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Transforming
Europe's Rail Freight

D5.4

Technical Specification of Wagon Power System and Communication System

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1 Executive Summary

This document represents "Deliverable 5.4 Technical Specification of Wagon Power System and Communication System" of the ERJU flagship project FP5-TRANS4M-R. This document reports results of task 5.5 "Technical Specification and Validation/Test Plan of the DAC Power and Data Communication solution".

The aim of this document is to provide the requirements specification defining the interoperable system interfaces and their basic functions for the Power and Communication System on wagon side as well as on traction unit side. A basis were the recommendations and results from EDDP, which have been refined and adapted. The requirements are also based on the reference system architecture from task 3.2 and task 3.3. Additional input requirements from industry-wide stakeholders - such as TIS - were also incorporated into this requirement specification.

The requirements were developed in many technical workshops with experts. The inputs have been considered, the technical concepts were evaluated, and the result defined as requirements.

The focus of this document is the subsystem requirements. These describe what is required for the interoperable system interface and further define the basic functions of the Power System and the Communication System required to operate the Full Digital Freight Train in Europe. The chapter "Systems of interest and input requirements" explains the conditions and constraints under which the requirements to be interpreted. The chapter "Technical subsystem specification" defines the requirements applicable to Power System and Communication System.

Keywords:

FDFT; Technical Enabler for FDFTO; Power system; Interoperable system interface; Communication system

2 Abbreviations, Acronyms and Definitions

2.1 Abbreviations & Acronyms

Abbreviation / Acronym	Description
ATEX	Synonym for EU directives for minimum safety requirements for workplaces and equipment used in explosive atmospheres, derived from french ATmospheres EXplosives
ATO	Automatic Train Operation
ATP	Automatic Train Control
BMS	Battery Management System
CCTV	Closed-circuit television - also known as video surveillance
CCU	Consist Control Unit
CPU	Central Processing Unit
DAC	Digital Automatic Coupler
DMI	Driver Machine Interface, driver's display
DPS	Distributed Power System
ECN	Ethernet Consist Network
EDDP	European DAC Delivery Programme
EMC	Electro Magnetic Compatibility
ETB	Ethernet Train Backbone
ETBN	Ethernet Train Backbone Node
F-ETB	Freight Ethernet Train Backbone
F-ETBN	Freight Ethernet Train Backbone Node
F-TCN	Freight Train Communication Network
FDF	Full digital freight
FDFT	Full digital freight train
FDFTO	Full digital freight train Operation
FP5	Flagship Project 5 FDFTO and Seamless Traffic
GNSS	Global navigation satellite system

IGMP	Internet Group Management Protocol
IP protocol	Internet Protocol
LAN	Local Area Network
LED	Light-emitting diode
LOBU	Locomotive On Board Unit, additional control system for FDFTO on locomotives
Loco	Locomotive
MAC	Media Access Control
MCG	Mobile Communication Gateway
MVB	Multifunction Vehicle Bus – Fieldbus used in rail vehicles
NC	Normally closed
NFC	Near Field Communication
NTP	Network Time Protocol
OSI	Open System Interconnection model
PCD	Passive Consist Detection
PDL	Power distribution line
PWS	Power Supply System
RMS value	effective value (root mean square)
SoC	State Of Charge
SoH	State Of Health
SPE	Single Pair Ethernet
SuC	System under Consideration
TCP	Transmission Control Protocol
TD	Train Directory
THD	Total Harmonic Distortion
TIS	Technical Innovation Circle for Rail Freight Transport
TRL	Technology Readiness Level
TRANS4M-R	ERJU Flagship Project 5 Synonym for "Transforming Europe's Rail Freight"

TSI	Technical Specifications for Interoperability from the European Union Agency for Railways
TTDP	Train Topology Discover Protocol
UDP	User Datagram Protocol
UNIX	family of multitasking, multi-user computer operating systems
UTC	Coordinated Universal Time
VLAN	Virtual Local Area Network
WP	Working Package
WPSS	Wagon Power Supply System
WTB	Wire Train Bus

2.2 Definition of Terms

Consist

A Consist is the smallest railway rolling stock entity for operation, containing one onboard unit (containing CCU, power management and battery) representing one node on DAC network.

It can be a Traction Unit, a single physical freight wagon as well as a fixed Composition of single vehicles (segments) which are not disconnected while operation.

From functional point of view a consist shall ensure different sets of functions within a train depending on the position the consist is located in a train.

Depending on the position of a consist in a train there are three logical consist types (or roles) defined:

- Leading Consist
- Last Consist
- Intermediate Consist.

Consist Composition

Consists coupled together by DAC. The connection is at least mechanically.

Polarion

Software environment used in TRANS4M-R

3 Background

The present document constitutes the Deliverable D5.4 "Technical Specification of Wagon Power System and Communication System" in the framework of the Flagship Project FP5-TRANS4M-R as described in the EU-RAIL MAWP. The document describes the results for the task 5.5 "Technical Specification and Validation/Test Plan: DAC energy supply & data, communication solution".

The project aims to boost innovation for the European rail freight sector, concretely by developing, validating, and demonstrating FP5-TRANS4M-R technical enablers. The work is complex and thus divided into several work packages highly dependent on each other. See WP structure below:

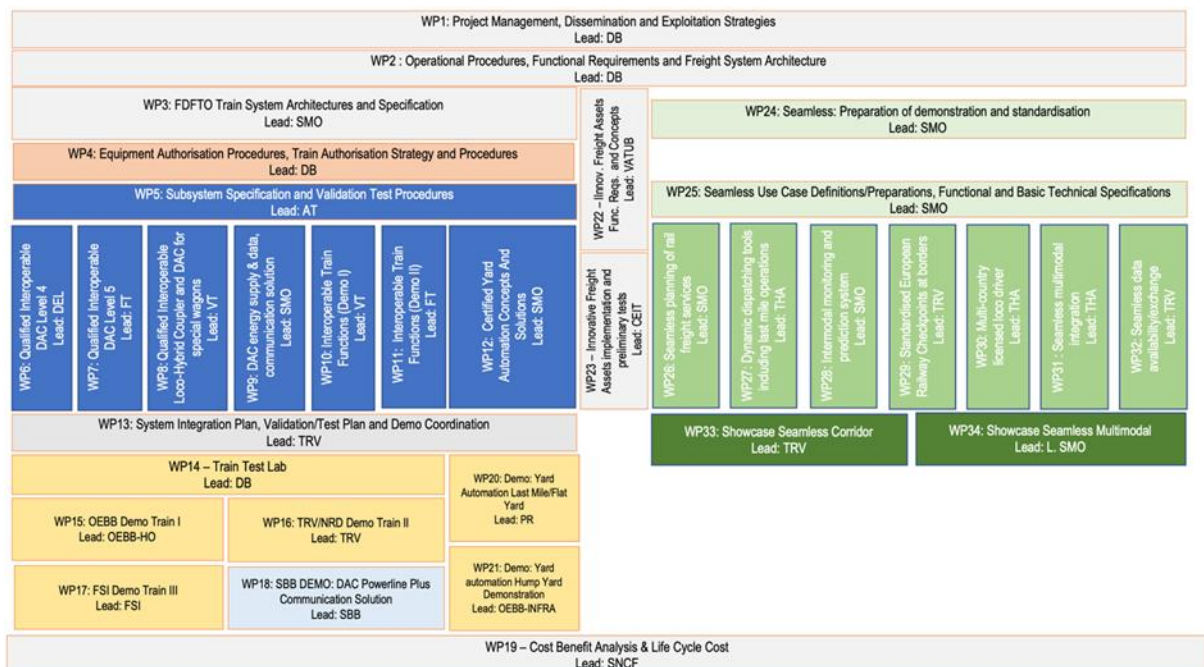


Figure 1: FP5-TRANS4M-R WP Structure

This document is created in WP5. It contributes to the definition of interoperability of vehicles in a train. This is done by identifying and defining the interoperable behaviour and information exchange within a FDFT and then breaking down to train functional requirements and consist functional requirements.

In addition to this document, further interoperability related specifications were created in this WP5 of the FP5. These are:

D5.1 – Functional Requirements Specification of Train Functions; please refer to /WP5_D5.1/ for details.

D5.2 - Technical Specifications of Wagon and Locomotive DAC up to Level 5; please refer to /WP5_D5.2/ for details.

4 Objective/Aim

This document has been prepared to provide technical specification and validation / test plan for the DAC energy supply and data communication solution. The objective of FP5-TRANS4M-R is to provide an electrical energy system and communication system with TRL8. This technical specification serves as a basis for the further development of these systems.

Table 1 Task descriptions

	Task definition from Grand Agreement (Task 5.5)	Output of WP5
Subtask 5.5.1	EDDP recommendations and outcomes for the power-system as well as for the communication-systems are building the basis for the task.	Systems of interest and input requirements
Subtask 5.5.2	KB will lead the translation of the results into a first preliminary requirements specification.	Methodology Technical Specification
Subtask 5.5.3	Additional user requirements from operators, coming from the specification prepared in WP3, further requirements from sector wide stakeholder groups – like TIS, involving wagon keepers – and tasks within this work package will be transferred by Alstom and Siemens into the requirements specification.	Systems of interest and input requirement Methodology Technical subsystem specification
Subtask 5.5.4	Company Faiveley Transportation will lead the consolidation and the joint review of the collected inputs, filter, sharpen and identify/fill the white spots finalizing the requirement specification for review by stakeholders.	Methodology Inputs from former programs and sector wide stakeholder groups Technical subsystem specification
Subtask 5.5.5	From the agreed input specification, the definition of the interoperable system interface and their basic functions the final power-system requirement specification and the	Technical subsystem specification

	communication requirement specification are defined.	
Subtask 5.5.6	The agreed and frozen specifications are the inputs for WP9.	Technical subsystem specification
Subtask 5.5.7	Based on the harmonized requirements a common system topology / architecture for the power system and communication system, considering the degrees of freedom for a vehicle-specific technical solution will serve to jointly define common subsystems, components, interfaces protocols and functions ensuring interoperability across manufacturer.	Technical subsystem specification
Subtask 5.5.8	A common system topology finalises the task and offers a baseline for the development and tests in WP9.	Technical subsystem specification

Within the framework of ERJU FP5-TRANS4M-R, not all developments that can be represent fully automated operation are carried out. For this reason, two development states need to be separated:

FP5 Basic State:

This state represents the scope of the FP5-TRANS4M-R project for semi-automated processes. In this document all requirements reflect this state, if not explicitly mentioned to another state.

Target State:

This state represents the future of rail freight transport, which depends on fully automated operations. In this document some outlooks are given to indicate what is required to provide fully automated operations, but the related requirements are out of scope for FP5-TRANS4M-R project.

5 Methodology

Task 5.5 "Technical specification and validation/test plan: DAC energy supply & data communication solution" has been started in Month 5 after the program start of FP5-TRANS4M-R.

As the specification work within D5.4 is closely linked with the final design to be developed and tested within WP9, the working team has been shared and supported by the experts from WP9, this means, detailed work has been done within WP9.

During WP9 meetings and additional workshops, the experts (also from other WPs) have identified important technical topics, which have been still open at project start (so called white spots). They have structured the items by technical topics and importance and found solutions by related concept developments and decisions. They have been deeply rediscussed, and the results are now included in this document as specification.

Once the concept development and selection for the dedicated items had been finalized, they have been presented and agreed/signed off within bi-weekly FPSE meetings. With this approach it could be ensured that the solution was agreed by all involved development partners.

The requirements for these items can be found in the chapter "[7 - Technical subsystem specification](#)" within this document.

The deliverable itself has been drafted within Polarion work environment, considering existing imported and re-assessed confirmed input requirements (EDDP WP). Existing or new requirements have been updated and refined based on progress in WP9 on technical concepts and signed off decisions of items in FPSE.

For the finalization of the deliverable the writing team (see authors) decided to continue working outside of Polarion while tracking the changes. The writing team has met on a weekly basis to present, discuss and update the overall document with the WP lead and project management. The power system part was provided by SMO for the traction unit specific requirement and by KB for the wagon specific requirements. The general requirements for the power system as well as the Power Distribution Line specific requirements were provided by both, SMO and KB. FT provided the energy storage part on the wagon specific requirements.

The communication system part was provided by AT and FT.

After the release of the input deliverables /WP3_D3.1/, /WP3_D3.2/, /WP3_D3.3/ and /WP4_D4.2/ the relevant requirements and concept have been considered in the deliverable rework. To do this the team met on several daily workshops to align and discuss the impact of the new inputs to the existing structure and documented requirements.

Topics with overlap with other subsystem specifications (e.g., /WP5_D5.1/ or /WP5_D5.2/) have been discussed in joint workshops with members from working group of deliverable D5.1 "Train functions" and D5.2 "Technical Specifications of Wagon and Locomotive DAC".

The outcome of these activities, including the derived requirements, are the basis for this document.

The resulting deliverable, specifically – General requirements and Power system –, are serving as input to the started standardization activities within the dedicated normative working group (CLC SC9XB WG44) for Electromechanical material on board rolling stock - WG 44 - Rolling Stock Digital Automatic Coupler (DAC) on European level.

The part of the specification describing the - Communication system - and the developed architecture elements have been aligned and agreed with European experts within a dedicated physical whole day workshop "FP5, Communication System, physical WP9-/WP10-Workshop "Reference Design" (with members of WP9 and WP10) on 2024-07-03 in Frankfurt/M. The elaborated results for the reference design are now stated as design input to IEC 61375-2-3 ED 2 CD 2024.

6 Systems of interest and input requirements

This document focuses on the power system and the communication system of the FDFT. To avoid possible confusion with traction power (provided by a traction unit), in this document "power" denotes always "electrical power".

The power system consists of several elements: a subsystem in the wagon named as the Wagon Power Supply System (WPSS) and a subsystem in the traction unit named as the Traction Unit Power Supply System (TUPSS). Both subsystems are connected by the Power Distribution Line (PDL). All together cover the overall topic "power system" in the FDFT.

The communication system is a subsystem of the FDFT, which covers the communication within a train composition or consist composition. Train-wide functions use this subsystem to exchange data between the individual vehicles via the F-ETB.

6.1 Inputs from former programs and sector wide stakeholder groups

From the EDDP phase of the ERJU project, a set of requirements have been identified and specified by sector wide stakeholders. The requirements have been collected and consolidated in the Shift2Rail programme foremost in the project "DACcelerate".

The requirements of this project have been used as input to this deliverable and have been further detailed, if necessary.

The document is publicly available at [DACCELERATE \(shift2rail.org\)](https://shift2rail.org/DACCELERATE).

"Deliverable D3.2, Requirement specifications and operational rules" /DACcelerate_D3.2/

From that deliverable, the requirements of the following chapters have been used:

/DACcelerate_D3.2/ chapter 3.2 Specifications for electrical power system

/DACcelerate_D3.2/ chapter 3.3 Specifications for communication system

6.2 Boundary conditions - train composition

In /DACcelerate_D3.2/, the boundary conditions for the FDFT and the train segments have been defined. They have been checked for being still applicable.

For the power system and the communication system, the definitions, related to a train segment are detailed below.

A train segment is composed of a single or several traction units and one or more wagons.

Several train segments can be coupled, thus forming the final train composition.

From the perspective of the power supply system, the following restrictions apply:

- Only one traction unit shall supply electrical power per train segment.

- Only traction units can interrupt the PDL (due to the availability of switching elements). For cost reason it isn't planned to support this in wagons. This means that power is supplied per train segment only.
- The output of electrical power that can be supplied by a traction unit is limited. This arises from boundary conditions in existing mainline traction units. The details are described more detailed in chapter "7.2.3.4- Technical requirements".

The maximum number of consists within a train segment, which can be supplied with electrical power by a traction unit, has been defined in /DACcelerate_D3.2/ to be 50 wagons.

IPTRANS-6779 -Train Segment, maximum number of consists: 50

Detailed Description	A train segment shall contain as maximum 50 consists.
Rationale	see /DACcelerate_D3.2/ for details

The longest known European freight train in operation has a maximum length of 835 m and operates between Maschen (Germany) and Padborg (Denmark). This defines the maximum length of a train segment that shall be supported.

IPTRANS-6775 -Maximum length of a train segment: 835 m

Detailed Description	The maximum length of a train segment must not exceed 835 meters.
Rationale	Longest known train currently operated between Maschen and Padborg

With the positive experience of the 835 m train service and the prospect of extending the train to 1670 m, a maximum length of 2 x 835 m train segments is set for the FDFT in order to be prepared for future extensions.

IPTRANS-6776 -Maximum length of a train composition: 1670 m

Detailed Description	The maximum length of the train composition must not exceed 1670 m. For Target State a long train approach of 1670 m shall be supported (up to 4 active traction units and up to 100 wagons).
Rationale	input requirement from /DACcelerate_D3.2/

IPTRANS-6777 -Maximum amount of active traction units in a train composition: 4

Detailed Description	A train composition shall not have more than 4 active traction units. A train composition can have 1 to 4 train segments. A train segment shall have exactly one active traction unit (providing traction power, electrical power).
Rationale	Boundary condition taken from /DACcelerate D3.2/

IPTRANS-6780 -Allocation of the wagons to the traction unit for a train segment

Detailed Description	The traction units shall always pull the wagons of the own segment. In shunting yards, the traction units also push the wagons.
Rationale	Allocation of the electric power feeding traction unit to the group of wagons, which shall be supplied, by this traction unit. Both outputs to the PDL at the end of loco are switched on selectively.

Train segments with single traction unit:

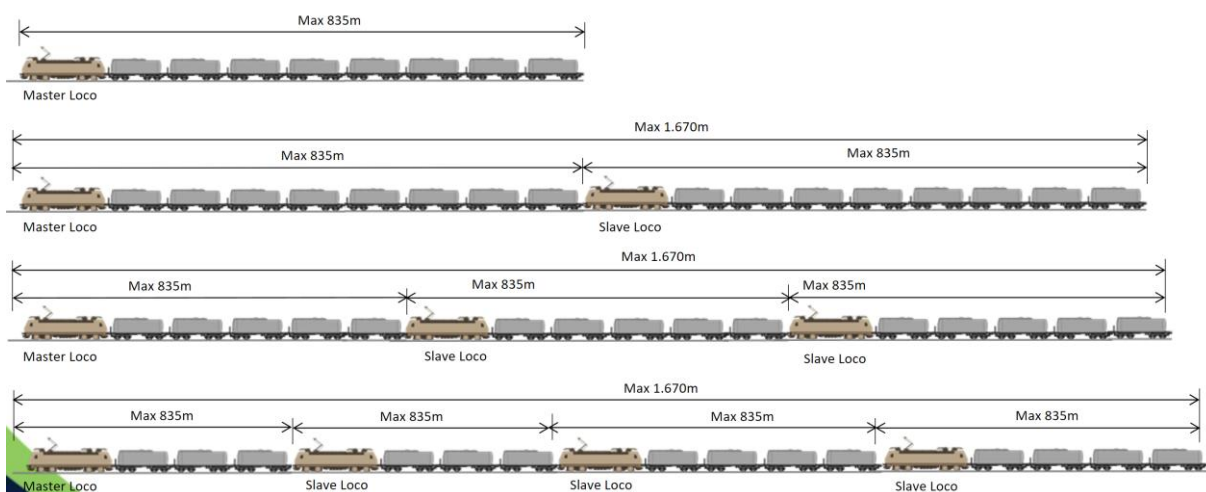


Figure 2: Train segments with single traction unit

Figure 2 shows different train compositions where each segment contains only one traction unit. Further, the maximum segments length and overall train length are illustrated for the different compositions.

Train segments with double traction / mixed traction

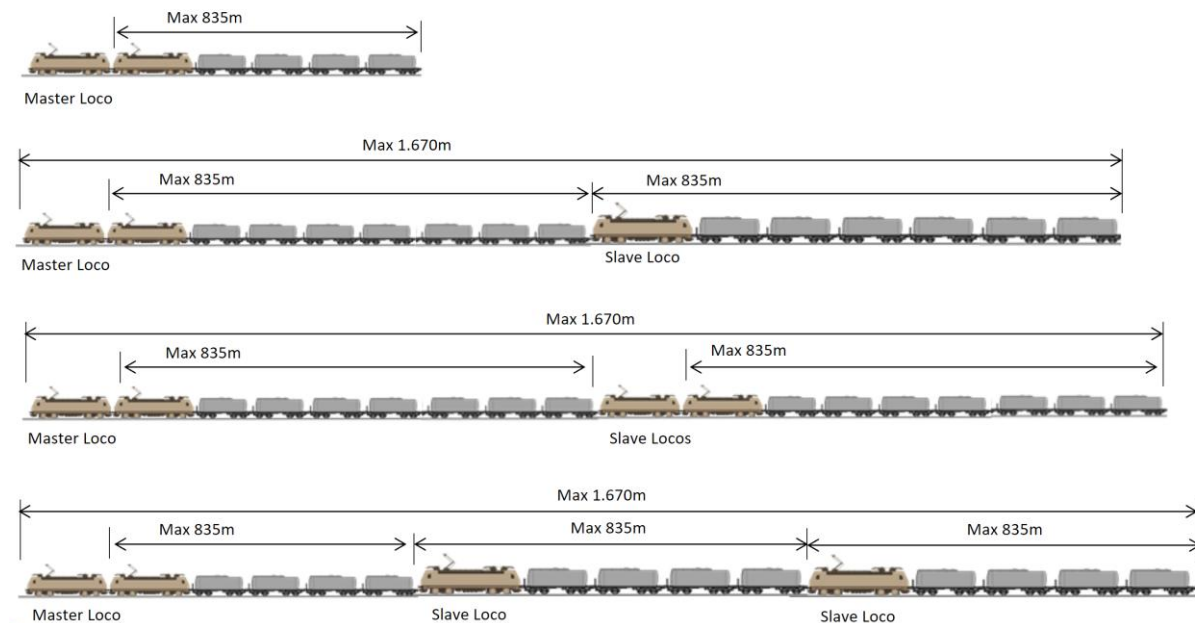


Figure 3: Train segments with double traction / mixed traction

Figure 3 shows different train compositions where each segment contains a double or mixed traction units. Further, the maximum segments length and overall train length are illustrated for the different compositions.

Train segments with push / pull

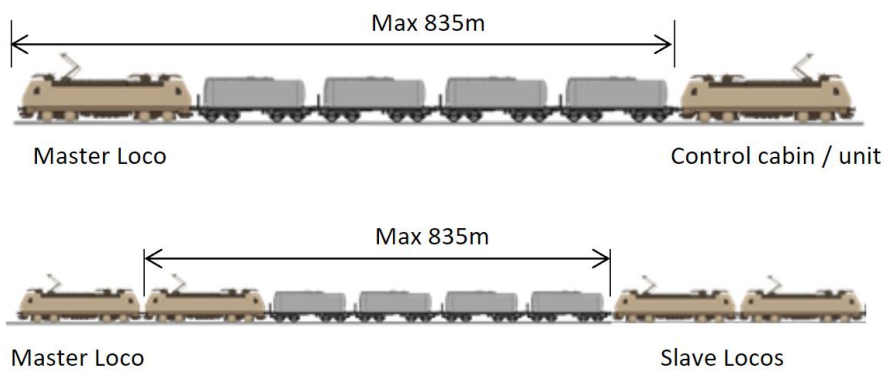


Figure 4: Train segments with push/pull

Figure 4 shows a train segment in push/pull configuration. This means, that on both ends of the segment, traction units are coupled to pull/push the segment. Push/pull can be done with single traction units at the ends, as well as with double traction units. Further, the maximum segment length is illustrated for the different configurations.

6.3 FDFTO technical architecture

The inputs from the FDFTO Train System Architecture (based on the preliminary operational procedures from WP2 /WP2_D2.1/ and FDFTO physical architecture from WP3 /WP3_D3.2/ was consolidated in WP9 by technical experts. They are the inputs for the V-Cycle, to be applied and specified accordingly in chapter "7 - Technical subsystem specification".

6.3.1 FDFTO wagon base system physical architecture

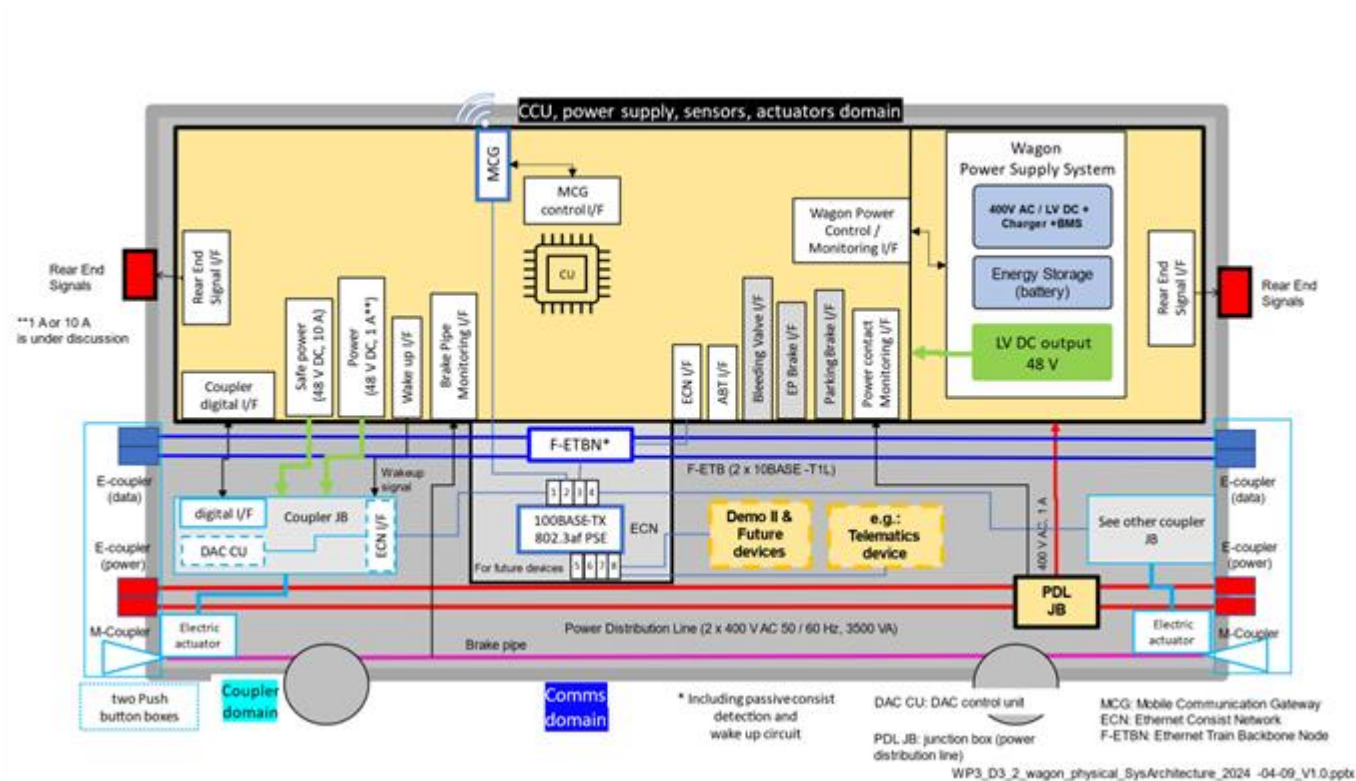


Figure 5: Overview on FDFTO wagon base system physical reference architecture

In Figure 5, the FDFTO wagon base system physical reference architecture is shown. This FDFTO wagon base system shall support all functional requirements as described in /WP3 D3.1/ by providing a consist internal communication system, a train-wide-communication system (the F-ETB), and a FDFT-Link (via MCG) for information exchange with the landside FDFT systems.

In addition to communication, the power supply and the consist related further requirements are defined (e.g., interface to main brake pipe, braking actuators, ...).

Please refer to /WP3 D3.2/, chapter 5.4 - FDFTO wagon base system physical architecture for more details.

6.3.2 FDFTO wagon digital / data reference system architecture

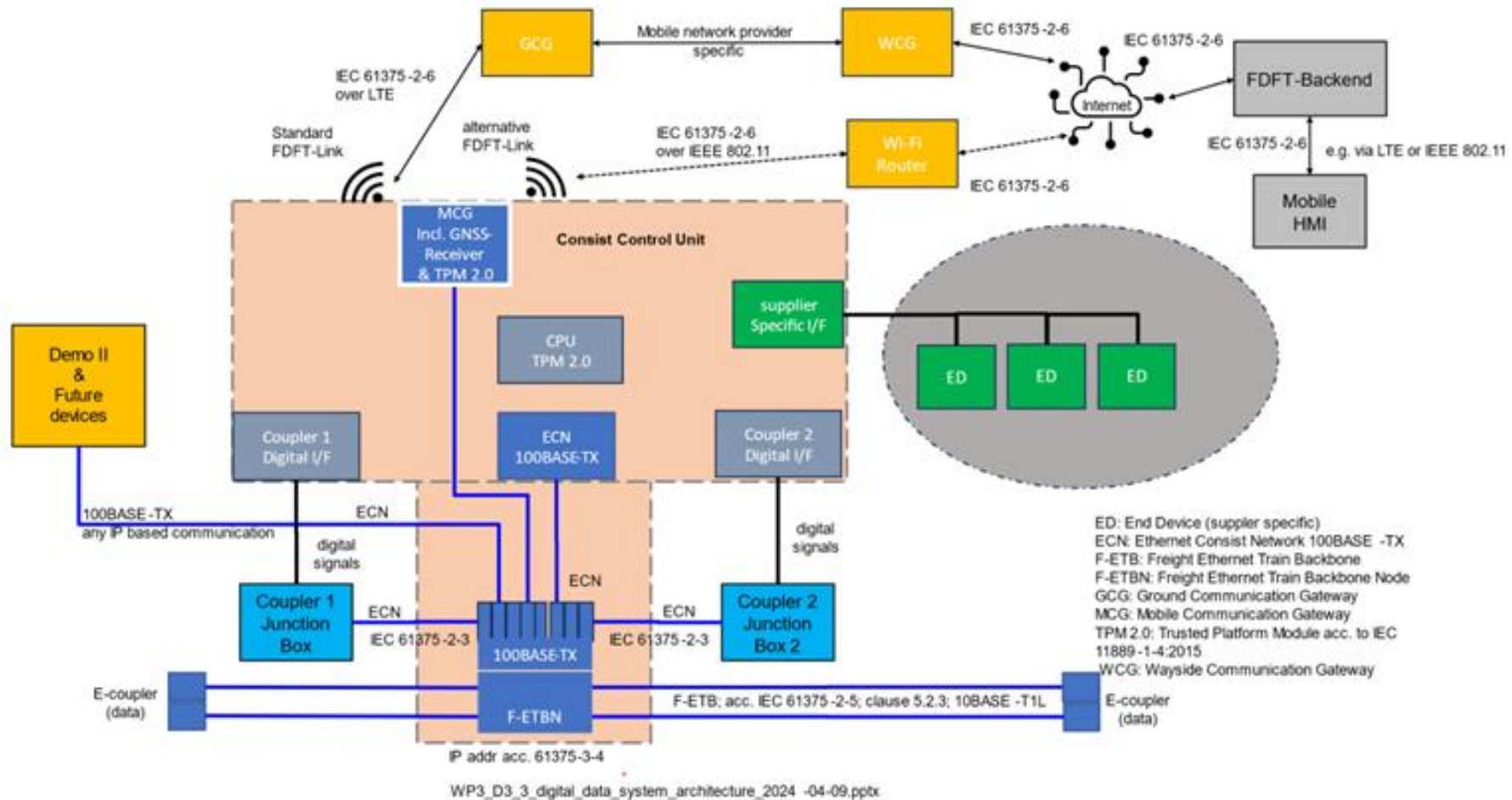


Figure 6 Figure 6: FDFTO Wagon Digital / Data Reference System Architecture

In Figure 6, the FDFT wagon digital/data reference system architecture is shown.

This wagon digital/data reference system architecture shall support all functional requirements as described in /WP3 D3.1/, user requirements as described in /WP2 D2.2/ and requirements resulting from specification of the physical reference system architecture /WP3 D3.2/ by specifying a consist internal communication system, a train-wide-communication system (F-TCN) and a wireless FDFT-Link for information exchange with the landside FDFT systems.

In addition to the message-based data communication, the necessary digital interface protocols are specified (e.g., passive consist detection, wake-up interface, digital interface to the coupler, push button-based control of coupler ...).

Please refer to /WP3 D3.3/, chapter 5.4 - FDFTO Wagon Digital / Data Reference System architecture for more details.

6.3.3 FDFTO traction unit base system physical architecture

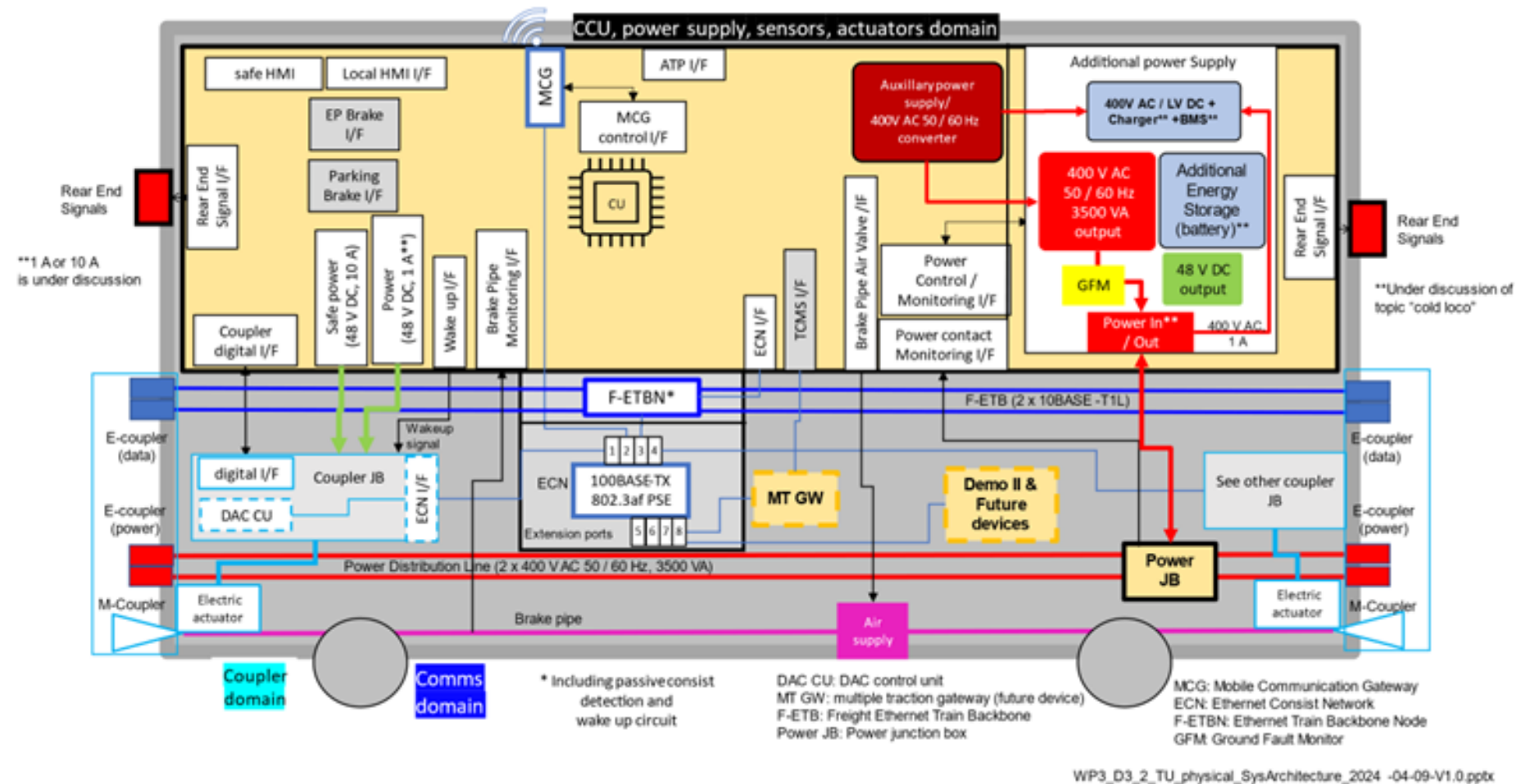


Figure 7: FDFTO traction unit base system physical architecture

In Figure 7, the FDFTO traction unit base system physical architecture is shown. This FDFTO traction unit base system shall support all functional requirements as described in /WP3 D3.1/ by providing a consist internal communication system, a train-wide-communication system (the F-ETB), and a FDFT-Link (via MCG) for wireless information exchange with the landside FDFT systems.

In addition to communication, the power supply and the traction unit related further requirements are defined (e.g., interface to main brake pipe, braking actuators, ...).

Please refer to /WP3 D3.2/ chapter 5.5 - FDFTO Traction Unit Base System physical architecture for more details.

6.3.4 FDFTO traction unit digital / data reference system architecture

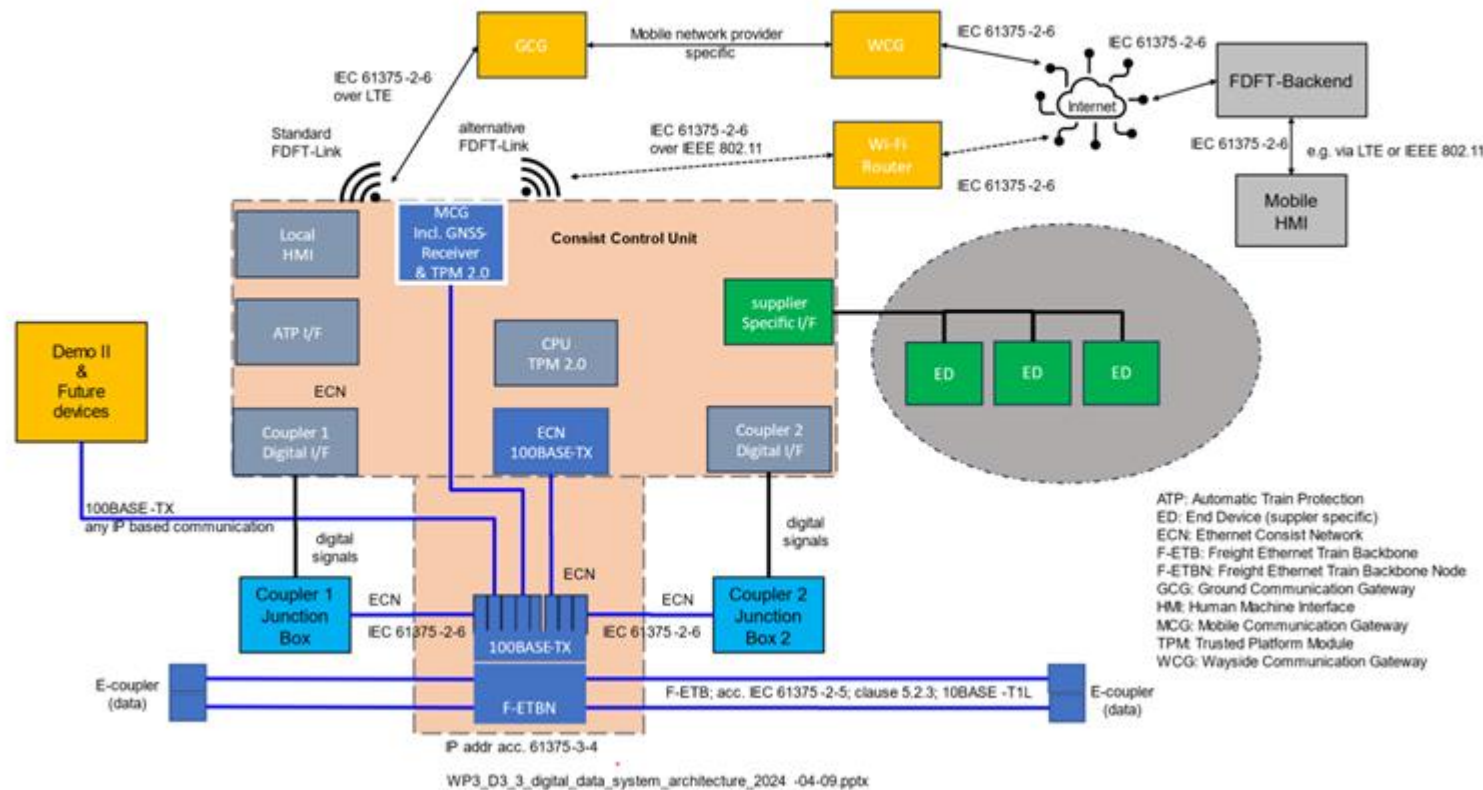


Figure 8: FDFTO traction unit digital / data reference system architecture

In Figure 8, the FDFT traction unit base system digital/data reference architecture is shown. This FDFT traction unit base system shall support all functional requirements as described in /WP3 D3.1/ by providing a consist internal communication system, a train-wide-communication system (the F-ETB), and a FDFT-Link (via MCG) for wireless information exchange with the landside FDFT systems.

In addition to communication, the power supply and the traction unit related further requirements are defined.

Please refer to /WP3 D3.3/ chapter 5.5 - FDFTO Traction Unit Digital / Data Reference System architecture for more details.

6.3.5 Additional Interfaces on Wagon and Locomotive

In the wagon & locomotive architecture figures shown above, several interfaces between the three different main domains (coupler; comms; CCU, powers supply sensors and actors domain) are shown. The first drafts of the interface definitions have been written down in D3.2 Physical Reference System Architecture FDFT /WP3_D3.2/, but need to be refined in order to ensure interoperability.

The interfaces considered include the following chapters from /WP3_D3.2/:

5.4.1.2 - E-coupler

5.6 - Common Interfaces

Especially the digital signal interface list within chapter 5.6.1.2 in D3.2 and D3.3 has been reworked based on the ongoing technical alignments.

In addition, proposals for the mechanical installations of the necessary technical equipment have been added to the document. Details can be found in D5.4 Appendix I Coupler common interface specification.

6.4 FDFTO train system architecture and specification

The technical requirements in this document are derived from the D3.2 Physical Reference System Architecture FDFT /WP3_D3.2/ and the D3.3 Digital & Data Reference System Architecture FDFT /WP3_D3.3/.

This includes the following chapters from /WP3_D3.2/:

5.4.3 - Wagon Power Supply System

5.5.3 - Traction Unit Power Supply System

5.6.2 - Communication System

5.6.2.1 - F-ETB (Ethernet Train Backbone)

5.7.8 - ATEX

5.7.1 - Environmental conditions

and the following chapters from /WP3_D3.3/:

5.4.3 - Wagon Power Supply System

5.5.3 - Traction Unit Power Supply System

5.6 - Common Interfaces

5.6.2 - Communication System

5.6.2.2 - F-ETB (Freight Ethernet Train Backbone)

6.5 Input requirements for the power system

As described in the FDFTO technical architecture, the TUPSS shall provide electrical power to the wagons via the PDL. The traction unit shall be equipped with the components needed for power conversion.

The necessary power to supply to the FDFT shall be taken from the existing internal power source of the traction unit and shall be converted into suitable voltage and current.

Since the existing components of the internal power supply of a traction unit only support the original requirements, when the traction unit has been designed, the resulting limits are to be respected.

Additional limitations in size and weight for adding additional components in the traction units shall be respected.

In order to cover all train configurations as explained in chapter "6.2- Boundary conditions - train composition" the following assumptions and pre-conditions shall be respected:

- Only one traction unit shall feed one train segment. This is also valid, when more than one traction units are part of one train segment.
- Within one train segment, the PDL shall not be interrupted by any vehicle.
- The consist composition, which is coupled at the rear end of a traction unit (in view of direction of running) is allocated to the traction unit. This TU shall supply the electrical power only to the consists of this train segment.
- In train compositions having more than one train segment, each first traction unit in a train segment with exception of the leading traction unit, shall isolate its TUPSS from the e-coupler at the front end of the TU. This is needed to ensure that only one TU is supplying electrical power to the same train segment.
- Each traction unit is allowed to supply its maximum available electrical power to the related train segment. This means, that the overall electrical power, available for a train composition, consisting of more than one train segment can be higher as in a train composition consisting of one train segment.

IPTRANS-7784 -FDFT train segment from perspective of power supply

Detailed Description	Per FDFT train segment only one traction unit shall supply electrical power to this segment. This traction unit will be named "active traction unit". Any other TUs that might be part of a train segment shall not supply electrical power to the PDL.
Rationale	Avoiding electrical issues by having more than one TU supplying electrical power to the PDL in the same train segment.

In the project DACcelerate /DACcelerate_D3.2/, a set of conditions and requirements have been defined for the development of an electrical power supply system for the FDFT. Based on the use cases for the intelligent freight train, as defined in /DACcelerate_D3.2/, the requirements for the electrical power supply system have been consolidated. As a result, a 400 V AC single phase electrical system is the preferred solution to be developed further.

IPTRANS-8856 -Power supply system: 400 V AC single phase

Detailed Description	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.
Rationale	Defined in /DACcelerate_D3.2/.

IPTRANS-7733 -Minimum electrical power capacity of an FDFT traction unit

Detailed Description	The electrical power supply system of an FDFT traction unit shall be able to supply at least:
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	P = 3 kW, with a minimum power factor of 0.8 S = 3.75 kVA
Rationale	according to /DACcelerate_D3.2/ a TU shall supply a train segment with a maximum of 50 wagons, having an input power requirement of 50 W per wagon considering the power losses in the PDL (caused by electrical resistance in wires and intermediate electrical contacts)

The limitation of available power does not allow use-cases on wagons with high power consumers like wagons transporting refrigerated goods.

IPTRANS-6787 -The power supply system shall not be used for applications other than FDFTO related

Detailed Description	The power supply system shall not be used for supplying power to applications other than FDFTO related ones (e.g.: refrigeration containers).
Rationale	The electrical power being available for supplying the PDL is very limited. It is needed to supply the FDFTO devices with electrical power or to re-charge their batteries.

6.6 Input requirements for the communication system

In EDDP WP1 SG3 Data and Communication, various communication technologies were analysed for the physical layer.

Technical criteria such as data rate, protocol layer, cycle times and latency were compared. In addition to purely technical criteria, the use of existing standards, industry availability, costs for equipment and infrastructure in the vehicle, as well as system complexity were also taken into consideration. Three technologies were shortlisted: 10BASE-T1L Single Pair Ethernet (IEEE802.3cg), Powerline Plus and Short-range radio system Wi-Fi. The final recommendation from the EDDP WP1 for physical layer technology is Single Pair Ethernet and Powerline Plus as the two technologies to be favoured. During the creation of the FP5-TRANS4M-R project, Single Pair Ethernet was selected as the technology to use, which also forms the basis for the WP5 and WP9, and Powerline Plus was selected as the back-up technology, which will be processed in WP18. In this document, Single Pair Ethernet is the physical layer standard for the communication system.

IPTRANS-6788 -Communication standard for the F-TCN: IEEE 10BASE-T1L

Detailed Description	For communication over the F-TCN, Single Pair Ethernet IEEE 10BASE-T1L shall be used as communication standard.
Rationale	As so called "passive consists" have to be bridged in case of device failures, the required cable length is more than inside only one vehicle. Up to 15 consecutive passive consists can be bridged, summing up to about 360 m of cable length to be bridged. IEEE 10BASE-T1L supports a length of a communication cable of up to 1000 m.

IPTRANS-6789 -The e-coupler shall provide 4 electrical contacts for use by F-ETB

Detailed Description	The e-coupler shall provide 4 electrical contacts for use by F-ETB.
Rationale	The F-ETB shall be laid out with redundancy. When using 2 pairs of SPE (IEEE 10BASE-T1L), four electrical contacts are needed in the e-coupler.

7 Technical subsystem specification

This chapter describes the requirements to the power supply system and the communication system, both are subsystems of the FDFT. They are the enablers for the train functions /WP5_D5.1/ and train operations /WP2_D2.1/.

7.1 General requirements

The general requirements in the following sub-chapters 7.1.1, 7.1.2 and 7.1.3 are applicable to the subsystems, which are specified in this document, i.e., for the power supply system and the communication system.

7.1.1 Non-functional requirements

The selected environmental requirements, which are defined in /WP3_D3.2/, shall be applied for all components of the power system and communication system for the wagons. For the traction units the corresponding environmental requirements with related values shall be applicable, which are already defined and applied at delivery for each dedicated vehicle type. Since the traction units are each authorized for their area of use, the following requirements apply for the wagons.

7.1.1.1 Environmental conditions

For the environmental conditions for electronic devices the following requirements are derived from the /WP3_D3.2/ chapter 5.7.1, 5.7.6 and 5.7.7.

- All devices shall support being operated in the air temperature range of class of the consist where installed, acc. to EN 50155:2021, table 1. This includes the accumulator / batteries being used.

IPTRANS-8705 -Temperature range

Detailed Description	The electronic devices shall be designed for the temperature class depending to the temperature class of the vehicle.
Rationale	Assures that the components of the wagon matching to the overall environmental conditions of the wagon regarding temperature class.

- All devices shall support being operated in the humidity range as defined in chapter 4.4 of EN 50125-1:2014. The following humidity values must be taken into account:
 - annual average: ≤ 75 % relative humidity
 - on 30 days a year continuously: between 75 % and 95 % relative humidity
 - on the other days occasionally: between 95 % and 100 % relative humidity
 - highest absolute humidity: 30 g/m³ occurring in tunnels.

IPTRANS-8706 -Humidity

Detailed Description	All electronic devices shall support being operated in the humidity range according to EN50125-1:2014 chapter 4.4
Rationale	Defined in EN 50125-1:2014

- All devices shall support being operated in an altitude between -150 m (within Channel Tunnel, -115 m) and more than 1400 m including the following tracks:
 - Gotthard (Switzerland): 1151 m,
 - Brenner (Italy): 1371 m,
 - Semmering (Austria): 985 m,
 - Finse (Norway): 1222 m.

This results in an Altitude class AX according to table 1 of EN 50125-1. This is relevant for both tightness & supporting of cooling by convection or ventilation.

IPTRANS-8707 -Altitude

Detailed Description	All electronic device shall be designed for altitude class AX according to EN50125-1:2014 - table 1 for a maximum altitude of 1371m (Brenner Italy).
Rationale	Brenner in Italy is the highest altitude for railway tracks in Europe.

- All outdoor devices shall support being operated in a windy environment with wind speeds up to 35 m/s. The additional wind speed, generated by the travelling speed of the consist shall be considered.

IPTRANS-8857 -Wind speed

Detailed Description	All outdoor devices shall support being operated in a windy environment with wind speeds up to 35 m/s. The additional wind speed, generated by the travelling speed of the consist shall be considered.
Rationale	Defined in EN 50125-1:2014

- All outdoor devices shall support being operated in a rain rate of up to 6 mm/min according to class 5K3 of EN 60721-3-5, concurrent to the occurring wind speed and vehicle movement.

IPTRANS-8858 -Rain rate

Detailed Description	All outdoor devices shall support being operated in a rain rate of up to 6 mm/min concurrent to the occurring wind speed and vehicle movement.
Rationale	Defined in EN 50125-1:2014

IPTRANS-8708 -Snow and hail

Detailed Description	All electronic devices shall be designed to support being operated in an environment, where snow and hail is expected. The class S3 (400
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	to 800 mm snow depth above the top of the railtrack) shall be applied according to EN50125-1:2014 table 3.
Rationale	Input requirement from architecture /WP3_D3.2/

IPTRANS-9369 -Ice forming and falling

Detailed Description	All outdoor mounted devices shall support being operated in an environment, where ice forming and falling shall be assumed.
Rationale	

IPTRANS-9370 -Solar radiation

Detailed Description	All outdoor mounted devices shall support being operated in an environment, where solar radiation occurs acc. to class R2 (high) of table 4 of EN 50125-1:2014.
Rationale	

IPTRANS-9371 -Lightning

Detailed Description	All outdoor mounted devices shall be protected against lightning on the vehicle refer to EN 50124-2.
Rationale	Vehicle operated in an environment, where effects of lightning can occur.

IPTRANS-9372 -Pollution

Detailed Description	All outdoor mounted devices shall be protected against pollution. The list of substances that shall be assumed, are listed in chapter 4.11 of EN 50125-1:2014.
Rationale	The vehicle will be operated in an environment, where pollutions occur.

IPTRANS-9373 -Large animals on the tracks

Detailed Description	All outdoor mounted devices shall be designed to be protected from damages occurred by large animals on the tracks according to chapter 4.12 of EN 50125-1:2014.
Rationale	Vehicle will be operated in an environment, where large animals could be on the tracks.

IPTRANS-7086 -Electrical connectors shall fulfill the requirements in EN-65847

Detailed Description	Electrical connectors shall comply to EN 62847 to fulfill requirements depending on the application, like implementation, locking, IP protection level, dielectric strength, mechanical strength, temperature class, corrosion protection.
Rationale	

7.1.1.2 Electrical Safety

IPTRANS-494 -Components for wagon equipment shall fulfill electrical safety requirements

Detailed Description	Components for wagon equipment shall fulfill electrical safety requirements according to EN 50153:2014.
Rationale	To protect people at the trackside from electrical hazards.

7.1.1.3 Mechanical stress

IPTRANS-499 -Shock and vibration

Detailed Description	Components for wagon equipment shall fulfill the requirements concerning shock and vibration according to EN 61373 category 1 .
Rationale	

7.1.1.4 Electromagnetic compatibility

Regarding electromagnetic effects the following standards apply:

- EN 50500 "Measurement procedures of magnetic field levels generated by electronic and electrical apparatus in the railway environment with respect to human exposure".
- EN 50121-3-2 "Railway applications - Electromagnetic compatibility – Rolling stock apparatus"
- EN 50238-1, EN 50238-2, EN 50238-3 "Railway applications – Compatibility between rolling stock and train detection systems"
- EN 50592 "Railway applications - Testing of rolling stock for electromagnetic compatibility with axle counters"
- EN 50617-1, EN 50617-2 "Railway Applications - Technical parameters of train detection systems for the interoperability of the trans-European railway system" – all parts
- EN 50728 "Railway applications - Rolling stock - Testing of rolling stock for electromagnetic compatibility with track circuits."

7.1.1.5 Fire safety

All devices shall be compliant with the requirements of /TSI WAG/, /TSI LOC&PAS/.

For cables and cable installations following two standards shall be respected:

IPTRANS-7094 -Fire safety measures for cable protections and installations

Detailed Description	Concerning fire safety cable protections and installations shall comply with EN 50355 and EN 50343.
Rationale	

7.1.1.6 Maintenance

A freight wagon as it is used in Europe is only in a workshop for an overhaul every 6 years if no impairments or damage to the wagon have occurred in the meantime. In order not to shorten the overhaul cycle by using automation components such as a power supply system, these systems must also be designed in such a way that overhauls coincide with the current cycle times.

IPTRANS-7088 -Overhaul cycle time of components

Detailed Description	The overhaul cycle for components of power system and communication system shall be at least 6 years, with the exception of the energy storage unit.
Rationale	

7.1.2 Safety related requirements

In /WP4 D4.2/ "Risk assessment and harmonized safety architecture" the potential hazards that a DAC-fitted FDFT could lead to are identified and analysed. This process used the results of /WP2 D.2.1/ "Preliminary operational procedures" as input. The result of this analysis being a HAZOP (Hazard and Operability) table that is an appendix of /WP4 D4.2/.

The main results of this work are the safety related requirements, which are given in Table 2.

Table 2 Safety Requirements and related TFFRs

TFFR [¹ /h]	Safety Requirement
10 ⁻⁹	Unintended decoupling / train separation during the train run without opening the brake pipe must be prevented. If a local decoupling mechanism is introduced, the same safety requirement as for the central decoupling function applies. Unauthorized access must be prevented.
	Without trackside line occupied monitoring, decoupling / train separation without information to the ATP must be avoided.
	Without trackside line occupied monitoring, train length determination must be provided correctly.
10 ⁻⁷	Unwanted decoupling, decoupling of wrong wagon in a protected area must be avoided. The brake percentage must be provided to the loco (on board channel) in a protected area.
10 ⁻⁶	Don't apply power if contacts are not coupled or covered.

	Indicate malfunction of coupling and exceedance of force limits to operator.
	Indicate "lost" consists (i.e., wagons, which are not anymore part of the train) to operator and / or ATP (automatic train protection system).
	Switch on end of train signal at the end of the vehicle being at end of train.

The given TFFRs in Table 2 indicate safety integrity levels, which are relevant for software related functions, EN 50129 defines the allocation between the TFFR and the safety integrity level.

Safety requirements from Table 2 with relevance to communication system:

"Without trackside line occupied monitoring, decoupling / train separation without information to the ATP must be avoided."

"Without trackside line occupied monitoring, train length determination must be provided correctly."

"Unwanted decoupling, decoupling of wrong wagon in a protected area must be avoided. The brake percentage must be provided to the loco (on board channel) in a protected area."

"Indicate malfunction of coupling and exceedance of force limits to operator."

"Indicate "lost" consists (i.e., wagons, which are not anymore part of the train) to operator and / or ATP (automatic train protection system)."

"Switch on end of train signal at the end of the vehicle being at end of train."

These safety requirements pertain to the higher-level communication system (application level) that is part of the train functions as outlined in /WP5_D5.1/. Currently, no safety requirements are derived from the train functions for the communication system as it described in this document.

Safety requirements from Table 2 with relevance to power system:

"Don't apply power if contacts are not coupled or covered."

This requirement will be addressed in chapter "7.2.1.1 - Personal protection" of this document. It is partially dependant on the specific mechanical design, particularly the closing mechanism of the e-coupler flap and its supervision to prevent direct access to power contacts. Additional or alternative measures for this safety requirement are also mentioned in the personal protection chapter for this safety requirement.

7.1.3 ATEX requirements

This chapter describes ATEX relevant requirements for components on freight wagons only, like the wagon power supply system and the communication system. Traction units operating in ATEX zones are out of scope of this chapter.

The normative regulation basis is the IEC 60079, ATEX Product Directive 2014/34/EU.

In rail freight transport, around 30% of freight wagons are suitable for transporting dangerous goods. The freight bulk material wagons and tank wagons move not only on public tracks, but also in industrial plants. Until now, most of freight wagons do not have any active systems and, as a result, the use of active systems is currently not specified in railway-specific standards. With the introduction of automation systems on vehicles transporting dangerous goods, the guidelines defined in the ATEX Product Directive 2014/34/EU must be applied first for the individual automation components. A design of the components which is fully in compliance with the ATEX requirements and certified for use it in ATEX relevant zones, will highly increase the development efforts, as well as the costs of these components. To find an approach how to reduce these efforts and costs, different strategies have been evaluated in the expert groups.

Strategy 1: design and homologate the full freight wagon as a system to be ATEX conform.

This leads into a complex homologation process for each type of wagon. This is not useful for existing wagons targeted to be equipped with the DAC.

Strategy 2: All active components need an ATEX approval /certification.

Here each individual component shall be designed and certified to be in compliance with the IEC 60079 for intrinsic safe usage in zone 1 / zone 21 as well as zone 2 / zone 22. The homologation approach of such a freight wagon is easier because pre-qualified / certified components can be installed on such a wagon. On the other side, this approach imposes much higher costs for the equipment itself.

Strategy 3: Combining an operational procedure together with reducing the requirements for explosion protection for certain components.

The main critical operation of electric equipment regarding ATEX requirements is the loading and unloading phase. In facilities like refineries there are different ATEX zones defined. Before entering such zones, the wagons have to be prepared (e.g., depleting the brake system to disable the brake and eliminate the risk of brake pads friction on a wheelset). That preparation process can be extended with some measures for the automation equipment.

Two measures shall be added in the preparation process:

- a) No 400 V AC power supply for the freight wagons via the Power Distribution Line. That means, no external energy shall be supplied to the freight wagon.

b) Disconnect / Switch off all automation equipment from the Low Voltage supply of the Wagon Power Supply. That means, that each electronic device, which gets its energy from the 48 V output of the WPSS is implicitly powered off.

Measure a) can be performed at the traction unit, by switching off the TUPSS. Measure b) is described more detailed below.

The main critical element on a FDFTO freight wagon is the energy storage, which is part of the Wagon Power Supply System. A circuit breaker shall be placed at the energy storage that can disconnect the energy storage from the remaining systems. As a result, the complete wagon is powered off. This circuit breaker shall be placed on the wagon in such a way, that operational staff can easily access it. In Figure 9 an illustration of the circuit breaker (on/off switch) is shown.

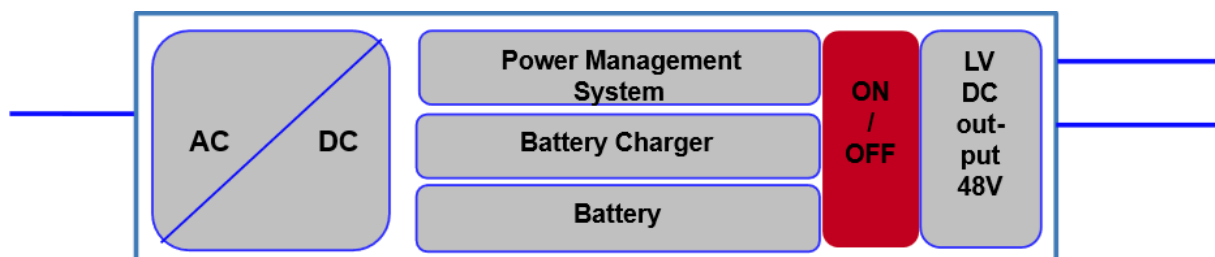


Figure 9: Circuit Breaker to detach the battery system

Powerless components can be handled as so called "simple apparatus" in context of the IEC 60079-11:2023 and will reduce the design and development efforts as well as the costs of these components. From IEC 60079-11 perspective these components shall be designed in such a way to fulfil the requirements under the following conditions:

- main supply is removed for the component, the component is not powered any more
- The components can be handled as "simple apparatus" (chapter 5.5 in IEC60079-11:2023).

Conclusion: For the WPSS and the communication system it is recommended to follow this approach. The energy storage itself remains to be designed as intrinsic safe system to fulfil the ATEX requirements for the zone 1 / zone 21 as well as zone 2 / zone 22.

Following requirements which shall be applied for components using in ATEX zones:

IPTRANS-7778 -Requirements regarding electrostatic hazards for equipment operating in ATEX zone 1 / zone 21

Detailed Description	Equipment used in consists operating also in ATEX Zones (up to Zone 2, Zone 22) shall minimize the use of chargeable insulating material (e.g., housings, pipes, connectors) or shall restrict surface and width sizes of components made of solid materials.
Rationale	Metallic or conductive housing, if grounded, reduce the risk of electrostatic charge generation.

IPTRANS-7785 -Requirements regarding Electromagnetic energy radiating equipment operating in ATEX zone 1 / zone 21

Detailed Description	The energy levels of radiated electromagnetic energy from radio frequency sources (9kHz to 60GHz) shall not exceed the threshold values given in the "Chapter 6.6.2" and "Table 5 - Threshold power" and "Table 6 - Threshold energy" of the standard IEC 60079-0 Issue 2017.
Rationale	Only in freight wagons used in ATEX Zones 1 and 21, additional measures must be taken for the electromagnetic energy radiating equipment (e.g. passive NFC-Tags) for non-powered equipment to ensure operational safety.

IPTRANS-8281 -Grounding of components made of dissipative material

Detailed Description	For consists operating also in ATEX Zones (up to Zone 2, Zone 22): Components with enclosures made of dissipative material shall be connected to ground /earth (car-body).
Rationale	Dissipate and neutralize by grounding reduces the risk of electrostatic discharge. Appropriate ground paths reduces the charge generation and accumulation. According to IEC 60079-32-1 Chapter 6.2.

IPTRANS-8282 -Limitation of thickness for insulating coating of earthed surfaces

Detailed Description	For consists operating also in ATEX Zones (up to Zone 2, Zone 22): To avoid brush discharges, the thickness of the layer (e.g. coating) shall not exceed a value of 0.2mm for usage in areas for gases and vapours of the group IIC in IEC 60079-32-1.
Rationale	Insulating coating on earthed surfaces can give rise to brush and/or propagating brush discharges depending on several factors. According to IEC 60079-32-1 Chapter 6.3.4.

IPTRANS-8283 -Total resistance of earthing pathes

Detailed Description	The total resistance of the earthing path for items in good contact with earth shall not exceed: • 10 Ohm for pure metallic connections • 1 MOhm for all other connections
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	• < 1 MOhm for moveable conductive items • 10 Ohm between cable and item to earth • 1 MOhm to 100 MOhm for items fabricated from dissipative materials (e.g., plastics with static dissipative additives like carbon black) • < 100 MOhm for housings with intrinsic safety circuits
Rationale	Components such as enclosures made of dissipative material shall be connected to earth according IEC 60079-32-1 Clause 13.

IPTRANS-6858 -Energy Storage Requirements for use in ATEX Zone1 and Zone 21

Detailed Description	Only freight wagons used in ATEX critical zones shall implement a circuit breaker/switch to detach electrically the energy storage from the other systems in the wagon power supply system. This circuit breaker must be well accessible by operation personnel.
Rationale	The circuit breaker enables the approach that other electric / electronic equipment can be handled as "simple apparatus" as described in IEC 60079-11:2023 Chapter 5.5.

7.2 Power system

The requirements defined in this chapter belong to the power supply system of the FDFT. The power supply system is separated into three partitions:

The partition with the power generation for the FDFT is described in chapter "7.2.3- Traction unit specific requirements".

The partition with the PDL, which is responsible to distribute the power within the whole train segment of the FDFT is described in chapter "7.2.2- Power Distribution Line specific requirements".

The partition with the power reception, in which the power will be taken, to convert it for the consists (wagons) is described in chapter "7.2.4- Wagon specific requirements". As introductory chapter "7.2.1- General requirements" has been established to specify mandatory overall topics, which must be respected to ensure safe and proper operation of the FDFT in view of protection and functionality.

7.2.1 General requirements

The following requirements apply to all, the TUPSS, the WPSS and as well as the PDL.

7.2.1.1 Personal protection (Electric safety)

The consists of the FDFT shall be supplied with electrical power so that the consumers are supplied to carry out the wagon and train related functions and the wagon battery can be (re-)charged.

The electrical power is delivered by the traction unit during the train run (the mission) or by an external power supply in the yard, when no supplying traction unit is available.

In order to increase the efficiency of the PDL, the supply voltage has been defined to be 400 V AC (single phase).

The voltage level 400 V AC is in the range of voltage band III according to EN 50153. Adequate precautions for the personal protection against electrical shock are important and mandatory requirements.

In chapter "7.1.2- Safety related requirements" it is requested that the 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. The (interface) connectors are shown in Figure 11, they allow the easy exchange of the e-coupler for effective maintenance. The active part of the (interface) connector with the contacts is entirely covered and protected by a grounded case.

IPTRANS-6790 -Personal protection against electrical shock

Detailed Description	Access is only permitted to (electrically) instructed persons and skilled persons provided that precautions against unintended direct contact are taken.
Rationale	Risk of danger by electrical shock: Power Distribution Line voltage of 400 V AC is in the Voltage Band III according to EN-50153.

The electrical equipment for the PDL on 400 V AC level and the connected components (the supply, consumers, cabling, connectors), which are installed in wagons and traction units, shall be protected against direct access to active parts (carrying 400 V AC) by applying the following measures:

- Inside a consist, the cabling for power distribution shall be installed in pipes and/or ducts (grounded, when made of metal) to protect the cabling itself against mechanical damage and to prevent direct access (e.g., damaged isolation).

IPTRANS-9352 -Installation of the power cables in the vehicle

Detailed Description	The cabling for the Power Distribution Line shall be installed in protection pipes and/or ducts (grounded to chassis, when made of metal)
Rationale	Requirement for the subsystems, the wagons and the traction units for installation the power cabling for protection against mechanical damage.

For the e-coupler, further measures shall be applied:

- To provide protection in case of a damaged insulation of cables inside the e-coupler or the catenary falls down on the e-coupler, all parts of the metal case of the e-coupler shall be grounded to the chassis via the main coupler.

IPTRANS-9353 -Grounding of metallic components of the e-coupler for the DAC

Detailed Description	All parts of the metal case of the e-coupler, including the flap, shall be grounded to the chassis via the main coupler.
Rationale	Protection earth as general requirement for all accessible metal components in railway business. Protection, when the overhead line falls down on the e-coupler. Protection, when the insulation of a cable is damaged to provoke an insulation fault, which is identified and recorded.

- The e-coupler connects the PDL between the consists via contact pins. A movable, protective cover, also named as flap, shall prevent direct access to the contact pins, when the DAC is in uncoupled state. See /WP5_D5.2/ for more information.

IPTRANS-6792 -Personal protection: access to electrical parts, contacts in the e-coupler

Detailed Description	The access to live parts (carrying 400 V) shall be inhibited in the uncoupled state and while the train function "prevent coupling" is active.
Rationale	Danger of life ! It is to be prevented that active parts, carrying high voltage 400 V, can be touched by a protective flap to cover the contacts of the e-coupler. The voltage of the PDL is 400 V AC and is in the band III according to EN 50153.

- The flaps of the e-couplers shall be fitted with warning signs "dangerous voltage" to make aware about the danger of high voltage at the power contacts inside the e-coupler.

IPTRANS-6791 -Warning labels for connectors in the PDL and e-couplers

Detailed Description	The e-coupler shall be fitted with warning labels for danger of electrical shock in according to EN 61310-1. They shall be well visible in open and closed state of the e-coupler. The same applies for the interface connectors between the fixed wiring inside the vehicles and the cables 400 V to the e-coupler. They shall be well visible in connected and not connected state of the interface connector.
Rationale	It shall be warned about the danger of electrical shock, while the voltage at 400 V is in band III according EN50153. Warning labels "Electrical hazards" shall be placed on/near all potentially accessible elements, where the parts with 400 V AC can be touched. Such locations are all detachable interface connectors, which are used in the vehicles as well as the flap of the e-coupler.

	The warning labels shall be visible well before getting near the related connectors and the e-coupler.
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For the case that the flap is not closed in uncoupled state, the risk of direct access to the 400 V AC contacts is high. Therefore, one or more additional measures shall be followed to avoid the risk of electrical hazard when touching one contact, when the flap is not closed in the uncoupled state. The additional measures are:

- Since the flap is coupled with the mechanical coupler via a rotating drive mechanism, and the brake pipe valve is also connected to the mechanical coupler, the brake pipe remains open as long as the e-coupler flap is not closed. This setup allows for indirect identification of the flap's closing state on the last wagon. The operator in the leading traction unit can monitor the brake pipe pressure using manometers or the DMI display before activating the PDL. In FP5 Basic State, the operator (loco driver) must activate the PDL after validation of the train composition. Therefore, it is recommended to additionally observe the brake pipe pressure before activating the PDL.
- A further possibility is the monitoring of the closing state of the flap without the help of operating personnel. The flap status (open/closed) shall be detected by using sensors in the flap of the e-coupler and shall be transmitted to the leading consist via the communication network (F-ETB). The operator in the leading consist gets the information of the closing state of the flap and must check and inspect this flap status before activating the PDL.

The mechanical coupling of brake pipe valve and the e-coupler flap is currently under discussion in WP6. The monitoring of the brake pipe valve pressure as well as the usage of flap sensors needs further elaboration by WP9, in alignment of WP4, WP6 and WP10, as noted in chapter 8.2.

7.2.1.2 Insulation monitoring concept

In order to provide a high availability of the FDFT also the power system shall ensure high reliability and availability. Furthermore, personal safety against electrical shock shall always be ensured. Insulated power systems (in following named as IT systems) fulfil both requirements. Therefore, an IT system is chosen for the execution for the FDFT power system according to IEC 60364-4-41.

Advantages of IT systems:

- A damage of the insulation system will not lead to a loss of the power supply.
- The touch of one line of the active part does not directly lead to a personal hazard.
- The rail potential (of the track) is not involved in the power supply, so no conducted disturbances to infrastructure is expected.

System boundaries and scope of monitoring:

- in the traction unit, the internal galvanic insulation which is realized by the way of power generation towards the power output
- the insulated PDL in the wagons including all contacts and plugs in the e-couplers, junction boxes or interface connectors
- the AC/DC-converter in each wagon of the train segment (also with galvanic insulation)

The nominal voltage of the system in scope is 400 V AC, which is in the range of voltage band III according to EN 50153.

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.

Capacitance effects on the PDL may lead to the fact that the high impedances required for an IT system (acc. to IEC 60364-4-21) cannot be ensured. This will be further investigated and is marked here as open topic (see chapter 8.2).

Grounding resistance:

It is to be ensured that the potential of the chassis is very close to the rail potential. For this, it is mandatory that the wagons (each wagon) have an adequate maximum grounding resistance between active part and rail in all conditions of operations, i.e. during running and at stand still.

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. The maximum grounding resistance shall also be valid, when measuring currents much below 50 A are applied. The grounding resistance value to avoid higher voltage between chassis and track potential than defined in voltage band I (acc. EN 50153) must be ensured. The selection of the economically and technically optimal solution is an open topic (see chapter 8.3).

Insulation monitoring:

The monitoring of the insulation system is mandatory.

IPTRANS-804 -Insulation monitoring system

Detailed Description	The impedance between active parts (insulated) against chassis of the vehicle (grounded to rail) of the PDL shall be evaluated and failures diagnostized from the traction unit which supplies power to the PDL. The trigger of the failure information (failure state of the 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%.
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	For failure localization in demo and pioneer trains option 1 shall be applied.
Rationale	Identify failures of the PDL isolation system. According to IEC TS 60479-1 values above 20 mA for current flowing through the human body impose a serious danger. This current value leads to a minimum impedance of 20 kOhm ($U/I = 400V/20mA = 20\text{ kOhm}$). Including a tolerance of 10 % of the PDL voltage leads to the trigger value of 22 kOhm. For insulation monitoring from the locomotive requirement 804 shall be amended as described above. For failure localization in demo and pioneer trains option 1 shall be applied, i.e. decoupling one wagon after the other mechanically, beginning at the end of train, until the insulation failure will not be detected anymore in the remaining part of train with the traction unit. Option 1 leads to lower efforts for the electrical system but resulting in higher efforts for operational procedures which only occur in case of a failure.

In the current realization in the FP5 Basic State the insulation system of the FDFT is monitored continuously only from the traction unit by fulfilment of this requirement IPTRANS-804.

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.

Background information for the assumption of the trigger impedance value:

It is assumed, that one wagon has an overall insulation resistance between 2.5 MOhm and 5 MOhm. For this threshold, 50 in parallel connected wagon-related impedances are to be considered. The failure information is reset, when the insulation resistance raises (for example after maintenance of the IT-system):

Reset:

When the insulation resistance raises 20% (impedance value: 120% of trigger impedance value). The hysteresis-value 20% is also assumed for the FP5 Basic State and will be finalized later after the field tests with DEMO1-trains.

Localization of the failure:

The supervision of the insulation system in the traction unit provides only the overall state in the observed scope within the system boundaries. For effective maintenance the failure in the insulation system needs to be localized. In the first state of development for FP5 Basic State the following options are possible:

Option 1) Decoupling one wagon after the other mechanically, beginning at the end of train, until the insulation failure will not be detected anymore in the remaining part of train with the traction unit.

Option 2) Installation of a 4-pole NC-contactor (normally closed) (for 2x2 wires at each end of wagon, i.e., 2 pieces per wagon). The aim is to switch off all 4 poles to the e-coupler on both ends of each wagon. The effort is increased much, but the failure can be found quickly and automatically. Switch off one wagon after the other, beginning at the end of train, until the insulation failure will not be detected anymore in the remaining part of train with the traction unit.

A NC-contactor-type is necessary to provide an uninterrupted train power distribution line in unenergized state.

Recommendation: Option 1 due to lower efforts for the development and the electrical system, and the resulting higher efforts in operational procedures would only occur in case of an error.

Operational handling of insulation faults:

The WP2 expert group "operations" shall define how to react in case of an identified insulation fault in order to prevent further risks for protection. This is an open item to be clarified in FP5-TRANS4M-R project, as described in chapter 8.2.

WP9 proposes a time-limited operation to finish the journey of the freight train as one option.

A further option is: To shut down the power supply immediately.

When the insulation monitoring device offers several trigger thresholds, more reactions can be defined accordingly, for example: warning message - time restriction for operation - immediate shut down.

For diagnostics: record this failure-event with date and time stamp.

IPTRANS-807 -The illustrations on DMI in driver's cab (protection-view, diagnostic messages)

Detailed Description	Each recorded failure of the insulation system shall be shown on the DMI in the driver's cab of the traction unit
Rationale	Insulation failures shall be reported to a train driver.

7.2.1.3 External power supply concept

External power supply is not considered a standard operation procedure, but external power supply shall be considered as a feature in the FDFTO. It is foreseen that parked wagons shall manage their energy consumption by themselves in order to avoid the necessity of external power supply and full discharge of on-board batteries (for reasons of availability and component protection).

For the case that external power supply is needed, the given interface via the e-coupler shall be used. No other interface connectors are foreseen. The power source on land side shall be galvanically isolated, since the reference potential on the land side is not identical with the rail potential 0 V.

IPTRANS-8164 -External power supply, Interface

Detailed Description	The interface for the external power supply shall be realized with the existing interface of the wagon. No other connectors or plugs shall be provided.
Rationale	The e-coupler of the DAC shall be used as interface for the external power supply of the wagons.

The requirement IPTRANS-6799 contains the specification values for the external power supply.

IPTRANS-6799 -Data and features of the external power supply

Detailed Description	Nominal voltage: The external power supply shall provide 400 V AC (single phase), 50 Hz at the output towards the wagon. Nominal power: The external power supply shall provide at least the same power rating 3.75 kVA, as a traction unit. Features: Galvanic isolation shall be foreseen between the power system of the land side and the output towards the wagons. An insulation monitoring system shall be provided at the wagon side output.
Rationale	The external power supply shall be compatible with the PDL. The external power supply shall deliver the same power as a traction unit. Different reference potentials of the land side and the track side require galvanic isolation of the external power supply. Insulation faults shall be also identified by the land side power supply.

7.2.1.4 EMC requirements

The communication system of the FDFT is an electromagnetically sensitive system and must not be disturbed by neighboured power cables.

The power system of the FDFT is quite robust, but - also due to the long distance from the feeding traction unit to the end of dedicated train section - measures must be considered to minimize the risk of emission of electrical and/or magnetic disturbances as described below.

The EMC behaviour is to be distinguished (according to the different frequency ranges) into

- conducted EMC, in the lower frequency range (up to some kHz), for example by magnetic or/and capacitive inductions.
- radiated EMC, in the higher frequency range (up to the MHz range)

Mandatory measures for conducted EMC are:

IPTRANS-9896 -Installation of the power cables and communication cables in the vehicle

Detailed Description	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.
Rationale	Protect electromagnetically sensitive communication system cables from disturbances caused by neighbouring power cables (conducted EMC).

Application of twisted or bundled wires or multi-pole cables to compensate magnetic fields. Since the cabling for the power system of the FDFT shall be executed as 2x2 wires the following variants are recommended to be chosen, as shown in Figure 10:

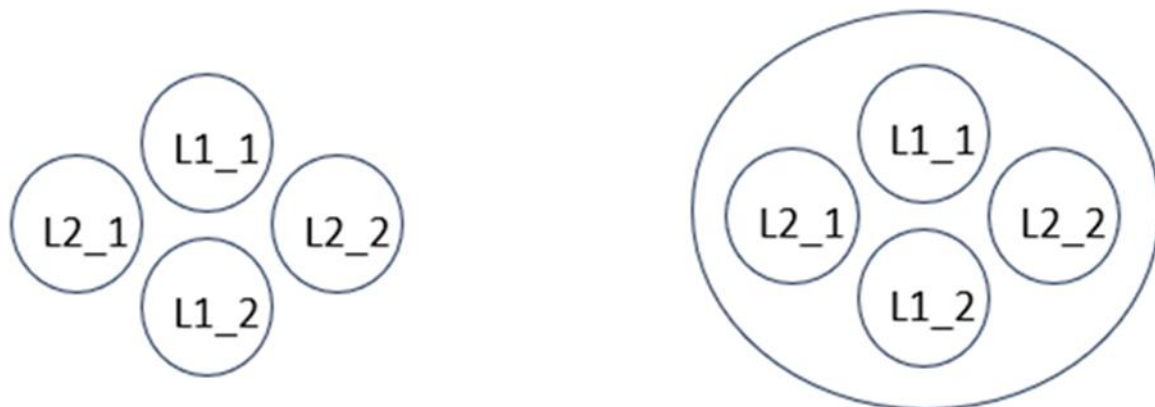


Figure 10: Variant left side: 4 single-pole cables, combined as 4-pole-bundle, Variant right side: 4-pole cable for both potentials L1 and L2.

EDDP has suggests the use of twisted cables /DACcelerate_D3.2/ requirement "Wagon_ELEC.021". However, for this frequency range, the choice between twisted or straight cables does not matter. Due to mechanical reasons flexible wires are recommended, as usual for railway applications.

Provision of galvanic isolation between different parts of the whole power supply system, especially near converters. The galvanic isolation suppresses disturbing currents between the two related sections of the power supply system.

Mandatory measures for radiated EMC:

- Application of adequate, proper grounding and shielding of the related cables, connectors and components.
- Apply the correct impedance of the cable to avoid reflections.

IPTRANS-7782 -EMC behaviour of the Power Supply System in the FDFT

Detailed Description	The Power Supply System of the FDFT (on traction units and on wagons) shall be compliant to the vehicle related EMC behaviour.
Rationale	The Power Supply System shall fulfil as minimum the EMC requirements, as given in EN 50121-3-2

IPTRANS-776 -EMC, Power Supply System on Traction Units

Detailed Description	The power supply system in the traction units shall be realized with galvanical isolation to the internal power network
Rationale	Conducted EMC emissions shall be suppressed.

IPTRANS-1049 -EMC, the Wagon Power Supply System

Detailed Description	The wagon power supply system shall comply with EN 50121-3-2 in terms of electromagnetic compatibility.
Rationale	EMC-related requirements from railway network operators and official bodies shall be fulfilled (e.g. EMV 06, TR-EMV, ...)

7.2.2 Power Distribution Line specific requirements

The traction unit supplies the PDL of its own segment of the FDFT with electrical power. The PDL distributes the electrical power to each consist in the dedicated segment.

The PDL shall ensure interoperable operation of the whole FDFT within the defined boundary conditions and boundary train configurations, as defined in chapter "6.2- Boundary conditions - train composition".

Figure 11 illustrates the functional schematic of the PDL, which is fed by the traction unit. This illustration is symbolic and presents the essential architecture including the main components of the PDL. This illustration is not binding for final execution. The flaps at the uncoupled end of the traction unit and the rear end of the last wagon shall be closed and so they are not shown in Figure 11, since they do not contribute to the function of power supply. All other flaps in the train composition are open due to coupled state, but they do also not contribute to the function of the PDL.

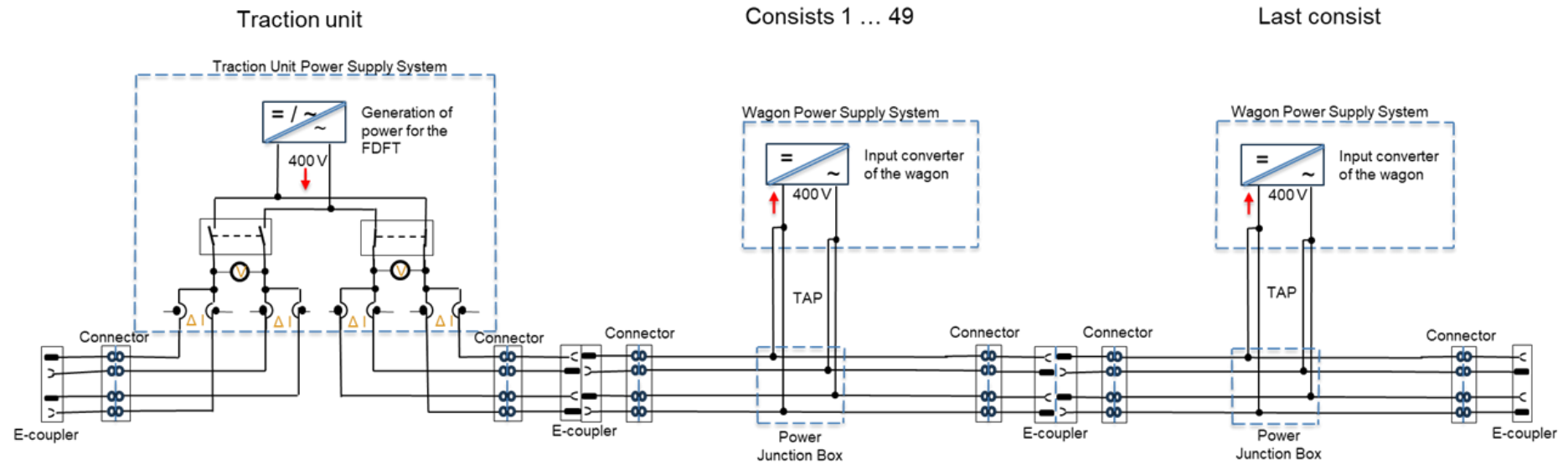


Figure 11: Overview of the power distribution line

The rear end of the traction unit is energized, so the power is distributed to the wagons, up to 50 in one train segment. The way of supervision of each current in a power cable is shown in Figure 11 for the traction unit. Each current shall be measured and be compared with the current over the second contact of the same potential. So, a single contact or cable in failure can be identified and localized, when the difference between both currents gets too high, in nominal state they shall have similar values. Additionally with differential current sensors on the consists more detailed location of contact or cable error is possible. Since an IT system is applied, a damaged cable will only be identified by an insulation fault.

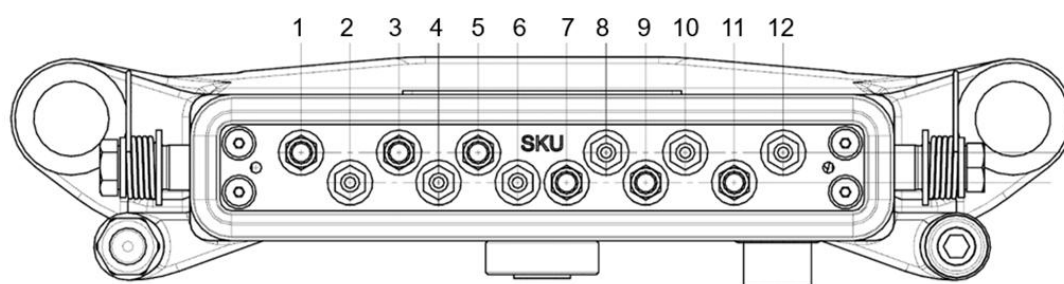


Figure 12: Preliminary contact layout of the e-coupler

Figure 12 shows the preliminary contact layout of the e-coupler. In the centre are the 2x2 contacts for train communication (Pin 5-8), F-TCN, which is based on SPE. The F-TCN (SPE) provides a 4-pole connection instead of 2x two-wire lines and is therefore a redundant communication connection.

The power contacts are located on the left and right side of the e-coupler (Pin 1-2 & 11-12). Two pairs of contacts for 400 V (two contacts for each phase and two contacts per polarity) are used and designed with redundancy due to the symmetry requirement of the e-coupler.

In addition, there are 4 spare contacts (3-4 & 9-10) for potential further usage.

IPTRANS-11594 -E-coupler interconnection point

Detailed Description	The following contact assignment shall be applied for interconnection at consist direction 1: • Pin 1 = L1_1 • Pin 2 = L2_1 • Pin 11 = L2_2 • Pin 12 = L1_2 The following contact assignment shall be applied for interconnection at consist direction 2: • Pin 1 = L1_2 • Pin 2 = L2_2 • Pin 11 = L2_1 • Pin 12 = L1_1
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Rationale	To ensure interchangeability of the e-coupler the electro-mechanical interface between the e-coupler interconnection point and the power cable must be defined.
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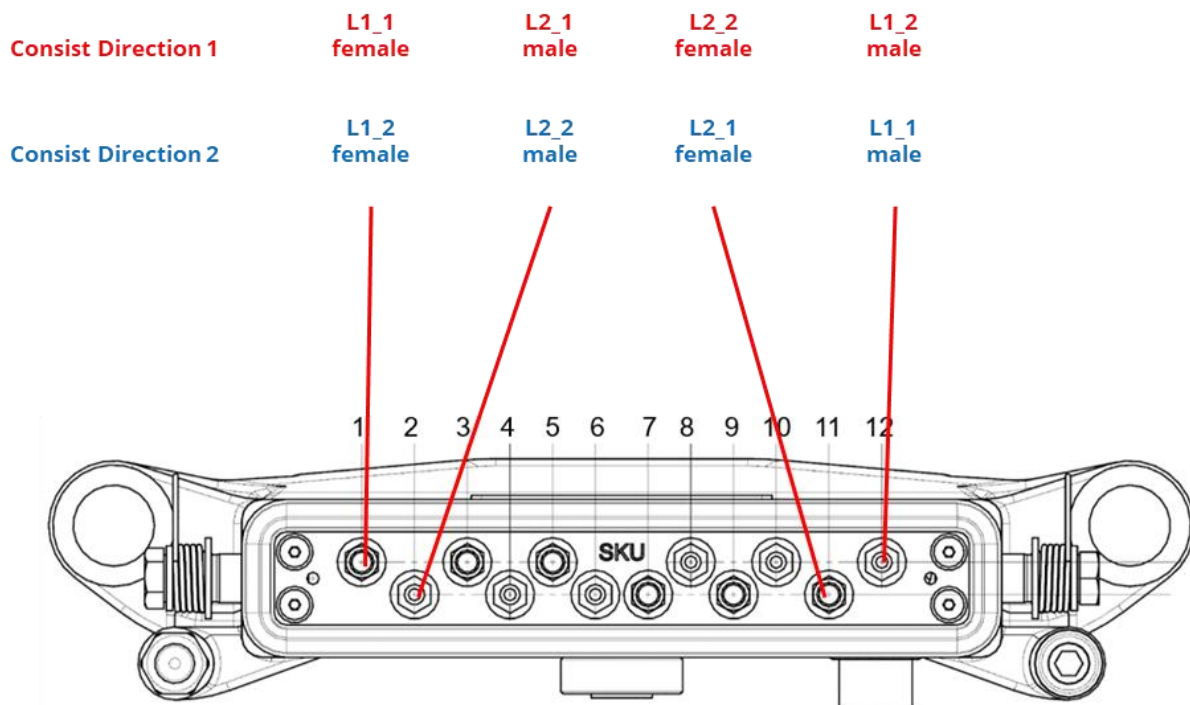


Figure 13: Power supply Pin Allocation

The Power Distribution Line shall be routed from the e-coupler with 4 wires in a protective hose to an interface plug connector (for exchangeability) on the wagon as shown in Figure 11. The definition of the interoperable plug will be defined in /WP5_D5.2/. The cabling inside the consist of one end to the other end is realised via permanently installed cables, meaning they will not have to be exchanged when a coupler from a different supplier is being replaced.

Considerations for the dimensioning of the PDL

In WP9 it has been defined that in worst case, the last consist shall receive at least (400 V AC - 10%) = 360 V. Worst case means full train segment of 50 consists, each 16 m long as assumed average length and taking 55 VA from the PDL. In order to ensure proper functionality, each wagon shall operate at lower tolerance value, i.e., -14% (=344 V) for overlapping as margin for operation.

Also assumed is a traction unit output voltage of 400 V (minimum of range) and a cable length inside each consist of 24 m (1.5 x length of consist).

This requirement would have been fulfilled with a single 4mm² wire. But with such a small size the total resistance of the cabling through the train would be around 13.5 Ohm (0.27 Ohm per wagon). This results in higher total cable loss of 260 W and that the short-circuit

current in case of a short on the last consist would only be 30 A which will most likely not trigger the overcurrent protection in the traction unit. This explains the choice of a suitable and higher size. Figure 14 and Figure 15 show the calculation details for 4 mm² and 6 mm² cable cross section.

Voltage calculation for 50 wagon train with fixed power per wagon

Power per wagon	S	55,0	VA
Source voltage	U_source	400	V
Cable length per wagon	L_cable	24	m
Contact resistance	R_contact	0,03	Ohm
Cable cross section	A_cable	4	mm ²
Min. voltage last wagon (limit)	U_50_lim	360	V
Max. source power (limit)	S_source_lim	3750	VA
Cable resistance (EN 60228)	R_cable	5,090	mOhm/m
Wagon loop resistance	R_wagon	0,274	Ohm
Source voltage	U_0	412,2	V
Source current	I_0	7,30	A
Voltage at last wagon	U_50	360,0	V
Source power	S_source	3010	W
Sum of wagon power	S_wagon_sum	2750	W
Ohmic losses	P_loss_ohmic	259,89	W
Short-circuit current	I_sc	30,05	A
Ratio SC/source current	I_sc / I_0	4,12	

Figure 14: Voltage calculation for 50 wagon train at 4 mm² cable cross section

Voltage calculation for 50 wagon train with fixed power per wagon

Power per wagon	S	55,0	VA
Source voltage	U_source	400	V
Cable length per wagon	L_cable	24	m
Contact resistance	R_contact	0,03	Ohm
Cable cross section	A_cable	6	mm ²
Min. voltage last wagon (limit)	U_50_lim	360	V
Max. source power (limit)	S_source_lim	3750	VA
Cable resistance (EN 60228)	R_cable	3,390	mOhm/m
Wagon loop resistance	R_wagon	0,193	Ohm
Source voltage	U_0	400,0	V
Source current	I_0	7,33	A
Voltage at last wagon	U_50	363,4	V
Source power	S_source	2932	W
Sum of wagon power	S_wagon_sum	2750	W
Ohmic losses	P_loss_ohmic	182,20	W
Short-circuit current	I_sc	41,51	A
Ratio SC/source current	I_sc / I_0	5,66	

Figure 15: Voltage calculation for 50 wagon train at 6 mm² cable cross section

Therefore, it was decided by the WP9 expert group to increase the cross section to 2x6 mm² parallel per phase, reducing ohmic losses to 182 W, increasing the short-circuit

current to 42 A (which will trigger the overcurrent protection) and raising the minimum voltage on the last consist to 366 V.

Even in case of some contact faults in the e-couplers or single wire cable breaks, the system will remain functional until the faults can be repaired.

IPTRANS-8860 -Cross section for PDL cables

Detailed Description	The cross section for the power distribution line cables shall be 2x6 mm ² per phase.
Rationale	Lower ohmic losses and increasing the short-circuit current and increasing the minimum voltage on the last consist leads to the decision to not use the minimum possible cross-section.

Resulting system boundary of the PDL:

Given that a maximum allowable voltage drop of 40 V is ensured by using a cross section of 4 mm² and considering the need to increase to 6 mm² for short-circuit protection. The power carrying capacity of the PDL is now higher than originally required. The resulting value will be calculated by the experts in WP9.

Redundancy of the FDFT power system:

The FDFT power system and the PDL itself are not redundant, only the contacts in the e-coupler of the DAC, even each contact is wired to the power supply systems of wagons and the auxiliary compartment in the machinery room (or adequate location) for the TUPSS of the traction unit.

IPTRANS-9354 -Redundancy of the power contacts in the e-coupler

Detailed Description	Each power contact in the e-coupler shall be redundant, i.e. two contacts are foreseen for each phase (the same potential).
Rationale	Maintain the power supply of the FDFT, even one contact fails (due to damage) by the remaining contact. Need for the function "contact monitoring".

IPTRANS-9898 -Power contact of e-coupler

Detailed Description	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.
Rationale	To maintain the short-circuit current of the PDL in case of a failure of one contact.

Protection of the PDL:

The PDL must be protected directly by the feeding traction unit, which contains all the related sensors and protection functions.

The PDL must be protected against:

- Overvoltage (see chapter "7.2.3.5.3.1- Protection against overvoltage")
- Overcurrent (overload and short circuit) (see chapter "7.2.3.5.3.2- Protection against overcurrent")

Contact Monitoring on vehicles (traction unit and wagon)

To obtain a sufficient level of system availability, and to account for the inherent symmetry requirement of e-couplers (free wagon orientation), it has been decided before the start of the ERJU project that redundancy for all electrical power contacts i.e., for the electrical power contacts in the e-coupler shall be foreseen /DACcelerate_D3.2/. Two contact pairs shall ensure connection for each of the two poles (400 V AC single phase), as described in IPTRANS-9354.

If one of the contact pairs does not establish a low-ohmic connection, the balance of current gets unsymmetrical, in worst situation, the full current will flow along the parallel path made up by the redundant pair. From a functional perspective, there will be no limitation of the system performance in this case, as the full current can be carried by a single contact pair, and the increase in contact resistance due to the loss of the parallel path is negligible, as long as only one or a small number of electric couplings are affected in a full FDFT.

However, without further measures, it is not possible to detect a failed contact pair. If detection is not possible, the electric couplers show as fully functional even if already one of the contact pairs has failed. As soon as the remaining functional contact pair also loses its connection, the Power Distribution Line would be interrupted, and no power supply is available for those vehicles that are lined up behind the faulty e-couplers.

Concept of the Contact Monitoring:

The cabling throughout the wagon shall be redundantly routed. A contact monitoring system with current sensors (e.g., absolute current sensors or differential current sensors) at the point where the WPSS draws power from PDL compares the current flow through both wires per polarity and can be used for detecting broken contact or a broken cable. A contact fault will result in unsymmetrical current distribution across the wires.

The trigger level shall be: 30% trigger threshold asymmetry in current distribution.
Reset to be at: 20% reset.

The threshold values for trigger and reset are current assumptions, they shall be verified and approved during the operations for the DEMO-trains.

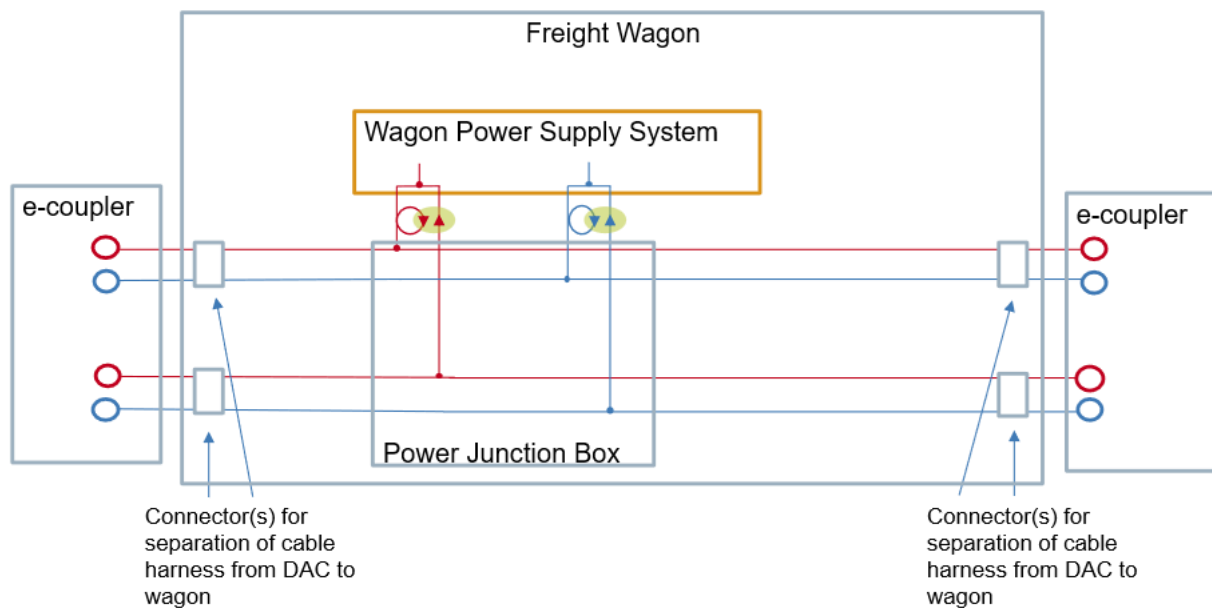


Figure 16: PDL installation of a consist

For the traction units also both method with current sensors for absolute current values and differential sensors are possible. The currents of each potential shall be similar in OK state, if they are too different (trigger threshold see above), a contact failure shall be identified. Each traction unit contains 8 current sensors for both ends, see Figure 11.

For wagons this evaluation is also usable, but the effort is higher. Higher effort is required, due to the lack of a single installation point for sensors in the wagon. Sensors need to be placed near the connectors to separate the cable harness from the DAC to the wagon, and the sensor cables must be routed to the CCU.

To ensure a high availability of the PDL, it shall be avoided that a contact fault on an e-coupler leads to loss of the energy supply in the following wagons after location of the damaged contact. The redundant cables must be merged after current sensing.

IPTRANS-6803 -Supervision of the redundant power contacts

Detailed Description	There shall be a monitoring system implemented to supervise the redundant power contacts.
Rationale	To achieve availability targets of the overall power supply system (on train level). In case one of the two contact pairs has a problem, a supervision can indicate this issue in a state where the system is still operable. Without a supervision of the power contact pairs, contact failure reveals itself (both contact pairs have a problem) in a late state where the power supply system on train level is interrupted and cannot feed the whole train segment any more.

IPTRANS-6804 -CCU shall evaluate the contact monitoring

Detailed Description	The supervision solutions shall monitor the current flowing along the parallel, redundant current paths. The current
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	sensors output shall be electrically connected to the consist control unit (CCU). The CCU shall evaluate the supervision functionality.
Rationale	The CCU can take care how to report a contact failure.

IPTRANS-8128 -Redundant input phases must be connected together

Detailed Description	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.
Rationale	To keep the redundancy over multiple coupled consists, in each consist the two cables for each phase shall be connected together.

7.2.3 Traction unit specific requirements

This chapter specifies the interoperable power system, which shall be integrated in the traction units, which haul the FDFTs in both operational modes (train run mode and shunting mode). Both operational modes are defined in /WP5_D5.1/, which specifies the train functions. The solutions, which will be developed according to this specification, consist of the components for the power generation and the CCU for the control tasks for FDFTO. For the implementation of the functions, for which the CCU is in charge, two options are possible:

Option 1:

Full integration of the functions for FDFTO in the ZSG of the traction unit. The ZSG software is extended by the FDFTO functions.

Option 2:

Application of a CCU for the FDFTO functions. The existing ZSG of the traction unit remains nearly unchanged, the CCU incorporates the FDFTO functionality with the train functions, the communication system and the control of the electrical power system on the traction unit.

The overall approach is that electrical power is taken from the internal power system of the traction unit. This electrical power shall be converted into the voltage and current needed for the FDFT.

Two main system approaches for the power conversion are tackled in this chapter: The system approach using a transformer (see chapter 10.6.1 for more details) and the system approach using an inverter (see chapter 10.6.2 for more details).

They provide solutions for nearly all types of traction units equipped with an onboard electrical power system.

The content of this specification is based on the "Specification energy system for the locomotive bases" created by EDDP WP1, see also /DACcelerate_D3.2/, chapter "3.2 - Specifications for electrical power system", and includes the results of the actual elaborations done in FP5-TRANS4M-R by the expert groups in WP9.

7.2.3.1 System overview

Two cases are to be considered for the TUPSS:

Case 1: Configuration of the leading traction unit

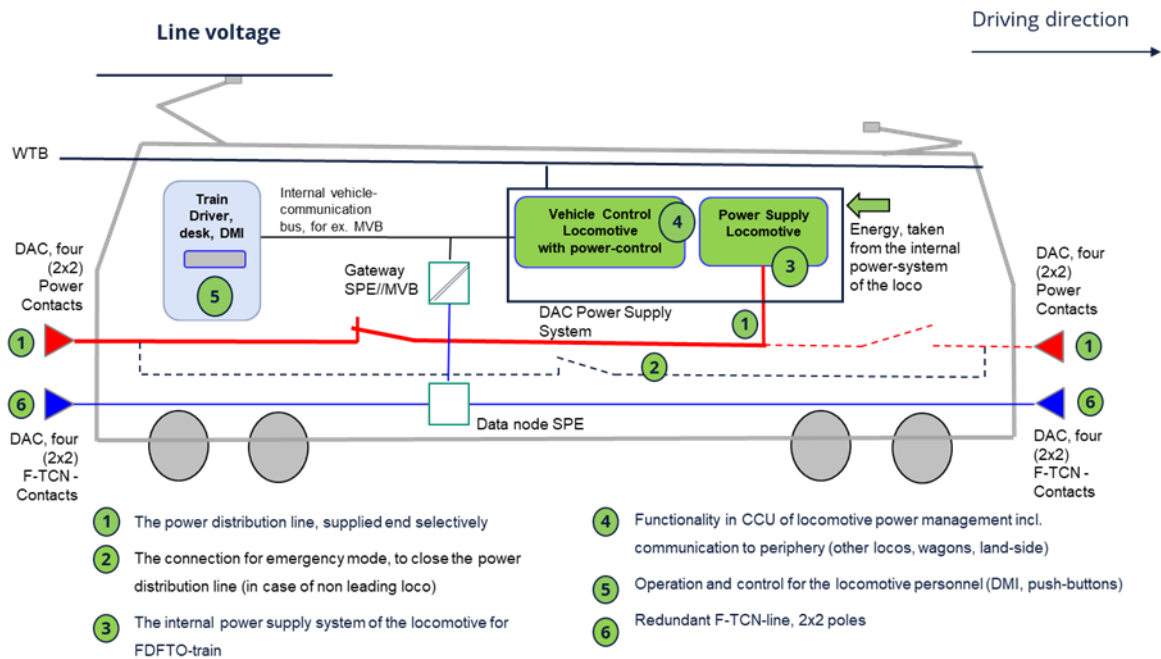


Figure 17: Traction unit (as leading consist) power supply system

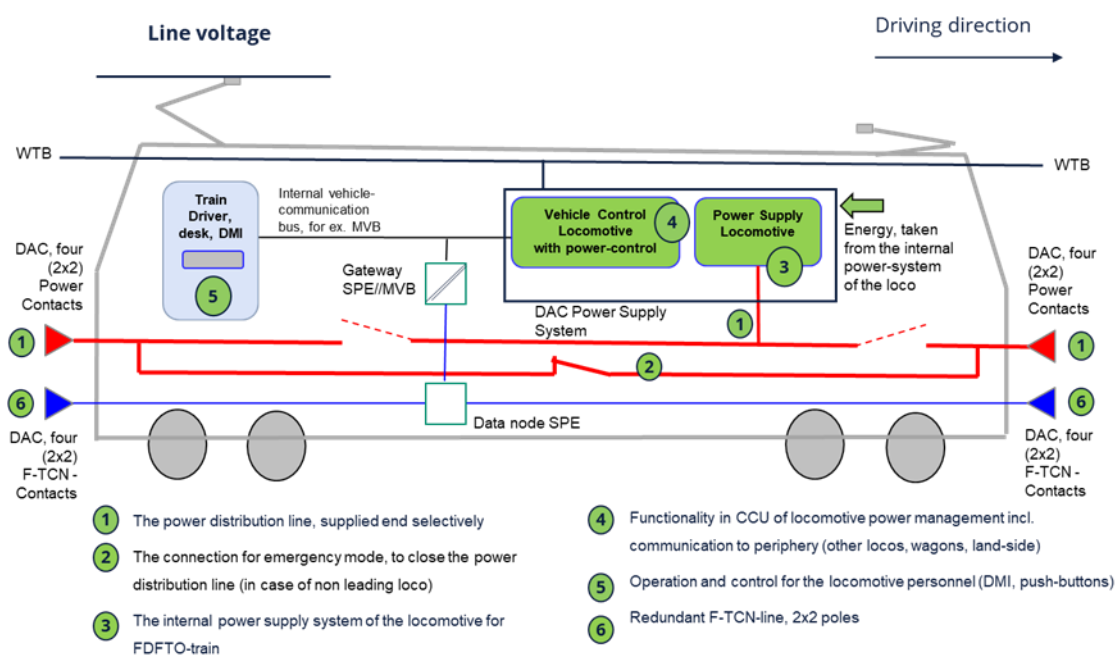
The leading traction unit normally provides the electrical power and takes it from its own internal power system. The leading traction unit contributes to the traction effort and are able to provide electrical energy. It sends commands to the guided traction unit and receives process data, feedback, and status messages from the guided traction unit. The leading traction unit is occupied by a loco driver.

In the configuration for the leading traction unit (see Figure 17) both e-couplers at the ends of the traction unit are energized selectively. Only the dedicated train section is supplied (in the rear in direction of running). The front end (e-coupler) is not energized.

It is necessary to interrupt the PDL, when more than one train segment is coupled to the entire train composition. Only one traction unit shall feed in the PDL of one train segment. The TUPSS shall be connected to and disconnected from the PDL with switching devices installed inside the traction unit.

Detailed Description	The TUPSS shall be connected / disconnected by a switching device to the PDL.
Rationale	Electrical separation of multiple train segments in a train composition.

Case 2: Configuration of the guided traction unit



The guided traction unit normally does not provide electrical power to the PDL. A guided traction unit contributes to the traction effort and has contact to the catenary. It receives commands from the leading traction unit and submits process data, feedback, and status messages to the leading traction unit. The guided traction unit is not occupied by a loco driver.

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Both ends are energized, another traction unit feeds the PDL, the guided traction unit is passive in view of providing power to the PDL.

In case of non-availability of the TUPSS in the leading traction unit such a guided traction unit will be defined to take over the power supply to the PDL.

This is possible because the guided traction unit receives energy from the catenary and can overtake to supply the PDL with its own TUPSS.

7.2.3.2 Supply of electrical power

Power shall be supplied to the train segment coupled to the rear end of the leading traction unit.

IPTRANS-9895 -Supply of electrical power only to rear end of traction unit

Detailed Description	Electrical power shall be supplied only to the train segment, which is coupled to the rear end of the leading traction unit.
Rationale	Electrical separation of multiple train segments.

7.2.3.3 Types of traction units

Four types of traction units are to be distinguished since they have or require different system solution approaches and architectures. The four types of traction units are:

- existing or (currently) delivered main line traction units,
- new developments for main line traction units (future usage),
- shunting traction units - only for operations in yards
- shunting traction units - also for operations on main lines

Existing or delivered main line traction units:

These traction units initially have not been planned to be equipped with a TUPSS for FDFTO.

In order to limit the impact on the existing ZSG of the traction unit, a CCU for the FDFTO functions is recommended to be integrated (option 2, as described at the beginning of chapter 7.2.3). The amount of signal interfaces to the ZSG is much lower, the needed components might also be installed in the machinery room, not only - but preferred - in closed components. Also, older traction units are to be considered in this category.

New developments of main line traction units:

These traction units are planned from early begin of development to be equipped with a TUPSS for FDFTO.

For this case a fully integrated solution for the TUPSS is also applicable (option 1, as described at the beginning of chapter 7.2.3). All needed components shall be installed in closed compartments, preferably in the machinery room.

For shunting traction units – only for yard operations:

Shunting traction units, which operate only in the yards, need not be mandatorily equipped with a TUPSS.

Reasons:

- Often a coupling and decoupling processes occurs. During coupling / decoupling the PDL shall be de-energized.
- Such traction units often have a hydraulic traction system. In this case, the power generation requires high effort with an additional gear to the main diesel-engine and an electrical generator to supply the PDL.

For shunting traction units – also for operations on main lines:

Shunting traction units, which operate also on main lines, shall be treated like a traction unit for main line operation. They should be equipped with a TUPSS.

Reasons:

- The possibility of recharging the batteries in the wagons is a useful effect to increase the availability of the wagons, being coupled with such a traction unit.
- Such traction units have often an electrical traction system. In this case, the power generation requires a similar effort like in main line traction units. The needed additional power for FTFDO must be available in the existing traction system.

Due to the fact, that there are many traction units with very different architectures, it is not the scope of this document to prescribe solutions to be integrated in all the traction units or to provide instructions for migration here, but to specify the interoperable interfaces of the TUPSS, so that each traction unit supplier is in the position to establish an interoperable design as solution for the TUPSS by its own.

Due to the fact, that the supply voltage of the PDL is in the voltage band III (EN 50153), a dedicated chapter (7.2.1.1) is provided for personal protection against electrical shock, which is applicable as for the whole FDFT, i.e., for the traction units and the wagons.

7.2.3.4 Technical requirements

This chapter defines the technical data and the behaviour of the TUPSS.

Output voltage at the e-coupler of the traction unit: 400 V AC +10% / -0%
Fixed regulated voltage within the applicable tolerance band of 400 V AC +10% / -0%, only the positive tolerance shall be applied, as given in EN 50533, in order to achieve at least 400 V -10% at end of train in maximum configuration.

This requirement is valid for the related train segment, which the feeding traction unit supplies.

IPTRANS-8206 -Regulation of the TUPSS output voltage to the PDL in the traction unit

Detailed Description	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).
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Rationale	Basis for regulation the voltage to the PDL inside the traction unit, way of application the standard: EN 50533 for the FDFT with up to 50 wagons and power consumption maximum 50 W / 55 VA for each wagon. It shall be ensured that the last wagon receives not less than 400 V AC - 10%.
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The output voltage of the TUPSS is regulated and monitored so that an overvoltage category 2 is chosen as basis for the insulation coordination of the whole PDL and the connected consumers according to EN 50124-1.

Fundamental frequency of the TUPSS

The fundamental frequency is defined in IPTRANS-8852 and is applicable for all types of traction units with a power supply system 400 V AC.

The requirement IPTRANS-8852 is valid for the related train segment, which the feeding traction unit supplies. Existing traction units have often an internal AC supply voltage with 60 Hz. The power supply systems in the yards have an AC supply voltage with 50 Hz (fed by public supply system). Some modern traction units apply a so called "eco-operation", i.e., a kind of "power save mode" for auxiliaries in the traction unit. In this operation the frequency is reduced from 60 Hz to 50 Hz and vice versa.

IPTRANS-8852 -Fundamental frequency of the output voltage of the traction unit

Detailed Description	The fundamental frequency of the output voltage of the traction unit shall be in the range between 50 Hz and 60 Hz.
Rationale	Existing traction units have often an internal AC supply voltage with 60 Hz. The power supply systems in the yards have an AC supply voltage with 50 Hz (fed by public supply system). Some modern traction units apply a so called "eco-operation", i.e., a power save mode for auxiliaries in the traction unit. The Frequency is reduced from 60 Hz to 50 Hz, what explains the variation or change between the frequency values 50 Hz and 60 Hz.

Shape and quality of the output voltage of the TUPSS:

The partition of (higher) harmonics in the output voltage shall be limited to ensure a sinusoidal wave form of the output voltage to the PDL. The input converters in the wagons use this wave form for synchronization of their control for power factor correction. The quantity "Total Harmonic Distortion" defines the partition of higher harmonics in the output voltage, it is specified hereafter and shall be applied for all types of TUPSSs, which provide power to the PDL.

IPTRANS-8853 -Shape and quality of the output voltage of the traction unit

Detailed Description	The voltage shape shall be sinusoidal Total Harmonic Distortion: THD $\leq 10\%$ at rated output power 3,75 kVA at at the e-coupler of the traction unit.
Rationale	Sinusoidal shape is needed for the power factor correction in the power control system of the wagons.

Output power (at the e-coupler) from the traction unit:

The TUPSS shall cover the needs:

- of the train with 50 wagons (each wagon takes maximal 50 W / 55 VA from the PDL)
- the power losses in the PDL (effective wire cross section: 2 x 6 mm² for PDL wiring)

The high fundamental power factor $\cos(\phi)$ is needed to exploit the PDL as maximum as possible and to minimize the voltage drop over the PDL.

IPTRANS-8208 -Minimum Power to be delivered by the TUPSS

Detailed Description	Minimum Power to be delivered by the TUPSS: $P = 3 \text{ kW}$ (real power) $S_1 = 3.2 \text{ kVA}$ (apparent power for the fundamental wave) $S = 3.75 \text{ kVA}$ (total apparent power including all harmonics) $\cos(\phi) = 0.9$ and power factor = 0.8
Rationale	A TUPSS shall provide at least 50 W per wagon for a 50 consist train segment plus losses in the PDL .

Number of poles for the FDFTO power system of the TUPSS:

The output to the PDL of the TUPSS has two poles to provide the insulated single phase power system.

IPTRANS-765 -Number of poles of the TUPSS power output

Detailed Description	The output of the TUPSS shall be bipolar.
Rationale	Providing a single phase 400 V AC power supply to the PDL.

IPTRANS-8190 -Fire Safety for Components used in traction units

Detailed Description	The design of components, which are used in traction units, shall be compliant to EN 45545.
Rationale	Compliance to fire safety, related standard to be applied, relevant for authorization- The parts EN 45545-1: 2013-03-01 EN 45545-2: 2020+A1:2023 EN 45545-5: + A1: 2015-10-01 are applicable.

IPTRANS-9400 -Overcurrent protection in view of fire safety

Detailed Description	The fusing of the PDL for overcurrent protection shall be applied for both poles. Both poles in circuit breaker shall be coupled.
Rationale	Selective protection in insulated systems.

7.2.3.5 Functional Requirements

In this chapter the functional requirements for the TUPSS are specified. In particular they are:

- the different activation modes of the TUPSS,
- the different deactivation modes of the TUPSS,
- the electrical protection of the TUPSS
- the illustrations on a driver's display.

The implementation of the four TUPSS related functions shall be included into CCU of the traction unit. The following alternative solutions shall be supported:

- It shall be possible to control the TUPSS by the ZSG, when an integrated control approach will be applied (see chapter 7.2.3, option 1).
- It shall be possible to control the TUPSS by the CCU in the traction unit (see chapter 7.2.3, option 2).
- Also, a combination of both solutions above shall be supported
- It shall be possible to control the TUPSS remotely (not in the scope of FP5 Basic State). For this solution, the function "distributed (traction) power" is necessary, which will be developed in /WP5_D5.7/.

IPTRANS-778 -Control activation and deactivation of TUPSS

Detailed Description	The activation and deactivation of the TUPSS shall be carried out only in the feeding traction unit.
Rationale	Functional architecture of the FDFT, definition of the source for the power supply on train level. The power supply shall be carried out - by the legacy vehicle control system or - alternatively by an independent control unit for the FDFTO functions or - a combination of both.

7.2.3.5.1 Activation of the TUPSS

The activation (start) of the TUPSS shall be realized inside the leading traction unit. The activation is triggered by an action of the loco driver or remotely (see below). When the FDFT is initialized, the following preparation steps are carried out by train functions. They are described hereafter.

Preparation:

Before activation of the TUPSS, the following pre-conditions must be checked and fulfilled by the train functions, as preparation steps on train level to enable the power supply into the PDL by closing the selected output switch towards the dedicated e-coupler (end of traction unit). The related train functions are developed in /WP5_D5.1/, which are aligned with the operational procedures in /WP2_D2.1/.

The following pre-conditions to enable the power supply into the PDL are to be checked by the train functions:

- The wake-up procedure of the FDFT has been performed.
- The communication system of the FDFT is initialized and operating.
- The train inauguration has been performed and the train composition is validated successfully.
- The FDFT has been brought in operational mode "train run". In this operational mode the power supply into the PDL is allowed.
- No failure is detected inside the TUPSS.
- No other power source is feeding into the PDL of the same train segment (e.g.: there might be another traction unit or external power supply already connected), as specified in IPTRANS-8854.

IPTRANS-8854 -Power source to feed the PDL

Detailed Description	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.
Rationale	The PDL is fed with 400 V AC. Different power sources are not synchronized in the phase shift and will cause high currents, when they are connected to the PDL, what could lead to damages. In order to identify, if another source is already feeding the PDL, the voltage on train-line shall be measured and evaluated. It shall be 0 V (tolerance range 0 V, ..., 40 V) at the end of the traction unit to be energized. In this case no other source feeds the PDL. The loco-control shall not enable switching on the output

	voltage (400 V AC), when a voltage above 0 V (up to 40 V) is detected. In this case it is identified that another source feeds in the PDL already. The tolerance value 40 V is used already in other locomotives and is proposed here.
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Activation, release of the power supply:

After preparation on train level the activation of the TUPSS shall be possible by the following ways:

- using conventional operating elements in the driver's desk by the loco driver
- using a dedicated DMI in the driver's desk by the loco driver
- remotely controlled from another traction unit (when the TUPSS in the originally chosen traction unit failed). This is not in FP5 Basic State. For this feature, the function "distributed (traction) power" is necessary, which will be developed in /WP5_D5.7/. For neighboured traction units the legacy communication system (18 pole UIC cable) offers a way for information exchange, but the needed interface between the FDFTO system and the existing ZSG of the traction unit is to be developed.
- For FP5 Basic State: For using conventional operating elements in the driver's desk, it shall be ensured that the activation is confirmed by the loco driver. It shall not be activated automatically.
- For Target State: The automatic activation of the TUPSS shall be realized without any action of operational personnel. For this feature, ATO and additional monitoring functions need to be developed by train functions (/WP5_D5.1/). For the wagons and the traction units it shall be ensured that the FDFT is not in a dangerous situation, before supplying power to the PDL.

Additional feature in context with the activation of the TUPSS:

If in operational mode "train run" the TUPSS is not switched on, the loco driver shall be informed about that the TUPSS has not been activated, even though it would be possible. This function shall be specified by /WP5_D5.1/.

IPTRANS-9401 -Advisory feature to activate the TUPSS

Detailed Description	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".
Rationale	It might be possible that the loco driver forgets to activate the TUPSS, even it would be possible to do so. In this case the batteries of the coupled wagons would not be recharged. This is to be avoided and the reason of this feature.

Power conversion in the TUPSS during activation:

Case differentiation for power conversion system employed is needed. A proposal for two concepts for implementation of the power conversion can be found in chapter 10.6 in the appendix.

The CCU of the TU shall support both the following approaches:

For both, transformer and inverter-based solutions:

Step 1: Switch on the AC output contactor, selectively on one of both e-couplers:

IPTRANS-8215 -Interlock of the output contactors of the TUPSS

Detailed Description	Both output contactors shall be interlocked against each other.
Rationale	Only one contactor shall be switched on in the train segment according to the direction of running at the rear end of the traction unit.

Transformer based specific steps:

Step 2: Employ a damping resistor to avoid too high inrush-currents and reflections on the PDL. The actual value of the damping resistor shall be defined in /WP9_D9.1/.

Step 3: Bypass the damping resistor to supply full voltage after some time. The value for the time will be defined in /WP9_D9.1/ and evaluated later in DEMO1-train tests.

Inverter based specific steps:

Step 2: Send the release signal from the control system in the traction unit (ZSG or CCU) to the lower ordinated independent control of the inverter. This triggers the ramp-up of the AC output voltage by the inverter.

Depending on the technical solution, which will be applied by the supplier of the traction unit, the following requirements shall be carried out to start the power conversion and the power supply into the PDL.

The following requirement is applicable to both approaches.

IPTRANS-8212 -Activation, start: Switch on and Ramp-up the supply-voltage

Detailed Description	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:
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	- 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.
Rationale	a) to avoid overvoltage along the PDL and at the inputs of the wagons and b) to limit the output current of the TUPSS (due to probable input capacitances of the (maximum 50) wagon input converters)

Activation by conventional operating element (switch, push button) on the driver's desk:

Activation of the power supply into the PDL shall be enabled by manual operation of a conventional operating element (switch, push button) preferable on the driver's desk (in the same traction unit). This is one of the described methods to activate the TUPSS.

IPTRANS-780 -Release of the TUPSS with conventional operating elements

Detailed Description	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).
Rationale	One of the three ways to activate the TUPSS to supply power to the PDL The other options are the activation with the DMI and the remote control.

Activation by a soft key on a DMI on the driver's desk:

Activation of the power supply into the PDL shall be enabled by manual operation of a soft key on a DMI on the driver's desk (in the same traction unit). This is also one of the described methods to activate the power supply, see above.

IPTRANS-781 -Release of the TUPSS by (soft) key on an existing DMI

Detailed Description	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)
Rationale	One of the three ways to activate the TUPSS to supply power to the PDL The other options are the activation with conventional elements and the remote control.

Activation by a remote control (triggered by another traction unit):

The activation of the TUPSS to supply power to the PDL may be enabled by a remote control (triggered by another traction unit). This related traction unit, whose TUPSS shall be activated, is in the state of a guided or remotely controlled traction unit. Guided and remotely controlled traction units are not the same operational cases, they are to be distinguished in view of the communication system.

Guided traction unit:

A guided traction unit gets the commands from neighboured traction unit.

The commands are transmitted via legacy communication, for example WTB or 18 pole UIC cable between neighboured traction units.

Remotely controlled traction unit:

A remotely controlled traction unit gets the commands via the F-TCN lines. Remotely controlled traction units need not to be neighboured, there can be wagons in between.

The behaviour in view of power supply is very similar, both – the guided and the remotely controlled traction unit - normally do not feed in power to the PDL. Only in case of a non-available TUPSS in the leading traction unit one guided or remotely controlled traction unit in the train composition provides the power supply. That's why this third method of activation of the power supply is needed. If more than one guided or remotely controlled traction unit belong to the train composition, the choice is carried out from the leading traction unit.

As specified before in ~~IPTRANS-8854~~, only one traction unit shall feed the PDL. That's why the choice from the leading traction unit is needed.

IPTRANS-782 -Release TUPSS remotely from another traction unit

Detailed Description	The release of the TUPSS inside the guided or remotely controlled traction unit shall be carried out by triggering from another, leading traction unit.
Rationale	One of the three ways to activate the TUPSS to supply power to the PDL The other options are the activation with conventional elements and the activation with a soft key on the DMI.

Each traction unit in the train segment shall be in the position to receive the command to release the power supply into the PDL from the leading traction unit within the train segment when the functionality "distributed (traction) power" is applicable (/WP5_D5.7/).

IPTRANS-8213 -Remote command to release the power supply in the traction unit

Detailed Description	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.
Rationale	Redundancy for the TUPSS by flexible usage of the TUPSS from another traction unit. This shall also be considered in context with the power management for the whole train segment.

Deactivation of the TUPSS

Deactivation due to normal operation:

The deactivation (shut down) of the TUPSS shall be realized inside the leading traction unit. The deactivation is normally triggered by an action of the loco driver or remotely like the activation. The deactivation shall be supported by the ZSG or the CCU in the traction unit.

The deactivation of the TUPSS shall be possible using, as specified below:

- conventional operating elements in the driver's desk
- a dedicated DMI in the driver's desk
- remote controlled as guided traction unit from another (leading) traction unit. The same applies for a traction unit in the mode "distributed (traction) power system", which will be developed in /WP5_D5.7/.

Deactivation due to failure situation:

The deactivation shall also be triggered, when a failure situation on train level or inside the TUPSS is identified.

Failures on train level, which lead to shut down or not to enable the TUPSS to provide power to the PDL:

- The train integrity is lost.
- A failure is recognized, which can lead to a dangerous situation, (see chapter "7.2.3.5.3 - Electrical protection")

During the train run (with activated TUPSS) the train operational mode is switched to "shunting mode"

IPTRANS-1061 -Behaviour of the TUPSS in case of loss of train integrity or accident

Detailed Description	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.
Rationale	Loss of train integrity may be the result of unintended uncoupling. Likely to be included as a future requirement in TSI.

IPTRANS-9899 -Disconnect power feeding to PDL when change to shunting mode

Detailed Description	The TUPSS shall be stop to provide power to the PDL, when the operation mode of the traction unit changes from operation mode into shunting mode.
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Rationale	In shunting mode no electrical power shall be provided to the PDL to avoid damages of power contacts during coupling/decoupling.
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Power conversion in the TUPSS during deactivation:

Case differentiation for power conversion system employed is needed.

Case 1: Transformer based:

Switch off the AC output contactor (see Figure 27 and Figure 28 in the appendix) in the traction unit. The TUPSS shall be disconnected from the PDL (IPTRANS-8219). See chapter "10.6.1- System approach using a transformer".

Case 2: Inverter based:

Ramp-down the AC output voltage by the inverter and then inhibit the release from ZSG or CCU to the lower ordinated independent control of the inverter (IPTRANS-8219). In case that a protective reaction is needed, the inverter shall be shut down immediately so that the power flow to the PDL is stopped immediately (IPTRANS-1061). See chapter "10.6.2- System approach using an inverter".

IPTRANS-8219 -Deactivation of the TUPSS for normal operation

Detailed Description	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
Rationale	For normal operation ramp down the output voltage to zero to avoid oscillations on the PDL. The ramp down is only valid for the solution inverter, which offers this feature. For the solution transformer only the switch off the output contactor is applicable.

The down slope is an assumed value, which shall be parameterized and validated in DEMO-train test phase.

Deactivation by conventional operating elements (switch, push button) on the driver's desk:

The deactivation of the TUPSS to supply power to the PDL shall be enabled by manual operation of a conventional operating element (switch, push button) preferable on the driver's desk (in the same traction unit).

IPTRANS-785 -Deactivation of the TUPSS with conventional operating elements

Detailed Description	The deactivation of the TUPSS inside the traction unit shall be carried out with conventional operating element (switch, push-
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	button), preferable in the driver's desk (of the same traction unit).
Rationale	One of the three ways to deactivate the TUPSS to supply power to the PDL. The other options are the deactivation with the DMI and by the remote control.

Deactivation by a soft key on a DMI on the driver's desk:

The deactivation of the TUPSS to supply power to the PDL shall be triggered by manual operation of a soft key on a DMI on the driver's desk (in the same traction unit).

IPTRANS-786 -Deactivation of the TUPSS by (soft) key on an existing DMI

Detailed Description	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).
Rationale	One of the three ways to deactivate the TUPSS to supply power to the PDL. The other options are the deactivation with conventional elements and by remote control.

Deactivation by a remote control (triggered by another traction unit):

It shall be possible to deactivate the TUPSS by a remote control (triggered by another traction unit). The traction unit, which TUPSS shall be deactivated, is in the state of a guided or remotely controlled traction unit.

IPTRANS-9402 -Deactivation of the TUPSS remotely from another traction unit

Detailed Description	The deactivation of the TUPSS inside the guided or remotely controlled traction unit shall be carried out by triggering from another, leading traction unit.
Rationale	One of the three ways to deactivate the TUPSS to supply power to the PDL. The other options are the deactivation with conventional elements and the deactivation with a soft key on the DMI.

Electrical protection functions

This chapter contains the electrical functions required for protection of the TUPSS. Traction units, which are not equipped with a TUPSS, are not concerned by the protection functions, which are specified hereafter.

As described in chapter 7.2.2, the PDL shall be protected directly by the TUPSS of the feeding traction unit, because it contains all the related sensors and functions for protection.

The protection function "monitoring of the insulation system" is treated in chapter 7.2.1.2.

The protection function "contact monitoring on vehicles (traction unit and wagon" is treated in chapter 7.2.2.

The FDFT electrical power system shall be protected by the feeding TUPSS against:

- Overvoltage
- Overcurrent (short circuit, overload)

IPTRANS-8222 -Electrical protection functions of the electrical power system for the FDFT

Detailed Description	The FDFT electrical power system shall be protected by the feeding traction unit against: • overvoltage • overcurrent
Rationale	General and generic requirement to prevent overstress and damage in the electrical power system at the train level.

This generic requirement is specified more detailed below in the following subchapters. The electrical protection concept is defined by the aspects for:

- The requirements for the protection functions
- The implementation of the protection functions in the TUPSS

Since the requirements are linked to the TUPSS, which shall be protected, the implementation of the protection functions depends strongly on the method of power conversion, which is chosen by the implementing supplier of the traction unit. Therefore, the two ways for the power conversion are to be distinguished accordingly.

All failures or faults, which have triggered a protection function and a reaction, shall be recorded, and evaluated in a non-volatile event storage system of the control unit (ZSG or CCU) of the traction unit.

IPTRANS-8223 -Recording of occurred failures in the TUPSS

Detailed Description	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.
Rationale	To get knowledge about occurring failures and faults for further evaluation.

Protection against overvoltage

The output voltage of the TUPSS of the feeding traction unit is regulated on a fixed value, as specified in IPTRANS-8206.

The output voltage shall be monitored to prevent damage of connected components in case of overvoltage.

An overvoltage protection in two steps shall be foreseen to increase the availability of the electrical power system, since the reaction for protection results in the interruption of the TUPSS. At the set threshold the protection reaction is triggered, at the reset threshold the protection reaction is stopped.

1st level: Slow protection with a lower trigger threshold, but with longer retardation time to trigger the reaction.

2nd level: Fast protection with a higher trigger threshold, but with immediate reaction (no retardation).

The threshold (set) values, which trigger the reaction for protection are above the regulation bandwidth and according to overvoltage category 2, defined in EN 50124-1.

Slow Protection against overvoltage:

IPTRANS-8224 -Slow protection against overvoltage at output of the TUPSS

Detailed Description	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: $V_{\text{threshold_set}} \geq 460 \text{ V AC (RMS)}$ over retardation time at 5 s Reset failure to stop the trigger protection reaction: $V_{\text{threshold_reset}} \leq 440 \text{ V AC (RMS)}$ over retardation time at 5 s
Rationale	The output voltage is outside the band width for regulation, but still no damage for connected components to expect. 460 V AC explained the output voltage to be 15 % above nominal value for 5 s, 440 V AC explained the output voltage to be at nominal value (+ 10 % tolerance), stable over 5 s.

The parameters are proposed values to be validated with tests on train level.

Fast Protection against overvoltage:

IPTRANS-8192 -Fast protection against overvoltage at output of the TUPSS

Detailed Description	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 $V_{\text{threshold_set}}$ to trigger the protection reaction: $V_{\text{threshold_set}} = 480 \text{ V} * \text{SQRT}(2)$, peak value, immediate reaction Reset failure if output voltage is below the $V_{\text{threshold_reset}}$ to stop the trigger protection reaction: $V_{\text{threshold_reset}} = 440 \text{ V AC (RMS)}$ over retardation time at 5 s
Rationale	Damage for connected components can be the result, immediate interruption of the power supply needed. 480 V * SQRT(2) explained to be output voltage 20 % above nominal value, peak value for reaction immediately, 440 V AC explained to be output voltage at nominal value (including +10 % tolerance), stable over 5 s. The parameters are proposed values to be validated in the FDFT.

Protection against overcurrent

Since the output voltage of the TUPSS is regulated at a fixed value, the output current of the TUPSS depends on the total load.

In case of overload or short-circuits anywhere along the PDL the output current is higher than the nominal value. The overcurrent could lead to (thermal) damage of the PDL and the connected components for the power conversion.

Therefore, the output current shall be monitored to prevent these mentioned damages.

Overcurrent can be the result of overload. In this case the output current is higher than the nominal current over a longer time (so long as overload is applied).

Overcurrent can also be the result of a short-circuit. In this case the output current is much higher than the nominal current. The size of the cable cross-section of the PDL has been chosen according to the safe short-circuit shutoff calculation, to ensure a proper clearing of the short-circuit over the long distance between the end of train and the source (feeding traction unit). See also [IPTRANS-8860](#).

An overcurrent protection in two levels shall be foreseen to react adequately on cases of overload and short-circuits. The reaction for protection results in the disconnection of the output of the TUPSS from the PDL. When the set threshold is reached, the protection mechanism is activated. When the reset threshold is reached the protection mechanism is deactivated.

1st level: Slow protection with a lower trigger threshold, but with longer retardation time to trigger the reaction for cases of overload.

2nd level: Instantaneous overcurrent protection, fast protection with a higher trigger threshold, but with immediate reaction (no retardation).

The threshold (set) values, which trigger the reaction for protection are above the nominal current value in both levels.

Slow protection against overcurrent:

The slow identification of overcurrent shall be executed by measurement of the output current of the TUPSS.

IPTRANS-9893 -Slow protection against overcurrent

Detailed Description	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 $I_{\text{threshold_set}}$ then the trigger protection reaction: $I_{\text{threshold_set}} = 11.3 \text{ A (RMS)}$, retardation time of 10 s If output current is below the $I_{\text{threshold_reset}}$ then stop the trigger protection reaction. $I_{\text{threshold_reset}} = 10.8 \text{ A (RMS)}$, retardation time of 10 s The threshold values and the retardation time shall be parametrizable.
Rationale	Slow protection of the TUPSS to clear overcurrent due to overload, disconnect the TUPSS from the PDL. Hysteresis: $I_{\text{threshold_set}} \geq 1,15 \cdot 1,05 \cdot (3.75 \text{ kVA} / 400 \text{ V}) \text{ A (RMS)}$ $I_{\text{threshold_reset}} \geq 1,15 \cdot 1,0 \cdot (3.75 \text{ kVA} / 400 \text{ V}) \text{ A (RMS)}$ retardation time: 10 s for set and reset 1,15: 15% additional current reserve due to expected higher harmonics in the output current of the TUPSS

The threshold values (trigger, reset) will be validated and finalized during the train tests at the DEMO1-trains, since a representative train length is needed.

Instantaneous protection against overcurrent:

The fast identification of overcurrent shall be executed by measurement of the output current of the TUPSS.

IPTRANS-8855 -Instantaneous protection against overcurrent

Detailed Description	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 $I_{\text{threshold_set}}$ then the trigger protection reaction: $I_{\text{threshold_set}} = 16.8 \text{ A (peak)}$ If output current is below $I_{\text{threshold_reset}}$ then stop the trigger protection reaction: $I_{\text{threshold_reset}} = 10.8 \text{ A (RMS)}$, retardation time 10 s The threshold values and retardation time shall be parametrizable.
Rationale	Fast protection of the TUPSS to clear short circuit failures, shut off the TUPSS. Hysteresis: $I_{\text{threshold_set}} \geq 1,15 \cdot 1,1 \cdot \text{SQRT}(2) \cdot (3.75 \text{ kVA} / 400 \text{ V}) \text{ A (peak)}$ $I_{\text{threshold_reset}} \geq 1,15 \cdot 1,0 \cdot (3.75 \text{ kVA} / 400 \text{ V}) \text{ A (RMS)}$ retardation time: none for set, immediate reaction for protection shall be applied. 1,15: 15% additional current reserve due to expected higher harmonics in the output current of the TUPSS

Illustrations on Drivers Display (DMI)

The FDFTO related train functions with their illustrations, to be shown on a DMI, are developed in /WP5_D5.1/, Appendix B. In this chapter only the electrical power system relevant information is described. On the DMI three levels are specified to be displayed:

- System level (FDFT)
- Subsystem level (TUPSS)
- Component level

The DMI is the essential control instrument for the driver of the traction unit with following elements:

- Observing the state of the electrical power system, process data and states of the traction units of the FDFT, display upcoming failures and diagnostic data.
- Operating by soft and hard keys for activation, deactivation of the TUPSS.

- Evaluation of messages for power management, failures, and diagnostics.

DM illustrations on system level, FDFT

The DMI illustrations on system level shall provide the operational overview of the train to the driver of the leading traction unit. The FDFT diagnostic messages shall inform about the status of all traction units, wagons and TUPSS in the train segment.

IPTRANS-8220 -Illustrations on the DMI on system level FDFT

Detailed Description	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
Rationale	Information for the loco driver about the operational overview of the FDFT TUPSS on system level.

DMI illustrations on subsystem level, TUPSS

The DMI illustrations subsystem level shall provide the operational overview of the TUPSS to the driver of the leading traction unit. The diagnostic messages on subsystem level shall inform about the status of the TUPSS in the feeding traction unit.

IPTRANS-8211 -Illustrations on the DMI on subsystem level TUPSS

Detailed Description	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
Rationale	Information for the loco driver about the operational overview of the TUPSS subsystem level:

Warning message to the driver of the traction unit:

When the FDFT is in "train run mode" and the TUPSS is not activated, but could be, the driver of the traction unit shall get a warning message in the sense: "Please check the activation of the TUPSS", see also chapter 7.2.3.5.1 and IPTRANS-9401.

DM illustrations on component level, for the TUPSS

The DMI illustrations on component level shall provide the operational overview of the components for the power conversion in the TUPSS to the driver of the leading traction unit. The diagnostic messages on component level shall inform about the status of the activated power components. The displayed content depends strongly on the applied technology for the power conversion and is therefore specified on a quite general level.

IPTRANS-9894 -Illustrations on the DMI on component level for the TUPSS

Detailed Description	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
Rationale	Information for the loco driver about the operational overview of the components of the TUPSS. The process information depends on the implementation of the power conversion in the TUPSS

Diagnostics of the TUPSS in the feeding traction unit

The diagnostics shall be structured into system level (FDFT), subsystem level (TUPSS) and component level. The diagnostics are also part of the train functions, which are developed in /WP5_D5.1/. with support of experts of WP9. The control system for the TUPSS (ZSG or CCU) shall evaluate the measured process data and binary signals for diagnostics.

IPTRANS-8207 -Structure and preparation of the process data for diagnostics

Detailed Description	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.
Rationale	Generation and storage of diagnostic messages according to the level structure (FDFT, TUPSS, components).

IPTRANS-8209 -Illustration of diagnostic messages on the DMI

Detailed Description	The diagnostic messages shall be shown on a dedicated screen on the DMI. Incoming messages shall override the shown messages.
Rationale	Visualisation of event and failures with time stamp and history.

7.2.4 Wagon specific requirements

This chapter specifies the interoperable power system, which shall be integrated in the wagons.

As described in the FDFT system architecture, the wagon power supply system is part of the CCU domain, and the technical implementation is supplier specific. The main task of the wagon power supply system is to supply power to the electrical and electronic wagon components in all FDFT operating modes.

The solutions, which will be developed according to this specification can be realized as a fully integrated wagon power supply including input converter, output converter and energy storage as a wagon power supply system for FDFTO.

Figure 19 shows an example of the wagon power supply system (3) and its interfaces. Interface 1 is the power distribution line that runs through the wagon. Interface 2 is used to establish the connection from the power distribution line to the input of the wagon power supply system by using a tap connection. A tap connection is a branch from the PDL to the WPSS for all four power lines.

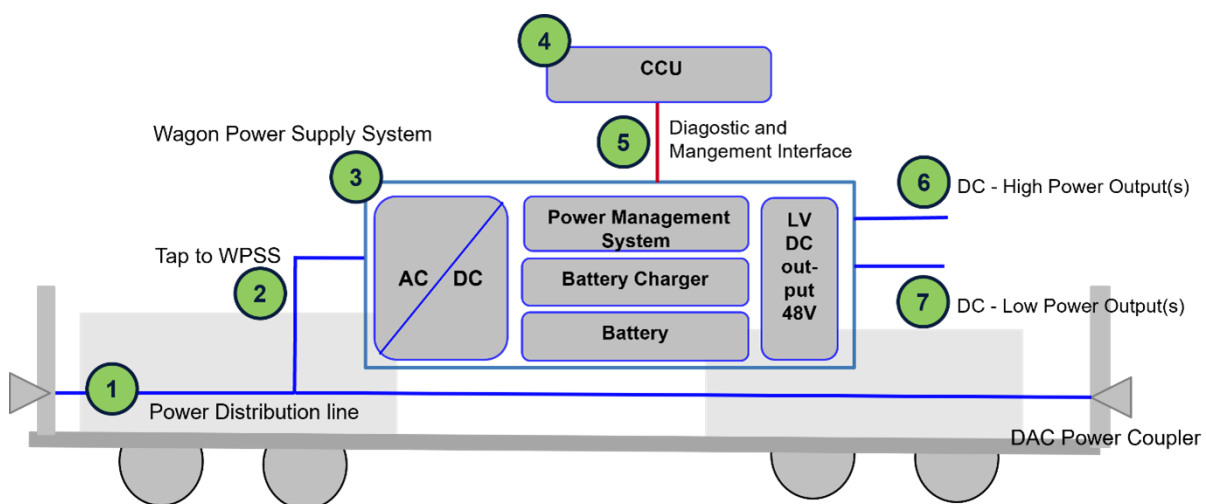


Figure 19: Wagon Power Supply System overview

The consumers on the wagon will be supplied with a low-voltage direct current supply of 48V from the WPSS. This applies to low-power consumers (7) (e.g., control devices, sensors) as well as high-power consumers (6) (e.g., actuators for uncoupling).

Due to power limitation of the Traction Unit Power Supply System the input power for each wagon power supply system is limited, i.e., each WPSS shall limit the power to be

drawn from the power distribution line. This power limit can be changed via a higher-level power management system as a functionality on train level with a new train function (not in scope of FP5 Basic State).

7.2.4.1 General requirements for the Wagon Power Supply System

IPTRANS-8173 -WPSS shall provide power to the wagon on-board equipment

Detailed Description	The WPSS shall provide power for electric and electronic components on freight wagons equipped with a Digital Automatic Coupler (DAC), where the DAC includes an electric coupler and the freight wagons are equipped with a Power Distribution Line (PDL). The WPS converts electric energy from the PDL and makes it available to the wagon on-board equipment.
Rationale	The WPSS converts electric a specified amount of energy from the Power Distribution Line and makes it available to the wagon on-board equipment.

The WPSS shall supply all consumers in a wagon with 48 V DC. In addition to standard consumers (low current requirement < 1 A), this also includes high-current consumers, in particular actuators, which are only operated for a short time (several seconds) but require a lot of current (< 10 A). Since only a limited power is available at the input of the WPSS, the peak power requirement cannot be covered by the power available at the input alone.

Furthermore, the input voltage is not always available (especially in FDFT operating modes outside of train run mode), since the supply from a traction unit is not always active, or a traction unit with a power supply system is not available (Shunting Locomotive).

Both scenarios result in the requirement that an energy storage element is necessary as a "buffer storage for energy" in order to provide the peak power at the output, as well as to provide the supply for consumers in periods without input voltage.

IPTRANS-428 -The WPSS incorporates an energy storage (battery)

Detailed Description	The WPSS incorporates an energy storage (battery) which supplies power for the wagon onboard equipment
Rationale	An energy storage as part of the WPSS will support the supply of on-board equipment to extend peak loads (e.g. driving an actuator) and interruptions from the PDL.

In a train, each vehicle only has a limited amount of input power from the PDL available. Higher-value functions such as train-wide energy management can distribute the available power to the individual vehicles in the best possible way (for further details see chapter "10.7- Power management (scope Target State)" in the Appendix). In order to reduce the complexity of the WPSS with regard to higher-value functions, the WPSS must

communicate its status to the CCU (such as the charge level of the energy storage device). The CCU hosts the higher-value function. A data interface between the CCU and WPSS shall be used for this purpose. The technical implementation is manufacturer specific.

IPTRANS-8186 -WPSS has a data interface for exchanging information

Detailed Description	As an option a data interface of the WPSS to the CCU will be used to exchange diagnostic information and exchange information to/from the leading consist.
Rationale	A data interface shall be provided by the WPSS as option to exchange information like diagnostic data to the CCU. That data interface shall be used to exchange information regarding power management via the CCU to/from the leading consist.

7.2.4.2 technical requirements

This subchapter defines the technical requirements for the wagon power supply system. These requirements are separated in requirements for the 400 V AC power input side and the 48 V DC power output side of the wagon power supply system itself.

Power input from power distribution line

The connection from the power distribution line can be realised directly at the input of the WPSS or also via a tap-off (see Figure 15). For the tap-off option a "power junction box" as described in /WP3_D3.2/ could be installed on each consist, in which the tap-off from both redundant power distribution lines to the power supply system is realised. This tap is a 4-wire connection to the WPSS so that contact monitoring can be installed at/in the WPSS. After contact monitoring, the redundant lines shall be brought together. This can be done in the power supply system itself. See chapter "7.2.2- Power Distribution Line specific requirements" for more information about contact monitoring.

IPTRANS-8200 -Carry out of electromechanical connection (taps) to the PDL with minimal ohmic losses

Detailed Description	Electromechanical connectors and connections on the tap shall designed to ensure that ohmic losses on the PDL will not increase by more than 15 mOhm.
Rationale	Ohmic losses on the PDL shall be minimized as possible by additional elements like connectors or connections.

IPTRANS-8704 -Cable cross section dimension of the tap from the power distribution line

Detailed Description	The cross section for each cable used in the tap shall be the same as used for the Power Distribution Line.
Rationale	By using the same cross section in the tap as for the Power Distribution Line, seperated fuses to protect the wiring in the tap can be avoided.

IPTRANS-513 -Input voltage operation range

Detailed Description	The Wagon Power Supply System shall be capable to operate at least in an input tolerance range of +10% / -14% of the nominal input voltage of 400 V AC.
Rationale	The 50 wagon scenario yields to a calculated value of 384 V at the last wagon. 400 V - 14% is defined as minimum input voltage for components in the power supply network according to EN 50533.

The input power that each wagon draws from the Power Distribution Line must be limited to avoid overloading the power source in the traction unit. More details about changing the limitation of the input power are described in chapter "10.7- Power management (scope Target State)".

IPTRANS-7090 -Default input power limitation

Detailed Description	The default input power limitation defines the maximum allowed power in Watt to consume, for each Wagon Power Supply System attached at a Power Distribution Line in a train segment. The maximum input power limit shall be 50 W / 55 VA.
Rationale	50 W derived from maximum power provided by the TUPSS distributed for the maximum amount of consists in a train segment including losses of the PDL.

To support in an overall system (traction unit feeds power to the PDL, 50 WPSSs takes energy from the PDL) a startup phase, some measures must be taken:

IPTRANS-517 -Inrush current limitation on startup

Detailed Description	The inrush current shall be limited. The maximum inrush current shall be less than 150 % of the nominal current for less than 1 second. The nominal current is 125 mA at 400 V.
Rationale	Limitation of the inrush current enable a stable ramp-up of the system with the maximum number of wagons.

IPTRANS-523 -In case of failure, the wagon energy system shall automatically switch off itself

Detailed Description	In case of failure, the wagon energy system shall automatically switch off itself and reliably interrupt power consumption from the power distribution line. Information about the failure shall be provided via the communication interface.
Rationale	To protect of the WPSS.

Power output

The WPSS will provide 48 V DC nominal for consumers on the consist. The output section will provide an output for high power consumers and an output for low power consumers. These two outputs will be provided to the CCU. The CCU takes care about distribution of the 48 V DC to the dedicated consumers.

IPTRANS-7092 -The Wagon Power Supply System shall provide a low power output

Detailed Description	The Wagon Power Supply System shall provide a low power output with 48 V DC (+/- 10%) and 1 A continuous to supply equipment like a CCU. Protection against short circuit and overload shall be applied.
Rationale	The smaller +/- 10% tolerance band (instead the band defined in the EN 50155) is required for actuator driving with lesser tolerances. For low power output the same tolerances shall be applied as for high power output.

IPTRANS-7091 -The Wagon Power Supply System shall provide a high power output

Detailed Description	The Wagon Power supply system shall provide a high power output with 48 V DC (+/- 10%) and 10 A for an ontime of at least 6 seconds as a single operation. Protection against short circuit and overload shall be applied.
Rationale	The Wagon Power Supply System shall provide a high power output to drive actuators. The ontime is the actuator movement time of 3 seconds + 3 seconds margin. The smaller +/- 10% tolerance band (instead the band defined in the EN 50155) is required for actuator driving with lesser tolerances.

IPTRANS-533 -Negative potential of the high- and low-power outputs of WPSS

Detailed Description	Requirements from chapter 7.2.4 in EN 50155 shall be considered. Wagon chassis shall not be used as conductor for negative potential.
Rationale	Due to EMC the components are connected with two wires (48 V DC, GND) for supply.

7.2.4.3 Diagnostic

Data that contributes to the diagnosis of the wagon power supply system should be made available to a higher-level system (CCU). A CCU can process this data into common diagnostic information and, if necessary, enrich and forward it. The technical implementation of the interface between the wagon power supply system and the CCU is manufacturer specific. The minimum information that shall be made available via this interface is listed in the requirement IPTRANS-526, the source of the information is derived from EDDP inputs.

IPTRANS-526 -Providing diagnostic information

Detailed Description	Upon request, the Wagon Power Supply System shall provide the following information about its diagnostic status by a diagnostic interface to the CCU. Following diagnostic information shall be provided, including but not limited to: - Supply voltage, current and power consumption from the power distribution line (analog or digital low-pass filtered with a time constant of 1 s) - Health status of the wagon power supply system (OK, OK with constraints, not OK) - State of charge (SoC) of battery [%] - State of health (SoH) of battery [% of initial capacity] - Current temperature of the system / the battery
Rationale	Diagnostic information provide forecast for maintenance planning.

7.2.4.4 Wagon onboard energy storage

Regarding fire safety, depending on the battery technology used, the standards for auxiliary batteries IEC 62973-x shall be applied.

IPTRANS-8859 -Auxiliary batteries fire safety

Detailed Description	Depending on the actual chemistry used in auxiliary batteries, fire safety measures shall comply with the related standard: IEC 62973-1, IEC 62973-2, IEC 62973-3, IEC 62973-4, IEC 62973-5.
Rationale	

IPTRANS-538 -Charging of battery shall be possible under all environmental conditions

Detailed Description	Charging of battery shall be possible under all environmental conditions. Environmental conditions shall meet TSI WAG requirements which apply to the wagon equipped with the Wagon Power Supply System.
Rationale	It is not possible to wait for better environment conditions to come.

IPTRANS-8189 -Option: Energy storage charge level visualization for yard personnel

Detailed Description	As an option an visual indication of the charge level of the energy storage unit can be offered. This visualization can be triggered by pressing a button and a LED bar shows the charge level for a few seconds. Both the button and the LED bar must be easily accessible for the yard personnel.
Rationale	Using an on-demand visualization to avoid unnecessary power consumption.

Power budget and energy storage capacity

The wagon on-board energy storage shall be able to supply to the electric components on the wagon, according to different wagon operational scenarios.

The main wagon operational scenarios used to dimension the CCU battery capacity are described below. These scenarios need to be refined based on test results and updates provided by different operational experts.

IPTRANS-7781 -Wagon energy storage

Detailed Description	The Wagon energy storage system (battery) capacity shall be dimensioned able to perform all the operational scenarios described by F IPTRANS-6795 F IPTRANS-6798 F IPTRANS-6811 F IPTRANS-6812
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Rationale	Dimensioning of energy storage needs to be in balance with usage and re-charge capabilities. Too less dimension will not fit to usage, to high dimension will not fit to re-charge capabilities.
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Note and Recommendation for specifying the battery capacitance for an individual wagon:

- Train operation in mainline (400 V AC available on PDL) shall guarantee a minimal battery state of charge (SoC) of 80% before entering the yard
- To save the battery charge, the consist CCU should have a low power mode capability, activated when the consist is not involved in any operation

A low power mode means, that a CCU can control to enable / disable separate functions and equipment to save energy. This feature shall be refined in WP9 and WP10. See chapter 8.2.

Boundary conditions to dimension the battery capacity:

Feature, IPTRANS-6795 -Yard standstill wagon battery usage

Initial nominal condition: Battery SoC is minimum of 80%

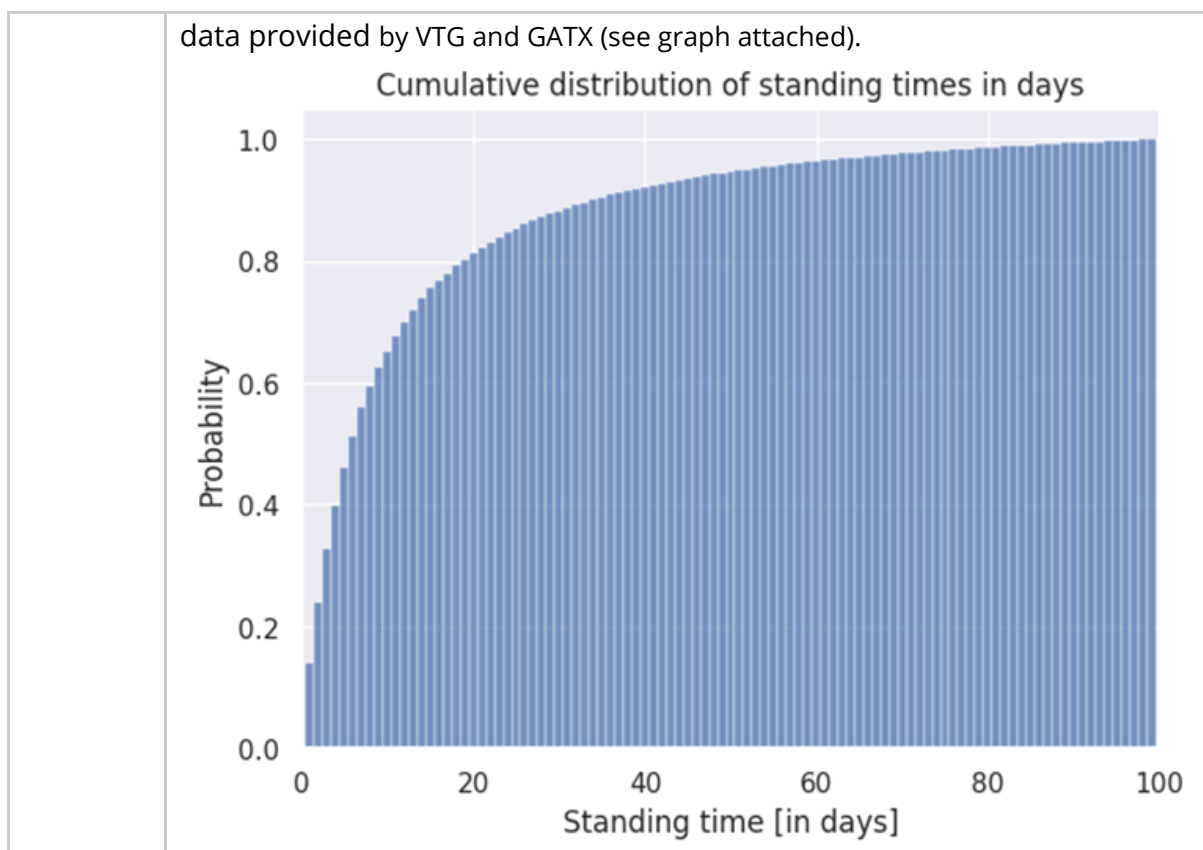
Operational Scenario Steps:

1. 30 days yard wagon standstill with CCU in low power mode

2. Yard operation

- Consist in operational mode powered by battery: 1h
- DAC decoupling action: 1 time
- ABT: 1 time
- If available, Automatic Parking Brake application: 1 time (apply/release)

Rationale	This operation scenario ensures that the wagon battery guarantees a charge for 30 days and then it has enough energy to perform the operations in yards before departure; at the train departure the 400 V AC power will be available to recharge the battery. The assumption for 30 day in standstill is also based on the operational
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Feature,IPTRANS-6798 -yard standstill wagon battery usage#2

Initial nominal condition: battery SoC is minimum of 80%

Operational Scenario Steps:

1. 30 days yard wagon standstill with the CCU in low power mode.

- MCG communication module in low power mode
- MCG wakes-up and CCU status transmitted every 30min

2. Yard operation

- Consist in operational powered by battery: 1h
- DAC decoupling action: 1 time
- ABT: 1 time
- Automatic Parking Brake application: 1 (apply, release)

Rationale	This operational scenario ensures that the wagon battery guarantees a charge for 30 days and then it has enough energy to perform the operations in yards before departure; at the train departure the 400 V AC power will be available to recharge the battery.
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Feature, IPTRANS-6811 -Wagon battery usage in yards

Initial nominal condition: Battery SoC is minimum of 80%

Yard wagon operation scenario:

- Consist in operation powered by battery: 3h (continuous or with consecutive low-power mode and consequently wake-up process)
- DAC decoupling action: 10 times
- If available, Automatic Parking Brake application: 2 times (apply, release)
- Train departure preparation with ABT execution: 1 time

Rationale	The assumption of 3h operational in yard on battery is based on the operational data provided by VTG and GATX.
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Feature, IPTRANS-6812 -train mainline wagon battery usage

Initial nominal condition: Battery SoC is minimum of 80%

Operational Scenario Steps:

1. Train on mainline, running in degraded mode functionality (no 400 V AC power available). Consist in operation powered by battery: 8h
2. Train arrives in yard
3. Yard operation (minimal)

- Consist in Operation powered by battery: 1h
- DAC decoupling action: 1 time
- If available, Automatic Parking Brake application: 1 time (apply, release)

Rationale	The assumption for 8h operational on battery is based on the operational data provided by VTG and GATX.
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7.3 Communication system

This section specifies the interoperable communication system to be provided by freight wagons and traction units. It bases on the physical reference system architecture FDFT as defined in FP5-TRANS4M-R deliverable D3.2.

7.3.1 Description of the SuC

The System under Consideration (SuC) is depicted in Figure 20 (blue parts only) and consists of the following parts shown in Table 3:

Table 3 Communication System parts

F-ETBN	Device interconnecting the F-ETB and the consist network (ECN) and provides services supporting the train wide communication like: • Ethernet communication on F-ETB • Routing IP packets between ECN and F-ETB • F-ETB bypass (in case F-ETBN is out-of-order) • Train network topology discovery (train inauguration) • Train composition detection • Train/consist wakeup function • Passive consist detection • Consist orientation detection Typically, there is one F-ETBN per consist. If this F-ETBN fails, the F-ETB bypass ensures that the F-ETB is not interrupted and that other consists are not affected by the fault. But the local consist will lose contact to other consists in that case. If this is not acceptable, there is the possibility to install a second, redundant F-ETBN (see IEC 61375-2-5 for further details).
F-ETB	Ethernet connection between consists along the train consisting of: • Ethernet cable with two SPE lines (F-ETB lines A and B) • Intermediate connectors and e-coupler contacts The two F-ETB lines A and B will support redundancy. In case of a line failure data traffic is redirected to the other line.
ECN	Ethernet based consist network (ECN) as defined in IEC 61375-3-4, which interconnects consist-local end devices and end systems (Example: Ethernet connection between DAC-CU and CCU).

The doubling of the F-ETB line (F-ETB lines A and B) and the F-ETB bypass supported by the F-ETBN ensure that there is no single point of failure in the communication system.

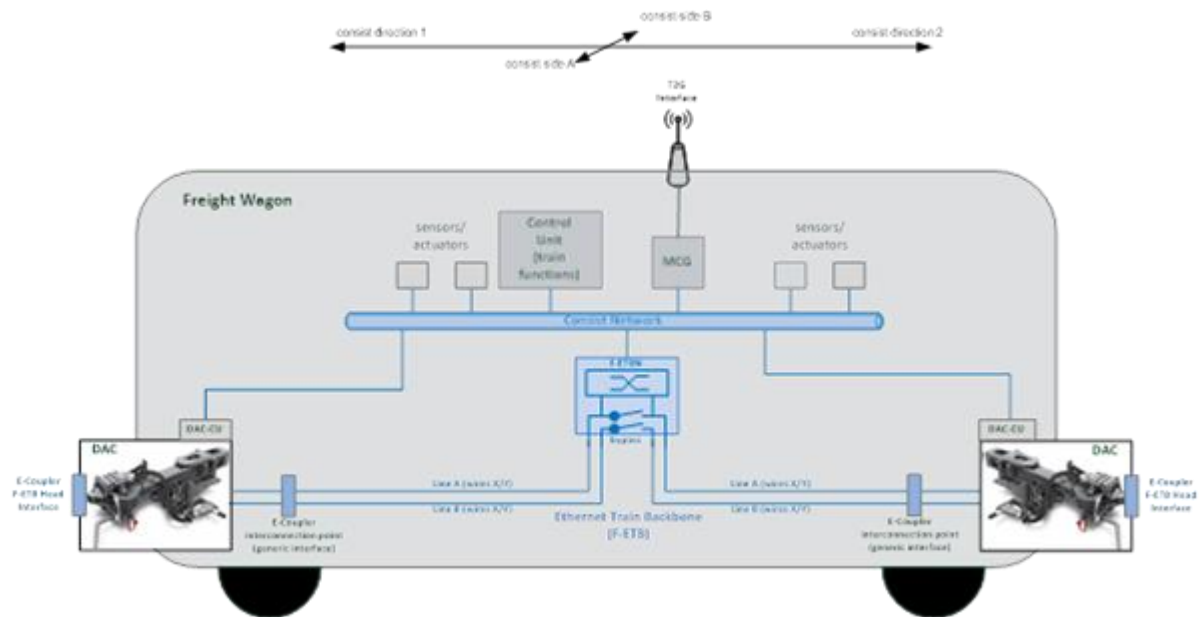


Figure 20: Communication System under Consideration

The Communication System provides two physical interfaces which require standardization to support connectivity and interchangeability:

Table 4 Physical interfaces of the Communication System

E-coupler F-ETB head interface	Defines the F-ETB contact pin arrangement in the e-coupler head and is specified in "Figure 12: Preliminary contact layout of the e-coupler". This interface is important to ensure connectivity between consists.
E-coupler interconnection point	Electro-mechanical interface between the e-coupler and the F-ETBN. This interface allows an e-coupler replacement without affecting the consist internal F-ETB cabling. The interface specification is subject of this document.

Not in scope of the communication system as defined with the SuC are:

- End devices and end systems themselves with their related functions and applications.
- Train to Ground communication

7.3.2 General constrains

7.3.2.1 Quantities

Quantities define the limits of the SuC.

IPTRANS-330 -Supported train compositions

Detailed Description	F-TCN shall support train compositions from 1 of up to 104 consists.
Rationale	Corresponding to 104 freight vehicles (100 freight wagons + 4 freight locomotives),

IPTRANS-331 -Max number of vehicles per consist

Detailed Description	F-TCN shall support from 1 to 32 vehicles (Loco or wagon) per consist, but not more than 104 vehicles per train in total.
Rationale	There can be consists with multiple vehicles.

IPTRANS-332 -Max number of ETBN

Detailed Description	In F-TCN, the maximum number of ETBN connected to the ETB shall not exceed 127.
Rationale	There is typically 1 F-ETBN per freight wagon and per traction unit, but some vehicles like traction units could be equipped with 2 ETBN for redundancy reasons. Hence, the number of F-ETBN may be greater than the number of vehicles. It is limited to max. 127, because only 7 bits are available in the address section of the TRDP as defined by IEC 61375-2-3.

IPTRANS-333 -Number of subsystems within a consist

Detailed Description	F-TCN shall support from 0 to 8 train-wide communicating subsystems (end devices or end systems) within a consist.
Rationale	Train wide communicating subsystems (network end devices) are those which are directly addressable from other consists. This number must be restricted in order to limit the size of the TTDB-CSTINFO (IEC 61375-2-3). There may be additional subsystems which communicate only within the local consist network. This number is not limited.

7.3.3 Interface specification

This section specifies all generic interfaces of the SuC. Generic interfaces are:

- F-ETB Interface: F-ETBN interface to the ETB medium
- E-coupler interconnection point: interface of e-coupler to the F-ETB cable
- ECN Interface: interface between ECN and subsystems (network end devices)

7.3.3.1 F-ETB interface

The ETB interface interconnects logically the consists of a train. For consist interoperability, mechanical detachability, electrical connectivity and data communication connectivity have to be ensured. Data connectivity is specified with IEC61375-2-5 and IEC61375-2-3 for the communication layers (lower OSI layers). Application data itself are specified with freight train specific application profiles. Only the specification of the communication layers is in F-TCN scope.

Ethernet ports

ETB ports

This section specifies physical layer properties of the ETB SPE ports.

IPTRANS-341 -10BASE-T1L support

Detailed Description	F-TCN shall support 10BASE-T1L as specified in [IEEE802.3cg] on ETB trunk ports.
Rationale	Single Pair Ethernet (10BASE-T1L) has been selected as communication technology for FDFT.

IPTRANS-342 -SPE voltage configuration

Detailed Description	F-TCN shall support the configuration of 1.0 Vpp or 2.4 Vpp operating mode of 10BASE-T1L. By default, F-TCN shall be configured for 2.4 Vpp.
Rationale	2.4 Vpp supports cable length of up to 1000 m, whereas 1.0 Vpp only 400 m. A cable length would be near to the required minimum of 360 m, allowing very low tolerances. See IPTRANS-348 for better rationale.

IPTRANS-343 -Autonegotiation

Detailed Description	F-TCN shall support the configuration of autonegotiation as specified in [IEEE802.3] clause 98 on ETB ports. By default, autonegotiation shall be disabled.
Rationale	Autonegotiation is used by two F-ETBN communication partners to agree on common link configuration parameters before the Ethernet link itself is established. For F-ETB this is for example used for: • master/slave assignment

	• agreement on voltage level • future upgrades to higher transmission speeds
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IPTRANS-344 -Flow control

Detailed Description	IEEE 802.3x flow control shall be disabled on F-TCN ETB ports.
Rationale	Flow control is problematic as it can lead to frame buffer overflow in Ethernet switches.

F-ETB cable

This section defines Ethernet cable properties for the cable interconnecting the F-ETBN with the DAC e-coupler.

IPTRANS-8280 -ETB cable

Detailed Description	For 10BASE-T1L based F-ETBN to e-Coupler interconnection, TCN Framework shall make use of railway suitable Ethernet cable (4 wires) with the following properties: • shielded • characteristic impedance: 100 Ohm • at least CAT5e in accordance to [IEC11801-1]. • at least AWG20 wire cross section • arranged in a quartet distribution (star quad stranding)
Rationale	Definition of the F-ETB cable. The cable carries both ETB lines A and B (ETB media). Star-quad arrangement mandatory to minimize crosstalk between ETB lines A and B.

Cabling system

This section contains requirements for the ETB cabling system inside the consist. The cabling system comprises the cables and their arrangements, but also intermediate connectors and couplers, like the DAC e-coupler. An important aspect is the shielding and grounding concept. By defining the cabling system, it is ensured that the quality of data communication between two F-ETBN is not impaired.

IPTRANS-346 -Link aggregation

Detailed Description	To support redundancy, the data transmission medium shall be doubled by providing two ETB lines along the train in an aggregated configuration as defined in [IEC61375-1].
Rationale	Link aggregation means to operate the two links as one logical link, see [IEEE802.1AX].

IPTRANS-347 -F-ETB segmentation

Detailed Description	The F-ETB, interconnecting all F-ETBN along the train, shall be segmented. One F-ETB segment connects two adjacent F-ETBN either directly (in case of F-ETBN redundancy) or over intermediate DAC.
Rationale	SPE (10BASE-T1L) defines point-to-point connections (is a so-called "switched" technology and not a bus). In order to implement the F-ETB, those point-to-point connections, called "F-ETB segments", are put in series. See also IEC 61375-1 for a more detailed definition.

IPTRANS-348 -ETB segment length

Detailed Description	F-ETB shall support ETB segments with a length of at least 400 m.
Rationale	IEEE 802.3cg (SPE) allows a segment length up to 1000m. This length is restricted for F-ETB due to the following reasons: - the many intermediate connectors and contacts (e-coupler contacts, e-coupler interconnection point, F-ETBN connector, F-ETBN bypass relay, ...), as well as the parasitic impedances of DC constant current sink stubs and DC voltage/current measurement stubs, lead to additional signal attenuation and signal distortion which impairs the signal quality - having two F-ETB lines in one 4-wire Ethernet cable may lead to additional crosstalk 400m is approximately the distance between two (active) Ethernet transceivers with 15 intermediate passive wagons - IEC 11801-1 Amendment 1 /30/ defines the cabling parameters for a 400 m segment length (class T1-A-400)

IPTRANS-349 -F-ETB cabling

Detailed Description	One ETB segment shall comply to the requirements set out in ISO/IEC 11801-1 Amendment 1.
Rationale	Define the electrical properties of the cable assembly making up the Ethernet connection between two F-ETBN transceivers. Note that the ISO/IEC 11801-1 Amendment 1 is still in draft status and might be subject to change.

IPTRANS-350 -Frame Error Ratio (FER)

Detailed Description	The Frame Error Ratio (FER) on one Ethernet link shall be lower than 10E-4 under normal conditions.
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Rationale	FER is the ratio of frames received in error to the total count of frames received. Note that IEEE 802.3 defines a bit error rate (BER) of 10E-10.
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IPTRANS-351 -EMC Immunity

Detailed Description	An ETB segment shall conform to [IEC62236-3-2] for EMC immunity referred to rolling stock apparatus. Criteria acceptance type A: during test, Frame Error Ratio (FER) shall be lower than 10E-2.
Rationale	Defined in IEC 61375-2-5 clause 4.1.

IPTRANS-352 -Cable shield grounding

Detailed Description	Inside a consist, all shields of cables and connectors shall be connected to the electrical ground of the wagon. The following conditions apply: - the cable shield shall be directly grounded at the connection to the F-ETBN device - the cable shield shall be directly grounded at the e-coupler interconnection point - Cable shield length between e-coupler interconnection point and e-coupler F-ETB front interface shall not exceed 2 meters.
Rationale	Cable and connector shielding and grounding is essential to reduce electro-magnetic influences on data communication. Direct grounding means to have a galvanic connection to the vehicle frame/carbody with very low impedance.

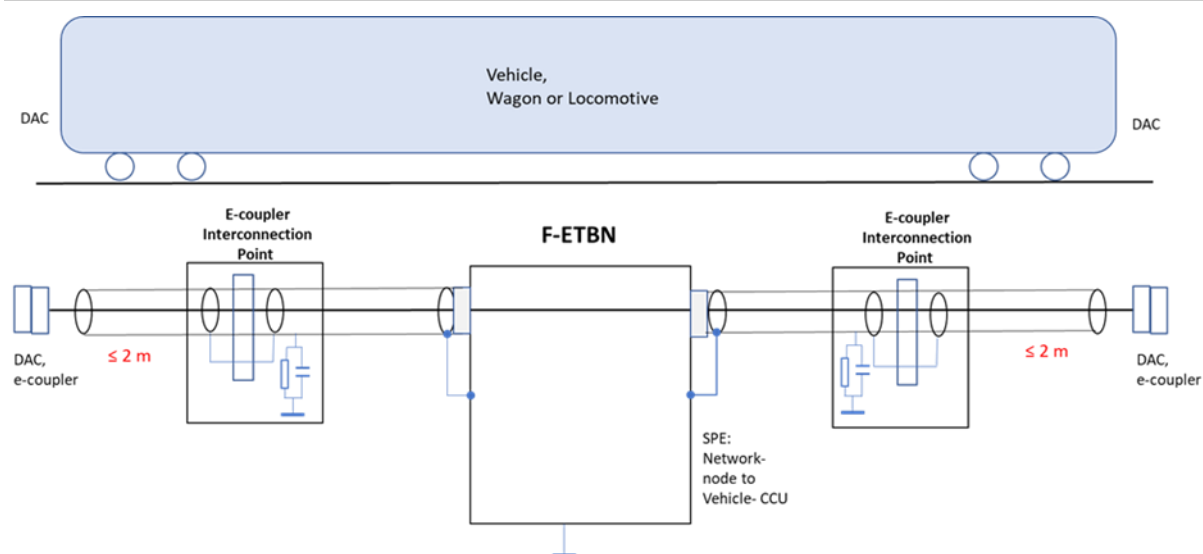


Figure 21: F-ETB grounding concept

IPTRANS-353 -Electrical isolation

Detailed Description	The F-TCN network device Ethernet interface shall withstand an isolation test voltage level of 500 V DC for 1 minute: - cable to cable - cable to shield
Rationale	Insulation resistance in accordance to [EN50155].

7.3.3.2 ECN interface

The ECN interface defines the connection of end devices to the ECN as defined in IEC 61375-3-4. With this interface, connected end devices are able to communicate locally (to end devices in own consist) or remotely (to end devices in other consists) on the base of Internet Protocols.

7.3.3.3 E-coupler interconnection point

The e-coupler interconnection point defines the electro-mechanical interface at the e-coupler to the F-ETB cable connection to the F-ETBN.

IPTRANS-8279 -E-coupler interconnection point

Detailed Description	For interconnecting ETB cable and e-coupler a Quintax (Harting) or compatible connector shall be used. The following contact assignment shall be applied for interconnection at consist direction 1: • Pin 5: ETB Line A wire D+ = E-coupler ETB1X • Pin 6: ETB Line A wire D- = E-coupler ETB1Y • Pin 7: ETB Line B wire D- = E-coupler ETB2X • Pin 8: ETB Line B wire D+ = E-coupler ETB2Y The following contact assignment shall be applied for interconnection at consist direction 2: • Pin 5: ETB Line B wire D+ = E-coupler ETB1X • Pin 6: ETB Line B wire D- = E-coupler ETB1Y • Pin 7: ETB Line A wire D- = E-coupler ETB2X • Pin 8: ETB Line A wire D+ = E-coupler ETB2Y
Rationale	To ensure interchangeability of the e-coupler the electro-mechanical interface between the e-coupler interconnection point and the ETB cable must be defined.

Consist Direction 1	ETB Line A Wire X (DCV+) female	ETB Line A Wire Y (DCV-) male	ETB Line B Wire Y (DCV-) female	ETB Lin B Wire X (DCV+) male
Consist Direction 2	ETB Line B Wire X (DCV+) female	ETB Line B Wire Y (DCV-) male	ETB Line A Wire Y (DCV-) female	ETB Line A Wire X (DCV+) male

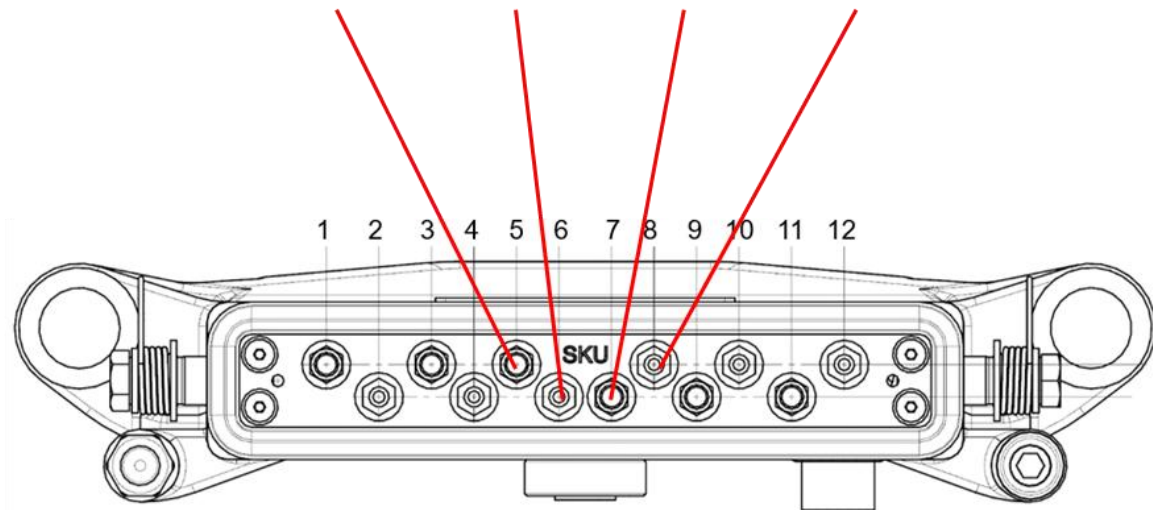


Figure 22: F-ETB PIN Allocation

7.3.4 Functional specification

7.3.4.1 Function "Support Ethernet Communication"

With this function, end devices (ED) and network devices (ND) connected to one Ethernet (V)LAN are able to exchange data with Ethernet frames on OSI Layer 2 as defined in IEEE 802.3 (Ethernet) and IEEE 802.1Q (bridging).

NOTE:For data exchange between different (V)LANs an OSI Layer 3 protocol is needed which for F-TCN will be the Internet Protocol (IP), see chapter 7.3.4.4.

Addressing

IPTRANS-360 -MAC Address

Detailed Description	In F-TCN, all sources and sinks of Ethernet frames shall be identified by a world-wide unique MAC address as specified in [IEEE802.1Q].
Rationale	Ethernet switches forwarding Ethernet frames are no sources or sinks of Ethernet frames. However, the CPU within managed switches can be source and sink of Ethernet frames and therefore receives at least one MAC address.

Frame relaying and filtering /bridging

IPTRANS-361 -Frame relaying

Detailed Description	Within its physical LANs, F-TCN shall relay Ethernet frames as defined in [IEEE802.1Q] to support the Ethernet frame transmission ED-ED, ED-ND and ND-ND.
Rationale	This gives the maximal throughput in data communication.

IPTRANS-363 -Congestion control

Detailed Description	An F-TCN output port that is congested or slow shall never affect the transmission of Ethernet frames to uncongested ports.
Rationale	Reasons for congestions can be: • traffic peak • different transmission speeds. F-TCN supports Ethernet connections of different transmission speed, like 10 MBit/s on F-ETB and 100 MBit/s on ECN or other 10 MBit/s connections on ECN. This potentially can lead to congestions on an Ethernet ports. This feature is normally automatically supported when using up-to-date switch core ICs.

Link redundancy

IPTRANS-364 -Link Aggregation

Detailed Description	F-TCN shall aggregate the ETB trunk links with dynamic configuration as specified in [IEEE802.1AX].
Rationale	Link aggregation means to operate the two ETB links as one logical link. In case both ETB links are operational, Ethernet frames are distributed on both links. In case one of the links fails, Ethernet frames originally allocated to the failed link are automatically redirected to the other intact link. Link aggregation is handled on ISO layer 2 and fully supported by the Ethernet switch-core hardware.

Virtual LAN

IPTRANS-366 -Port based VLAN.

Detailed Description	The F-TCN shall support the configuration of port based VLAN.
Rationale	Port based VLANs are helpful in some special cases, like for instance to ensure cyber security for a maintenance Ethernet port which can be used to connect service devices.

IPTRANS-367 -802.1Q VLAN

Detailed Description	F-TCN ED and ND ports shall be configurable to support 802.1Q VLANs in accordance to [IEEE802.1Q], meaning that an ingressing Ethernet frame with a valid Ethernet tag shall be allocated to the VLAN identified by the VID (VLAN Identifier) in the Ethernet tag.
Rationale	VLAN tagging ingress policy

IPTRANS-368 -Default VLAN

Detailed Description	F-TCN shall support the configuration of a default VLAN on ED ports configured for 802.1Q VLAN.
Rationale	Default VLAN is used in some cases, see below.

IPTRANS-369 -Untagged Ethernet frame

Detailed Description	On ED ports configured for 802.1Q VLAN, an ingressing, untagged Ethernet frame shall be allocated to the default VLAN associated to the Ethernet port.
Rationale	This requirement rules the case that an untagged Ethernet frame is received. Consequence is that a default VLAN must be configured.

IPTRANS-370 -Discarding unspecified VID

Detailed Description	On ED ports configured for 802.1Q VLAN, an ingressing tagged Ethernet frame with VID = 0 shall be discarded.
Rationale	For cyber security

IPTRANS-371 -Discarding invalid VID

Detailed Description	An ingressing tagged Ethernet frame with invalid VID shall be discarded on an 802.1Q configured Ethernet port.
Rationale	For cyber security reasons

IPTRANS-372 -Frame tagging configuration

Detailed Description	Ethernet frame untagging/tagging during port egress as defined in [IEEE802.3] clause 3.5 and [IEEE802.1Q] (VLAN) shall be configurable for all ED ports, especially: i) Frames shall always egress untagged. ii) Frames shall always egress tagged. If the frame was untagged at ingress, it shall be tagged with the default VID. iii) Frames shall egress unmodified. If the frame was untagged at ingress, it shall egress untagged. If the frame was tagged at ingress, it shall egress tagged with the original VID.
Rationale	Define configuration options

Frame priority

IPTRANS-373 -Default port priority configuration

Detailed Description	F-TCN shall support the configuration of a default port priority (Prio 0 ... 7) which determines the priority for the frame forwarding of ingressing Ethernet frames in case none of the configuration settings underneath applies.
Rationale	Define configuration options.

IPTRANS-374 -Port priority configuration

Detailed Description	The F-TCN shall support the configuration of port priority which determines the priority for the frame forwarding of ingressing Ethernet frames by a static setting (Prio 0 ... 7).
Rationale	Define configuration options.

IPTRANS-375 -VLAN tag priority configuration

Detailed Description	F-TCN shall support the configuration of VLAN tag priority which determines the priority for the frame forwarding of ingressing Ethernet frames from the 3-bit Priority Code Point (PCP) of the VLAN tag. Following list defines the priorities for devices supporting 8 priority levels and for devices supporting only 4 priority levels:
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	111 = Prio 7 / Prio 3 110 = Prio 6 / Prio 3 101 = Prio 5 / Prio 2 100 = Prio 4 / Prio 2 011 = Prio 3 / Prio 1 010 = Prio 2 / Prio 1 001 = Prio 1 / Prio 0 000 = Prio 0 / Prio 0 NOTE: Prio 0 is the lowest priority
Rationale	Define configuration options.

IPTRANS-376 -IP DSCP priority configuration

Detailed Description	F-TCN shall support the configuration of IP DSCP priority which determines the priority for the frame forwarding from the most significant 3 bits of the 6-bit IP DSCP field. Following list defines the priorities for devices supporting 8 priority levels and for devices supporting only 4 priority levels: 111XXX = Prio 7 / Prio 3 110XXX = Prio 6 / Prio 3 101XXX = Prio 5 / Prio 2 100XXX = Prio 4 / Prio 2 011XXX = Prio 3 / Prio 1 010XXX = Prio 2 / Prio 1 001XXX = Prio 1 / Prio 0 000XXX = Prio 0 / Prio 0
Rationale	Define configuration options.

IPTRANS-377 -Ethernet frame priorities

Detailed Description	F-TCN shall support at least 4 Ethernet frame priorities. The priority of a frame shall be determined during frame ingress by (in priority order): 1. Statically assigned port priority 2. Priority information in the Ethernet tag of the MAC header [IEEE802.1Q] for VLAN tagged frames 3. Priority given in the IP header (DSCP/ToS field) of untagged frames
Rationale	Define the handling of received priority information.

IPTRANS-378 -Overriding the priority information

Detailed Description	The F-TCN shall support overriding the priority information within [IEEE802.1Q] VLAN tags of egressing frames with the priority determined during frame ingress.
Rationale	Control of frame priorities.

IPTRANS-379 -Transmission of mixed criticality data

Detailed Description	When transmitting mixed criticality data within the F-TCN, data with lesser criticality should be transmitted with lower priority.
Rationale	This shall avoid that critical operational data frames are dropped by the ND in case of (temporary) overload situations

Proposed usage of priorities (source: IEC 61375-2-5):

Table 5 Proposed usage of priority for Data Classes

Data Class	Priority (8 levels)	Priority (4 levels)	Remarks
Supervisory data	7	3	Used for network control, not used for network management. EXAMPLE: train inauguration protocol, spanning tree protocols or redundancy protocols.
Time critical process data	6	3	Process data of low volume requiring low latency and low frame loss in case of network overload situations
Ordinary process data	5	2	
Time critical stream data	4	2	EXAMPLE: cab radio, audio stream
Message Data	3	1	Sporadic data for control and management
Preferred stream data	2	1	EXAMPLE: rear view camera
Broadband stream data	1	0	EXAMPLE: CCTV
Best effort	0	0	
7/3 = highest priority, 0 = lowest priority			

NOTE: This classification corresponds to the classification made in UNISIG SUBSET-147. For each priority, a separated forwarding queue shall be supported, meaning that a minimum of 4 (4 priority levels) or 8 (8 priority levels) queues per IEEE 802.3 Bridge Port shall be provided.

Traffic shaping/policing

This function is currently not requested.

IGMP snooping

IPTRANS-380 -IGMP Snooping

Detailed Description	The F-TCN shall optimize the forwarding of IP Multicast frames by implementing IGMP snooping in accordance to [RFC4541].
Rationale	To avoid overload of ND and ED.

Port network access control (PNAC)

This function is currently not requested.

Need of this function depends on the cyber security concept. Can be used for ED authentication and for consist-to-consist authentication.

Port mirroring

IPTRANS-381 -F-ETBN monitoring port

Detailed Description	F-TCN should support the configuration of a monitoring F-ETBN switch port for mirroring ingress and/or egress Ethernet frames from at least one switch source port to the switch monitoring port. Following configuration modes should be supported: i) permanently and automatically enabled by static preconfiguration (enabled automatically after reboot) ii) temporarily enabled via the local service interface (disabled automatically after reboot).
Rationale	Useful function for: - network diagnostics - cyber security: network intrusion detection systems

Frame pre-emption

This function is currently not requested.

7.3.4.2 Function "Support ETB Bypass"

The ETB bypass is used to bypass an F-ETBN in case the F-ETBN is passive (e.g., defective or powerless).

The schematics of the bypass function is shown in Figure 23. If the consist/F-ETBN is powerless or out-of-order, all relays 1A/1B/2A/2B are (automatically) switched to bypass (rest position of monostable relay).

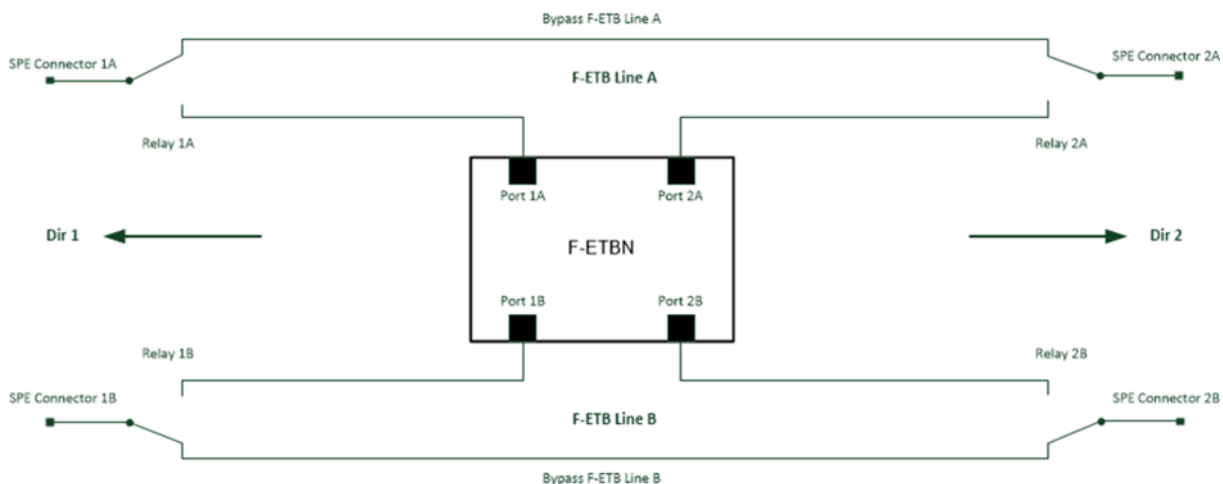


Figure 23: Bypass function schematics

IPTRANS-383 -Bypass function

Detailed Description	F-ETBN devices of the F-TCN shall provide a bypass function which supports the following connectivities: 1. connect/disconnect F-ETB line A Dir 1 to/from bypass line A 2. connect/disconnect F-ETB line B Dir 1 to/from bypass line B 3. connect/disconnect F-ETB line A Dir 2 to/from bypass line A 4. connect/disconnect F-ETB line B Dir 2 to/from bypass line B
Rationale	Bypass definition.

IPTRANS-384 -Bypass operation

Detailed Description	F-ETBN devices of the F-TCN shall bypass the F-ETBN on both F-ETB lines to continue the F-ETB lines if the F-ETBN is out-of-order, e.g., powerless or reset.
Rationale	To avoid a single fault compromising the F-ETB communication.

IPTRANS-385 -Bypass deactivation

Detailed Description	F-ETBN management shall deactivate bypassing only after a wake-up request.
Rationale	Bypass is only deactivated after an (active) wake-up request. Unsolicited deactivation of the bypass as for example during train operation may lead to a temporary communication loss and must therefore be avoided.

IPTRANS-386 -Bypass control

Detailed Description	The bypass function shall be controllable by the F-ETBN management for enabling/disabling bypass.
Rationale	F-ETBN management should have the possibility to actively control the bypass function. Activating bypass is automatically done when a F-ETBN gets out-of-order, but it should also be possible to activate the bypass on F-ETBN management demand. Deactivating bypass is always solely done by F-ETBN management in a controlled manner, e.g. when the F-ETBN has been woken up.

IPTRANS-387 -Stuck bypass relay

Detailed Description	If one of the bypass switches inside the wagon cannot be switched from bypassing state to normal operation state then the F-ETBN shall disconnect itself from both F-ETB lines.
Rationale	One bypass relay stuck in bypassing state while the other bypass relay is in operational mode is a severe fault impacting the F-ETB inauguration and normal F-ETB communication.

7.3.4.3 Function "Train Network Topology discovery"

The function "Train Network Topology Discovery" is that part of the train inauguration which discovers the train network topology. The Train Network Topology Discovery is specified in IEC 61375-2-5 (called "ETB inauguration"). The train inauguration protocol defined in this standard works as follows: neighbourhood of F-ETBNs is discovered by exchange of HELLO frames between adjacent F-ETBNs, and the discovery result, together with the information of the consist the F-ETBN belongs to (identified by the cstUUID value), is communicated to all other F-ETBN with TOPOLOGY frames. Each F-ETBN, after having received TOPOLOGY frames from all (active) F-ETBN, is able to determine the sequence and orientation of all F-ETBN and related consists along the ETB. This information is stored in the Train Network Directory (TND) and is constantly kept up to date. With this information, F-ETBNs are able to configure their IP routes for application data exchange between ECN and ETB. After the Train Network Topology Discovery, train wide communication based on IP (and IP addresses) is possible.

Consist identification

IPTRANS-389 -Consist identification

Detailed Description	To support the train inauguration in F-TCN, each consist shall be identified by a unique 128 bit consist identification number ("CstUUID") compliant to RFC4122.
Rationale	Train inauguration requires a worldwide unique consist identification.

Train inauguration protocol

IPTRANS-390 -Train Network Directory computation

Detailed Description	F-TCN shall discover the actual ETB topology and generate a Train Network Directory as defined in [IEC61375-2-5]. This means in particular: - determine the physical (sequence of ETBN) and logical (sequence of consist subnets) topology by implementing the TTDP and assigning network addresses to ECN subnets and ETBN - compute the Train Network Directory - support late insertion
Rationale	The Train Network Directory contains the information from the F-ETB inauguration.

IPTRANS-391 -IP routing

Detailed Description	F-TCN shall support the routing of IP datagrams between ECN and ETB as defined in [IEC61375-2-5]. In particular it needs to be observed: - routing of unicast IP datagrams following the network IP
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	address map as defined in [IEC61375-2-5]. R-NAT as defined in [IEC61375-3-4] shall be applied to translate between consist local IP addresses and train-wide IP addresses. - routing of multicast IP datagrams (of known/preconfigured IP MC groups) in accordance to [IEC61375-2-5] and [IEC61375-2-3]. R-NAT as defined in [IEC61375-3-4] shall be applied to translate between consist local IP addresses and train-wide IP addresses.
Rationale	F-TCN has to update the ETBN internal IP routing tables after each ETB topology change (physical or logical).

7.3.4.4 Function "Support IP communication"

The function "support IP communication" shall ensure that end devices and network devices connected to F-TCN are able to exchange data using protocols which are based on IP as defined in RFC791. IP based protocols, which are important for the F-TCN, are the transport layer protocols UDP and TCP, the redundancy protocol VRRP, the group management protocol IGMP and application layer protocols like NTP, DHCP and TRDP. Also, DNS, which is used to resolve 'names' to IP addresses, is itself based on IP. This section defines all that what is needed for IP communication, starting with addressing of IP datagrams, the protocol itself, and routing of IP datagrams between different (V)LANs. For data transfer within the different (V)LANs, IP datagrams are encapsulated in Ethernet frames. Furthermore, the transport layer with its protocols UDP and TCP is specified.

Addressing

IPTRANS-393 -IP address

Detailed Description	In the F-TCN, all ED, which are connected to the F-TCN and use train wide communication (sender/receiver), and all managed ND, shall be identified by at least one IP address out of the IP address range 10.0.0.0/18. This address shall be unique within a consist.
Rationale	i)[IEC61375-2-5] defines an IP address range of 10.0.0.0/9 for the consist network. But for ED which shall be addressable train wide over ETB, an IP address out of the range 10.0.0.0/18 must be selected. ii) Redundant ED using VRRP may have a physical IP address each and a shared virtual IP address. iii) ED with connections to different (V)LANs will have an IP address for each (V)LAN.

IPTRANS-394 -IP addressing scheme

Detailed Description	The F-TCN shall implement the mandatory parts of the IP addressing scheme for the train subnet as defined in [IEC61375-2-5] clauses 6.4 and 6.5.
Rationale	These addresses are used for train-wide communication.

IP address resolution

IPTRANS-395 -ARP support

Detailed Description	The F-TCN shall support ARP as defined in [RFC826] for resolving IP addresses to MAC addresses.
Rationale	In F-TCN context used for addressing network devices, meaning that network devices have to respond to an ARP request if their address is queried.

Data exchange

IPTRANS-396 -IP data exchange between ED

Detailed Description	The F-TCN shall support Internet Protocol (IP) Version 4 (IPv4) as defined in [RFC791] for the exchange of data by means of IP datagrams between the ED, connected to the network, in particular: - communication between ED located in the same consist - communication between ED located in different consists
Rationale	This is a high level requirement defining the overall purpose of the TCN Framework

IPTRANS-397 -IP data exchange between ED and ND

Detailed Description	The F-TCN shall support Internet Protocol (IP) Version 4 (IPv4) as defined in [RFC791] for the exchange of IP datagrams between ED and ND and between ND itself.
Rationale	This is relevant for the communication with hosts residing on network devices and providing services to ED.

IPTRANS-398 -Maximal IP datagram size

Detailed Description	The F-TCN shall support the maximal IP datagram size of 64 KByte (65535 octets). For IP datagrams larger than the MTU of the used network technology, IP fragmentation shall be applied.
Rationale	This is the maximum defined size for IP datagrams. All devices must be able to receive those datagrams.

IPTRANS-399 -IP datagram initialization

Detailed Description	F-TCN network devices generating IP datagrams to be sent on ECN or ETB shall ensure that no IP datagrams are transmitted before the payload of the IP datagrams have been initialized.
Rationale	To avoid sending IP datagrams with invalid content. Only related to the originators of telegrams. Devices which only pass through datagrams like switches and routers are not meant.

IPTRANS-400 -Unicast IP datagram routing

Detailed Description	To enable data communication between ED/ND connected to different (V)LANs in single- and multi-consist train, the F-ETBN shall support IP-routing of unicast IP datagrams.
Rationale	Send unicast IP datagrams to any other train-wide addressable device. Receive unicast IP datagrams from any other train-wide addressable device.

IPTRANS-401 -Multicast IP datagram routing

Detailed Description	To enable data communication between ED/ND connected to different (V)LANs in single- and multi-consist train, the F-TCN shall support IP-routing of multicast IP datagrams.
Rationale	Send multicast IP datagrams to any other train-wide addressable device. Receive multicast IP datagrams from any other train-wide addressable device.

IPTRANS-402 -IP-routing priority

Detailed Description	The F-TCN shall support priority IP-routing observing the priority given in the IP header (DSCP field , precedence bits).
Rationale	Defines capability of the IP router to observe IP datagram priorities.

7.3.4.5 Function "Support Train Composition Detection"

The function "Support Train Composition Detection" intends to provide information about the actual train composition to end devices application software. A train composition is determined by the following parameters:

- the number of consists (parameter 'NumConsistsInTrain')
- the sequence number of each consist in the train (parameter "TrnCstNo")
- the orientation of each consist in the train with respect to the train reference direction (parameter 'Orientation')
- the consists static properties (id, owner, type, supported functions, ...)
- the consists dynamic properties (e.g., "leading")

The actual train composition information is kept in an internal database, where it can be retrieved from users by using respective interface protocols.

The train inauguration function, which is responsible to determine the train composition, can be split into three sub-functions, which are related to the computation of the TTDB and the notification of a train topology change. These three functions are:

- ETB inauguration (as specified in IEC 61375-2-5)
- Train directory computation (as specified in IEC 61375-2-3)
- operational train directory computation (as specified in IEC 61375-2-3)

ETB inauguration was subject of subchapter "7.3.4.3.2-Train inauguration protocol", while the (operational) train directory computation is subject of this section.

More specific, the information about the actual train composition is provided by the train directory computation function as specified in IEC 61375-2-3 in two different views:

1. The Train Directory (TD) in combination with the consist information (Consist Info List) provides the information about the train length, sequence, orientation and static properties of consists. The TD only changes in case train composition is changed by connecting or removing consists and when train inauguration inhibit as specified in IEC 61375-2-5 is not active.
2. The Operational Train Directory (OTD) adds information about the operational train reference direction which is determined by the position of the leading consist. As this information can change during train service (changing leading cabs), the Operational Train Directory can also change during service.

Both views are implemented with one common database, the Train Topology DataBase (TTDB). Computation of the TTDB is performed by a logical instance called ECSP (ETB Control Service Provider), which uses the TND as computed during train network topology discovery (see IEC 61375-2-5) as base. The distinction between the functions "train network topology discovery" and "train composition detection" has been made in the standards because the functions itself can be allocated to different OSI layers: the "train network topology discovery" function belongs to logical link control and networking (OSI Layers 2 and 3), while the "train composition detection" function is allocated to the application layer (OSI Layer 7).

TTDB computation

IPTRANS-405 -TTDB computation

Detailed Description	F-TCN shall compute and maintain a TTDB in accordance to [IEC61375-2-3]. This involves in particular: - sending CSTINFO datagram after ETB inauguration and on demand - periodic transmission of ETBCTRL datagram - computation of TTDB based on train network directory, CSTINFO and ETBCTRL
Rationale	TTDB contains the result of the train composition discovery.

ETB control functions

ETB control functions are used to control the train composition detection:

- select one consist to be the leading consist (typically the attended driver's cab). The OTD depends on the position of the leading consist.
- Confirm the train composition detection result

- Correct the train composition detection result, e.g., by inserting discovered passive consists (optional)
- Inhibit the automatic computation of a new TD in case of a train composition change. This is to avoid longer communication interruption during train run.

IPTRANS-406 -Leading consist

Detailed Description	F-TCN shall support the function "Leading" as defined in [IEC61375-2-3].
Rationale	To determine the leading consist.

IPTRANS-407 -Inauguration confirmation/correction

Detailed Description	F-TCN shall support the function "Confirmation/Correction" as defined in [IEC61375-2-3].
Rationale	To confirm and correct the train composition.

IPTRANS-408 -Inauguration inhibit

Detailed Description	F-TCN shall support the function "inauguration inhibit" as defined in [IEC61375-2-5].
Rationale	To prevent ETB inauguration and temporary unavailability of ETB communication in critical operational phases, like during the coupling of two trains.

7.3.4.6 Function "End Device IP configuration"

Not defined as this function doesn't affect interoperability. Function is related to DHCP [RFC2131] which automatically configures connected end devices for IP communication. For example, it assigns an IP address to the end device.

7.3.4.7 Function "Support Name Based Addressing"

It is more convenient for applications to use speaking 'names' instead of IP addresses for addressing communications partners. As an example, for World Wide Web (WWW) communication one uses URLs like '<https://polarion.rail-research.europa.eu/>' and not the related IP address. The same can be done for addressing communication partners in trains. Here, IEC 61375-2-3 defines a suitable URI schema.

IPTRANS-410 -DNS service

Detailed Description	F-TCN shall provide a DNS service which resolves TCN Domain names (TCN-URI) to IP addresses as it is specified in [IEC61375-2-3].
Rationale	TCN-URI are used in TRDP communication.

7.3.4.8 Function "Handle Date and Time"

Date and time information is needed for several purposes, as for instance for time stamping of diagnostic messages. It is also important for checking the validity of security certificates.

Time sourcing

The task of the F-TCN is to distribute time information received from a primary NTP server which itself is not in the scope of the F-TCN (NTP server might for example be located in the MCG or the CCU). The expectation is that the primary NTP server uses a high precision and battery buffered local clock together with external time sources for generating a local UTC time for distribution to all NTP clients. The back-up time of the Real Time Clock device and the allowed clock deviation over time (e.g., 20ppm for a duration of one week) is expected to be defined.

Time distribution

IPTRANS-412 -UTC time distribution

Detailed Description	F-TCN shall support the distribution of the UTC time within the consist network via NTP protocol version 4 [RFC5905]. The distributed information shall contain: - Leap indication shall be supported - Leap Indicator = "11" if no trustable time is available - Precision shall be supported - Clock Reference Identifier "XLOC": no external synchronization (local clock only) "XEXT": external synchronization (e.g. GNSS) - Stratum set by NTP time server - low value (typically = 1) if there is external synchronization to clock signal (e.g. GNSS) - high value (>> 1) if there is no external synchronization (low time precision)
Rationale	Distributing date&time information.

IPTRANS-413 -NTP priority

Detailed Description	When transmitting NTP Time Request and NTP Time Reply, F-TCN network devices shall set the Differentiated Services Code Point (DSCP), part of the Differentiated Services (DS) in the IP header, to Expedited Forwarding (101110B), in compliance to [RFC4594].
Rationale	Define the priority for transmission of NTP datagrams.

Availability

IPTRANS-415 -Year 2038 problem

Detailed Description	The F-TCN shall ensure full functionality of its network devices if the UNIX time overruns in year 2038.
Rationale	Computer systems that use time for critical computations may encounter fatal errors if the Y2038 problem is not addressed.

7.3.4.9 Function "Support ETB Control"

This function allows applications to control ETB functionality and to retrieve information about the actual train composition. There are no requirements defined as this function doesn't affect interoperability.

A recommended implementation of the ETB control interface is defined in IEC61375-2-3 Annex E. This control interface supports the following functions:

- Set/reset inauguration inhibit
- Set/reset leading consist
- Sleep request
- Wake-up request
- Train composition correction
- Train composition confirmation
- Passive consist detection request
- TTDB access (read-only)
- DNS access
- Bypass control
- TLV extension of HELLO frame (used for automatic decoupling)
- Switching on/off DC voltage on specific F-ETB link segments to support DC based consist orientation detection

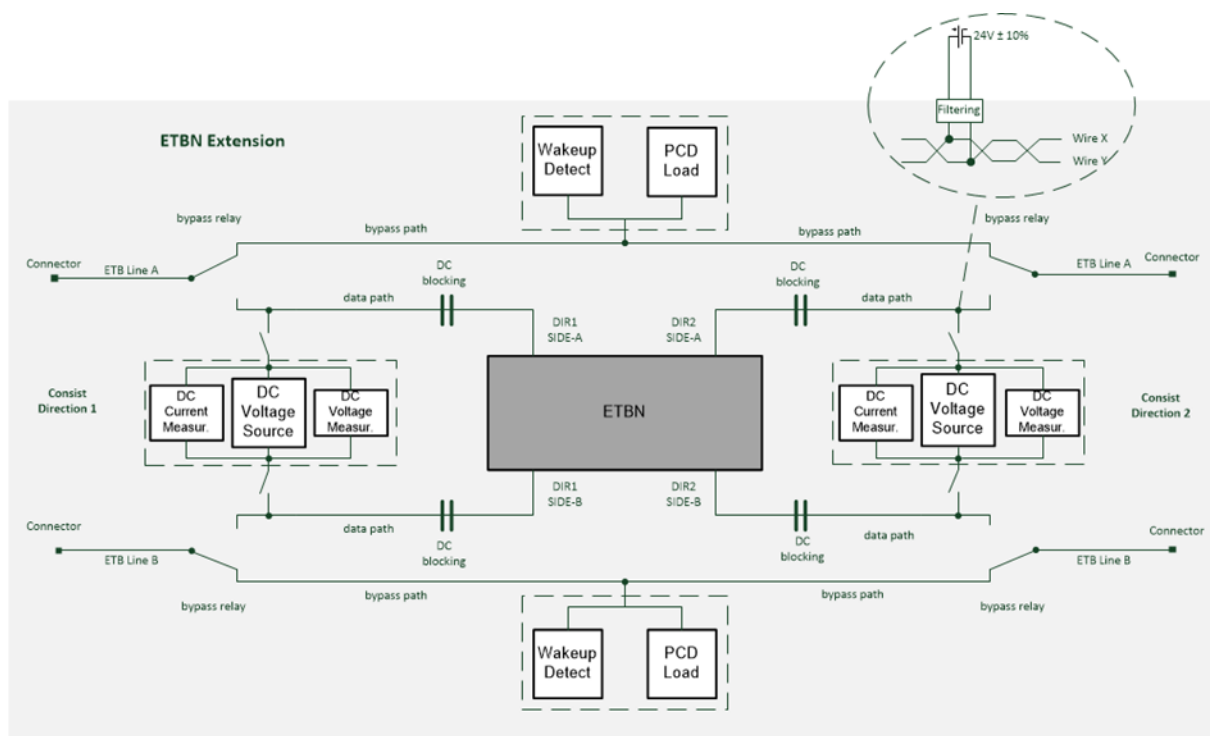


Figure 24: ETBN Extensions

The above general block scheme identifies the parts necessary to implement the new F-ETB functionalities of DAC equipped consists, related to:

- Consist wake-up
- Passive Consist detection
- (Independent) consist orientation detection

used during a train composition from a condition of low power mode.

The involved block diagram parts are:

Table 6 Legend of ETBN extensions

ETBN	Ethernet Train Backbone Node
DC Voltage Source	Voltage source used for wake-up, passive consist detection and independent consist orientation detection
DC Voltage Measurement	Voltage measurement used for independent consist orientation detection
DC Current Measurement	Current measurement used for passive consist detection
Wake-up Detect	Voltage sensor for detecting a wake-up signal
PCD Load	Constant current sink used for passive consist detection (PCD)

See also the description of the wake-up function in IEC 61375-2-3 Edition 2 (2024) CD subclause 6.9 and Annex J.

7.3.4.10 Function "Support Wake-up concept"

Freight wagons without external power supply will enter sleep mode on demand or automatically after a defined time to save battery energy.

For waking a train, a simple mechanism is needed which consumes very little power during the time the wagon is in standby. Such a simple mechanism is to provide a current sensor connected to the F-ETB data line, and to use a DC voltage applied to the F-ETB data line for waking up the freight wagons. To initiate the wake-up, at least one of the consists in the actual train composition, as for example the powered traction unit, has to launch the wake-up process.

The wake-up of a sleeping consist may be triggered also by some event like a pressed local push button or a received radio signal (which however asks for an always active radio receiver).

Rationale:

The DAC wagons wake-up process is implemented over the F-ETB because using this method the wake-up process of a DAC train can be standardized for both yard and mainline operations.

Reference:

The detailed CCU functional block schema related to a single F-ETB (SPE) communication network is described in Figure 25 below.

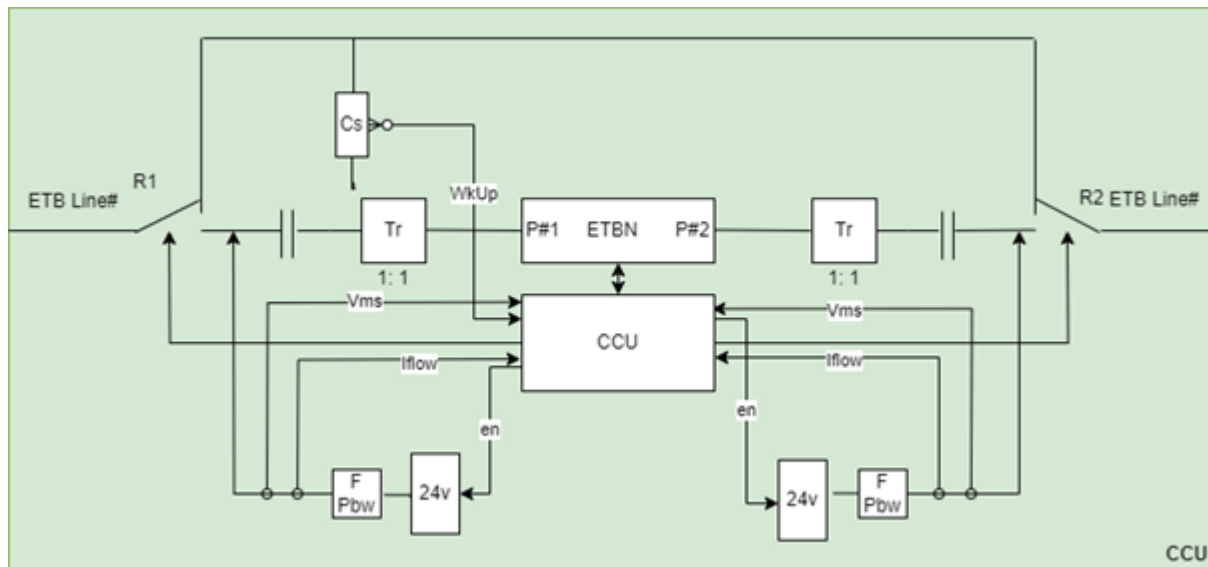


Figure 25: CCU wake-up block schema

Table 7 Legend of the CCU wake-up block schema

R#1/2	F-ETB bypass Relay
Tr (1:1)	F-ETB galvanically isolated Transformer
24v	DC power supply 24 V
FPbw	Band-Pass Filter
Vms	Voltage measurement
Iflow	Current measurement
Cs	Current sense circuit
WkUp	Wake-up signal

IPTRANS-6524 -The consist wake-up shall be based on a 24 V DC signal

Detailed Description	The consists (wagon) wake-up of a DAC train shall be based on a 24 V DC signal.
Rationale	DC voltage can be used in parallel of data communication on the F-ETB lines. 24 V can be simple generated from the 48 V supply of the ETBN.

IPTRANS-6761 -F-ETB wake-up power supply

Detailed Description	A 24 V DC (galvanic isolated) power supply shall be implemented to provide the 24 V wake-up signal: admissible voltage range 24 V +/- 10%
Rationale	24 V DC voltage is preferred solution because it simplifies the voltage generator from CCU supply (48 V).

IPTRANS-6765 -ETB wake-up power supply output current

Detailed Description	The 24 V galvanic isolated power supply shall be able to drive a minimum current of 110 mA.
Rationale	Wake-up shall be possible for 52 vehicles: $52 \times 2 \text{ mA/consist} = 104 \text{ mA} + 6 \text{ mA reserve} = 110 \text{ mA}$ minimum output current.

IPTRANS-6762 -F-ETB wake-up power supply overcurrent protection

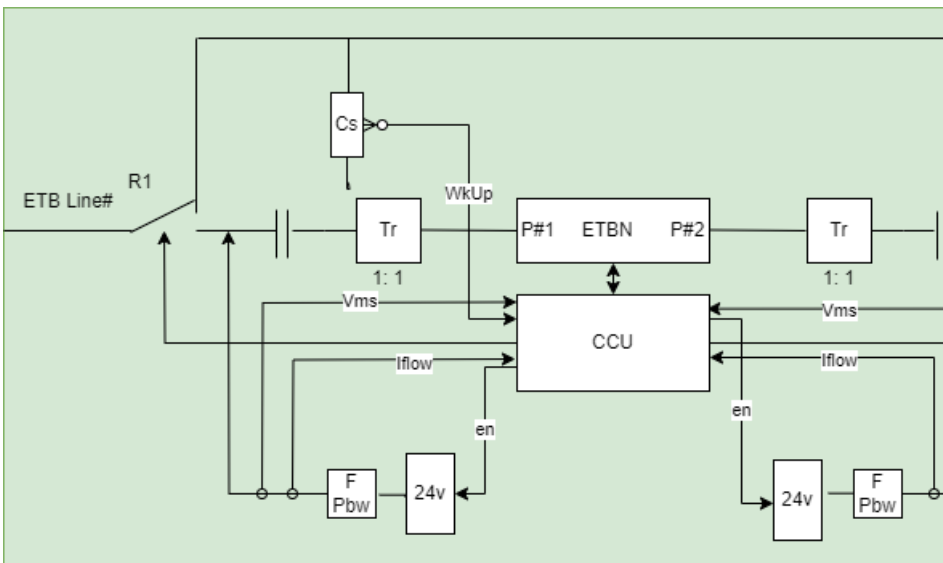
Detailed Description	The wake-up power supply source shall be protected for an overcurrent of 300 mA.
Rationale	Prevent the F-ETB lines from damages.

IPTRANS-6763 -F-ETB wake-up power supply diagnostic

Detailed Description	The information of overcurrent protection active from the F-ETB wake up power supply shall be provided as diagnostic information to the CCU.
Rationale	Diagnostic information, i.e., failure conditions like overcurrent protection active, are required for functions like passive consist detection, to determine, if the result of the function is correct, or cannot be used due to error conditions pending.

IPTRANS-6760 -F-ETB wake-up power supply tap to network lines

Detailed Description	The 24 V galvanically isolated power supply shall be connected to the ETB lines between the F-ETBN port and the by-pass path.
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Rationale	The communication between two active F-ETBNs will remain uninterrupted when a passive consist detection function (based on 24 V DC) is used in parallel.

IPTRANS-6764 -F-ETB wake-up power supply control

Detailed Description	The 24 V galvanic isolated power supply shall be controlled (ON/OFF) by the CCU.
Rationale	Controlling the power supply allows to apply 24 V on the F-ETB lines only if wake-up or other functions are active.

IPTRANS-6766 -ETB wake-up power supply filter to tap

Detailed Description	To protect the SPE communication, in case of 24 V DC still applied on the network line, a Band-Pass filter shall be implemented between the 24 V DC power supply and the SPE net lines.
Rationale	The filter shall ensure that IEEE 802.3cg clause 104.4.6.3 requirements related to ripple and transients are fulfilled.

IPTRANS-6768 -ETB wake-up ETB port protection

Detailed Description	A decoupling capacitor (C) shall be implemented between the SPE isolation transformer and the by-pass relays of the ETBN.
Rationale	The SPE communication ports shall be protected from 24 V DC.

Reference

Referring to the CCU wake-up block schema Figure 25, the DC blocking capacitor (C) should have a value of 100 nF/100 V.

IPTRANS-6769 -ETB wake-up CCU wake-up

Detailed Description	The CCU wake-up input signal shall be triggered from ETB wake-up sources
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Rationale	CCU is the main control system of the wagon, which controls the other devices like the F-ETBN.
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IPTRANS-6770 -ETB wake-up - CS circuit

Detailed Description	In any wagons CCU, a Current Sink (CS) circuit shall be implemented. The output of the Current Sink shall be used to wake-up the CCU processor unit.
Rationale	CCU is the main control system of the wagon, which controls the other devices like the F-ETBN.

IPTRANS-6771 -CCU wake-up input signals

Detailed Description	The CCU wake-up input circuit should be triggered from different further sources (e.g. push-button, radio)
Rationale	CCU is the main control system of the wagon, which controls the other devices like the F-ETBN.

IPTRANS-6772 -CS circuit layout

Detailed Description	The Current Sink (CS) shall be connected to the ETB communication lines in the by-pass.
Rationale	To isolate the CS circuit from the SPE communication when the CCU node is operational: Relay R1 and R2 closed.

IPTRANS-6773 -CS resolution

Detailed Description	The current of the CS circuit shall be 2 mA (nominal) +/- 2%
Rationale	Elaborated in the expert workshops: tolerance sufficient for more than 15 passive consists in a row.

Figure 26 shows a reference design of a Current Sink (CS) circuit supporting the wake-up and passive consist detection functions.

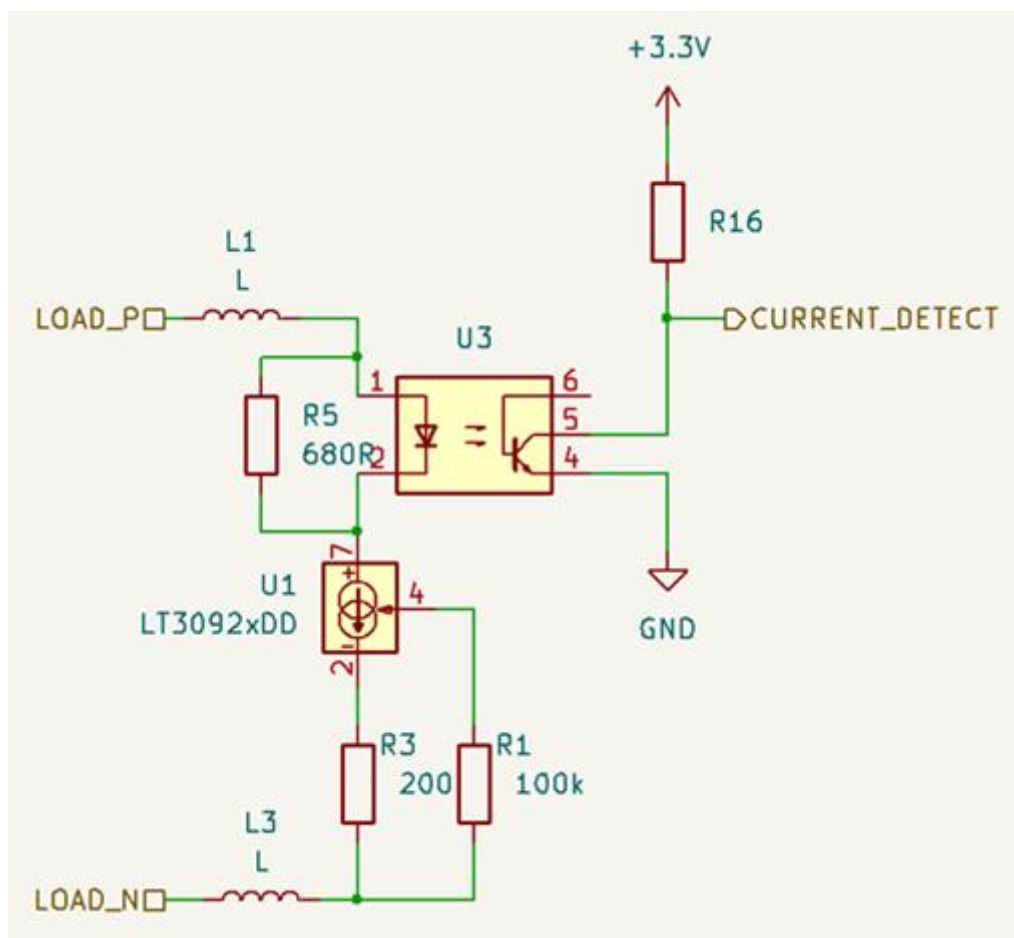


Figure 26 Current Sink (CS) and current detect circuit

IPTRANS-6774 -CS circuit galvanic isolated

Detailed Description	The digital wake-up output signal of the CS shall be galvanic isolated.
Rationale	Galvanic isolation required, to avoid using the F-ETB lines as equipotential compensation.

7.3.4.11 Function "Support Passive Consist Detection"

This function supports safe train inauguration by providing a mean to detect passive consists along the train composition.

In a freight train, the probability of having passive consists (e.g., battery flat) in the train composition is comparably higher than for passenger trains. Therefore, a possibility to detect passive consists is needed in order to achieve a real picture of the train composition.

For detecting passive consists, the DC voltage used for wake-up can be used again. The concept is that each wagon provides a constant current sink. For detecting passive consist between active consists and also at train ends, a DC voltage is applied, and the DC current flow is measured. The higher the current, the more passive consists are there. Due to the

constant current sink in passive wagons, the consumed current per wagon is known, and measuring the overall current allows to deduce the number of passive consists in between two active consists or at train ends.

Once discovered, the confirmation/correction function shall be further defined as part of the FDFTO train functions.

A specification of the PCD function is given in IEC 61375-2-3 Second edition (2024) CD subclause 6.10 and Annex J-.

Rationale:

The DAC wagons passive consist detection process is implemented over the ETBN, because using this approach the function uses the same component/circuits defined for wake-up process.

Reference: See the CCU block scheme of Figure 25.

IPTRANS-6781 -ETB Current Measure (CM)

Detailed Description	In any CCU wagon a Current Measure (CM) circuit shall be designed to implement the DAC wagons passive consist detection process
Rationale	Technical part of passive consist detection solution.

IPTRANS-6782 -ETB CM layout

Detailed Description	The Current Measure (CM) circuit shall be connected to the ETB communication lines at the DC Voltage source.
Rationale	Technical part of passive consist detection solution.

IPTRANS-6783 -ETB PCD Wagon

Detailed Description	The current measurement (CM) shall be implemented with a current-sense circuit able to detect for each passive consist the 2 mA current sink (1 passive consist = 2 mA, 2 passive consists = 4 mA, ..).
Rationale	Technical part of passive consist detection solution.

IPTRANS-6833 -ETB CM resolution

Detailed Description	The precision of the Current Measurement (CM) shall be +/- 2%
Rationale	Elaborated in the expert workshops: tolerance sufficient for more than 15 passive consists in a row.

Reference

The Figure 27 shows a reference design of a current measurement (CM) circuit supporting passive consist detection function.

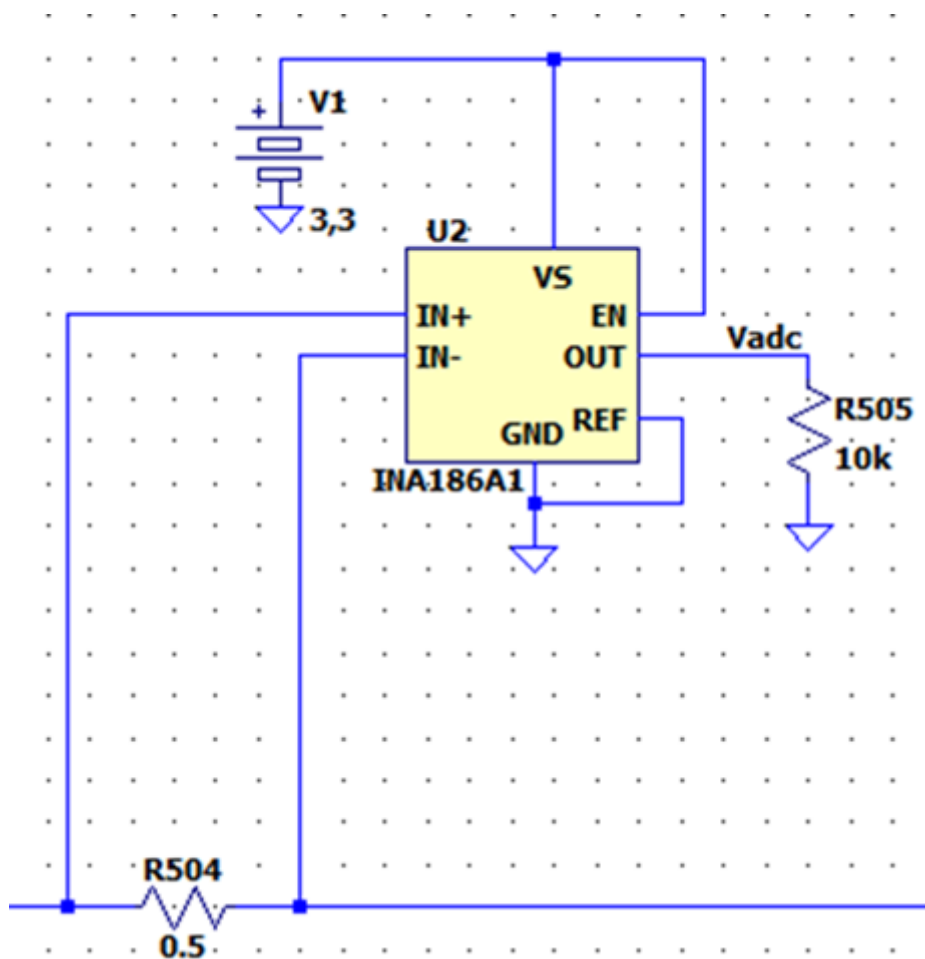


Figure 27: Current Measure Circuit

IPTRANS-8193 -CM circuit galvanic isolated

Detailed Description	The CM circuit connected to the ETB lines shall be galvanically isolated from CCU.
Rationale	Galvanic isolation required, to avoid using the F-ETB lines as equipotential compensation.

7.3.4.12 Function "DC based consist orientation detection"

This function supports safe train inauguration by providing a mean to detect consist orientation.

The consist orientation determined during ETB train inauguration can be independently checked between two adjacent active consists by one consist applying a DC voltage (same used for the wake-up processes) on a connecting ETB link segment and the other consist measuring the voltage on that ETB link segment. If no voltage is measured, it is assumed that one of the consists used the wrong direction and that orientation information is incorrect.

A specification of this function is given in IEC 61375-2-3 Edition 2 (2024) CD subclause 6.11.

Rationale:

The consist orientation function is implemented over the F-ETB network, because using this approach the function uses the same component/circuits defined for wake-up process.

To implement this function, the 24 V power supply approach from IPTRANS-6761 shall be used.

IPTRANS-7389 -DC Orientation

Detailed Description	In any consist, a Voltage Measure (VM) circuit shall be designed to detect DC voltage on the F-ETB lines.
Rationale	The DC consist orientation functionality is based on DC-voltage detection on the F-ETB lines.

IPTRANS-7390 -DC Orientation

Detailed Description	The Voltage Measure (VM) circuit shall be connected to the ETB communication lines, after the by-pass relays of the ETBN.
Rationale	Technical part of wagon orientation solution.

IPTRANS-7391 -DC Orientation - voltage threshold

Detailed Description	The threshold voltage value for the Voltage Measurement (VM) detection circuit shall be 8 V (based on the 24 V DC supply voltage).
Rationale	Technical part of wagon orientation solution.

IPTRANS-8194 -VM Circuit galvanic isolated

Detailed Description	The VM circuit connected to the ETB lines shall be galvanically isolated from CCU.
Rationale	Galvanic isolation required, to avoid using the F-ETB lines as equipotential compensation.

7.3.5 Requirements regarding cyber security

Cybersecurity shall be supported by the devices (CCU, DAC CU, ...) using the communication system.

Cybersecurity shall be supported by all components of the communication system (F-ETBN, F-ETB, ECN, MCG):

- The F-ETBN (Freight Ethernet Backbone Node) shall support the cybersecurity requirements out of D3.3.
- The F-ETB (Freight Ethernet Backbone) shall be transparent to cybersecurity.
- The ECN (Ethernet Consist Network) shall be transparent to cybersecurity.
- The MCG (Mobile Communication Gateway) shall support the cybersecurity requirements out of D3.3.

The FDFT-Link (via the MCG) to the FDFTO backend systems needs to be considered in the overall FDFTO-system cybersecurity assessment. Please note that the FDFT-Link (via the MCG) to the FDFTO backend systems is not part of basic package.

Zone and conduit model shall be as described in D3.3, chapter 5.6.1.2.

8 Conclusions

8.1 Achievements

This document constitutes deliverable D5.4 "Technical Specification of Wagon Power System and Communication System" of ERJU Flagship Area 5 project FP5-TRANS4M-R. The project aims to boost innovation for European rail freight sector, concretely by developing, validating, and demonstrating TRANS4M-R technical enablers.

The objective of this document is to provide the requirements specification for the power system and the communication system, for rolling stock fitted with a DAC to enable the operation of full digital freight trains throughout Europe.

This has been done based on the definition of the interoperable system interfaces and their basic functions.

The deliverable D5.4 will serve – together with /WP5_D5.1/ "Functional Requirements Specification of Train Functions" and /WP5_D5.2/ "Technical Specifications of Wagon and Locomotive DAC up to Level 5" as a foundation for authorisation of FDFTO and will define the basis for the development of the innovations for WP5 ... WP12.

Based on the harmonized requirements, a common system topology / architecture for the power system and communication system, considering the degrees of freedom for a vehicle-specific technical solution has been developed. It will serve to jointly define common subsystems, components, interfaces, protocols and functions ensuring interoperability across manufacturers.

While designing the architecture, open topics have been identified. These open topics have to be solved in the future work within FP5 in WP9.

Nevertheless, with this document the groundwork has been done for a common development of the FDFT.

All other WPs can use this document as their foundation.

Based on the continuous development in TRANS4M-R, the feedback from the freight sector and on new concepts, the requirements in this technical specification will be implemented within FP5 and other projects to come.

8.2 Closed open topics

Communication system preliminary requirements:

Following requirements of the communication system are still preliminary and needs to be finalized in WP9 with results from testing:

IPTRANS-349	Standard IEC 11801-1 Amendment 1 /30/ supporting SPE is under preparation and its usability for the F-ETB segment defined in this specification needs still to be evaluated and verified in the lab.
IPTRANS-352	An optimized shielding and grounding concept of the F-ETB can only be defined when measurement results from the lab and from field tests are available. During those tests, different grounding configurations will be applied and evaluated. This is also related to requirement IPTRANS-349.

A proposal for the configurations on test implementation has been added to the requirement items 349 and 352, so within the framework of TRANS4M-R project these items can be considered as closed.

Communication system standardization:

All communication system functions affecting consist interoperability are presently subject of standardization in IEC TC9 WG43. Committee draft versions of the relevant standard parts are already (IEC CD 61375-2-3) or will be soon (IEC CD 61375-2-5) published and circulated for comments to National Committees. Recent conceptual changes in the communication system specification are not included in these drafts, but the intention is to include in the next draft version. Those changes are (list not exhaustive):

- Using one cable (star-quad) for both F-ETB lines A and B
- Modifications in passive consist detection
- Concept change of independent consist orientation detection

The inclusion of the conceptual changes shall be ensured by the National Committees which this document can be used as input for.

Cybersecurity

The topic of cybersecurity is currently under discussion so that the necessary input for the consideration is pending. This topic will be covered by the Cybersecurity Expert Group of FP5. Although this topic will be covered by the Cybersecurity Expert Group of FP5, for WP9 the following points are relevant and will be described in more detail in new chapter 7.3.5 "Cybersecurity" of this document."

Power system test plan

The test plan belongs to the development of the power system.

The test plan is included as Appendix T1 - Test plan for power distribution system to this document. For the needs of WP9 it serves as foundation for the test specification which will be elaborated in task 9.2.

Communication system test plan

The test plan belongs to the development of the communication system.

The test plan is included as Appendix T2 - Test plan for communication system to this document. For the needs of WP9 it serves as foundation for the test specification which will be elaborated in task 9.2.

Operational handling of insulation faults

Further alignment with WP2 is necessary to define how to handle an indicated insulation fault. See also chapter 7.2.1.2.

A monitoring system, being in the locomotive, detecting insulation faults will be established, see adopted requirement item 804. The operational handling of insulation faults shall be defined in WP2.

Wagon Power Supply System

A low power mode for the whole wagon equipment controlled by the CCU to enable / disable separate functions and equipment needs to be further detailed with WP9 and WP10 to assure, that the overall energy consumption of a wagon will be used in an optimized way, to avoid wasting energy. The energy storage of a WPSS cannot be dimensioned unlimited.

The requirement **R**IPTRANS-7090 limits the maximum power drawn per wagon from the PDL to 50W / 55VA. Since this power must be sufficient to recharge the battery while supporting train functions, an efficient use of energy and the possibility to use low-power modes for the battery-powered components is mandatory. The paragraph "Boundary conditions to dimension the battery capacity" of chapter 7.2.4.4.1 of this document defines some operating scenarios, which in turn give requirements to the energy storage capacity. However, the specific definition of the storage capacity depends on the implementation of the CCU and connected components on the wagon and is therefore supplier specific.

8.3 Remaining open items

Capacitance effects on the Power Distribution Line:

Measurements on the DAC4EU-train have been carried out (May 2024), the results show a quite high capacitance value between conductors of the power distribution line as active part against the chassis, on rail-potential. This results in a lower impedance of the IT system (power distribution line), than expected. When touching an electric contact in the e-coupler and using 400 V AC, this can result in an electric shock.

The high values of the line-to-ground capacitances result from the high length of the PDL in the FDFT (cable length up to $835 \text{ m} \times 1.5 = 1250 \text{ m}$).

This open topic is treated within currently ongoing investigations by WP4, WP9 and WP14. Measurements and assessments will be done in order to clearly define the requirements for the final solution.

Personal protection

Further alignment with other WPs is necessary to finalize the measures to fulfil personal protection in the electric safety context. The WPs are WP3, WP4, WP6, WP9 and WP10. See also chapter 7.2.1.1.

9 References

References to international standards and regulations used in this document.

Reference	Title	Name	Issued
/1/	EN-50153	Rolling stock - protective provisions relating to electrical hazards	May 2014
/2/	EN-61310-1	Safety of machinery - Indication, marking and actuation - Part1	2008
/3/	EN-50122-1	Fixed installations - Electrical safety, earthing and the return circuit - Part 1: Protective provisions against electric shock	2022
/4/	IEC 63171-6	Connectors for electrical and electronic equipment - Part 6: Detail specification for 2-way and 4-way (data/power), shielded, free a fixed connectors for power and data transmission with frequencies up to 600 MHz	2020
/5/	IEC 61156-1	Multicore and symmetrical pair/quad cables for digital communications - Part 1: Generic specification	2023
/6/	IEC 60079-10-1	Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres	2020
/7/	IEC 60079-10-2	Explosive atmospheres - Part 10-2: Classification of areas - Explosive dust atmospheres	2015
/8/	IEC 60079-11	Explosive atmospheres - Part 11: Equipment protection by intrinsic safety "i"	2023
/9/	IEC 60079-0	Explosive atmospheres - Part 0: Equipment - General requirements	2017
/10/	EN 50355	Railway applications - Railway rolling stock cables having special fire performance - Guide to use	2013

/11/	EN 50343	Railway applications - Rolling stock - Rules for installation of cabling	2024
/12/	EN 62847	Railway applications - Rolling stock - Electrical connectors, requirements, and test methods	2023
/13/	IEC 61373	Railway applications - Rolling stock equipment - Shock and Vibration Tests	2010
/14/	EN 50121-3-2	Railway applications – Electromagnetic compatibility – Part 3-2: Rolling stock – Apparatus	2020
/15/	EN 50533	Railway applications - Three-phase train line voltage characteristics	2011
/16/	IEEE 802.3cg	IEEE Standard for Ethernet - Amendment 5: Physical Layers Specifications and Management Parameters for 10 Mb/s Operation and Associated Power Delivery over a Single Balanced Pair of Conductors	2019
/17/	IEC 60079-32-1	Explosive atmospheres - Part 32-1: Electrostatic hazards, guidance	2017
/18/	EN 61557-8	Electrical safety in low voltage distribution systems up to 1000 V AC and 1500 V DC - Equipment for testing, measuring or monitoring of protective measures - Part 8: Insulation monitoring devices for IT systems	2015
/19/	IEC 60364-4-41	Low-voltage electrical installations - Part 4-41: Protection for safety - Protection against electric shock	2017
/20/	EN 50155	Railway applications - Rolling stock - Electronic equipment	2022
/21/	TSI WAG (EU)321/2013	Technical specification for interoperability for the "rolling stock - wagons" subsystem	2013

/22/	IEC 61375-2-5	Electronic railway equipment - Train communication network (TCN) - Part 2-5: Ethernet train backbone	2015
/23/	IEC 61375-2-3	Electronic railway equipment - Train communication network (TCN) - Part 2-3: TCN communication profile	2015
/24/	IEC 63171-6	Connectors for electrical and electronic equipment - Part 6: Detail specification for 2-way and 4-way (data/power), shielded, free and fixed connectors for power and data transmission with frequencies up to 600 MHz	2020
/25/	IEC 60603-2	Connectors for frequencies below 3 MHz for use with printed boards - Part 2: Detail specification for two-part connectors with assessed quality, for printed boards, for basic grid of 2.54 mm (0.1 in) with common mounting features	2006
/26/	IEEE 802.3	IEEE Standard for Ethernet	2022
/27/	IEC 61156-13	Multicore and symmetrical pair/quad cables for digital communications - Part 13: Symmetrical single pair cables with transmission characteristics up to 20 MHz - Horizontal floor wiring - Sectional specification	2023
/28/	IEC 61375-1	Electronic railway equipment - Train communication network (TCN) - Part 1: General architecture	2012
/29/	IEEE 802.1ax	IEEE Standard for Local and Metropolitan Area Networks - Link Aggregation	2020

/30/	IEC 11801-1	ISO/IEC CDV 11801-1 AMD 1 Amendment 1 - Information technology - Generic cabling for customer premises - Part 1: General requirements	2023
/31/	IEC 62236-3-2	Railway applications - Electromagnetic compatibility - Part 3-2: Rolling stock - Apparatus	2018
/32/	IEEE 802.1Q	IEEE Standard for Local and Metropolitan Area Networks - Bridges and Bridged Networks	2022
/33/	RFC4541	Considerations for Internet Group Management Protocol (IGMP) and Multicast Listener Discovery (MLD) Snooping Switches	2006
/34/	RFC4122	A Universally Unique Identifier (UUID) URN Namespace	2005
/35/	IEC 61375-3-4	Electronic railway equipment - Train communication network (TCN) - Part 3-4: Ethernet Consist Network (ECN)	2017
/36/	RFC791	Internet Protocol	1981
/37/	RFC826	An Ethernet Address Resolution Protocol: Or Converting Network Protocol Addresses to 48.bit Ethernet Address for Transmission on Ethernet Hardware	1982
/38/	RFC5905	Network Time Protocol Version 4: Protocol and Algorithms Specification	2010
/39/	RFC4594	Configuration Guidelines for DiffServ Service Classes	2006
/40/	IEC 61375-2-3	Electronic railway equipment - Train communication network (TCN) - Part 2-3: TCN communication profile	2024 [CD]

/41/	TSI WAG	Technical specification for interoperability relating to the subsystem 'rolling stock — freight wagons'	2013 including amendments M1 ... M5
/42/	TSI LOC&PAS	Technical specification for interoperability relating to the 'rolling stock — locomotives and passenger rolling stock subsystem	2014 including amendments M1 ... M5
/43/	EN 50125-1	Railway applications – Environmental conditions for equipment Part 1: Rolling stock and on-board equipment	2014-11
/44/	IEC 62973-1	Railway applications - Rolling stock - Batteries for auxiliary power supply systems - Part 1: General requirements	2018
/45/	IEC 62973-2	Railway applications - Rolling stock - Batteries for auxiliary power supply systems - Part 2: Nickel Cadmium (NiCd) batteries	2020
/46/	IEC 62973-3	Railway applications - Rolling stock - Batteries for auxiliary power supply systems- Part 3: Lead acid batteries	2024
/47/	IEC 62973-4	Railway applications - Rolling stock - Batteries for auxiliary power supply systems - Part 4: Secondary sealed nickel-metal hydride batteries	2021
/48/	IEC 62973-5	Railway applications - Rolling stock - Batteries for auxiliary power supply systems - Part 5: Lithium-ion batteries	2023
/49/	EN 50500	Product family standard to demonstrate the compliance of electronic and electrical apparatus in the railway environment with	2015

		the basic restrictions related to human exposure to electromagnetic fields.	
/50/	EN 50129	Railway applications - Communication, signalling and processing systems - Safety related electronic systems for signalling	2018
/51/	EN 50238-1	Railway applications – Compatibility between rolling stock and train detection systems – Part 1: General	2019
/52/	EN 50238-2	Railway applications – Compatibility between rolling stock and train detection systems – Part 2: Compatibility with track circuits	2020
/53/	EN 50238-3	Railway applications – Compatibility between rolling stock and train detection systems – Part 3: Compatibility with axle counters	2022
/54/	EN 50592	Railway applications – Testing of rolling stock for electromagnetic compatibility with axle counters	2016
/55/	EN 50617-1	Railway applications – Technical parameters of train detection systems for the interoperability of the trans-European railway system – Part 1: Track circuits	2015
/56/	EN 50617-2	Railway applications – Technical parameters of train detection systems for the interoperability of the trans-European railway system – Part 2: Axle counters	2015
/57/	EN 50728	Railway applications – Rolling stock – Testing for	2023

		electromagnetic compatibility with track circuits	
/58/	EN 50124-1	Railway applications – Insulation coordination – Part 1: Basic requirements – Clearances and creepage distances for all electrical and electronical equipment	2017
/59/	EN 45545-1	Railway applications - Fire protection on railway vehicles - Part 1: General	2013
/60/	EN 45545-2	Railway applications - Fire protection on railway vehicles - Part 2: Requirements for fire behaviour of materials and components	2020
/61/	EN 45545-5	Railway applications - Fire protection on railway vehicles - Part 3: Fire resistance requirements for fire barriers	2024

References to other documents and reports of the FP5-TRANS4M-R project

Reference	Title	Name	Issued Version
/WP2_D2.1/	FP5-TRANS4M-R D2.1	D2.1 Preliminary Operational Procedures	V2.0
/WP3_D3.1/	FP5-TRANS4M-R D3.1	D3.1 System Requirements Specification FDFT	V1.0
/WP3_D3.2/	FP5-TRANS4M-R D3.2	D3.2 Physical reference system architecture FDFT	V2.0
/WP3_D3.3/	FP5-TRANS4M-R D3.3	D3.3 Digital & Data Reference System Architecture FDFT	V2.0
/WP4_D4.2/	FP5-TRANS4M-R D4.2	Risk assessment and harmonized safety architecture	V1.0
/WP5_D5.1/	FP5-TRANS4M-R D5.1	Functional Requirements Specification of Train Functions	V1.0

/WP5_D5.2/	FP5-TRANS4M-R D5.2	Technical Specifications of Wagon and Locomotive DAC up to Level 5	V1.0
/WP9/	FP5-TRANS4M-R WP9	DAC energy supply & data, communication solution	In work
/WP9_D9.1/	FP5-TRANS4M-R D9.1	Interoperable Power supply system for locomotives	In work

References to other documents and reports outside of FP5-TRANS4M-R project

Reference	GA Number	Name	Issued Version
/DACcelerate_D3.2/	101046657	Deliverable D3.2 Requirement Specifications and Operational Rules DACCELERATE (shift2rail.org)	V1.0

10 Appendices

10.1 [T1] Test plan for power system

The test plan is included as Appendix T1 - Test plan for power distribution system to this document.

10.2 [T2] Test plan for communication system

The test plan is included as Appendix T2 - Test plan for communication system to this document.

10.3 [I] Additional Interfaces on Wagon and Locomotive

The detailed overview on updated definitions can be found in Appendix I Coupler common interface specification

10.4 Further potential for system improvement in Target State

TUPSS supply to PDL in yards to recharge wagons:

When the traction unit is in "shunting mode", the activation of the TUPSS to the PDL is inhibited due to the frequent decoupling and coupling actions in the yard. Coupling/decoupling under power will damage the power contacts in the e-coupler. An additional dedicated action/mode is needed to overcome this inhibition, when a traction unit with an equipped TUPSS is available, to apply power to the PDL to recharge the batteries in the coupled wagons.

10.5 System overview of the "cold" or "dead" traction unit

Overview in the scope for Target State:

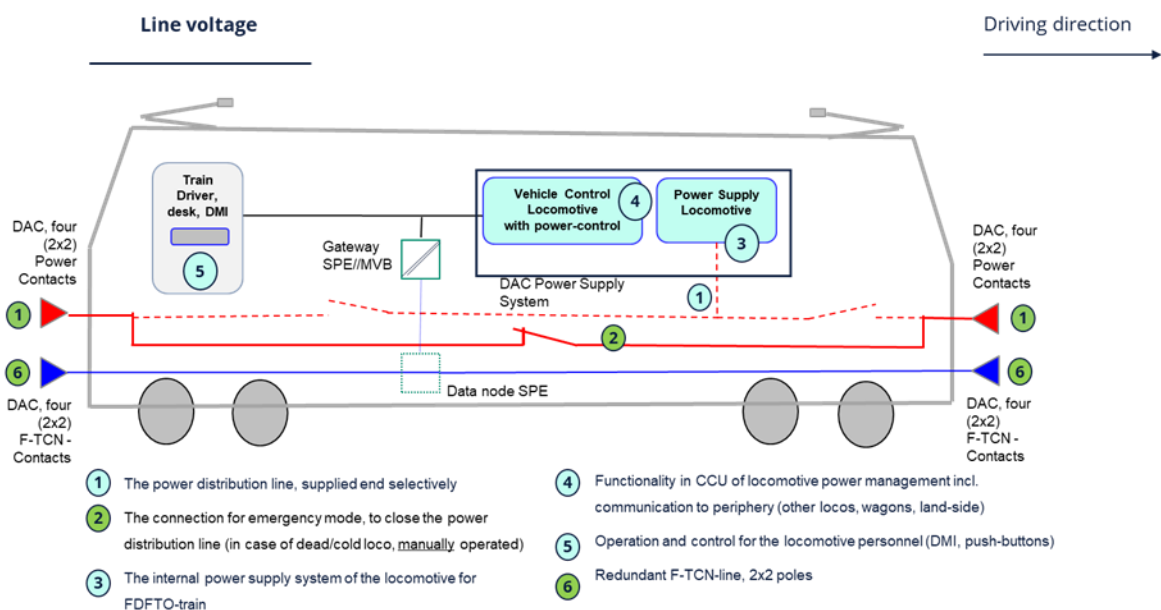


Figure 28: Cold or Dead traction unit

The "cold" or "dead" traction unit is not in the position to receive and convert electrical energy from the catenary via its power system into the train power distribution line. Only for a limited time the most important control devices remain in operation. They are supplied by the loco on-board battery, which is not recharged anymore.

The "cold" or "dead" traction unit does not provide electrical power into the PDL.

Both ends are connected by an additional bypass-switch to form an uninterrupted train PDL. Both ends are energized, another traction unit feeds in, the "cold" or "dead" traction unit is passive. The PDL is not interrupted (bypass-switch is ON)

This loco participates as an passive member in the F-TCN-network (for train composition and train integrity).

This loco must not be the last consist at the end of train (active consist is needed for first stage).

Overview in the scope for Target State in the future:

From operator side it is expected that a "cold" or "dead" traction unit can be arranged anywhere in the train and at the end of the train. Especially for this use case, such a "cold" or "dead" traction unit must fulfil train functions and participates at the train composition detection.

Since a "cold" or "dead" traction unit has no contact to the catenary anymore, needed parts of the whole control system and functions for FDFTO are to be supplied from the FDFT PDL.

This feature is currently under investigation, since it has a huge impact on the loco-architecture. The power flow is inverted, the "dead loco" is now a power sink, not a power source anymore, as in normal state.

The FDFTO train functions, including decoupling, automatic brake-test ABT, park-brake request consumers and actuators in this "dead-loco" are to be operated.

Operational functions (not only FDFTO) must be excluded from the existing loco-control and included (copied) into an additional CCU.

For the control of the tail lights, the knowledge of the country (railway-network) is mandatory, which is embedded in the existing loco-control (ZSG + ATP-system).

The power demand from the train power distribution line is higher than the normal power budget for a wagon, since more consumers are to be supplied than in a freight wagon.

An additional energy storage device must be provided in a cubical or somewhere in the traction unit, since actuators with a higher power consumptions are to be operated (even for short term).

In the current project phase it is fundamentally to be reflected in deeper investigations, how such a feature will be realized.

10.6 Examples for power conversion

A further important aspect is, that there are two basic principles for power conversion, which have each their strong advantages, therefore both principles are specified herein.

The two basic methods for power conversion are:

- System approach using a Transformer
- System approach using an Inverter

10.6.1 System approach using a transformer

Internal AUX-power
supply of the loco

3AC 440V, 60 Hz or
3AC 480V, 60Hz or
3AC 400V, 50Hz

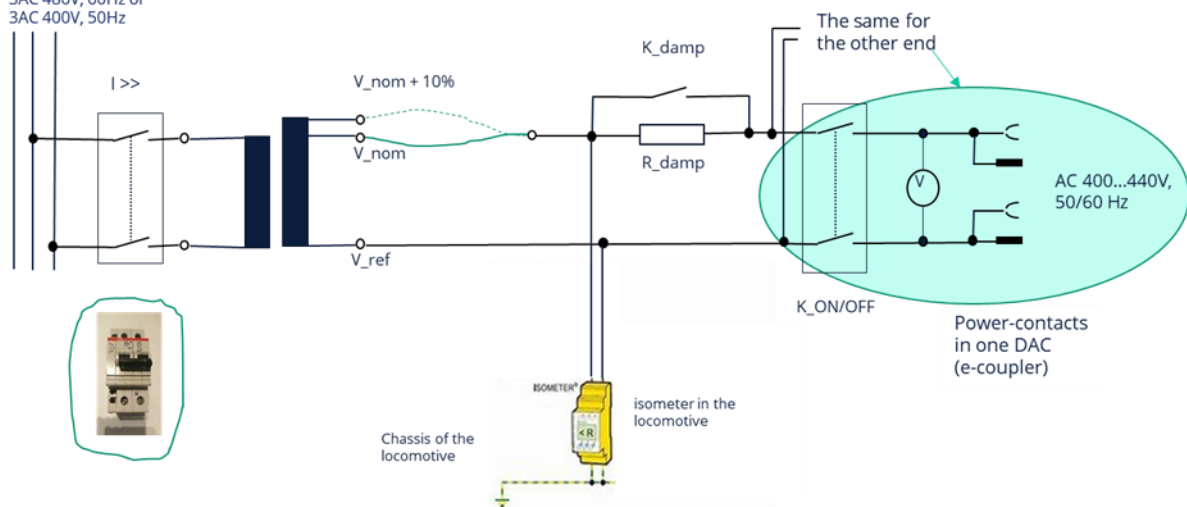


Figure 29: System approach using a transformer

The system approach using a transformer is applicable, when:

An internal electrical power system is available, which has a sinusoidal voltage shape with a fundamental frequency of 50 Hz, ..., 60 Hz.

The output voltage is adjusted by the ratio.

The transformer ensures the mandatory galvanic insulation between the output to the FDFT via the e-coupler and the internal power system of the traction unit.

The voltage is directly switched on via a damping resistor to avoid reflections on the train power distribution line and too high inrush currents. The damping resistor is bypassed after a short time.

The advantages are high robustness and a low fit-rate.

10.6.2 System approach using an inverter

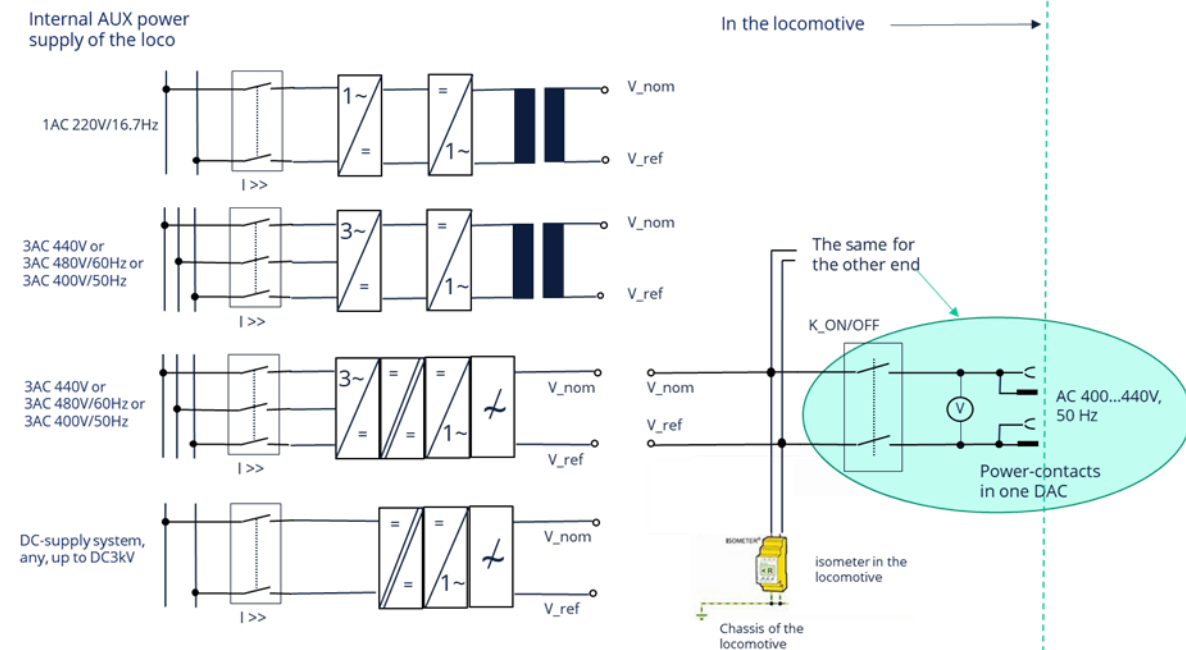


Figure 30: System approach using an inverter

The system approach using an inverter is applicable, when:

Any internal electrical power system is available, which provides the needed power.
 The output voltage and the frequency are adjusted by the inverter.
 The output-voltage of the inverter must be sine-wave filtered.
 The galvanic insulation between the output to the FDFT via the e-coupler and the internal power system of the traction unit can be realized by a conventional transformer or by a high frequency switched DC/DC-converter.
 The output voltage can be ramped up to avoid reflections on the train power distribution line and too high inrush currents.
 The advantages are more flexible and sophisticated functions versus lower robustness and higher availability.

10.7 Power management (scope Target State)

The purpose of power management is to achieve a better exploitation between the available power from the feeding traction unit and the needed power from the consumers (wagons). For example, if only 25 instead of 50 wagons are in the train segment, each wagon can take twice of the default 50 W from the PDL. This needs a coordinating function, which will be the power management.

IPTRANS-810 -In case of shorter trains: the supplying locomotive can negotiate the power limits for wagons

Detailed Description	In case of shorter trains: the supplying locomotive receives the request to allow the reception of higher power than 50 W from PDL.
Rationale	in order to achieve a better exploitation of the installed power and the train-line

IPTRANS-8216 -Traction unit power supply capability as input to power management function

Detailed Description	In the first step of activation of the power system each traction unit of the dedicated and validated train composition shall recognize and diagnose its capability to supply power into the PDL and give related information for power management to chose the suitable traction unit to supply the PDL, also in cases of disturbances and degradation's. In most cases the master traction unit feeds the PDL. As pre-condition: The train shall be initialised and composed before making this choice. This will be done without activated TUPSS (AC 400 V) from each traction unit, related to the dedicated train section.
Rationale	In case the designated TUPSS is less performant than a second available TUPSS, the better performant TUPSS can be choosen.

When the feeding traction unit is determined, the activation can be initialized by the loco driver, when all related conditions are fulfilled.

The first step in the power management process is the definition of the starting value sv for each wagon.

Whereas the FP5 Basic State comprises an inflexible exploitation of the available power to the train with various numbers of wagons, a linear power management shall be applied to the FDFTO to define the starting value for the power for each wagon of the validated train composition.

First Step: Starting point with linear power management:

IPTRANS-8217 -Power Management with linear starting value

Detailed Description	After train inauguration and validation of the train composition it is known: - Available power: 50 wagons x 55 VA per wagon = 2.75 kVA - number of wagons in the train composition So the starting value is set to be : $sv = 2.75 \text{ kVA} / \text{number of wagons in composition}$
Rationale	With this approach the available power is distributed adequately to the variable number of wagons in the validated train composition.

Second Step: Operating with negotiate power management:

The aim of the first step is extended by the prioritization of the power reception.

IPTRANS-8218 -Operation with negotiate power management function

Detailed Description	The information from each wagon energy storage about it's State of Charge shall be provided to the power management function.
Rationale	There are wagons, whose battery might be discharged and those, whose batteries are properly charged. The available power shall be prioritized to be distributed to those wagons, whose batteries are discharged, whereas the wagons with highly charged batteries will consume lesser power.

Case differentiation in the negotiate power management:

1) All wagons in the FDFT are properly charged:

no further reaction, each wagon receives the power budget, which is determined by linear power management in the first step

2) Inhomogeneous charging state of the wagons:

Not all wagons are properly charged.

The leading loco gets the charging state from each wagon BMS.

This loco is in the position to allocate a higher power budget to the wagons with the lower charging state in dependence of remaining available power.

The leading traction unit submits via the communication system to each wagon CCU the set point for the admitted power consumption from the PDL (400 V).

The wagon CCU transfers this set point value to the related wagon BMS for regulation.

This process is carried out continuously, when the charging state recovers, the reaction is reduced or changed to other wagons, which need a higher power budget.

The reception of the maximum available power of 3 kW / 3.75 kVA will not be exceeded in order not to provoke an overcurrent protective reaction.

Design characteristics for the wagon power system:

Since the efficiency and the power factor decrease at partial load (the less load the deeper efficiency and power factor), the negotiate power management process must be limited in the reaction that the rated power of the AC/DC converters are not too oversized to the generally applied load.

This requirement relates to the first case **1) All wagons in the FDFT are properly charged**, see above.

IPTRANS-1067 -The wagon energy system may negotiate admissible power consumption

Detailed Description	The wagon energy system may negotiate admissible power consumption with the superior system by requesting admission for more power then the nominal one via the communication channel. If the superior system acknowledges admission to take more power, the wagon energy system may draw power from the PDL up to the admitted power. If no admission received, the wagon energy system shall stay to the nominal power.
Rationale	Draw more power from the power distribution line if the trains consists of less than the maximum number of wagons. Charge battery faster, enable future applications based on the architecture.

IPTRANS-8214 -Power management related illustrations on DMI in driver's cab

Detailed Description	Following illustrations on DMI in driver's cab (concerning power management) shall be considered: - display the train composition, - display the status of the energy supply of the master loco, - display the status of the energy supply of the guided or slave locos, - display the requested power-consumption's of each (insulated) section of the whole train-composition, - Button/soft-key to confirm the requested power-consumption(s) on driver's desk or DMI (preferable after check with positive result in the traction unit control system) as release to the wagon(s).
Rationale	Needed information that a driver can check and confirm a requested change of power distribution (e.g., prioritize individual wagons).