean temperature of the feet, heads, and cabin is around 43°C, close the vehicle doors, switch on the sunlight simulating lamps adjusting their number and intensity in such a way that the radiation measured with solar meter at occupant compartment roof height is equal to 900 W/m^2.

The following conditions have to be maintained :

- until the mean temperature, measured at dummy's heads, is 63 to 65 °C
- until the mean occupant temperature is >50°C
- until the mean foot temperature is 43°C

At this point, the test can start setting the A/C electric fan at maximum speed and switching on the compressor. The test has to be carried out following the phases included in Table 8.

Table 8 – Cool-down phases

Time (min.)	Speed [km/h]	Wind speed [km/h]	Manual gear	Auto gear
0	32	32	2^	D
30	64	64	3^	D
60	96	96	5^	D
90	Idle	3 to 8	N	N
120	32	32	2^	D
140 approx	idle	3 to 8	N	N

In addition, there is a checkpoint located at the head level. The temperature has to reach 22°C after 1/2h to be compliant with the system approval.

4 Conclusions

The battery pack is the key component in SELFIE Project. A detailed list of tests has been defined in order to assess the battery capabilities as well as of its safety and reliability.

The battery thermal management during fast charging is the most critical function of the whole thermal system architecture. The testing procedure has been designed in order to stress the system and assess its capability and performance.

Moreover, a complete test matrix with defined use cases has been delivered. The document also includes a detailed description of the thermal performance assessment procedure for the cabin.

Abbreviations and Definitions

Term	Definition
A/C	Air Conditioning
CSD	Cold Storage Device
CVT	Current Vehicle Tested
LT	Low Temperature
N.A.	Not Applicable
PTC	Positive Temperature Coefficient (Heater)
RAD	Radiator
RH	Relative Humidity
SOC	State of Charge
WCND	Water Condenser
WLTP	Worldwide Harmonised Light Vehicles Test Procedure
ECE	From Emission Test Cycle speed profile. It is synonymous of UDC (Urban Driving Cycle)

References

(1) ISO12405 - Electrically propelled road vehicles — Test specification for lithium-ion traction battery packs and systems.

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