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Transforming
Europe's Rail Freight

D5.4 Appendix T1

Test plan for power distribution system

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1. Introduction

This document defines one part of the validation/test plan of the DAC Power and Data Communication solution (FP5-TRANS4M-R Task 5.5) and serves as a supplement (appendix [T1]) to the FP5-TRANS4M-R Deliverable 5.4 "Technical Specification of Wagon Power System and Communication System" V2.0.

One of the remaining open points of Deliverable 5.4 (D5.4) was the definition of a test plan for the Power Supply and Distribution system. This open item is going to be closed with this document.

Keywords:

FDFT; Technical Enabler for FDFTO; PSS; Power Supply System; Power Distribution Line; PDL; Traction Unit; TUPSS; Wagon; WPSS



2. Terms & Abbreviations, acronyms and definitions

See /WP5 D5.4/ chapter 2.



3. Test plan for PDL system

According to the FP5-TRANS4M-R Grand Agreement, WP5 Task 5.5 shall provide the specification and the related validation/test plan for the Power Supply system (PSS) and Power Distribution Line (PDL) subsystem. WP9 shall, in collaboration with WP14, carry out “developer-tests” in order to ensure the suitable system approaches for the FDFTO train power system for locomotives and wagons. More specifically, WP9 shall (see GA, WP9 Sub-Task 9.2.1):

- setup and integrate power tests equipment for interoperability
- Verify and validate full PDL functionality in the train test lab (WP13 + WP14)

This test plan is focused on the first bullet to ensure that interoperable and integrable train power supply system equipment is delivered to the train test lab.

Final validation and test results shall be documented as part of D14.3: “Test and Validation Report for the energy system (Locos and wagons) and data communication system”.

3.1 Scope of the test plan for the PSS and PDL

The scope of this test plan is the Power Supply System and Power Distribution Line of the whole FDFT and the external power supply to ensure interoperability among consists being equipped with devices or components from different suppliers. This includes also those functions, which are used for supporting train functions defined in D5.1, like:

- Consist power and battery management supporting the train function “Train monitoring status”. This includes all the power management functions required at train level as defined in 7.2.3.5.4 of D5.4
- The testing of the related train functions is not in the scope of the test plan for the PSS and PDL.
- Due to the special ATEX requirements on devices which are intended to be used in such ATEX environments, these devices are excluded from this power test plan.

3.1.1 System under Test (SuT)

The FDFT forms the SuT, including the complete train PDL and the power supply subsystems for the Traction Units and Wagons, as defined in chapters 7.2.2, 7.2.3 and 7.2.4 of /WP5 D5.4/

3.1.2 Test strategy

Test Groups

Due to the time limitations for the component development and due to the fact that different tests may require a different test setup and laboratory equipment, one strategic objective is to parallelize tests where appropriate. This can best be organized by defining test groups, where each test group uses a specific setup and laboratory equipment.

An overview of the different test groups and the related test setups ("test environment") is presented in Table.1.

ID.	TEST ACTIVITY	TEST ENV.	COMMENTS
3.3.1	Burst immunity	Supplier	Both for Loco and wagon PSS equipment
3.3.2	Emission immunity	Supplier	Both for Loco and wagon PSS equipment
3.3.3	Wagon PSS	Supplier	Test of WPSS of AC front-input part.
3.3.4	Wagon PSS	Supplier	Test of WPSS output source
3.3.5	Wagon PSS	Supplier	WPSS output protection and safety
3.3.6	Wagon PSS	Supplier	WPSS equipment isolation test
3.3.7	Wagon PSS	Supplier	WPSS Battery Management System
3.3.8	Traction Unit PSS	Supplier	Test of TUPSS output source
3.3.9	Traction Unit PSS	Supplier	Test of TUPSS output protection and electrical safety
3.3.10	Traction Unit PSS	Supplier	TUPSS equipment isolation test
3.3.11	PDL Train Layout	TTL	PDL train system integration and safety
3.3.12	PDL Train Layout	TTL	AC power source distribution for up to 50 wagons
3.3.13	PDL external ground PSS	Supplier	PDL external ground PSS equipment output power and protection and safety
3.3.14	PDL Shielding & grounding	TTL	PDL Personal protection
3.3.15	PDL Shielding & grounding	TTL	PDL Isolation fault

Table 1: Test activities

Test process

The testing and verification process shall follow the V model as depicted below. Base are the input requirements given within this document for the FDFT power distribution line system with the objective of a finally 100% requirements coverage.

Not in scope are tests on product and component level, but prerequisite of participating in the train power supply system test is a successful execution of component and product tests at equipment supplier side. This is to prevent that immature products hinder the progress of system level tests.

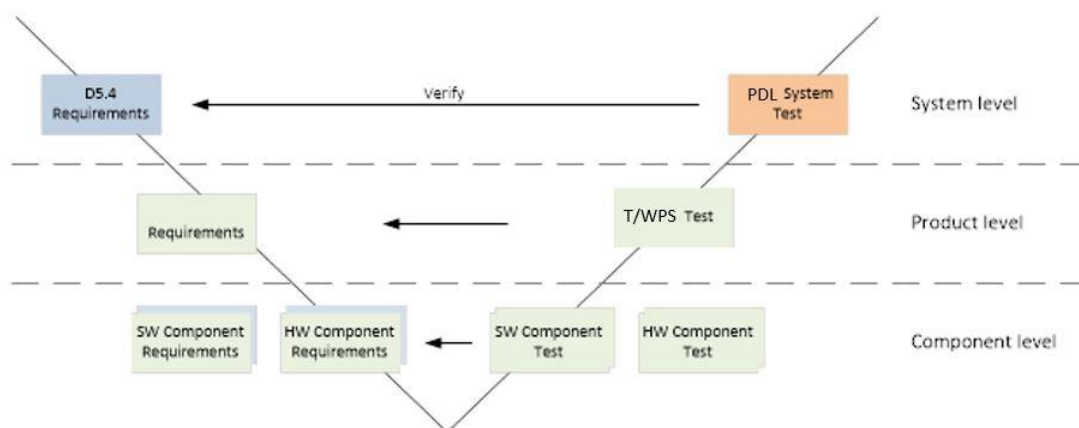


Figure 1: Overall PSS & PDL test strategy

Definition of test cases

Test cases and inspection items derived from the requirements can be categorized into verification activities, measurement activities and test activities.

The characteristics of these activities are defined in Table.2.

Category	Description	Keywords	Example
Verification activities	Verification of procedures, processes and documents	verification, verify	Verify that ...
Measurement activities	Measurement and recording of physical quantities (e.g. size, distance, voltage, current, temperature, time). Does not include a pass or fail verdict.	measurement, measure	Measure the
Test activities	Check of properties or measurement results. Includes a pass or fail verdict.	test, check	Check that ... Test the ...

Table 2: Test case categories (source: /WP5 62/)

Test documentation

Tests and test results executed at equipment supplier premises shall be documented in the deliverables /WP9 D9.1/ (locomotives = traction units) and /WP9 D9.2/ (wagons).

Tests and test results executed by vehicle supplier shall be documented in deliverables of /WP9 D9.5/ and TTL shall be documented in the deliverables of WP14.



3.1.3 Test activities

This chapter defines the different testing activities for the execution of the system test groups, basically intended for test planning.

For the test execution itself more detailed test specifications, which are derived from the requirements set out in this document, should be provided.

General

Test responsibility

All beneficiaries providing FDFT power supply systems shall name one test responsible. These beneficiaries are SMO, KB, VOI, FT, ALSTOM.

Test location

Supplier: equipment supplier premises or vehicle supplier premises

TTL: Train Test Lab (Berlin)

Test infrastructure

Test infrastructure is defined by the different test groups which are listed in Table 3.

Test Env.	Laboratory equipment (test laboratory)	SuT requirements (supplier)
Supplier	Supplier responsibility	PSS prototype
TTL	As defined by WP13 and WP14.	Integrable and interoperable PSS prototypes of TRL ≥ 6

Table 3: Test infrastructure requirements

3.2 Traceability Matrix

The traceability matrix maps the FDFT Power Supply and Power Distribution Line system requirements to the different test activities and test IDs which can be used as input for a detailed test specification.

Requ.ID	Title / Description	Test ID
IPTRANS-9896	The cabling for the PDL and F-ETB lines shall be installed to comply with the conducted EMC measures specified in EN 50343. When using the same ducts or pipes, it is recommended to use separated conduits or similar methods.	3.3.2
IPTRANS-7782	EMC behaviour of the Power Supply System in the FDFT	3.3.1 3.3.2
IPTRANS-1049	EMC, the Wagon Power Supply System	3.3.1 3.3.2
IPTRANS-6804	CCU shall evaluate the power contact monitoring: The supervision solutions shall monitor the current flowing along the parallel, redundant current paths. The current	3.3.3 3.3.8

Requ.ID	Title / Description	Test ID
	sensors output shall be electrically connected to the consist control unit (CCU). The CCU shall evaluate the supervision functionality.	
IPTRANS-8128	The Power Distribution Line throughout the wagon uses two cables for each phase (redundancy of the e-coupler contacts), in sum 2x2. The two wires per phase shall be connected together at a single point in the consist. It is recommended to use the input section of the Wagon Power Supply System for that location to allow also the possibility of power contact monitoring.	3.3.3
IPTRANS-8852	The fundamental frequency of the output voltage of the traction unit shall be in the range between 50 Hz and 60 Hz.	3.3.3 3.3.8
IPTRANS-8853	The voltage shape shall be sinusoidal Total Harmonic Distortion: THD $\leq 10\%$ at rated output power 3,75 kVA at the e-coupler of the traction unit.	3.3.3 3.3.8
IPTRANS-8222	Electrical protection functions of the electrical power system for the FDFT: The FDFT electrical power system shall be protected by the feeding traction unit against: • overvoltage • overcurrent	3.3.4 3.3.9 3.3.11
IPTRANS-8173	WPSS shall provide power to the wagon on-board equipment	3.3.3
IPTRANS-428	The WPSS incorporates an energy storage (battery)	3.3.7
IPTRANS-8186	WPSS has a data interface for exchanging information	3.3.7
IPTRANS-8200	Carry out of electromechanical connection (taps) to the PDL with minimal ohmic losses	3.3.11
IPTRANS-8704	Cable cross section dimension of the tap from the power distribution line	3.3.11
IPTRANS-513	Input voltage operation range	3.3.3
IPTRANS-7090	Default input power limitation	3.3.3
IPTRANS-517	Inrush current limitation on startup	3.3.3
IPTRANS-523	In case of failure, the wagon energy system shall automatically switch off itself	3.3.3
IPTRANS-7092	The Wagon Power Supply System shall provide a low-power output	3.3.4
IPTRANS-7091	The Wagon Power Supply System shall provide a high-power output	3.3.4
IPTRANS-533	Negative potential of the high- and low-power outputs of WPSS	3.3.4
IPTRANS-526	Providing diagnostic information	3.3.7
IPTRANS-8859	Auxiliary batteries fire safety	3.3.7
IPTRANS-538	Charging of battery shall be possible under all environmental conditions	3.3.7
IPTRANS-8189 -	Energy storage charge level visualization for yard personnel	3.3.7

Requ.ID	Title / Description	Test ID
Option		
IPTRANS-7781	Wagon energy storage	3.3.7
IPTRANS-6795 - Feature	Yard standstill wagon battery usage	3.3.7
IPTRANS-6798 - Feature	Yard standstill wagon battery usage#2	3.3.7
IPTRANS-6811 - Feature	Wagon battery usage in yards	3.3.7
IPTRANS-6812 - Feature	Train mainline wagon battery usage	3.3.7
IPTRANS-7784	Per FDFT train segment only one traction unit shall supply electrical power to this segment.	3.3.9 3.3.12
IPTRANS-7094	Concerning fire safety cable protections and installations shall comply with EN 50355 and EN 50343.	3.3.9
D5.4, section 7.2.1.1	PDL must not be activated, when the contacts are not coupled or covered. This requirement relates to the e-coupler of the DAC and the (interface) connectors of the PDL between the e-coupler and the fixed and protected consist wiring	3.3.9 3.3.11 3.3.14
IPTRANS-6790	Access is only permitted to (electrically) instructed persons and skilled persons provided that precautions against unintended direct contact are taken.	3.3.5 3.3.9
IPTRANS-9352	The cabling for the Power Distribution Line shall be installed in protection pipes and/or ducts (grounded to chassis, when made of metal)	3.3.5 3.3.9
IPTRANS-9353	All parts of the metal case of the e-coupler, including the flap, shall be grounded to the chassis via the main coupler.	3.3.5 3.3.9
IPTRANS-6791	The e-coupler (and each interface connector) shall be fitted with warning labels for danger of electrical shock in according to EN 61310-1.	3.3.5 3.3.9
D5.4, section 7.2.1.2, page 51	an IT system is chosen for the execution for the FDFT power system according to IEC 60364-4-41. For such insulated power networks (IT-systems) it is mandatory to supervise the proper state of the insulation system (according to EN 60364-4-41) of the whole system, which belongs to the scope of monitoring.	3.3.9 3.3.15
D5.4, section 7.2.1.2, page 52 + 53	The maximum grounding resistance of 150 mOhm (according to EN 50153) to ensure an adequate reference potential and current to ground/chassis for detection, is to be kept.	3.3.5 3.3.9
IPTRANS-804	The impedance between active parts (insulated) against chassis of the vehicle (grounded to rail) of the PDL shall be evaluated and failures detected from the traction unit which supplies power to the PDL.	3.3.10 3.3.15
D5.4, section	The trigger of the failure information (failure state of the	3.3.10

Requ.ID	Title / Description	Test ID
7.2.1.2, page 52	insulation system) shall be set, when the insulation resistance falls below the value of 22 kOhm. The failure information shall be reset, when the insulation resistance raises by 20%. For failure localization in demo and pioneer trains option 1 shall be applied.	3.3.15
IPTRANS-8190	Fire safety for components used in traction units: The design of components, which are used in traction units, shall be compliant to EN 45545. Check with WP5 w. r. to wagons Remark: to be finalized in Polarion: "Check with WP5 with respect to wagons"	3.3.9
IPTRANS-9400	Overcurrent protection in view of fire safety: The fusing of the PDL for overcurrent protection shall be applied for both poles. Both poles in circuit breaker shall be coupled.	3.3.9
IPTRANS-1061	Behaviour of the TUPSS in case of loss of train integrity or accident: In case of loss of train integrity or accident, the power supply from the traction unit shall be shut down. This shut down shall be realized automatically and immediately in case of detected integrity loss or derailment, or by procedures in any other case.	3.3.9
IPTRANS-6792	The access to live parts (carrying 400 V) shall be inhibited in the uncoupled state and while the train function "prevent coupling" is active.	3.3.5 3.3.9 3.3.14
IPTRANS-8856	The electrical power supply system shall be based on 400 V AC, single phase. The electrical power shall be supplied by the traction unit power supply system (TUPSS) and is distributed via the power distribution line (PDL) to the consists.	3.3.8
IPTRANS-7733	The electrical power supply system of an FDFT traction unit shall be able to supply at least: $P = 3 \text{ kW}$, with a minimum power factor of 0.8 $S = 3.75 \text{ kVA}$	3.3.8
IPTRANS-6787	The power supply system shall not be used for supplying power to applications other than FDFTO related ones (e.g.: refrigeration containers)	3.3.3 3.3.12
IPTRANS-8860	The cross section for the power distribution line cables shall be $2 \times 6 \text{ mm}^2$ per phase.	3.3.3 3.3.8 3.3.12
IPTRANS-9354	Each power contact in the e-coupler shall be redundant, i.e. two contacts are foreseen for each phase (the same potential).	3.3.3 3.3.8 3.3.11
IPTRANS-9898	A single power contact in the e-coupler shall be able to carry the short-circuit current of the PDL as well as the nominal current without limitations.	3.3.3 3.3.8 3.3.11

Requ.ID	Title / Description	Test ID
IPTRANS-767	The TUPSS shall be connected / disconnected by a switching device to the PDL.	3.3.8 3.3.11
IPTRANS-9895	Electrical power shall be supplied only to the train segment, which is coupled to the rear end of the leading traction unit.	3.3.9 3.3.11
IPTRANS-8206	Regulation voltage 400 V AC +10/ -0%, at the output of the traction unit, available at the e-coupler (only the positive tolerance, as defined in EN 50533, shall be applied).	3.3.8
IPTRANS-8208	Minimum Power to be delivered by the TUPSS: P = 3 kW (real power) S1 = 3.2 kVA (apparent power for the fundamental wave) S = 3.75 kVA (total apparent power including all harmonics) cos(phi) = 0.9 and power factor = 0.8	3.3.8
IPTRANS-765	The output of the TUPSS shall be bipolar. Providing a single phase 400 V AC power supply to the PDL.	3.3.8
IPTRANS-778	The activation and deactivation of the TUPSS shall be carried out only in the feeding traction unit.	3.3.9
IPTRANS-8854	Only one single source shall feed the PDL of the same train segment. Before the release of the power conversion, It shall be checked in the dedicated traction unit that there is no other source already feeding the PDL.	3.3.9
IPTRANS-9401	An advisory message shall be shown on the DMI in the leading traction unit, when the FDFT is in train run mode and the TUPSS is ready to supply the PDL. The message shall be in the sense: "Please check the power supply into the PDL".	3.3.8
IPTRANS-8215	Both output contactors of the TUPSS shall be interlocked against each other.	3.3.9
IPTRANS-8212	After the dedicated output contactor has been closed, the power supply shall be started in the following ways: Solution with transformer: - in first step: switch on the output voltage to the PDL via a damping resistor, - in second step: bypass damping resistor to get full voltage on the PDL. - alternative: Ramp up of primary voltage, if the traction unit supports this feature. Solution with inverter: - Ramp up the output voltage from zero to 400 V AC The slope for ramping up the output voltage shall be changeable by parametrization, default value for ramp slope: 100 V/s.	3.3.8
IPTRANS-780	The release of the TUPSS inside the traction unit shall be carried out with conventional operating element (switch, push-button), preferable in the driver's desk (of the same traction unit).	3.3.8
IPTRANS-781	Release of the TUPSS inside the traction unit shall be carried out with a (soft) key on an existing DMI in the driver's desk (of the same traction unit)	3.3.8

Requ.ID	Title / Description	Test ID
IPTRANS-782	The release of the TUPSS inside the guided or remotely controlled traction unit shall be carried out by triggering from another, leading traction unit.	3.3.8
IPTRANS-8213	Each traction unit in the train composition shall be in the position to receive the command to activate the TUPSS from the leading traction unit within the train segment.	3.3.8
IPTRANS-9899	The TUPSS shall be stopped to provide power to the PDL, when the operation mode of the traction unit changes from operation mode into shunting mode.	3.3.8
IPTRANS-8219	For normal operation (no protection) the deactivation of the TUPSS shall be carried out in the feeding traction unit in the following ways: a) Solution Transformer: Switch off of the output voltage to zero directly b) Solution Inverter: Ramp-down the output voltage to zero for normal operation Maximum slope down of the output voltage: 200 V/s	3.3.8
IPTRANS-785	The deactivation of the TUPSS inside the traction unit shall be carried out with conventional operating element (switch, push-button), preferable in the driver's desk (of the same traction unit).	3.3.8
IPTRANS-786	The deactivation of the TUPSS inside the traction unit shall be carried out with a (soft) key on an existing DMI in the driver's desk (of the same traction unit).	3.3.8
IPTRANS-9402	The deactivation of the TUPSS inside the guided or remotely controlled traction unit shall be carried out by triggering from another, leading traction unit.	3.3.8
IPTRANS-8223	All failures or faults, which have triggered a protection function with a related reaction, shall be recorded in a non-volatile event storage system of the control unit (ZSG or CCU) in the traction unit.	3.3.9
IPTRANS-8224	The output of the TUPSS to the PDL shall be protected against overvoltage with retarded protection (shut off the TUPSS). The parameters shall be changeable by parameterization. Set failure to trigger the protection reaction: $V_{threshold_set}$ 460 V AC (RMS) over retardation time at 5 s Reset failure to stop the trigger protection reaction: $V_{threshold_reset}$ 440 V AC (RMS) over retardation time at 5 s	3.3.9
IPTRANS-8192	The output of the TUPSS to the PDL shall be protected against overvoltage with immediate reaction for protection (shut off the TUPSS). The parameters shall be changeable by parameterization. Set failure if output voltage is above the $V_{threshold_set}$ to trigger the protection reaction: $V_{threshold_set} = 480 \text{ V} * \text{SQRT}(2)$, peak value, immediate reaction Reset failure if output voltage is below the $V_{threshold_reset}$ to stop the trigger protection reaction: $V_{threshold_reset} = 440 \text{ V AC (RMS)}$ over retardation time at	3.3.9

Requ.ID	Title / Description	Test ID
	5 s	
IPTRANS-9893	Slow protection against overcurrent: The TUPSS shall be protected against overcurrent with retardation. The trigger level shall be lower than the trigger level for detection of short-circuits: If output current is above the I_threshold_set then the trigger protection reaction: I_threshold_set = 11.3 A (RMS), retardation time of 10 s If output current is below the I_threshold_reset then stop the trigger protection reaction. I_threshold_reset = 10.8 A (RMS), retardation time of 10 s the threshold values and the retardation time shall be parametrizable.	3.3.9
IPTRANS-8855	Instantaneous protection against overcurrent: The electrical power system shall be protected against overcurrent without any retardation. The trigger level shall be higher than the trigger level for detection of overload: If output current is above the I_threshold_set then the trigger protection reaction: I_threshold_set = 16.8 A (peak) If output current is below I_threshold_reset then stop the trigger protection reaction: I_threshold_reset = 10.8 A (RMS), retardation time 10 s The threshold values and retardation time shall be parametrizable.	3.3.9
IPTRANS-8220	Following power system related basic information shall be shown on the DMI of the leading traction unit: • the status of the TUPSS in the leading traction unit and those in the non-leading traction units (each ON / OFF) • distribution of the power from the feeding TUPSS to the wagons in the same train segment • the warning message concerning the activation of the TUPSS, as specified in IPTRANS-9401	3.3.8
IPTRANS-8211	Following basic information shall be shown on the DMI of the leading traction unit for the TUPSS: • show "ok" or "failure" status of the TUPSS • show "activated" or "not activated" status of the TUPSS • the delivered power to the PDL in [VA] • output voltage (RMS) in [V] • output current (RMS) in [A] • fundamental frequency in [Hz] • the status of the switching devices each of the TUPSS • the status of the circuit breakers each of the TUPSS • the consumed power from the PDL for each wagon selectively [VA], the dedicated wagon shall be selected on the DMI at first • the demanded power from the PDL for each wagon selectively [VA], the dedicated wagon shall be selected on the DMI at first	3.3.8

Requ.ID	Title / Description	Test ID
IPTRANS-9894	Following basic information shall be shown on the DMI of the leading traction unit for the components of the TUPSS: • show "ok" or "failure" status of each controlled power component • show "activated" or "not activated" status of each controlled power component • the temperatures of each power component in [°C] • the status of the switching devices each of the TUPSS • the status of the circuit breakers each of the TUPSS	3.3.8
IPTRANS-8207	The control unit for the TUPSS shall evaluate measured quantities and binary process data to prepare the diagnostics data. The diagnostics data shall be structured according to the FDFT system, to the TUPSS subsystem and to the components level. The diagnostics data shall be recorded in a non-volatile data storage system. The diagnostic data shall be enriched with date and time at the instance of occurrence.	3.3.8
IPTRANS-8209	TUPSS: The diagnostic messages shall be shown on a dedicated screen on the DMI. Incoming messages shall override the shown messages.	3.3.8



3.3 Test activities

This chapter defines the different testing activities for the execution of the system test groups, basically intended for test planning. For the test execution itself, more detailed test specifications, which are derived from the requirements set out in this document, should be provided.

3.3.1 EMC, Burst immunity

Test goals

The SuT shall be subject to a series of functional tests during the EMC test to verify its correct functional behaviour.

Test environment

Supplier's laboratory

Test setup

The EMC test shall be done according to the ports topology of the SuT with external system (in our case the PDL).

Tests and measurements

Tests and measurements are based on EN 50121-3-2. Those include:

- Fast Transient Insensitiveness as defined in EN 50121-3-2 tables 7.2, 8.2
- RF Conducted Insensitiveness as defined in EN 50121-3-2 tables 7.1, 8.1
- Conducted emission as defined in EN 50121-3-2 tables 4.1
- Surge transient as defined in EN 50121-3-2 tables 7.3



3.3.2 EMC, Emission immunity

Test goals

The SuT shall be subjected to a series of functional tests during the EMC test to verify its correct functional behaviour according to IPTRANS-9896.

Test environment

Supplier's lab. The validation of the cabling for conformity to EMC-rules and to instructions of /WP5 D5.4/ are to be carried out in the wagon (and/or locomotive) supplier's premises.

Note: TTL to be discussed with WP14 - Retrofit and responsibility of the wagons for EMC is to be clarified

Test setup

The EMC test shall be done according to the enclosure of the SuT.

Tests and measurements

Tests and measurements are based on EN 50121-3-2. Those include:

- Radiated emission as defined in EN 50121-3-2 table 6.1
- RF Insensitiveness as defined in EN 50121-3-2 tables 9.1, 9.2



3.3.3 WPSS power input

The wagon receives all its power / energy through the 400 V AC input of the WPSS. This interface interacts with the complete train PSS and therefore plays a key role in the behaviour of this system.

Assuring consistent and a clearly defined performance of this interface over all suppliers, is vital for interoperability within the FDFT consist.

Key properties like input capacitance, power draw (inrush current limitation), dynamic behaviour (e.g., at system startup) and fault performance must be verified.

Test goals

verify,

- that the WPSS can handle the full performance spectrum of the vehicle power supply (PDL) also in extreme situations without negative implication on its ability to deliver power to the wagon.
- that the WPSS input converter behaves as specified (e.g. power input and inrush current limitation), inflicting minimal influence on other components connected to the PDL, even if faulty.
- the WPSS's ability to act as an integral and highly available part of the PDL while covering important system level functions like contact monitoring

Test environment

Supplier's laboratory, TTL

Test setup

Some of the requirements shall be tested in a complete FDFT setup with a physical or simulated PDL at max length (50 wagons) and the ability to simulate faults or anomalies.

Other requirements can be checked in a simple lab test setup at the supplier premises with a function generator simulating the PDL and a downstream load, however with the freedom to simulate extreme situations.

Again, other measurements will require a climatically variable environment.

Tests and measurements

Variations of: voltage

- power
- frequency
- power factor
- environmental conditions as specified
- The current received over both PDL lines, simulating faulty e-coupler contacts



3.3.4 WPSS power output

The Wagon Power Supply System shall provide highly available & sufficient 48V DC power to all on-wagon consumers while insuring isolation to the wagon chassis and to the PDL. It shall be able to detect and cope with anomalies in the wagon electrical system.

Test goals

Verify,

- that the WPSS provides the 48VDC power at the specified quality level required under normal and extreme operating conditions (including environmental conditions)
- the WPSS's ability to act as an integral and highly available part of the PDL while covering important system level functions like contact monitoring.
- the WPSS reactions to key electrical faults or anomalies on the output side

Test environment

Supplier's laboratory, TTL

Test setup

Some of the measurements will require a WPSS with energy input from a function generator & full wagon system setup with all components.

Other measurements will require a highly flexible downstream environment (energy sink) to simulate faults or possible anomalies.

Again, other measurements will require a variable climatic environment.

Tests and measurements

Variations of:

- output conditions (electrical properties of the downstream wagon electrical system, like power draw etc.) within the full range specified
- environmental conditions as specified



3.3.5 WPSS output protection and safety

Test goals

Test the correctness of mechanical and electrical installation of the physical WPSS equipment on a DAC wagon and related safety protection.

Test environment

TTL

Test setup

Not relevant.

Tests and measurements

- Check availability of user manual and installation manual of the WPSS
- Visual inspection of the WPSS installation
- Visual inspection of the wagon layout of the PDL cabling
- Check the ground/chassis resistance according to EN 50153 to ensure an adequate reference potential and personal protection



3.3.6 WPSS equipment isolation

The complete electronic equipment on the wagon shall be electrically isolated from the chassis. On the PDL side (400 V) this has electrical safety and EMC reasons, on the consist side (very low voltage 48 V) it has functional and EMC reasons.

For safety reasons, the PDL side shall also be insulated from the very low voltage side.

Test goals

Make sure that the whole WPSS system is electrically safe to be used and tolerant to EMC. In conformance with EN 60664.

Test environment

Supplier's laboratory

Test setup

At the supplier's discretion, standard HV test equipment

Tests and measurements

- Hi-Pot test PDL to Chassis + very low-voltage side
- Insulation test PDL to chassis + very low-voltage side
- Hi-Pot test very low-voltage side to chassis
- Insulation test very low-voltage side to chassis

3.3.7 WPSS energy storage (Battery Management System)

Test goals

The WPSS incorporates a local energy storage equipment (Battery Management System and related rechargeable battery pack) which is supplier specific.

Anyway, the BMS shall be qualified according to the specification in /WP5 D5.4/ chapter 7.2.

Test environment

Supplier's laboratory

Test setup

The principal test setup is supplier specific, according to own BMS design.

Tests and measurements

Tests and measurements are in according to the D5,4 requirements. In detail those include:

- Qualification of the WPSS BMS according to EN 62973
- BMS capability to provide battery information of SoC and SoH
- WPSS battery dimension able to fulfil the Operational Use Case of D5.4
- WPSS battery design and dimensioning able to fulfil the life duration use case of D5.4, according to the specified operational temperature range.



3.3.8 Traction Unit PSS output source

Operational qualities:

The traction unit shall supply the dedicated train section, it is important and to be verified, that the output parameters are all in the specified ranges to ensure interoperable operation of the FDFT.

Per FDFT train segment only one traction unit shall supply electrical power to this segment.

The following quantities are to be verified per test:

- The output voltage: at the end of the traction unit and at the last wagon (at maximum train configuration with 50 wagons and a total length of 835 m)
- The fundamental frequency (50 Hz or 60 Hz)
- The distortion factor (max. 10%)
- The delivered power: real power, apparent power, cos phi, power factor
- Selective energizing: only the dedicated train section shall be supplied
- Stable run up behaviour: Run up without tripping protection
- Stable shut down behaviour (overvoltage)

Test goals

- Verification of the specified voltage range at nominal load and at no load
- Verification of the voltage drop over the PDL
- Verification of the specified technical data in D5.4, mentioned above
- Verification of the least power, supplied by the TUPSS
- Verification of the selective energizing at the end of TU
- Verification of the run-up behaviour of the power supply of the FDFT
- Verification of the shutdown behaviour of the power supply of the FDFT
- Verification of contact monitoring function and protection in the TU

Test environment:

TTL

.Test setup:

A test train composition consisting of:

- the TU under test shall be available to be used for this test.
- 50 wagons to evaluate the voltage drop over the PDL at the end of (longest) train composition
- Simulation of coupled state and successful validation of the train composition (release condition to activate 400 V AC)

.Tests and measurements

- Measure the output voltage at the end of the TU and the end of the FDFT at longest train composition (50 wagons and 865 m total length)



- Measure the output currents at the TUPPS in steady state at nominal load, at start up and at shut down
- Measure the output voltage at the TUPPS in steady state at nominal load, at start up and at shut down
- Measure the real power at the traction unit
- Measure the apparent power at the traction unit
- Measure the fundamental frequency and the distortion factor
- Measure the output voltage at the e-coupler and the last wagon
- Verify, that the TUPSS insulation monitoring system has actually triggered a fault signal in the measured impedance range and the CCU of the TU has processed this triggered fault signal.
- Check the behaviour of the TUPSS in case of a broken contact issue in the e-coupler of the TU



3.3.9 Traction Unit PSS output protection and electrical safety

The low grounding resistance offers a stable reference potential near rail-potential level for the insulation monitoring. The low grounding resistance ensures that the voltage on metallic parts (chassis itself and parts mounted to chassis) are on nearly rail-potential.

Contact monitoring:

- A failure in one of the four coupler contacts (in the e-coupler) must not lead to the loss of power supply to the PDL.
- Too different partial currents of the same potential must be detected as contact fault

Overvoltage protection:

- The output voltage shall be supervised to prevent damage at connected components to the PDL.

Overcurrent protection:

- Overcurrent must be switched off in order to prevent damage at components connected to the PDL.

Overcurrent protection in view of fire safety:

- The fusing of the PDL for overcurrent protection shall be applied onto both poles.
- Both poles in the circuit breaker shall be coupled mechanically to ensure simultaneous breaking.

Behaviour of the TUPSS in case of loss of train integrity or accident:

- In case of loss of train integrity or accident, the power supply from the traction unit shall be shut down. This shutdown shall be realized automatically and immediately in case of detected integrity loss or derailment.
- The access to live parts (carrying 400 V) shall be inhibited in the uncoupled state and while the train function "prevent coupling" is active.



Test goals:

- Verification of the (personal) protection by means of proper installation of the PSS.
- The installation of the PSS cannot be measured, but a damage of the insulation system shall be detected.
- The installation of the cables for the PDL shall be carried out by cable ducts or routing in metallic pipes for protection according to IPTRANS-9352.
- Metallic cases of devices and connectors shall be grounded to chassis according to IPTRANS-9353.
- Validation that the access to live parts (carrying 400 V) is inhibited in the uncoupled state and the train function "prevent coupling" is active.
- Verification of the proper grounding of all metallic parts to the chassis of the TU
- Verification that the TUPSS is only activated during intended use cases of the FDFT.
- Verification that the PDL is only activated, when the FDFT is not shunted (i.e. often coupled/decoupled).
- Verification of the implemented contact monitoring of each e-coupler on each end of the TU
- Verification of the electrical protection of the PDL against overvoltage and over current by the TUPSS to prevent damage.
- Validation of the implemented supervision of the insulation system and its processing before switching on 400 V AC.
- Validation that the TUPSS output is switched off by the external signal provided by the CCU due to loss of train integrity (by train function)

Test environment:

on premises of the supplier of the TU and at the TTL.

Test setup:

A test train composition consisting of

- the TU under test shall be available to be used for this test.
- 50 wagons to provoke a short circuit detection at end of (longest) train composition

A 2-pole-PDL cable with adapter-plug to connect to the energized e-coupler to:

- provoke an insulation fault shall be available. See also section ".1.5 Traction Unit PSS equipment isolation test"
- Simulation of coupled state

Tests and measurements:

- Verify that the case of the e-coupler is grounded to the shaft of the coupler and the chassis of the TU.
- Verify that the e-coupler is fitted with yellow warning signs for danger "high voltage" according to EN 61310-1 (as required by IPTRANS-6791)



- Verify in the vehicle schematics and BoM of the TU all components on level 400 V AC, contained for the TUPSS insulation monitoring system of the TU.
- Verify in the technical data sheet of this TUPSS insulation monitoring system, that the impedance between insulated, active parts of the AC output against chassis of the TU under test (grounded to rail) is evaluated and failures are diagnosed from this TU.
- Verify that the access to the power contacts is inhibited by a closed flap of the e-coupler (covering the contacts) according to IPTRANS-6792
- The validation that the access to live parts (carrying 400 V) is inhibited in the uncoupled state and the train function "prevent coupling" is active can only be tested, when the couplers of the TU under test and the wagons are fitted with an air valve in the coupler heads. If not, this validation shall be carried out only by visual inspection. The insulation monitoring shall be carried out before switching on 400 V AC.
- Verify in the diagnosis data of the TU under test, that after a provoked failure the dedicated protection reaction in the TUPSS is processed and diagnosed.
- Measure the actual impedance level of the provoked insulation fault at the not coupled end of the TU under test, that this measured impedance is at least 22 kOhms or above.
- Measure the output currents at the TUPPS and validate the over current protection.
- Measure the output voltage at the e-coupler (or adequate interface connector) and the last wagon
- Measure the output voltage at the e-coupler (or adequate interface connector) and validate the over voltage protection.
- Measure the output voltage at the e-coupler (or adequate interface connector) to be zero to validate the switch off 400 V AC, when the train integrity is lost.
- Measure that the voltage between the chassis and the rail does not exceed 25 V (voltage band I according to EN 50153)
- Verify, that the TUPSS insulation monitoring system has actually triggered a fault signal in the measured impedance range and the CCU of the TU has processed this triggered fault signal.



3.3.10 Traction Unit PSS equipment isolation test

The impedance between active parts (insulated) against chassis of the vehicle (grounded to rail) of the PDL shall be evaluated and failures shall be diagnosed from the traction unit which supplies power to the PDL;

The state of the insulation system is evaluated by the supervision of the impedance between the active potentials and the chassis of the vehicle. A binary failure information is generated.

The trigger of the failure information (failure state of the insulation system) is set, when the insulation resistance falls below the value of: 22 kOhm ... 100 kOhm (the lower value of the range is derived from the current limited to 20 mA to avoid danger for life).

Test goals:

- Verification, that the TUPSS under test is equipped with an insulation monitoring device (according to EN 60364-4-41) to supervise the insulation of all parts, carrying 400 V AC in the TU, which are connected to the PDL. The scope is limited to the power contacts of both e-couplers at both ends of the TU.
- Verification, that the impedance between all active parts of the TUPSS (carrying 400 V AC) are insulated against the chassis of the TU (grounded to rail) is evaluated. Verification, that insulation failures are diagnosed from the TU under test, which normally supplies power to the PDL of the related train segment (of the FDFT).
- Verification, that a binary failure information is generated by this insulation monitoring device and that this failure information is processed in the CCU of the TUPSS under test.
- Verification, that the trigger of the failure information (failure state of the insulation system) is set, when the insulation resistance falls below the value of: 22 kOhm. The failure information is reset, when the insulation resistance raises above the value of: 26.4 kOhm. The range values are given for information only: The trigger value can be adjusted between 5 kOhm and 100 kOhm.

Test environment:

TTL or on the premises of the supplier of the TU.

Test setup

A test train composition consisting of:

- the TU under test shall be available to be used for this test
- A 2-pole-PDL cable with adapter-plug to connect to the energized e-coupler to provoke an insulation fault shall be available.

Tests and measurements

- Verify in the vehicle schematics and BoM of the TU all components at level 400 V AC, are contained in the TUPSS insulation monitoring system of the TU.



- Verify in the technical data sheet of this TUPSS insulation monitoring system, that the impedance between insulated, active parts of the AC output against chassis of the TU under test (grounded to rail) is evaluated and failures are diagnosed from this TU.
- Verify in the diagnosis data of the TU under test, that after a provoked insulation fault either in the TUPSS or at the e-coupler (Junction Box of the coupled end) of the TU, a binary failure information is generated by this insulation monitoring system and processed by the CCU of this TU under test.
- Measure the actual impedance level of the provoked insulation fault at the not coupled end of the TU under test, that this measured impedance is at least 22 kOhm or above.
- Verify, that the TUPSS insulation monitoring system has actually triggered a fault signal in the measured impedance range and the CCU of the TU has processed this triggered fault signal.



3.3.11 PDL train system integration and safety

System integration:

Cable cross section dimension of the power distribution line, chosen to ensure that the last wagon receives not less than -10% of nominal voltage at maximum train configuration, when the traction unit feeds in with nominal voltage.

The contact monitoring is carried out by the measurement of the current in each contact of the e-coupler. The currents of each potential are compared to each other. In case of a too high difference, at least one contact must be maintained.

The power supply must be blocked, when another source already feeds the related train section.

Safety and Protection:

The PDL is protected by the traction unit, including the contact and insulation monitoring.

Carry out of electromechanical connection (taps) to the PDL with minimal ohmic losses.

PDL must not be activated, when the e-coupler contacts are not coupled or covered.

Test goals:

- Verify that the cabling of the PDL is realized with least cross section $2 \times 6 \text{ mm}^2$ per phase in order to ensure the maximum voltage drop of 40 V over whole length of the PDL in a train composition with 50 wagons (train length 835 m).
- Verify the contact monitoring function
- Verify that the PDL will not be energized, when the e-coupler contacts are not coupled.
- Verify that the PDL will not be energized, when another source feeds the related section of the PDL.

Test environment:

TTL

Test setup:

A test train composition consisting of:

- the TU to supply and protect the PDL.
- the 50 wagons for the FDFT being available to be used for the test of the voltage drop
- The lever to decouple a train section manually to provoke the shutdown of the power supply.
- Disconnect one contact from e-coupler to simulate a contact fault.



Tests and measurements:

-Verification by means of checking technical documentation

- (cable/wiring list) that the PDL is realized with cable cross sections of $2 \times 6 \text{ mm}^2$ per phase.
- Measurement of the voltage drop over the entire PDL in a 50 wagon configuration (train length 835 m) to validate the theoretical calculation and the cross section of $2 \times 6 \text{ mm}^2$ per phase
- Measure the currents in the e-coupler (with simulated contact fault)
- Measure the output voltage in case of a decoupled part of the FDFT to verify that it is 0 V.



3.3.12 AC power distribution for up to 50 wagons

- Verification, that per FDFT train segment only one traction unit shall supply electrical power to this segment.
- Verification, that each TUPSS is able to supply power to the PDL of each train segment sufficient for up to 50 wagons.
- Verification, that the power supply system actually is not used for supplying power to applications other than FDFTO related ones (e.g.: refrigeration containers)
- Verification, that the cross section for the PDL cables actually is 2x6 mm² per phase (400 V potential).

Test environment:

TTL

Test setup:

- A first test train composition consisting of two train segments each consisting of one TU (master and slave locomotives in single traction) and at least one wagon shall be available in TTL. The 400 V power supply to the PDL of this test train composition shall be activated.
- A second test train composition consisting of one TU in single traction and 50 wagons shall be available in TTL. The 400 V power supply to the PDL of this test train composition shall be activated.

Tests and measurements:

- For first test train composition, verify, that per each train segment only one TU actually supplies electrical power to this train segment.
- For first test train composition, check, that in the slave locomotive, the power is not transferred through from the DAC e-coupler on its front end to the DAC e-coupler at its rear end. If such power transfer through the slave locomotive was detected, this test part is failed.
- For second test train composition, measure the TUPSS output voltage and current and calculate the actual output power (apparent power S and real power P) of the TUPSS.
Check, that the TUPSS output power is at least 3.75 kVA and 3.0 kW. If these figures of minimum output power were not achieved or not exceeded, this test part is failed.
- For second test train composition, verify in all test wagon's electrical schematics for power supply lines and circuitries, that no other 400 V load of the wagon is connected other than the WPSS,
- For second test train composition, verify in all test wagon's electrical schematics for PDL circuitries or in their Bill of Materials, that for each of the 400 V wires, the cross section area is 6 mm² or bigger.



3.3.13 PDL external PSS equipment output power and protection and safety

Within FP5, no external PSS equipment will be developed and tested.

Therefore, this chapter of the test plan remains empty.

Test goals:

Test environment:

Test setup:

Tests and measurements:



3.3.14 PDL personal protection

Test goals:

- Verification, that any power supply by the TUPSS to the PDL of a train segment actually is not activated, when the e-coupler contacts at the end of the train or at the TU itself are not coupled or not covered.
- Verification, that the access to live parts (carrying 400 V) actually is inhibited in the uncoupled state of each DAC and while the train function "prevent coupling" is active.

Test environment:

TTL

Test setup:

A test train composition consisting of one TU and at least two wagons shall be available in TTL.

Tests and measurements:

- Verify, that any power supply by the TUPSS to the PDL of a train segment actually is not activated, when the e-coupler contacts at the end of the train or at the TU itself are not coupled or provoked to not being covered by the flap.
- Check, whether the diagnosis data on the TU do indicate, that the TUPSS is actually inhibited from active power supply and that the reason for the inhibit is a recognized open flap of e-coupler at the end of the test train.
- Verify, that the access to live parts (carrying 400 V) actually is inhibited in the uncoupled state of each DAC and while the train function "prevent coupling" is active.
- Measure at the e-coupler PDL contacts of the last DAC of the test train (or in the corresponding junction box), whether there is any voltage in the range of 360V to 440V to be measured.



3.3.15 PDL isolation fault detection

Test goals:

- Verification, that each TUPSS is equipped with an insulation fault detection system (according to EN 60364-4-41) for the monitoring of the PDL.
- Verification, that the impedance between active parts of the PDL insulated against chassis of the vehicle (grounded to rail) is evaluated and failures are diagnosed from each TU which supplies power to the PDL of this train segment.
- Verification, that a binary failure information is generated by this insulation monitoring system and processed by the TUPSS and /or the CCU of the TU.
- Verification, that the trigger of the failure information (failure state of the insulation system) is set, when the insulation resistance falls below the value of: 50 kOhm ... 100 kOhm (the range values are assumed).

Test environment:

TTL or on premises of the supplier of the TU.

Test setup:

A test train composition consisting of one TU and a simulated PDL over some wagons of the train segment connected to the coupled e-coupler of the TU shall be available and used for testing. The simulated PDL over some wagons shall consist either of at least two test wagons (in TTL) or alternatively of a 2-pole-PDL cable of at least 50 m of length and at least one Power Supply Unit (similar or equal to a WPSS unit) connected to the free end of the simulated PDL cable (on premises of the TU supplier).

Tests and measurements:

- Verify in the vehicle schematics and BoM of the TU, that there are components depicted and contained for the TUPSS insulation monitoring system of the PDL.
- Verify in the technical data sheet of this TUPSS insulation monitoring system, that the impedance between active parts of the PDL insulated against chassis of the vehicle (grounded to rail) is evaluated and failures are diagnosed from each TU.
- Verify in the diagnosis data of the TU, that after a provoked insulation fault either in the last wagon of the test train or at the not coupled end of the simulated PDL cable, a binary failure information is generated by this insulation monitoring system and processed by the TUPSS and /or the CCU of the TU.
- Measure the actual impedance level of the provoked insulation fault at the not coupled end of the simulated PDL cable and check, that this measured impedance is in range of 49 kOhm to 99 kOhm. Verify, that the TUPSS insulation monitoring system has actually triggered a fault signal in the measured impedance range and the CCU of the TU has processed this triggered fault signal.



4. References

References are listed in /WP5 D5.4/.