Schedule 5(s)

Traction Power Supply System (TPSS)

California High-Speed Rail Authority

Standard Specifications

TSCC Specifications

SPEC-0023 – Traction Power Supply System (TPSS)

Rev. 1.0

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Document Revision History – TPSS Specifications

Second Edition

December 2025

Revision	Date	Revision Description
0.0	September 22, 2025	First Edition
1.0	December 2025	Second Edition for Addendum 2

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1 INTRODUCTION

1.1 Scope of the System Technical Specification

1.1.1 The scope of this Technical Specification is to define the California High-Speed Rail Authority's (Authority) Requirements for Traction Power Supply System, hereinafter: TPSS.

1.1.2 These requirements shall be implemented and managed in conjunction with all other requirements that together constitute the Agreement.

1.1.3 The requirements are formulated using the following words and their meanings:

- **"Shall":** Indicates mandatory requirement that must be strictly implemented. Any impossibility to fulfil this requirement must be agreed through a derogation case (see change management procedure);
- "**Should**": Indicates preferred course of action, recommendations. No agreement of derogation is necessary, there may exist valid reasons in particular circumstances to ignore a particular item, but the full implications must be understood and carefully weighed before choosing a different course - for example the same goal is reached by other solutions, which are permissible within the binding standards or documents;
- **"Must"**: Indicates an obligation or a mandatory requirement; and
- **"May"**: Indicates a permissible course of action within the limits of the standards, but which is not mandatory to be fulfilled.

2 REFERENCE STANDARDS AND DOCUMENTS

2.1 General

2.1.1 The Track and Systems Contractors ("TSCC Contractor") shall apply the then-current standards, guidelines and specifications provided in this chapter for all stages of the design, test, manufacture, supply, delivery, assembly, installation, testing, commissioning and training.

2.2 TSI

2.2.1 The applicable TSIs are listed below:

No	Standard	Title
[R1]	ENE TSI	COMMISSION REGULATION (EU) No 1301/2014 of 18 November 2014 on the technical specifications for interoperability relating to the 'energy' subsystem of the rail system in the Union including the Commission Implementing Regulation (EU) 2018/868 of 13 June 2018, Commission Implementing Regulation (EU) 2019/776 of 16 May 2019 and Commission Implementing Regulation (EU) 2023/1694 of 10 August 2023
[R2]	SRT TSI	COMMISSION REGULATION (EU) No 1303/2014 of 18 November 2014 - concerning the technical specification for interoperability relating to 'safety in railway tunnels' of the rail system of the European Union including commission regulation (EU) 2016/912 of 9 June 2016 L 153 28 10.6.2016 and commission implementing regulation (EU) 2019/776 of 16 May 2019

TABLE 72 LIST OF TSI AND REGULATIONS

2.3 Standards

2.3.1 The relevant standards to be used for TPSS are listed below:

No	Standard	Title
[R3]	BS EN 50163:2004+A3:2022	Railway applications — Supply voltages of traction systems
[R4]	BS EN 50641:2020	Railway applications — Fixed installations – Requirements for the validation of simulation tools used for the design of electric traction power supply systems
[R5]	BS EN 50317:2025	Railway applications — Current collection systems – Requirements for validation of measurements of the dynamic interaction between pantograph and overhead contact line
[R6]	BSEN 50119:2020	Railway applications — Fixed installations – Electric traction overhead contact lines
[R7]	BSEN 50318:2018+A1:2022	Railway applications — Current collection systems – Validation of simulation of the dynamic interaction between pantograph and overhead contact line
[R8]	BS EN 50121 - 1	Railway applications — Fixed installations – Electromagnetic compatibility – Part 1: General

No	Standard	Title
[R9]	BS EN 50121 - 2	Railway applications — Fixed installations – Electromagnetic compatibility – Part 2: Emission of the whole railway system to the outside world
[R10]	BS EN 50121 – 5	Railway applications — Fixed installations – Electromagnetic compatibility – Part 5: Emission and immunity of fixed power supply installations and apparatus
[R11]	EN 50122 – 1:2022+A1:2025	Fixed installations for Railway applications – Electrical safety, earthing and the return circuit – Part 1: Protective provisions against electric shock
[R12]	EN 50122 – 3:2022+A1:2025	Fixed installations for railway applications– Electrical safety, earthing and the return circuit – Part 3: Mutual interaction of AC and DC traction systems
[R13]	EN 50124 - 1	Railway applications — Insulation coordination – Part 1: Basic requirements – clearances and creepage distances for all electrical and electronic requirements
[R14]	EN 50124 – 2:2017	Railway applications. Insulation coordination — Overvoltage and related protection
[R15]	EN 50125 - 2	Railway applications – Environmental conditions for equipment – Part 2: fixed electrical installations
[R16]	EN 50152 – 1:2012+A1:2013	Railway applications — Fixed installations – Particular requirements for alternating current switchgear - Circuit-breakers with nominal voltage above 1kV
[R17]	EN 50152 – 1:2012	Railway applications — Fixed installations – Particular requirements for alternating current switchgear -Disconnectors, earthing switches and switches with nominal voltage above 1kV
[R18]	EN 50388 - 1	Railway applications — Fixed installations and rolling stock – Technical criteria for the coordination between electric traction power supply systems and rolling stock to achieve interoperability - Part 1: General
[R19]	EN 50633:2016	Railway applications. Fixed installations. Protection principles for AC and DC electric traction systems.
[R20]	EN 50126:2017+A1:2024	Railway Applications - The Specification and Demonstration of Reliability, Availability, Maintainability and Safety
[R21]	EN IEC 60146-1-1:2024	Semiconductor converters. General requirements and lime commutated converters. Specification of basic requirements.
[R22]	EN 60146 – 1 – 3:1993	Semiconductor convertors. General requirements and line commutated convertors - Transformers and reactors

No	Standard	Title
[R23]	EN 60146 – 2:2000	Semiconductors convertors —General requirements and line commutated convertorsSelf-commutated semiconductor convertors including direct DC convertors
[R24]	EN 50328:2003	Railway applications — Fixed installations – Electronic power convertors for substations
[R25]	EN 50329:2003+A1:2010	Railway applications — Fixed installations – Traction transformers
[R26]	EN 62305-3:2024	Protection against lightning - Physical damage to structures and life hazard
[R27]	EN 60529:1992+A2:2013	Degrees of protection provided by enclosures (IP Code)
[R28]	EN IEC 62305 – 1:2024	Protection against lightning – General Principles
[R29]	EN 62305 – 2:2024	Protection against lightning – Risk management
[R30]	EN 62305 – 4 :2024	Protection against lightning – Electrical and Electronic systems within structures
[R31]	EN 50178:1998	Electronic equipment for use in power installations
[R32]	EN IEC 60068-3-3:2019	Environmental testing – Supporting documentation and guidance. Siesmic test methods for equipment
[R33]	IEC 60050 Series	International Electrotechnical Vocabulary
[R34]	IEC 60255 Series	Measuring relays and protection equipment
[R35]	IEC 60502-1:2021	Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) – All parts
[R36]	IEC 60076 Series	Power transformers
[R37]	IEC 60099 Series	Surge arresters
[R38]	IEC 60146 Series	Semiconductor converters
[R39]	IEC 62271 Series	High-voltage switchgear and control gear – All parts
[R40]	IEC 61000 Series	Electromagnetic compatibility (EMC)
[R41]	IEC 60870 - 5	Telecontrol equipment and systems – Part 5: Transmission protocols

No	Standard	Title
[R42]	IEC 61508 – 1:2010	Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 1: General requirements
[R43]	IEC 61850:2025	Communication networks and systems for power utility automation
[R44]	IEC 62351:2025	Power systems management and associated information exchange – Data and communications security Network and system security for industrial process measurement and control
[R45]	IEC TS 62443-1-1:2009	Industrial communication networks – Network and system security – Part 1-1: Terminology, concepts and models
[R46]	IEC 60085:2007	Electrical insulation - Thermal evaluation and designation
[R47]	IEC 60228:2023	Conductors of insulated cables
[R48]	IEC 60332-1-1:2004+AMD1:2015	Tests on electric and optical fiber cables under fire conditions - Part 1-2: Test for vertical flame propagation for a single insulated wire or cable - Procedure for 1 kW pre-mixed flame.Tests on electric and optical fiber cables under fire conditions - Part 3-24: Test for vertical flame spread of vertically-mounted bunched wires or cables.
[R49]	IEC 60364 Series	Low-voltage electrical installations
[R50]	IEC 60479 Series	Effects of current on human beings and livestock, Part 1: General aspects.
[R51]	IEC 60670 Series	Boxes and enclosures for electrical accessories for household and similar fixed electrical installations
[R52]	IEC 60754-1:2011+AMD1:2019	Test on gases evolved during combustion of materials from cables - Part 1: Determination of the halogen acid gas content
[R53]	IEC 60754-2:2011+AMD1:2019	Test on gases evolved during combustion of materials from cables - Part 2: Determination of acidity (by pH measurement) and conductivity.
[R54]	IEC 60811 Series	Electric and optical fiber cables - Test methods for non-metallic materials
[R55]	IEC 60947:2025	Low-voltage switchgear and control-gear – All parts
[R56]	IEEE 80	Guide for Safety in AC Substation Grounding
[R57]	IEEE 142	Recommended Practice for Grounding of Industrial and Commercial Power Systems
[R58]	IEEE 242	Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems

No	Standard	Title
[R59]	IEEE 399	Recommended Practice for Industrial and Commercial Power Systems Analysis
[R60]	IEEE 400 Series	Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems Rated 5 kV and above
[R61]	IEEE 473	Recommended Practice for an Electromagnetic Site Survey (10 kHz to 10 GHz)
[R62]	IEEE 485	Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications
[R63]	IEE 519	Standard for Harmonic Control in Electric Power Systems
[R64]	IEEE 525	Guide for the Design and Installation of Cable Systems in Substations
[R65]	IEEE 551	Recommended Practice for Calculating AC Short-Circuit Currents in Industrial and Commercial Power Systems
[R66]	IEEE 575	Guide for Bonding Shields and Sheaths of Single-Conductor Power Cables Rated 5 kV through 500 kV
[R67]	IEEE 1309	Standard for Calibration of Electromagnetic Field Sensors and Probes (Excluding Antennas) from 9 kHz to 40 GHz
[R68]	IEEE 1159	Recommended Practice for Monitoring Electric Power Quality
[R69]	IEEE 1184	Guide for Batteries for Uninterruptible Power Supply Systems
[R70]	IEEE 1547.2	Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces
[R71]	IEEE 1679.1	Guide for the Characterization and Evaluation of Lithium-Based Batteries in Stationary Applications
[R72]	IEEE 1686	Standard for Intelligent Electronic Devices Cybersecurity Capabilities
[R73]	IEEE 1711	Trial-Use Standard for a Cryptographic Protocol for Cyber Security of Substation Serial Links
[R74]	IEEE 1815	Standard for Electric Power Systems Communications-Distributed Network Protocol (DNP3)
[R75]	IEEE 2030 Series	Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads
[R76]	IEEE 2030.7/2030.8	Standard for the Specification of Microgrid Controllers & Standard for the Testing of Microgrid Controllers
[R77]	IEEE 3002.2	Recommended Practice for Conducting Load-Flow Studies and Analysis of Industrial and Commercial Power Systems

No	Standard	Title
[R78]	IEEE C37 Series	Series of standards for power switchgear, including circuit breakers, switchgear assemblies, and related components, used in power systems for protection, control, and interruption of electrical currents
[R79]	IEEE C57 Series	Series comprising technical standards and guides for power, distribution, and regulating transformers, covering general requirements, design, testing, operation, and maintenance, including specifics on loading, insulation, tap changers, and transformer condition monitoring
[R80]	AREMA	Chapter 17 – High-Speed Rail Systems Chapter 33 – Electrical Energy Utilization Chapter 34 – Energy Storage & Alternative Power Supply Chapter 36 – Electric Traction Chapter 37 – Environmental & Sustainability

TABLE 73 LIST OF APPLICABLE STANDARDS

2.4 National Laws and Regulations

2.4.1 The then-current version of the following indicative national laws and regulations shall be applied. The TSCC Contractor is responsible for the compliance with the country's legislation and correct application of regulations also if they are not listed:

No	Standard	Description
[R81]	**Code of Federal Regulations (CFR) Title 49**	Transportation - Part 229, 236, 238 and 239
[R82]	**Code of Federal Regulations (CFR) Title 29**	Labor - Part 1910
[R83]	**California Public utilities Commission (CPUC)**	General Order 95, 128, 176
[R84]	**CEQA**	California Environmental Quality Act
[R85]	**NESC**	National Electrical Safety Code
[R86]	**NFPA 70**	National Electrical Code
[R87]	**NFPA 70 E**	National Fire Protection Association - Electrical Safety in the Workplace
[R88]	**NFPA 72**	National Fire Alarm and Signaling Code

No	Standard	Description
[R89]	**NFPA 130**	National Fire Protection Association - Fixed guideway transit and passenger rail systems

TABLE 23 LIST OF APPLICABLE CALIFORNIAN REGULATIONS

2.5 UIC Recommendations

UIC 552 – Electrical power supply for trains – Standard technical characteristics of the train line

3 TERMS, DEFINITIONS, AND ABBREVIATIONS

3.1.1 All the terms, definitions and abbreviations are provided in: Schedule 5(t) and Schedule 16

4 SYSTEM DESCRIPTION

4.1 General Requirements and Scope of the TPSS

4.1.1 The traction power supply system is described in Schedule 16 Scope of Work

4.1.2 This System Technical Specification (STS) has been developed on the basis of that description and supplements the traction power section of the SoW.

4.1.3 Where any ambiguity or inconsistency exists between the SoW and this Specification, the TSCC Contractor shall seek clarification from the Authority prior to design development.

4.1.4 All works, equipment, and systems shall comply with applicable federal, state, and local laws and regulations, including utility interconnection requirements, as well as international and regional standards (e.g. EN, IEC, IEEE, ANSI, etc.) referenced in this Specification. In the event of conflicting requirements between referenced standards or regulations, the following hierarchy shall apply unless otherwise directed by the Authority:

4.1.4.1 Federal, state, and local laws, authority having jurisdiction and regulations (including utility requirements);

4.1.4.2 Contractual requirements defined in this Specification;

4.1.4.3 Applicable international and regional standards (e.g., EN, IEC, IEEE, ANSI, IMC etc.); and

4.1.4.4 Industry best practice where no specific standard applies.

4.1.5 Where requirements differ in stringency, the TSCC Contractor shall comply with the most stringent (worst-case) requirement applicable. Any conflicts shall be brought to the attention of the Authority for resolution before proceeding with design or procurement.

4.1.6 This STS defines the high-level functional and performance requirements for the TPSS System. It establishes the Authority expectations and requirements, but it is the responsibility of the TSCC Contractor to:

4.1.6.1 Develop detailed designs, construction and manufactures drawings, develop simulation models, calculations and studies for all TPSS systems and equipment; and

4.1.6.2 The TSCC Contractor shall define and provide the detailed technical requirements necessary for Verification and Validation (V&V) of the CHSR project in alignment with the systems requirements specifications. These requirements shall be:

4.1.6.2.1 Derived from the outputs specified in Schedules 1-4 and Schedule 16.

4.1.6.2.2 Incorporated into the project Dynamic Object-Oriented Requirements System (DOORS) database;

4.1.6.2.3 Supported by clearly defined acceptance criteria and tolerances, based on the relevant norms and/or standards;

4.1.6.2.4 Identify the proposed method of V&V (e.g., comprising of the following: Inspection, Demonstration, Test, and Analysis); and

4.1.6.2.5 Each requirement shall include explicitly defined acceptance criteria and tolerances to ensure verifiability.

4.1.6.3 The TSCC Contractor shall prepare and produce Factory Acceptance Test (FAT) procedures, Site Acceptance Test (SAT) procedures, and Static and Dynamic Integrated Test procedures in accordance with EN 50126 to demonstrate compliance with this Specification:

4.1.6.3.1 All test procedures shall explicitly reference the detailed requirements and acceptance criteria/tolerances defined in Clause 4.1.6.2;

4.1.6.3.2 Pass/fail outcomes shall only be determined on the basis of compliance with these acceptance criteria/tolerances;

4.1.6.3.3 All test procedures shall be submitted to the Authority for review and acceptance prior to execution; and

4.1.6.3.4 Test results shall include documented evidence demonstrating conformity with the defined criteria/tolerances.

4.1.6.4 The TSCC Contractor shall develop an Inspection and Test Plan (ITP) in accordance with its Quality Assurance and Quality Control processes.

4.1.6.5 The ITP shall clearly identify all hold points and witness points for the Authority's review and acceptance, and shall demonstrate compliance with the Verification and Validation requirements defined in this document.

The ITP shall:

4.1.6.5.1 Identify all hold points and witness points for the Authority's review and acceptance;

4.1.6.5.2 Demonstrate how the Verification and Validation requirements defined in Clause 4.1.6.2 will be satisfied, and how the FAT, SAT, and Integrated Test procedures defined in Clause 4.1.6.3 will be implemented;

4.1.6.5.3 Be updated throughout the project lifecycle to reflect design, manufacturing, installation, and testing activities; and

4.1.6.5.4 The TSCC Contractor shall provide traceability between each requirement, its acceptance criteria/tolerances, and the method of demonstration.

4.1.6.6 The TSCC Contractor shall produce vendor level technical specifications for procurement of all TPSS equipment.

4.1.6.7 The TSCC Contractor shall ensure all designs, equipment, and tests meet the performance, safety, and interoperability requirements defined herein.

4.1.6.8 All detailed design deliverables, studies, models, calculations, procurement specifications, and test plans and procedures shall be submitted to the Authority for review and acceptance prior to procurement, installation, or commissioning.

4.1.7 The TPSS shall interface with future Clean Energy Contractor(s), hereinafter referred to as the "Upstream Power Supplier."

4.1.7.1 "Clean Energy" shall mean renewable or sustainable energy resources, including but not limited to photovoltaic generation systems with battery energy storage, or such other technologies as the Authority may designate consistent with applicable laws and regulations.

4.1.7.2 "Upstream Power Supplier" shall mean the party responsible for developing, owning, operating, or otherwise providing Clean Energy, interconnected with the utility and operating in parallel therewith, for delivery of the power to the TPSS.

4.1.7.3 The TPS shall interface with the upstream energy power supplier at the Point of Common Coupling (PCC) nominally 34.5 kV or as confirmed with the utility/clean energy Contractor, but the TSCC Contractor shall verify and confirm the actual service voltage during design development and adjust all related equipment ratings, insulation levels, and interface details accordingly.

4.1.8 At the Traction Power Sub-Stations sites as defined in the SoW will facilitate equipment from both the upstream power supplier as well as the TPSS facilities.

4.1.9 The upstream energy power supplier will be responsible for providing the switchgear identified as the PCC, with the TSCC Contractor verifying the service voltage and coordinating all interface requirements.

4.1.10 All coordination with the upstream energy power supplier shall be captured in an Interface Control Document (ICD) managed by the Authority.

4.1.11 The TPSS shall provide a safe, high-quality and reliable power supply for the Rail Systems as defined in clause 4.3.6.

4.1.12 The TPSS shall be designed to ensure continuous power is available for traction loads under all operating conditions.

4.1.13 The TPSS shall provide reliable and safe traction power under normal, degraded, and emergency operating conditions, supporting staged railway operations from initial service through full build-out.

4.2 Scalability & Phasing Plan

4.2.1 The TSCC Contractor shall submit a Scalability & Phasing Plan demonstrating how the traction power system will be delivered and operated across progressive project phases.

4.2.2 The Scalability & Phasing Plan shall show required civil footprint, equipment staging, any temporary works, and operational constraints.

4.2.3 All TPSS equipment (e.g. SFCs, switchgear, transformers, autotransformers, paralleling posts, switching stations, etc.) shall be modular and capable of being extended in-situ without demolition.

4.2.4 The TSCC Contractor shall consider providing spare bays, spare cable ducts, spare cable trays, and space in buildings sized for final equipment.

4.2.5 All new permanent works shall be installed to final configuration where practicable to avoid rework.

4.2.6 Any temporary equipment shall be removable with minimum disruption to the operational railway.

4.2.7 All temporary equipment must meet the same safety, protection and earthing requirements as permanent equipment. Temporary operation shall be fully tested (FAT/SAT) and shall include dynamic tests using representative rolling stock.

4.2.8 The TSCC Contractor shall guarantee minimum traction power performance for each phase.

4.2.9 The TSCC Contractor shall deliver a modular, phased traction power design enabling staged operations as defined in clause 4.2.1.

4.3 TPSS Consumers

4.3.1 The TSCC Contractor shall ensure interoperability of the TPSS with:

4.3.1.1 Upstream power supplier;

4.3.1.2 The Overhead Contact System;

4.3.1.3 Rolling stock;

4.3.1.4 SCADA/Energy Management System;

4.3.1.5 Track and civil structures; and

4.3.1.6 Medium/Low Voltage Non-Traction Power Supplies as applicable.

4.4 Design life

4.4.1 The design life of the TPSS equipment shall be in compliance with the requirements of the Authority's Design Criteria Manual, Chapter 2 Basis of Design and Schedule 16 Scope of Works (SoW).

5 INTERFACE REQUIREMENTS WITH UPSTREAM POWER SUPPLIER

5.1 Part 1: Principal Agreement and Interface Provisions

5.1.1 The TPSS shall ensure that the upstream power supplier design is fully coordinated and integrated via ICD process to guarantee safe, reliable, and integrated operation.

5.1.2 The TSCC Contractor shall not assume fixed upstream power supplier parameters. Instead, the TSCC Contractor shall obtain all necessary interface data as defined in the agreed ICD from the upstream power supplier. Such data shall include, but not be limited to:

5.1.2.1 Energy Management System (EMS), real time data acquisition, control strategies, communication protocols, remote control monitoring, alarm event management and operator actions.

5.1.2.2 Steady state and transient voltage and frequency ranges at PCC;

5.1.2.3 Network impedance and fault level characteristics (positive, negative, and zero sequence);

5.1.2.4 Minimum and maximum short-circuit levels at PCC (3-phase and Single Line Ground (SLD), Root Mean Square (RMS) + DC component) with X/R ratios;

5.1.2.5 Voltage variation and stability characteristics under load and generation changes;

5.1.2.6 Operational configurations for redundancy and degraded modes;

5.1.2.7 Power quality parameters (e.g., harmonics, flicker, unbalance) and distortion limits;

5.1.2.8 Dynamic and transient behavior (e.g., inertia, inverter droop, response times);

5.1.2.9 Steady state & dynamic models for load flow and transient stability studies;

5.1.2.10 Single line and protection schematics for all operating states e.g. normal conditions and conditions without utility, Photovoltaic (PV) Generation/Battery Energy Storage System (BESS);

5.1.2.11 Thevenin equivalents at PCC (magnitude & angle) for each operating state — positive/negative/zero sequences;

5.1.2.12 Impedance vs frequency (0–3 kHz) or equivalent impedance scan to identify any risks to the rail systems and neighbors;

5.1.2.13 Harmonic background (3rd–50th), flicker statistics and predicted harmonic injections from PV/BESS;

5.1.2.14 Control modes of PV/BESS e.g. grid-forming, droop, fault ride-through, reactive power capability;

5.1.2.15 Dynamic models Root Mean Square values & Electromagnetic Transient (EMT) e.g. including inverter control models, PLL/droop settings, Volt/VAR/Volt/Watt controls;

5.1.2.16 BESS State of Charge (SOC) behavior and fault ride-through logic;

5.1.2.17 Expected reclosing/auto-reclose schemes, breaker characteristics, protection clearing times and protection coordination times;

5.1.2.18 Expected operating modes (e.g., normal, degraded, islanded, black start) and transitions;

5.1.2.19 Fire safety report for on-site BESS (if co-located): thermal runaway risk, suppression system specification, and ventilation requirements; and

5.1.2.20 Site access, equipment footprints, cable routing and civil constraints for shared areas. Civil works outside the TSCC Contractor’s boundary remain with the upstream power supplier contractor.

5.1.3 The TSCC Contractor shall not be responsible for generating or guaranteeing the accuracy of the upstream data as defined in Clause 5.1.2. Responsibility for provision of this data rests with the upstream power supplier.

5.1.4 However, the TSCC Contractor shall incorporate all upstream-power-supplier parameters defined in Clause 5.1.2 into its design and shall perform modelling, studies, and calculations covering the full electrical system downstream of the PCC at the utility service voltage (medium voltage, nominally 34.5 kV or as confirmed with the serving utility). The studies shall address the following:

5.1.4.1 The Traction feeders to the SFCs;

5.1.4.2 Non traction feeders to technical buildings via RMUs and step-down transformers; and

5.1.4.3 Downstream electrical loads supplied by those feeders (e.g., traction, auxiliary systems, signaling, communications, and building systems) to the extent necessary to demonstrate system compliance, power quality, voltage stability, and fault levels.

5.1.5 The TSCC Contractor shall demonstrate that the overall integrated design is fully compliant with:

5.1.5.1 The Rail Systems requirements of this Specification;

5.1.5.2 Applicable Utility Grid Codes and Standards;

5.1.5.3 TSCC Contractor studies/designs must be accepted by the utility via an ICD and authority before energization; and

5.1.5.4 Any gaps, inconsistencies, or missing data as defined in clause 5.1.2 in the ICD shall be promptly identified and reported to the Authority for resolution with the upstream power supplier contractor.

5.1.6 The TSCC Contractor shall incorporate the upstream power supplier inverter control characteristics, as defined in Clauses 5.1.2.14 to 5.1.2.18, into its modelling and studies to demonstrate that power flow, voltage stability, and protection coordination within the traction and non-traction networks remain compliant with this Specification and the applicable Grid Codes.

5.1.7 The TSCC Contractor shall coordinate with the Authority and the upstream power supplier contractor to confirm equipment footprints, access routes, and construction and testing/commissioning sequencing to avoid schedule conflicts and ensure safe energization.

5.1.8 The TPSS shall ensure a minimum separation distance is maintained between TPSS equipment and upstream power supplier equipment, in accordance with IEC/IEEE insulation coordination requirements and NFPA fire separation codes.

5.1.9 Shared use of duct banks is permitted only where agreed in writing, with physical or metallic barriers to prevent induced voltages and electromagnetic coupling.

5.1.10 The TSCC Contractor shall ensure a temporary power supply, if necessary, for construction, installation, testing, and commissioning works.

5.1.11 The TSCC Contractor shall coordinate with the upstream power supplier via the ICD to ensure a single integrated earthing system is implemented, demonstrated, and documented across the site to avoid hazardous potential differences between TPSS and upstream power supply equipment.

5.1.12 The integrated earthing system shall comply with IEEE 80 and EN 50522 series and shall be validated through step-and-touch voltage studies and confirmed by on-site test results.

5.1.13 The TSCC Contractor shall provide all traction-side grounding, bonding, and equipotential connections up to a defined interface bar, where the upstream power supplier shall connect their system.

5.1.14 The TSCC Contractor shall coordinate with the upstream power supplier to ensure that BESS earthing practices (e.g., DC grounding) do not compromise the railway return current system.

5.1.15 The TSCC Contractor shall clearly define the protection zones of TPSS equipment versus upstream-side equipment.

5.1.16 Fault contribution and minimum/maximum fault current levels shall be declared by the upstream power supplier contractor. The TSCC Contractor shall design protection selectivity, accordingly, as defined in Clauses 4.1.12 to 4.1.14.

5.1.17 The TSCC Contractor shall ensure that traction-side protection (SFCs, feeders, OCS) remains selective and coordinated under all shared substation operating modes.

5.1.18 Control of upstream power supplier assets shall remain with the upstream operator. The TSCC Contractor shall provide, via an agreed ICD, the required interface relays, interoperability protocols, and signal exchange list to enable control, monitoring, safe isolation and interlocking with the operation control room operator.

5.1.19 The TSCC Contractor shall provide communication, emergency procedures, developed jointly with the upstream power supplier through the ICD, and validated during integrated testing and commissioning.

5.2 Part 2: Alternative Execution and Contingency Provisions

The provisions of this Part 2 are included to ensure continuity of the project in the event that the upstream power supplier works are deferred. The TSCC Contractor shall therefore ensure TPSS reliability with utility only supplies while incorporating provisions for seamless future integration of clean energy sources.

In the event of a deferral of the clean energy scope, and for the avoidance of doubt, the final service voltage at the Point of Common Coupling (PCC) shall be determined during design development in coordination with the serving utility. All references to 34.5 kV within this specification shall be understood as indicative only. The Designer shall verify and confirm the actual service voltage and shall adjust all associated system architecture, equipment ratings, insulation levels, and interface details accordingly.

5.2.1 The TSCC Contractor shall design the TPSS to operate reliably with power supply from the utility grid alone, in the event that the upstream power supplier energy sources are not yet commissioned as defined in clause 5.1.

5.2.2 The PCC medium-voltage switchgear (nominally 34.5 kV or as confirmed with the serving utility) shall normally be provided by the upstream energy supplier. In the event that the upstream energy supplier does not proceed, the TSCC Contractor shall design, provide, install, and commission the PCC medium-voltage switchgear, including all associated protection, control, auxiliaries, and interfaces compatible with the confirmed utility service voltage and step-down transformer.

5.2.3 The TSCC Contractor shall be responsible for coordinating and agreeing all necessary design, protection, and operational parameters with the utility provider, in accordance with the Interface Control Document (ICD), to ensure reliable and secure TPSS operation under the utility only scenarios.

5.2.4 The TSCC Contractor shall incorporate provisions to facilitate the later integration of additional upstream clean energy sources without requiring major redesign of the TPSS. These provisions shall include, as a minimum:

5.2.4.1 Interface capacity and protection settings at the PCC (utility service voltage) to accommodate future multi-source operation;

5.2.4.2 Space allocation and design allowances for future control, protection, and communication interfaces to integrate clean energy controls with TPSS SCADA and protection systems;

5.2.4.3 Selectivity, inverter control and protection logic designed such that future additional fault current contributions from the clean energy can be accommodated through parameter adjustment, without replacing TPSS equipment;

5.2.4.4 Earthing and bonding system design compatible with both utility only operation and later clean energy integration; and

5.2.4.5 SCADA and control system interface protocols designed to allow seamless extension for clean energy monitoring and control, consistent with this specification.

5.2.5 The TSCC Contractor shall demonstrate, through the studies and deliverables defined in Clause 5.1.4, that the overall interconnected traction power system, including the upstream power supplier, is stable, secure and compliant with all specified requirements.

5.2.6 These studies shall be performed irrespective of whether the clean energy facilities are commissioned concurrently with the traction power system or deferred to a later stage.

5.2.7 The TSCC Contractor shall ensure that control and protection coordination of the traction power system is compatible with both conventional utility supply and inverter-based clean energy supply, including:

5.2.7.1 Fault ride-through and dynamic response to regenerative braking conditions;

5.2.7.2 Management of fault contributions and protection selectivity during abnormal events; and

5.2.7.3 Stability under both upstream and downstream (traction network/trains) disturbances.

5.2.8 These requirements shall be incorporated into the system design, regardless of whether renewable clean energy facilities are commissioned at the same time as the traction power system or at a later date to be integrated into the system.

6 SYSTEM REQUIREMENTS

6.1 General Requirements

6.1.1 The TSCC Contractor shall provide Traction Power Supply Systems at Authority's provided land parcels.

6.1.2 The TPSS system shall be future-proof, based on the most up-to-date and proven technology, if any unproven technology is to be used, this shall be submitted for approval by the Authority before design begins.

6.1.3 Proven technology means that the TPSS system shall be based on components that have been proven in similar service and configured in an arrangement that has been demonstrated in a report to provide the required performance.

6.1.4 The TSCC Contractor shall provide as a minimum, but not limited to, the following parts of the TPSS systems;

6.1.4.1 Medium-voltage outgoing feeder cables from the PCC to the Static Frequency Converters (SFC), nominally 34.5 kV or as confirmed with the serving utility;

6.1.4.2 Static Frequency Converters, including power conversion, transformers, filters, control, protection, and redundant cooling systems;

6.1.4.3 2x25 kV outgoing feeders from the SFC to the switchgear;

6.1.4.4 2x25 kV outgoing feeders for the connections to the OCS track side switches;

6.1.4.5 Interconnection power, control and communication cables;

6.1.4.6 Autotransformers;

6.1.4.7 Switchgear, circuit breakers, isolators, disconnectors, ground switches;

6.1.4.8 Surge arresters;

6.1.4.9 Return cables;

6.1.4.10 Interlocking;

6.1.4.11 Traction Power Supply Facility, Switching Station and Paralleling Stations;

6.1.4.12 Grounding and bonding systems, for Traction Power Supply Facilities, Switching Station and Paralleling Stations for earthing grids;

6.1.4.13 Bonding of rails and metallic structures;

6.1.4.14 Lightning protection systems;

6.1.4.15 Civil, Structural and MEP works for Traction Power Supply Facilities, Switching Station and Paralleling Stations, including duct banks, trenches, HVAC, fire protection, lighting, outdoor lighting, small power and auxiliary AC/DC supplies;

6.1.4.16 Protection systems;

6.1.4.17 SCADA systems, integrated into the Railway Operation Control Room with IEC 61850/IEC 60870 protocols; and

6.1.4.18 Local and remote control, monitoring and system integration.

6.2 Environmental Requirements

6.2.1 The TSCC Contractor shall ensure that all traction power supply system (TPSS) equipment complies with the environmental conditions defined in EN 50125-2 “Railway applications — Environmental conditions for equipment — Part 2: Fixed electrical installations”, unless otherwise specified.

6.2.1.1 Equipment shall be suitable for operation under the site-specific environmental conditions as defined in the Design Criteria Manual chapter 35 for each TPSS location.

6.2.1.2 Where the Design Criteria Manual Chapter 35 does not define certain environmental parameters, the TSCC Contractor shall apply the relevant Environmental Class (e.g., Class TX) as defined in EN 50125-2 for outdoor equipment.

6.2.1.3 The TSCC Contractor shall confirm site specific environmental limits such as ambient temperature, humidity, altitude, and solar radiation with the Engineer before finalizing equipment design and testing documentation.

6.2.1.4 All design, selection, and testing of TPSS equipment shall demonstrate compliance with the applicable environmental conditions referenced above.

6.2.2 The TPSS equipment shall be designed to operate satisfactorily under all variations of load, pressure, and temperature that may occur under normal and abnormal operating conditions.

6.2.3 The ingress protection (IP) rating, in accordance with EN 60529, shall be at least IP41 for indoor TPSS equipment and at least IP65 for outdoor TPSS equipment.

6.2.4 The TPSS equipment shall be protected against pests and local fauna.

6.2.5 The TPSS shall be designed to minimize electrical energy losses and to remain suitable for the local environmental and site-specific conditions.

6.3 Functional Requirements

6.3.1 The TSCC Contractor shall implement energy efficiency optimization solutions with the support of intelligent metering function and plant automation.

6.3.2 The TPSS shall be designed for continuous duty operation under the railway’s specified service patterns, including sustained high-speed operation and regenerative braking.

6.3.3 The TPSS equipment shall be designed to withstand short-term overloads and regenerative surges without damage or unsafe operation.

6.3.4 The system shall remain stable under dynamic operating conditions, including:

6.3.4.1 Rapid train acceleration and braking;

6.3.4.2 Simultaneous demand from multiple trains; and

6.3.4.3 Transitions between normal and degraded modes of supply.

6.3.5 The TPSS protection systems shall maintain selectivity and discrimination under all operating conditions, including minimum and maximum short-circuit levels.

6.3.6 The TSCC Contractor shall support and act on study outputs as defined in Section 5 and provide mitigation proposals where instability or unacceptable system behavior is identified.

6.3.7 The TSCC Contractor must ensure that the TPSS design is fully coordinated with the upstream power supplier architecture to guarantee safe, reliable, and interoperable operation.

6.3.8 The TSCC Contractor shall demonstrate, through modelling, calculations and studies, that the traction power system (from Point of Common Coupling to pantograph & return system) remains compliant under the full range of upstream operating conditions.

6.3.9 TSCC Contractor must ensure all simulations shall be carried out using approved validated and certified software according to EN 50641 to model the upstream network, medium voltage network, static frequency converter (SFC), traction system, protection schemes, EMC, grounding and return/bonding systems.

6.3.10 The SFCs shall be capable of stable parallel operation in a closed synchronous mesh configuration with other substations.

6.3.11 The SFC shall be capable of bidirectional power flow, including regenerative braking absorption.

6.3.12 The TPSS shall ensure the fault current contribution is sufficient for downstream protection selectivity, based on declared PCC minimum fault levels.

6.3.13 Harmonic emissions shall comply with IEC 61000-3-6/IEEE 519 at PCC, with filters provided where required.

6.3.14 The TSCC Contractor shall ensure that electromagnetic compatibility (EMC), earthing, bonding, and return current designs are verified for the integrated system, including interface with neighbors, rolling stock, signaling, telecoms and civil assets.

6.3.15 The TSCC Contractor shall provide a fully integrated earthing and bonding system to ensure personnel safety, equipment protection, and system stability.

6.3.16 The TSCC Contractor shall ensure the return current system shall be designed in accordance with EN 50122 and IEEE 80, ensuring safe management of return currents and limiting step and touch potentials.

6.3.17 The TPSS shall comply with EMC requirements in accordance with EN 50121-5, EN 50388, and applicable parts of the IEC/EN 61000 series (including IEC 61000-3-6 and IEC 61000-4), IEEE 519 and CPUC Rule 21.

6.3.18 TSCC Contractor shall ensure the earthing and bonding design shall account for co-location with upstream power supply equipment (e.g. BESS, filters, PCC switchgear) to avoid hazardous potential differences.

6.3.19 The TSCC Contractor shall develop simulation models, using approved validated and certified software according to EN 50641 & calculations and studies of the traction system and the overall power system including the Medium Voltage supply to the Power Supplies for:

6.3.19.1 Steady-state load flow & traction modelling;

6.3.19.2 AC & DC Short-circuit studies;

6.3.19.3 Protection coordination & selectivity studies;

6.3.19.4 Arc Flash rating of equipment;

6.3.19.5 Insulation coordination;

6.3.19.6 Lightning protection;

6.3.19.7 Dynamic and transient performances;

6.3.19.8 Harmonic and power quality behavior;

6.3.19.9 Earthing & Bonding, EMC and return current distribution; and

6.3.19.10 Interlocking & operational concept.

6.3.20 The TSCC Contractor shall develop and submit from the simulation models and studies as defined in 6.3.21 & Section 7 the following deliverables but not limited to. In order to ensure a fully compliant integrated rail systems power supply design as stipulated in this document.

6.4 Performance Requirements

6.4.1 The TPSS shall be designed to meet the following performance requirements:

6.4.2 The maximum line speed design in accordance with EN 50163 and EN 50388.

6.4.2.1 The TPSS sizing shall be in accordance with the peak & prolonged frequency of the planned train services.

6.4.2.2 The Traction Power System shall be designed with full redundancy to ensure continuous operation under the following single electrical contingency conditions (failures/planned outages):

6.4.2.2.1 Loss of any one incoming sources;

6.4.2.2.2 Loss of any one static frequency converter;

6.4.2.2.3 Loss of any outgoing distribution equipment/feeder;

6.4.2.2.4 Loss of any one autotransformer paralleling/switching station; and

6.4.2.2.5 Loss of any negative feeder.

6.4.3 Degradation of train performance may be accepted in case of double electrical contingency conditions (simultaneous occurrence of more than 1 single electrical contingency condition in any electrical section). The degradation shall be defined by traffic operation study.

6.4.4 The TSCC Contractor shall design for overload capacity, short-term peak load during train acceleration, and safe handling of regenerative braking without instability.

6.4.5 The TPSS Contractor shall ensure that the voltage at the train pantograph under normal and disturbed operating conditions remains within the limits specified in EN 50163 and EN 50388:

6.4.5.1 This includes maintaining acceptable voltage drops under maximum traction load, limiting voltage dips and flicker caused by load changes or regenerative braking;

6.4.5.2 Ensuring compatibility with all rolling stock types; and

6.4.5.3 Compliance shall be demonstrated through design calculations, validated simulation models, and, where applicable, testing with prototype or reference rolling stock.

6.4.6 The TPSS shall allow seamless integration with the utility upstream power supplier to maintain voltage and frequency at the overhead contact system within specified limits (per EN 50163/EN 50388 or equivalent), under normal, peak and degraded load conditions.

6.4.7 The TPSS shall manage power flow between the utility upstream power supplier and regenerative braking from traction loads to optimize energy efficiency, minimize losses, and maintain supply availability.

6.4.8 The TPSS shall be protected against electrical faults through appropriately rated protection devices and fault detection/isolation mechanisms, ensuring minimum disruption to operations in accordance with applicable standards.

6.4.9 The TSCC Contractor shall make provisions for automatically switching between power sources to maintain supply availability.

6.4.10 The TSCC Contractor should incorporate power factor correction equipment if required to improve the system's efficiency and minimize losses, when integrating renewable clean energy sources or during low-load conditions.

6.4.11 The TPSS shall ensure that all control, monitoring and protection devices are connected to a centralized SCADA system with real-time monitoring capabilities for system operators.

6.4.12 The TPSS shall ensure interoperability by defining and implementing necessary communication standards (e.g. SCADA protocols, IEC 61850, IEC 60870-5-104) for seamless operation, monitoring, and control.

6.4.13 The TSCC Contractor shall provide reliable and secure communication and data transfer from the TPSS field devices to the centralized SCADA system in accordance with defined protocols and cybersecurity requirements.

6.4.14 Each traction substation facility, switching station, and paralleling post shall be equipped with auxiliary power systems to support protection, control, SCADA, communications, lighting, outdoor lighting, HVAC, fire detection/suppression, and security systems.

6.4.15 Auxiliary LV Supply shall normally be derived from a dedicated auxiliary transformer connected to the medium-voltage bus (nominally 34.5 kV or as confirmed with the serving utility) or local utility service, with redundancy or backup supply as per the Authority requirements.

6.4.16 DC Systems and Batteries shall provide uninterrupted supply to:

6.4.16.1 Protection relays and interlocking devices;

6.4.16.2 Control and SCADA systems;

6.4.16.3 Telecoms and security devices; and

6.4.16.4 Emergency lighting, alarms, and essential auxiliaries.

6.4.17 Batteries shall be sized for a minimum 6 hours autonomy (or Authority-specified requirement) under full critical load.

6.4.18 Battery Chargers shall be provided with alarm & monitoring and shall all be integrated into the SCADA system.

6.4.19 UPS Systems shall be online double-conversion type, configured with redundancy (N+1), and sized to carry all critical loads during switchover to DC systems or auxiliary transformer supply.

6.4.20 LV distribution shall include protection, discrimination, and monitoring, with design documentation (SLDs, load schedules, sizing calculations) submitted for review.

6.4.21 All auxiliary systems shall be designed for maintainability, with clear access, hot-swappable components where practicable, and health monitoring integrated into SCADA.

6.4.22 The TPSS shall provide a dedicated Traction Power SCADA system integrated with the Authority's OCC (Operations Control Centre).

6.4.23 The TPS shall provide HMI displays at substations, OCC, and remote operator workstations.

6.4.24 Provide alarms, events, sequence of events recording, trending, and power quality monitoring.

6.4.25 Substation Automation shall be based on IEC 61850 architecture, with IEDs and protection relays supporting GOOSE messaging for fast peer-to-peer communication.

6.4.26 SCADA Communication Protocols: IEC 60870-5-104 or DNP3 shall be used for remote communication between substations and OCC (Authority preference to be confirmed).

6.4.27 Gateways shall be provided where protocol conversion is required.

6.4.28 The TPSS shall provide alarms, events, sequence of events recording, trending, and power quality monitoring.

6.4.29 The TPSS shall provide remote monitoring and control of but not limited to:

6.4.29.1.1 SFCs and transformers;

6.4.29.1.2 Switchgear, circuit breakers, and disconnect/isolators switches;

6.4.29.1.3 Traction Power Supply Facilities, Switching Stations and Paralleling Posts;

6.4.29.1.4 Auxiliary and protection systems; and

6.4.29.1.5 Fire, HVAC, security alarms (as required).

6.4.30 The TSCC Contractor shall develop and submit for Authority's acceptance the HMI to be implemented for the TPSS in the Sub-Station and the OCC for control and monitoring.

6.4.31 The TPSS shall coordinate with the upstream power supplier's SCADA for exchange of operational signals, breaker status, fault alarms, load flow, power quality, and renewable integration status.

6.4.32 The TPSS Contractor shall provide a complete Interface Signal Exchange List (ISEL) defining all alarms, events, analog/digital measurements, and control signals exchanged between traction power SCADA, upstream power supplier SCADA, and OCC.

6.4.33 All signals shall include time stamping with millisecond accuracy; time synchronization shall be achieved via GPS or NTP/PTP across all devices.

6.4.34 TPSS shall provide redundancy and availability for dual redundant fiber optic communication paths between traction substations, switching stations, paralleling post and OCC.

6.4.35 TPSS shall ensure the network architecture shall eliminate single point of failure and provide automatic change over.

6.4.36 The TSCC Contractor shall provide as-built drawings, certificates, test logs, commissioning records, and software/hardware configuration details at final handover.

6.4.37 The TSCC Contractor shall provide spare parts list, maintenance tools and training.

6.5 Electrical Protection Requirements

6.5.1 The TPSS shall clearly define the protection zones of traction-side equipment versus upstream-side equipment.

6.5.2 The TSCC Contractor shall design protection selectivity accordingly taking into consideration fault contribution and minimum/maximum fault current levels from upstream power supply and regenerative braking.

6.5.3 The TPSS shall ensure that traction-side protection (SFCs, feeders, OCS) remains selective and coordinated under all shared substation operating modes.

6.5.4 The OCS circuit breakers shall be provided with intelligent electronic microprocessor-based protective relays and devices to protect against short-circuits and conductor overloading conditions.

6.5.5 The TPSS protection design shall take into account the limited short circuit current capability of the SFC systems.

6.5.6 The protection system shall be able to distinguish between short circuits fault and overloading conditions.

6.5.7 Each circuit breaker shall be equipped with a primary and backup protection.

6.5.8 The TPSS shall consider double end feeding.

6.5.9 The TPSS shall consider automatic reclosing protection to be implemented all sequencies shall be described.

6.6 EMC/Earthing & Bonding System Requirements

6.6.1 The TSCC Contractor shall ensure that EMC/earthing and bonding of the TPSS system are designed and implemented to prevent or minimizing risks such as:

6.6.1.1 Electric shock hazards to personnel and equipment;

6.6.1.2 Ground potential differences; and

6.6.1.3 Electromagnetic interference (EMI) affecting system operation and external equipment.

6.6.2 The TSCC Contractor shall demonstrate compliance with EMC/earthing and bonding requirements through design calculations, grounding studies, and field testing. The verification shall include:

6.6.2.1 Emissions and immunity testing;

6.6.2.2 Measurements of ground resistance;

6.6.2.3 Touch, step & transferred voltages; and

6.6.2.4 Assessment of potential gradients and EMI mitigation.

6.6.3 All designs and tests shall comply with relevant standards, including:

6.6.3.1 EN 50122-1, EN 50388, EN 50121-5, IEC 61000 series as applicable to traction power systems, to demonstrate compliance with EMC limits;

6.6.3.2 IEEE Std 80 (Guide for Safety in AC Substation Grounding);

6.6.3.3 IEEE Std 142 (Green Book – Grounding of Industrial and Commercial Power Systems); and

6.6.3.4 IEEE Std 81 (Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials).

6.6.4 The TPSS shall develop a detailed design for the earthing and bonding system, ensuring:

6.6.4.1 Correct grounding of all metallic parts, electrical installations, and structural components;

6.6.4.2 Electrical continuity between all conductive parts to prevent any floating potentials;

6.6.4.3 Adequate separation of functional and protective earth connections;

6.6.4.4 Suitable earthing electrodes (e.g., earth rods, earthing plates, or grids) to meet the system's current and fault requirements; and

6.6.4.5 Earth resistance is within permissible limits for safe operation.

6.6.5 The TPSS System shall be connected to the running rails by at least 2 return cables. Each return cable shall be of sufficient size to carry the maximum load current, thereby allowing for the failure of 1 return cable.

6.6.6 In direct proximity to operational DC railway, earthing and bonding solutions of all metallic structures shall be compatible with the requirements of EN 50122-3.

6.6.7 The TSCC Contractor shall ensure the earthing system, its components and bonding conductors shall be capable of distributing and discharging the fault current without exceeding thermal and mechanical design limits based on backup protection operating time.

6.6.8 TSCC Contractor shall make provisions for all the sub-system of the earthing & bonding to be tested.

6.6.9 The TSCC Contractor shall ensure that the earthing system shall maintain its integrity for the expected installation lifetime with due allowance for corrosion and mechanical constraints.

6.6.10 Minimum cross-sections shall be calculated taken into account mechanical strength, stability against corrosion and thermal strength.

6.6.11 Earthing system performance shall avoid damage to equipment due to excessive potential rise, potential differences within the earthing system and due to excessive currents flowing in auxiliary paths not intended for carrying parts of the fault current.

6.6.12 The TSCC Contractor's system shall identify sources of electromagnetic emissions and highlight potential sources of interference and their interactions within the TPSS and its sub-systems.

6.6.13 The TPSS shall develop and implement design solutions to mitigate EMC risks, including but not limited to:

6.6.13.1 Ensuring appropriate shielding for sensitive components and wiring;

6.6.13.2 Implement effective grounding techniques to reduce electromagnetic interference;

6.6.13.3 Install filters to limit conducted emissions and improve immunity; and

6.6.13.4 Optimize component and wiring layout to mitigate any coupling and interference.

6.6.14 The TSCC Contractor shall perform electromagnetic modelling and simulation to predict the system's performance in terms of emissions and immunity.

6.6.15 The TSCC Contractor shall develop a detailed test plan procedure for the planning and execution of testing of earthing/bonding, and emissions and immunity, as defined in clause 6.6.2. The test plan shall include all relevant standards and verification methods as defined in clause 4.1.6.3 and shall be submitted to the Authority for review and approval.

6.6.16 The TSCC Contractor shall use simulation tools to test different scenarios and verify the effectiveness of EMC mitigation techniques before procurement and construction.

6.6.17 The TSCC Contractor shall maintain a thorough audit trail of all TPSS EMC-related activities, including risk assessments, design decisions, tests, and modifications. Ensuring that all EMC-related documentation is easily accessible for review by internal or external auditors.

6.7 TPSS System Integration and Interoperability Requirements

6.7.1 The TPSS shall model the complete power system, as defined in clause 6.3.19 & Section 7.

6.7.2 The TPSS shall demonstrate full interoperability compliance as defined in clause 6.7.1 of all assets under the following conditions:

6.7.2.1 Normal and degraded operation;

6.7.2.2 Light & Full Load;

6.7.2.3 Engineering hours;

6.7.2.4 Regenerative braking with multiple trains under both light & full loads; and

6.7.2.5 Different operational configurations (single-source operation) to simulate disturbance modes for instance loss of utility or clean energy as defined in clause 6.7.2.

6.7.3 The TPSS Contractor shall ensure compliance with EN 50388 (traction power supply and rolling stock interface).

6.7.4 The TPSS shall ensure compliance with the utility grid codes.

6.8 Security and Cybersecurity Requirements

6.8.1 The TPSS shall be fully compliant with the Authority's cybersecurity policies.

6.8.2 All traction SCADA and communication systems shall comply with IEC 62443 for industrial cybersecurity, including applicable system and component level requirements.

6.8.3 Segregation between traction power SCADA, signaling, and telecom networks shall be implemented, either physically or logically, to prevent unauthorized access and interference.

6.8.4 Secure remote access for diagnostic or maintenance purposes shall be provided using strong authentication and encrypted communication, with full logging and audit trails of all access and actions.

6.9 Civil, Structural, Buildings & MEP Requirements

6.9.1 The TSCC Contractor shall design and construct buildings for the traction substations facility, switching stations, and paralleling posts.

6.9.2 Facilities for housing electrical equipment shall comply with this Specification and shall also be designed and constructed in accordance with Schedule 16 Section 4 Civil Works as defined in the SoW.

6.9.3 Facilities for housing electrical equipment, whether provided as permanent buildings or modular housings, shall include, but not be limited to, the following:

6.9.3.1 HVAC systems to maintain equipment environmental conditions;

6.9.3.2 Fire detection and suppression systems (FM-200, inert gas, or sprinklers as appropriate);

6.9.3.3 Emergency lighting, small power, and auxiliary supply systems;

6.9.3.4 Civil foundations, plinths, hard standing access roads, turning space for maintenance vehicles;

6.9.3.5 Anti tress pass fencing, controlled access gates, CCTV, and outdoor lighting;

6.9.3.6 All appropriate operational signage (e.g. warning, danger signs, location, mileage emergency contacts etc.);

6.9.3.7 Drainage, bunding, and environmental protection measures;

6.9.3.8 Noise mitigation and seismic design;

6.9.3.9 Fire safety and emergency response provisions; and

6.9.3.10 Spare ducts and space for future expansion.

6.9.4 The TSCC Contractor shall deliver site layout drawings and civil design packs including all calculations related to civil works, building structures, HVAC and MEP works.

6.9.5 Buildings shall meet applicable fire, seismic, and occupational safety codes.

6.9.6 The TSCC Contractor shall design substation civil works to allow independent secure access for TPSS staff and upstream supplier staff.

6.9.7 Shared areas (roads, parking, emergency exits) shall be coordinated in the site layout plan.

6.10 Reliability, Availability, Maintainability, and Safety (RAMS) Requirements

6.10.1 The TPSS shall comply with the safety requirements defined in the TSCC Contractor's Safety Analysis Report.

6.10.2 The TSCC Contractor shall prepare a Safety Case for the TPSS, in accordance with:

6.10.2.1 EN 50126 (RAMS);

6.10.2.2 EN 50128 (software systems, if applicable); and

6.10.2.3 EN 50129 (safety-related electronic systems).

6.10.3 The Safety Case shall include hazard identification, risk assessment, and mitigation strategies for traction power equipment and interfaces.

6.10.4 The TSCC Contractor shall treat TPSS safety as an integral part of the design, commencing at project initiation, to ensure potential hazards are identified, assessed and resolved with minimal impact on schedule and cost.

6.10.5 The TPSS design and operational procedures shall incorporate fail-safe principles such that failures shall not disable the system, cause human injury, damage equipment, or result in inadvertent operation of critical equipment.

6.10.6 TPSS equipment shall be located and arranged so that access for operation, maintenance, or repair does not require personnel to be exposed to hazards such as entrapment, chemical burns, electric shock, sharp edges, or toxic atmospheres.

6.10.7 TPSS design and operational procedures shall include suitable warning and caution notes in operational, assembly, maintenance and repair documentation, and shall provide distinctive markings on hazardous components, equipment, or facilities for personnel protection.

6.10.8 Energy equipment shall be located so as not to infringe on required personnel protection.

6.10.9 Emergency stop/isolation buttons shall be provided in TSCC Contractor's technical rooms to enable rapid disconnection of electrical supply in case of fire or other emergencies.

6.10.10 The TSCC Contractor shall prepare and maintain a RAMS program for the TPSS addressing:

6.10.10.1 Reliability: component failure rates, redundancy provisions;

6.10.10.2 Availability: minimum service continuity levels during failures;

6.10.10.3 Maintainability: access, spares, diagnostics, and modular replacement; and

6.10.10.4 Safety: compliance with SIL requirements for protection and control systems.

6.10.11 The RAMS program shall also ensure that:

6.10.11.1 The system continues to operate safely at reduced capacity during degraded operation or equipment failure.

6.10.11.2 Power supply interlocking maintains minimum protection against unsafe operations.

6.10.11.3 Degraded modes and equipment failures are monitored and logged for RAM reporting.

6.10.11.4 Subsystem RAM requirements are specified where FMECA identifies failure modes affecting maintenance, operations, or safety, using a risk-based approach.

6.10.11.5 Trial operation tests shall include staff readiness for degraded modes and emergency conditions, following operator and maintainer procedures.

6.10.12 The RAMS targets shall align with overall railway system performance requirements as defined by the Authority.

6.10.13 Through design, installation, and testing & commissioning, the TSCC Contractor shall ensure that TPSS equipment and subsystems can be safely energized, with all associated risks controlled, documented, and verified.

6.10.14 The TSCC Contractor shall maintain an auditable record of safety analyses, hazard logs, risk assessments, test results, and energization authorizations to demonstrate compliance with RAMS obligations and to satisfy oversight by the FRA or other regulatory authorities.

6.10.15 The RAMS program shall address interfaces between TPSS, upstream power suppliers, auxiliary systems, and protection/control systems, ensuring hazards are managed across system boundaries.

6.10.16 Testing and commissioning of TPSS equipment and subsystems shall be carried out in accordance with the procedures and Inspection Test Plans defined in Clauses 4.1.6.3 and 4.1.6.4. The results shall form part of the evidence base for the Safety Case and RAMS Program.

6.10.17 Safety and RAMS requirements defined in Clauses 6.10.13 through 6.10.16 shall be treated as derived safety and RAMS requirements. These requirements shall be inserted into the Project Requirements Management System (e.g., DOORS) in accordance with Clause 4.1.6.2, with full traceability to higher-level safety requirements and RAMS program deliverables, and maintained as auditable evidence throughout the project lifecycle.

7 ELECTRICAL CALCULATIONS, MODELLING AND STUDIES REQUIREMENTS

7.1.1 The TSCC Contractor shall update models at each project phase and provide them to the Authority for system level integration.

7.1.2 The studies shall demonstrate safe and stable operation as defined in 6.7.

7.1.3 The TSCC Contractor shall deliver EMC & earthing and bonding design reports.

7.1.4 The TSCC Contractor shall deliver protection coordination studies and relay settings from the upstream energy power supply to downstream final loads.

7.1.5 The TSCC Contractor shall provide a grid connection study verifying compliance with utility interconnection requirements.

7.1.6 The TSCC Contractor shall provide a dynamic stability study assessing voltage and frequency stability under various conditions.

7.1.7 The TSCC Contractor shall submit a harmonic distortion analysis report ensuring compliance with IEEE 519 limits for voltage and current harmonic content.

7.1.8 The TSCC Contractor shall submit an insulation coordination study, defining the required insulation levels for the TPSS & components.

7.1.9 The TSCC Contractor shall provide energy losses evaluation report for the whole traction power system.

7.1.10 The TSCC Contractor shall provide protection study for DC faults from the PV generation and Battery Energy Storage System to ensure safety, reliability, and protection of the traction power system.

7.1.11 The TSCC Contractor shall provide a lightning protection study, including direct strike shielding and surge arresters to protect the TPSS Systems.

7.1.12 The TSCC Contractor shall provide an arc flash study to ascertain the minimum PPE requirements for the maintenance operator.

7.1.13 The TSCC Contractor shall submit an electromagnetic interference (EMI) and transient overvoltage study, addressing switching transients, harmonics, and electromagnetic disturbances.

7.1.14 The TSCC Contractor shall provide a voltage profile analysis at key system nodes in the rail systems, including the 34.5 kV bus bar (nominally 34.5 kV or as confirmed with the utility/clean energy contractor), SFC outputs 2X25 kV, OCS, and non-traction buildings, ensuring voltage remains within allowable limits under all operating conditions.

7.1.15 The TSCC Contractor shall demonstrate the voltage (V) current (A) active (P) and reactive (Q) power across all the traction power system elements, including utility, PV/BESS, traction loads, and non-traction loads.

7.1.16 The TSCC Contractor shall demonstrate the power factor, ensuring overall power factor compliance at the point of common coupling (PCC) and across the traction power system.

7.1.17 The TSCC Contractor shall demonstrate the loading analysis for the traction power system, ensuring loading remains within thermal and electrical design limits under steady-state and transient conditions.

7.1.18 The TSCC Contractor shall provide a consolidated power quality report, evaluating flicker, transients, and voltage unbalance under normal and worst-case conditions.

7.1.19 The TSCC Contractor shall develop a phase imbalance and neutral current study, ensuring balanced power distribution across phases to minimize system inefficiencies.

7.1.20 The TSCC Contractor shall submit a ferro resonance study, evaluating potential issues from switching effects.

7.1.21 The TSCC Contractor shall provide a Ferranti effect analysis, modelling voltage rise in lightly loaded long transmission/distribution cables.

7.1.22 The TSCC Contractor shall develop a controlled switching strategy to minimize transient effects from breaker operations.

7.1.23 The TSCC Contractor shall submit a voltage stability study ensuring voltage levels are maintained under various operating conditions in particular reference to the upstream power supply network.

7.1.24 The TSCC Contractor shall demonstrate simulation studies modelling train movement, acceleration, coasting, braking, and regenerative power.

7.1.25 The TSCC Contractor shall demonstrate simulation studies to determine thermal limits for the Overhead Contact & Return System.

7.1.26 The TSCC Contractor shall submit a voltage drop analysis along the Overhead Contact System modelling expected voltage variations from the substation to the trains under peak, non-peak and contingency conditions.

7.1.27 The TSCC Contractor shall submit a train voltage profile study, ensuring voltage at the pantograph remains within operational limits under all operating conditions.

7.1.28 The TSCC Contractor shall submit a traction return path and grounding study, analyzing return current distribution back to the source.

7.1.29 The TSCC Contractor shall provide an earthing and bonding study to prevent injury, corrosion and unintended current paths.

7.1.30 The TSCC Contractor shall submit a regenerative braking power flow analysis, evaluating how regenerated energy is distributed to the OCS, non-traction loads, and BESS.

7.1.31 The TSCC Contractor shall provide cable sizing calculations for all outgoing feeders, considering voltage drop, thermal limits, and fault current withstand capability as per the installation methods.

7.1.32 The TSCC Contractor shall submit a SFC performance study, including power conversion efficiency, voltage control, and response to regenerative braking.

7.1.33 The TSCC Contractor shall provide a protection and fault clearance strategy for the 2x25 kV traction supply.

7.1.34 The TSCC Contractor shall submit cable screen and bonding requirements, ensuring conformance of the shielding and grounding of HV, LV & control/communication cables.

7.1.35 The TSCC Contractor shall provide the EMC separation requirements, defining minimum clearances and segregation for high-voltage, low-voltage, and control/communication circuits.

7.1.36 The TSCC Contractor shall provide cable routing and cable tray design, ensuring compliance with fire safety and mechanical protection requirements.

7.1.37 The TSCC Contractor shall develop a Safety Compliance Plan, covering PPE, arc flash mitigation, and personnel training.

7.1.38 The TSCC Contractor shall provide the operational philosophy including the interlocking methods.

7.1.39 The TSCC Contractor shall provide the operational diagrams (e.g. isolation/single line diagrams etc.) and the O&M manuals for the systems.

8 INTERFACES REQUIREMENTS

8.1 General Requirements

8.1.1 Interfaces are classified as below:

8.1.1.1 Third Party interfaces: interfaces between TSCC Contractor systems and systems provided by Third Party (excluding Authority's contractors);

8.1.1.2 External interfaces: interface between TSCC Contractor systems and systems provided by the Authority's contractors (Civils Packages, Stations contractor, Facilities contractor, Solar PV and BESS contractors); and

8.1.1.3 Interfaces between systems within the TSCC Contractor's scope.

8.1.2 The TSCC Contractor shall develop design considering the identified Third Parties, External and Internal interfaces to ensure the required functionalities and performance described in this specification.

8.1.3 The TSCC Contractor shall, if necessary, propose any additional interfaces required to ensure the functionalities and performance described in this specification.

8.2 Third Parties Interfaces

8.2.1 Federal Railroad Administration.

8.2.2 Utility Provider.

8.2.3 Upstream Power Supplier

8.3 External Interfaces

8.3.1 The TSCC Contractor shall manage the electrical interfaces for the connection at the PCC with the upstream power supplier contractor.

8.3.2 The TPSS interface to the upstream power supplier will be at the cable terminations within the 34.5 kV outgoing feeders switchgear at the PCC (nominally 34.5 kV or as confirmed with the utility/clean energy contractor).

8.3.3 The TSCC Contractor shall coordinate with the Federal Railroad Administration to meet their requirements for the energization of the power supply.

8.4 Internal Interfaces

8.4.1 The TSCC Contractor shall ensure all necessary load profiles, connected equipment data, and electrical parameters of the non-traction systems connected to 34.5kV Medium Voltage Network (nominally 34.5 kV or as confirmed with the utility/clean energy contractor), is considered for the detailed system modelling, calculations, studies, to perform the overall integrated power supply design as defined in clause 6.3.19.

8.4.2 The interface point shall be the secondary side terminals of the auxiliary transformer for the non-traction systems.

8.4.3 The TSCC Contractor shall provide LV Power Supply to the following TPSS Systems;

8.4.3.1 Traction Power Supply Facility;

8.4.3.2 Switching Station; and

8.4.3.3 Paralleling Station.

8.4.4 As defined in the Standard Specifications STS Medium Voltage & Low Voltage Power Supply TSCC Contractor Specifications.

8.4.5 TPSS interface to the OCS will be at the track side switch.

8.4.6 The TPSS will not be responsible for the design, procurement and installation of the track side switch. This shall be provided by the OCS contractor.

8.4.7 The connection between the Traction Power Supply Facility, Switching Station and Paralleling Station for the 2X25 kV feeders to the OCS track side switch should be designed and installed by the TSCC Contractor.

8.4.8 TPSS will supply the LV power and control/communication cables to the track side switch located outside the Traction Power Supply Facility, Switching Station and Paralleling Station.

8.4.9 In the instance where the track side switch is not located in the vicinity as defined in clause 8.4.5. The LV power and control/communication cable shall be supplied by the nearest non traction system building.

8.4.10 The connection between the return circuit and the running rails at the Traction Power Supply Facility, Switching Station and Paralleling Station shall be designed and installed by the TSCC Contractor.

9 MATERIALS, PRODUCT, AND COMPONENTS REQUIREMENTS

9.1 General Requirements

9.1.1 All materials supplied shall conform to the requirements and test methods of the relevant standards and regulations.

9.1.2 All materials supplied shall be of sufficient grade and quality to meet the designed life requirements.

9.1.3 Electrical equipment and cables shall be de-rated according to the method of installation, manufacturer's recommendations or applicable codes and standards, for the design conditions.

9.1.4 The TPSS equipment shall be complete with all parts and accessories or material which are useful for efficient operation of the TPSS system components. Such accessories and materials shall be deemed to be within the scope of this specification whether specifically mentioned or not.

9.1.5 The supply shall include all supporting structures, embedded parts, auxiliary equipment, mechanical linkages, auxiliary circuits wiring, interlocking devices necessary for their efficient operation. All such parts and accessories shall be deemed to be within the scope of this specification whether specifically mentioned or not.

9.1.6 TSCC Contractor power equipment shall be designed ensuring adequate protection from rodent action. Additionally, the TSCC Contractor shall implement any measures ensuring rodent eradication.

9.1.7 The supply of material products and components shall include where appropriate UV protection is.

9.2 LV Distribution

9.2.1 Refer to Standard Specifications STS Medium Voltage & Low Voltage Power Supply TSCC Contractor Specifications.