Electrification Standard Design Criteria

Document information

Owner: Director, Engineering, PCJPB

Revision History

Revision	Date Approved	Approved By	Key Changes
Rev 1	January 1, 2026	**Bin Zhang**, Director-Engineering	Significant changes throughout the document-Sections updated in OCS, new chapters added for Traction Power, Grounding and Bonding , EMI-EMC and SCADA
Rev 0	January 1, 2024		Initial version

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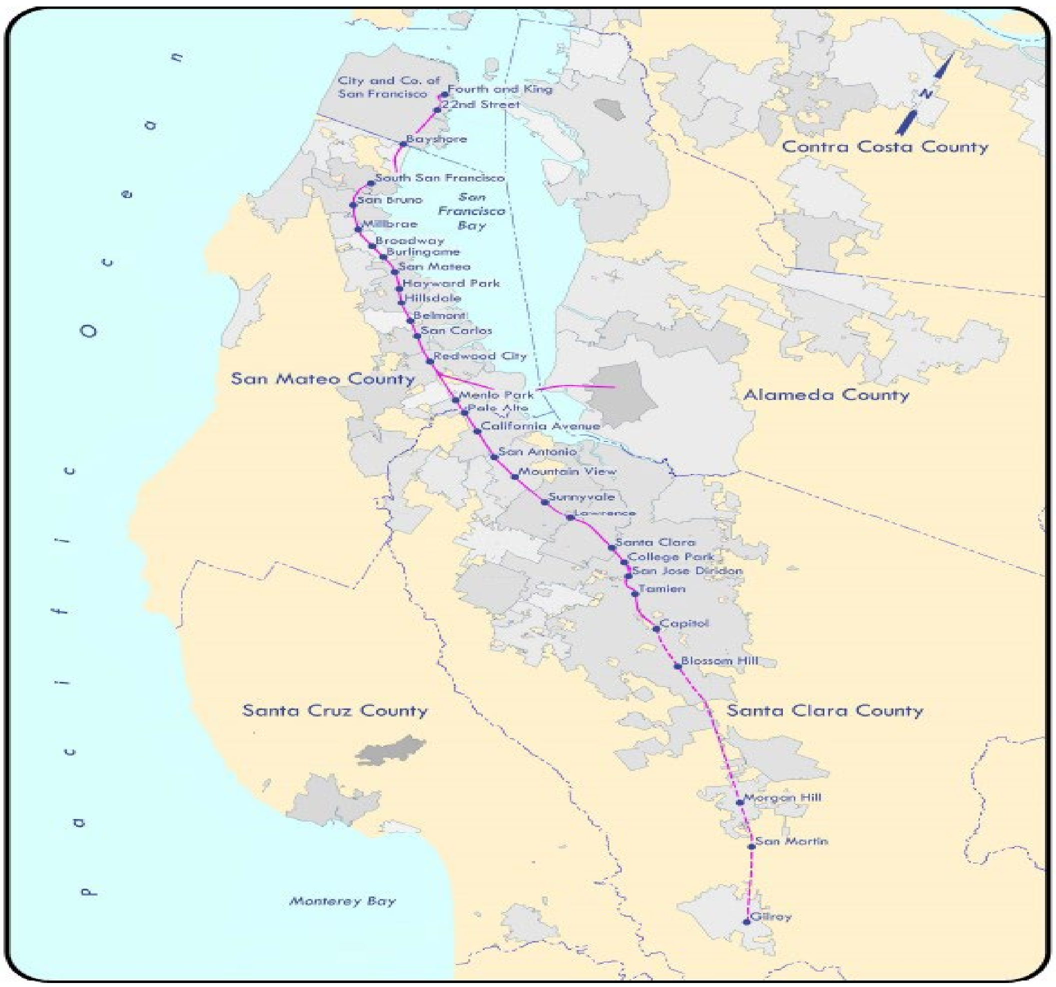
CHAPTER 1

GENERAL

1.0 General

Caltrain is a commuter rail service operating on a 77-mile corridor between the cities of San Francisco and Gilroy owned by the Peninsula Corridor Joint Powers Board (PCJPB). This includes 52 route miles of rail corridor between San Francisco and San Jose, and approximately 25 additional miles of trackage rights from San Jose to Gilroy. The 51 mile right of way owned by PCJPB from San Francisco terminus at 4th and King Street (MP 0.00) in the North to south of Tamien station (MP 49.1-03) is electrified with 25kV 60 Hz single phase AC auto transformer overhead contact system. There are four tunnels in the northern section of the corridor where overhead conductor rail is installed. A Central Equipment & Maintenance Facility (CEMOF) is located at MP 46.0 in San Jose.

- **Figure 1: Caltrain Right of way**



- **Table 1: Abbreviations and Acronyms**

Term	Definition
AC	Alternating Current
ACSR	Aluminum Conductor Steel Reinforced
AT	Autotransformer
ATC	Automatic Train Control
ATF	Autotransformer Feeder
BCCF	Backup Central Control Facility
BWA	Balance Weight Anchor
CalMod	Caltrain Modernization Project
Caltrain	Caltrain is the name used for the passenger train service owned and operated by the Peninsula Corridor Joint Powers Board
CCF	Central Control Facility
CCTV	Closed Circuit Television
CENELEC	European Committee for Electrotechnical Standardization
CHSRA	California High Speed Rail Authority
CIC	Communications Interface Cabinet
COTS	Commercial Off-The-Shelf
CPUC	California Public Utilities Commission
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FRT	Fixed Remote Telemetry
GSM-R	Global System for Mobile Communications – Railway
HDEW	Hazard Detection/Early Warning
HV	High voltage
HVAC	Heating, Ventilation, and Air Conditioning
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IIMP	Integrated Information Management Platform
MOD	Motor Operated Disconnect Switch
MOI	Maintenance of Infrastructure
MPA	Midpoint Anchor
MPE	Maximum Permissible Exposure
mph	miles per hour
N.C.	Normally Closed
N.O.	Normally Open

NEC	National Electric Code
NEMA	National Electrical Manufacturers Association
NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
O&M	Operations and Maintenance
OCC	Operations Control Center
OCR	Overhead Conductor Rail
OCS	Overhead Contact System
OSP	Outside Plant Cable
PCJPB	Peninsula Corridor Joint Powers Board
PS	Paralleling Station
PTC	Positive Train Control
RCC	Regional Control Center
RGB	Rack Grounding Busbar
ROCS	Rail Operations Control System
ROW	Right of Way
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SRG/SRS	Signal Reference Grid/Signal Reference Structure
STP	Shielded Twisted Pair
SWS	Switching Station
TPSS	Traction Power Substation
TBB	Telecommunication Bonding Backbone
TBBIBC	Telecommunication Bonding Backbone Interconnecting Bonding Conductor
TES	Traction Electrification System
TGB	Telecommunications Grounding Busbar
TPF	Traction Power Facility
TPS	Traction Power System
TSR	Temporary Speed Restriction
WPC	Wayside Power Cubicle

1.1 Definitions

Agency - The railroad or other jurisdictional entity that is responsible for the operation and maintenance of the railroad.

Auto-Transformer Feeder (ATF) - The ATF is a paralleling 25kV AC conductor which together with the 25kV AC OCS conductor forms the 2X25kV AC distribution system along the railway. The parallel ATF is connected via circuit breakers and disconnect switches to one terminal of a Main Power Transformer (MPT) and secondary winding on the Autotransformer (AT) in the TPF’s.

Bond - A bond is an electrical connection from one conductive element to another for the purpose of maintaining a common electrical potential (equipotential).

Catenary Feeder (parallel) - An energized conductor (25 kV nominal) emanating from the Catenary bus at a TPF through a circuit breaker and disconnect switch and supported on the same structures as, and parallel with the OCS to feed sections of Catenary remote from the TPF.

Contact Wire - A solid grooved, bare aerial, overhead electrical conductor of an OCS that is suspended above the rail vehicles and which supplies the electrically powered vehicles with electrical energy through roof-mounted current collection equipment (pantographs) and with which the current collectors make direct electrical contact.

Collector Head - That part of the pantograph which runs under and in contact with and collects current from the overhead contact wire or conductor rail.

Cross Bond - Any electrical connection intended to connect two or more conductors of the return circuit in parallel.

De-energized - Electrical apparatus, such as overhead wires, substation conductors, cables, switches and circuit breakers when disconnected from an electrical power source(s) but not grounded. NOTE: Dangerous to life until properly grounded

Direct Traction System Grounding - The direct connection between conductive parts and the traction system ground. Note: Grounding via impedance bonds, required by reason of signaling system track circuit considerations, is considered to be direct grounding.

Drain Bond - An impedance bond installed to connect the rails to traction power facilities, such as substations, switching stations, and paralleling stations, where no insulated joints exist in the tracks in the vicinity of the traction power facility.

Electrical Section or Feed Section - The section between the phase break of the traction power substation and the phase break of the adjacent switching station that is normally fed by one main transformer of the substation.

Elementary Electrical Section - The smallest section of the OCS power distribution system that can be isolated from other sections or feeders of the system by means of disconnect switches and/or circuit breakers.

Energized (Live) Part - An energized part is a conductor or conductive part that is energized under normal service conditions but does not include the running rails or parts connected to them. Energized parts include roof-mounted equipment on electric vehicles, such as pantographs, train line conductors, and resistor units. The full length of insulators connected to energized parts and static wire shall be classified as energized when considering electrical clearance requirements.

Fault Condition - The presence of an unintended and undesirable conductive path in an electric power system.

Floating Section - A section of wire (catenary and/or feeder) with no electrical connections to a power supply or to a grounding circuit that has tendency to develop induced voltage. OCS deadend may be electrically bonded to the catenary structure where a solid bond connection is established through the steelwork; otherwise, a separate bonding conductor shall be run between the deadend and the structure.

Impedance Bond - An autotransformer device designed to permit traction electrification return current to bypass insulated joints while providing operation and isolation of adjacent signaling track circuits.

Leakage Current - A current that flows to ground or to extraneous conductive parts, following a path or paths other than the normal intended path, but which is not of sufficient magnitude to create a fault.

Messenger Wire (Catenary Wire) - A longitudinal bare stranded conductor that physically supports the contact wire or wires either directly or indirectly by means of hangers and hanger clips and is electrically common with the contact wire(s).

Touch Potential - The difference in electrical voltage between metallic objects or structures that may be bridged by direct hand-to-hand or hand-to-feet contact.

Overhead Conductor Rail - Contact line system that utilizes a rigid metallic aluminum section (rail) to grip the lobe of the contact wire and supports it in a position similar to conventional wiring systems (without a messenger wire).

Overhead Contact System (OCS) - The aerial distribution supply system that delivers electrical power from traction power facilities to the pantographs of high-speed electric trains, comprising of catenary and contact wires, hangers, associated supports and structures (including poles, portals and their foundations), manual and/or motor operated disconnect switches, section insulators, section phase breaks, conductor termination and tensioning devices, downguy, and other overhead line hardware and fittings.

Paralleling (Balancing) Stations (PS) - An installation that helps boost the OCS voltage and reduce the running rail return current by means of the autotransformer feed configuration, by balancing the traction load current in the OCS and ATF conductors. The autotransformer feeder (ATF) and the catenary feeder conductors are connected to the two outer terminals (X2 and X1) of the autotransformer winding at this location, with the central terminal connected to the rail return system. OCS sections are connected in parallel at PS locations.

Rail Joint Bond - A conductor that ensures the electrical continuity of a running rail at an uninsulated, bolted rail joint.

Rail Potential - The voltage at the rails with respect to ground due to traction return or fault current flowing in the rails and the impedance of the rails to ground.

Regenerative Braking - A system in which the drive motors of the electric vehicles operate as generators and provide dynamic braking of the vehicle, while at the same time returning power to the OCS that can be used by receptive vehicles on the system.

Right of Way Classification - Right-of-Way (ROW) classifications are defined in CPUC GO No. 143-B Rule 9.04.
Semi-Exclusive ROW - Right-of-Way with at-grade crossings, protected between crossings by a fence or substantial barrier, as appropriate to the location.

Sectionalization - Separation of the distribution system into electrical sections to limit the length of the track to be de-energized following fault, or for system maintenance. Sectionalizing can be performed at substations, paralleling stations and switching stations, as well as at interlockings where crossovers and turnouts are installed.

Standing Surface - Any point on a surface where people may stand or walk.

Static Wire - A wire, usually installed aerially adjacent to or above the catenary conductors and autotransformer feeders, that connect OCS support structures collectively to ground or to the grounded running rails to protect people and installations in case of an electrical fault. In an AC electrification system, the static wire forms a part of the traction power return circuit and is connected to the running rails via impedance bonds at specific intervals and to the traction power facility ground grids. If mounted aerially, the static wire may also be used to protect the OCS against lightning strikes. It is sometimes termed “aerial ground wire” or “aerial earth wire.”

Surge Arrester or Surge Suppressor - A protective device for limiting surge voltages on equipment by discharging or bypassing surge current; it limits the flow of power follow- on current to ground and is capable of repeating these functions.

Switching Station (SWS) - This is an installation where the supplies from two adjacent TPSS are electrically separated and where electrical energy can be supplied to an adjacent, normally separated electrical section during contingency power supply conditions. It also acts as a Paralleling Station.

Traction Electrification System (TES) - The combination of equipment that supplies power to electric trains, including the traction power system (TPS) and the overhead contact system (OCS).

Traction Power Facilities (TPF) - TPF is a general term that encompasses substations, switching stations, and paralleling stations.

Traction Power System (TPS) - TPS is the railway traction power network, comprised of three types of TPF (traction power substations, switching station, and paralleling (balancing) stations) which provides energy to electric trains. In addition, the TPS provides connections to the OCS and to the traction return and grounding system and includes wayside power control cubicles for control and operation of wayside motor-operated disconnect switches.

Traction Power Substations (TPSS) - An electrical installation where power is received at high voltage and transformed to the voltage and characteristics required at the catenary and autotransformer feeders for the nominal 2x25 kV system, containing equipment such as transformers, circuit breakers and disconnect switches. It also includes the incoming lines from the power supply utility.

Traction Power Return System - All conductors including the grounding system for the electrified railway tracks, which form the intended path of the traction return current from the wheelsets of the traction units to the substations under normal operating conditions and the total return current under fault conditions. The conductors may be of the following types:

- Running rails and track bonds
- Impedance bonds and cross bonding connections

- Static wires, and buried ground conductors
- Return cables, including all substation return circuit bonding and grounding interconnections
- Earth

Traction System Ground - The traction system ground consists of the running rails, the aerial static wires and all conductive parts connected thereto, and which are solidly connected to ground.

Tunnel Ground - The electrical interconnection of the reinforcing steel in reinforced concrete tunnels and, in the case of other modes of construction, the conductive interconnection of the metallic parts of the tunnel.

1.2 Overview

1.2.1 Purpose and Extent

This document establishes standard criteria, guidelines, and requirements for the design of 25kV AC Electrification infrastructure and system elements in the Caltrain right of way.

This Electrification standard includes design criteria for traction power supply systems, overhead contact system and traction power return system, grounding and bonding, corrosion control, electromagnetic interference and compatibility, and supervisory control and data acquisition subsystems.

The intended use of these criteria is for Caltrain Electrification Projects, unless indicated otherwise.

1.2.2 Applicability

This standard applies to existing Caltrain's 25 kV AC TES, all new 25kV AC TES installations and any future upgrades or modifications existing system.

1.2.3 Design Standard Classifications

The following terms are used to classify the requirements:

- "Recommended" – Standard to be equaled or exceeded where there are no major physical, cost, or schedule constraints. Designers should use "Recommended" values to the extent practical.
- "Minimum/Maximum" – Represent limits. Designers shall make every effort to avoid the use of minimum/maximum values. These values will require approval from JPB Caltrain where constraints make the use of "Recommended" values impracticable.
- "Shall" – Indicates mandatory requirement that must be strictly implemented. Waiver is permissible only under approval of design variance.
- "Should" – Indicates preferred course of action. Design variance is not required if it is not exercised.
- "May" – Indicates permissible course of action within the limits of the standards. Design variance is not required if it is not exercised.

1.2.4 Other Caltrain Electrification Standards

The following documents shall be considered with this Electrification Standard Design Criteria.

- Caltrain Electrification Standard Specifications

- Caltrain Electrification Standard Drawings
- Caltrain CADD Manual
- California High-Speed Rail Authority and Federal Railroad Administration 2005 Final Program Environmental Impact Report/Environmental Impact Statement for the Proposed California High-Speed Train System.
- Bay Area to Central Valley Program Environmental Impact Report/Environmental Impact Statement

1.3 Basis of Design

The Caltrain Electrification system shall be a 2 x 25 kV AC single phase, 60 Hz autotransformer traction electrification system that shall meet the physical, functional, and performance requirements set out in this document and in the project specific basis of design as applicable.

1.4 Regulations, Codes, Standards, and Guidelines

The international, federal, state, and industry specific regulations, codes, standards, and guidelines pertaining to each area of design are listed below and shall be complied to. These lists are not all inclusive. It is the Designer and/or Contractor's responsibility to determine additional regulations, codes, and standards that are applicable. Unless a specific publication edition is identified, the latest edition shall apply. Deviations from these provisions stated herein require approval from the JPB or its representative and their decisions regarding conflicts shall be final. Federal and state regulations and codes govern passenger and freight rail systems in the U.S. These regulations are typically the basis of design and govern the operation of conventional rail networks and are applicable to the basis of design and they govern the operation of rail systems with speeds under 150 mph.

1.4.1 Traction Power

- American Railway Engineering and Maintenance-of-Way Association (AREMA)
  - AREMA Manual for Railway Engineering, Volume 3 Infrastructure and Passenger, Chapter 33 Electric Energy Utilization
- California Code of Regulations (CCR)
- California Building Standards Code (CBSC), Title 24 of California Code of Regulations (CCR)
- California Public Utility Commission (CPUC) General Orders (GOs)
  - GO 95: Overhead Electric Line Construction
  - GO 128: Construction of Underground Electric Supply and Communications System
- European Standards (EN for European Norms)
  - EN 50121-1: Railway applications – Electromagnetic Compatibility
  - EN 50122-1: Protective Provisioning Relating to Electrical Safety and Earthing
  - EN 50124-1: Railway applications – Insulation Coordination
  - EN 50124-2: Railway applications – Overvoltages and Related Protection
  - EN 50152: Railway Applications–Fixed Installations–Particular Requirements for ac Switchgear Part 1: Single-phase circuit-breakers with Um above 1 kV Part 2: Single-phase disconnectors, earthing switches and switches with Um above 1 kV.
  - EN 50160: Voltage Characteristics of Electricity Supplied by Public Distribution Systems
  - EN 50163: Railway Applications – Supply Voltages of Traction Systems,
  - EN 50329: Railway Applications – Fixed Installations – Traction Transformers
  - EN 50388: Railway Applications – Power Supply and Rolling Stock – Technical Criteria for the Coordination Between Power Supply (Substation) and Rolling Stock to achieve Interoperability

- Insulated Cable Engineers' Association (ICEA) Standards
- International Electro-technical Commission (IEC) Standards
- Institute of Electrical and Electronics Engineers (IEEE) Standards
- National Electrical Manufacturers Association (NEMA) Standards
- National Fire Protection Association (NFPA) Codes and Standards
- Underwriters' Laboratories (UL) Publications

1.4.2 Overhead Contact System

- American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering, Chapter 33 Electrical Energy Utilization
- European Committee for Electrotechnical Standardization (CENELEC) Standards
  - EN 50119: Electric Traction Overhead Contact Lines
  - EN 50122-1 Part 1: Protective Provisions Relating to Electrical Safety and Earthing
  - EN 50124-1: Insulation Coordination: Part 1 – Basic Requirements
  - EN 50149: Electric Traction: Copper and Copper Alloy Grooved Contact Wires
  - EN 50317: Railway applications. Current collection systems.
- California Code of Regulations (CCR) Title 8, Division 1, Chapter 4, Subchapter 5: Electrical Safety Orders
- Institute of Electrical and Electronics Engineers (IEEE)
- California Public Utilities Commission (CPUC) General Orders (GOs)
  - CPUC GO 26-D: Regulations Governing Clearances on Railroads and Street Railroads with Reference to Side and Overhead Structure Parallel Tracks, Crossings of Public Roads, Highways and Streets
  - CPUC GO 95: Rules for Overhead Electric Line Construction
  - CPUC GO 118: Regulations Governing the Construction, Reconstruction, and Maintenance of Walkways Adjacent to Railroad Trackage and the Control of Vegetation Adjacent Thereto.
- Technical Specification for Interoperability (TSI) Energy, Technical Specifications for the Interoperability of Electrical Energy Subsystems.
- American Concrete Institute (ACI 318) Codes
- National Electrical Safety Code (NESC)
- American National Standards Institute (ANSI) Codes
- American Society of Civil Engineers (ASCE) Codes
- International Building Code (IBC)
- California Building Code (CBC)
- Minimum Design Loads for Buildings and Other Structures (ASCE 7)
- American Welding Society: Structural Welding Code- Steel (AWS D1.1)

1.4.3 Grounding and Bonding

- California Code of Regulations, Title 24 (California Building Standards Code which includes the California Electrical Code)
- California Public Utilities Commission (CPUC) General Order (GO) 95
- International Electrotechnical Commission (IEC) 60479: Effects of Current on Human Beings and Livestock – Part 1 General Aspects
- Institute of Electrical and Electronics Engineers (IEEE)
- American National Standards Institute (ANSI): ANSI-TIA-EIA-607-A "Grounding and Bonding Requirements for Telecommunications in Commercial Buildings"
- National Fire Protection Association (NFPA)
- European Standards (EN)

- EN 50119: Railway Applications – Fixed Installations – Electric Traction Overhead Contact Lines
- EN 50122-1: Railway Applications – Fixed Installations - Part 1. Protective provisions relating to electrical safety and earthing
- EN 50124-1: Railway Applications – Insulation Coordination – Part 1. Basic requirements – Clearances and creepage distances for all electrical and electronic equipment

- The Manual for Railway Engineering of the American Railway Engineering and Maintenance of Way Association (AREMA Manual)
- Underwriters Laboratories (UL)

1.4.4 Corrosion Control

- American Concrete Institute (ACI)
- American National Standards Institute (ANSI)
- American Railway Engineering and Maintenance-of-Way Association (AREMA)
- American Society of Mechanical Engineers (ASME)
- American Society of Testing and Materials International (ASTM)
- American Water Works Association (AWWA)
- California Department of Transportation (Caltrans)
- Concrete Reinforcing Steel Institute (CRSI)
- Electronic Industries Association (EIA)
- Environmental Protection Agency (EPA)
- European Standards (EN for European Norms)
- Insulated Cable Engineers Associated (ICEA)
- International Electrotechnical Commission (IEC)
- Illuminating Engineering Society of North America (IESNA)
- Institute of Electrical and Electronics Engineers (IEEE)
- International Organization for Standardization (ISO)
- National Association of Corrosion Engineers International (NACE)
- National Electrical Manufacturers Association (NEMA)
- National Fire Protection Association (NFPA)
- Occupational Safety and Health Administration (OSHA)
- State of California Codes and Code of Regulations
- Steel Structures Painting Council (SSPC)
- Underwriters' Laboratories (UL)

1.4.5 Electromagnetic Interference and Compatibility

- APTA
  - SS-E-010-98: Standard for the Development of an Electromagnetic Compatibility Plan
- AREMA
  - Communications & Signals Manual including Section 10 (Wire and Cable) and Section 20 (Inductive Interference)
  - Manual for Railway Engineering including Chapter 33 Electrical Energy Utilization
- European Committee for Electrotechnical Standardization (CENELEC) Standards
  - EN 45502-2-2: IEEE 802.3: Active Implantable Medical Devices, Part 2.2, Particular requirements for active implantable medical devices intended to treat tachyarrhythmia (includes implantable defibrillators)

  - EN 50119: Electric Traction Overhead Contact Lines
  - EN 50121-1: Railway applications - Electromagnetic compatibility, Part 1: General
  - EN 50121-2: Railway applications - Electromagnetic compatibility Part 2: Emission of the whole railway system to the outside world
  - EN 50121-3-1: Railway applications – Electromagnetic compatibility – Part 3-1: Rolling stock – Train and complete vehicle
  - EN 50121-3-2: Railway applications - Electromagnetic compatibility – Part 3-2: Rolling stock – Apparatus
  - EN 50121-4: Railway applications - Electromagnetic Compatibility, Part 4: Emission and immunity of signaling and telecommunications apparatus
  - EN 50121-5: Railway applications - Electromagnetic compatibility -- Part 5: emission and immunity of fixed power supply installations and apparatus
  - EN 50122-1 Part 1: Protective Provisions Relating to Electrical Safety and Earthing
  - EN 50124-1: Insulation Coordination: Part 1 – Basic Requirements
  - EN 50500: Measurement procedures of magnetic field levels generated by electric and electrical apparatus in the railway environment with respect to human exposure
- CPUC
  - General Order 52: Construction and operation of power and communication lines for prevention or mitigation of inductive interference
  - General Order 95: Rules for Overhead Electrical Line Construction
  - General Order 128: Rules for Construction of Underground Electric Supply and Communication Systems
- FCC
  - FCC Part 15: Title 47
  - FCC OET 65: Evaluating Compliance with FCC Guidelines for Human Exposure to Radio frequency Electromagnetic Fields, FCC Office of Engineering and Technology Bulletin 65, Edition 97-10
- FTA
  - UMTA-MA-06-0153-85-11: Radiated Interference in Rapid Transit Signaling Systems - Volume II: Suggested Test Procedures
  - UMTA-MA-06-0153-85-6: Conductive Interference in Rapid Transit Signaling Systems Volume II: Suggested Test Procedures
  - UMTA-MA-06-0153-85-8: Inductive Interference in Rapid Transit Signaling Systems - Volume II: Suggested Test Procedures
- Institute of Electrical and Electronics Engineers (IEEE) Standards
  - IEEE Std C2: National Electrical Safety Code
  - IEEE Std C37.20: IEEE Standard for Metal-Enclosed Low-Voltage Power Interrupter
  - IEEE Std 80: IEEE Guide for Safety in AC Substation Grounding
  - IEEE Std 81.2: IEEE Guide for Measurement of Impedance and Safety Characteristics of Large, Extended or Interconnected Grounding Systems
  - IEEE Std C95.1: IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 3 kHz – 300 GHz
  - IEEE Std C95.6: IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0 – 3 kHz
  - IEEE Std 142: IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems
  - IEEE Std 518: IEEE Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources
  - IEEE Std 519: IEEE Recommended Practice and Requirements for Harmonic Control in Electrical Power Systems
  - IEEE Std 525: IEEE Guide for the Design and Installation of Cable Systems in Substations

- IEEE Std 1100: Recommended Practice for Powering and Grounding Electronic Equipment
- IEEE Std 1143: IEEE Guide on Shielding Practice for Low Voltage Cables
- IEEE Std 1159: IEEE Recommended Practice for Monitoring Electric Power Quality

- USDOD
  - MIL-HDBK-237D: Electromagnetic Compatibility/Interference Plan Requirements
  - MIL-HDBK-419A: Grounding Bonding and Shielding for Electronic Equipment and Facilities (Volume I, Basic Theory, 1987)
  - MIL-STD-461F: Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference
  - MIL-STD-462D: Measurement of Electromagnetic Interference Characteristics

- ITU
  - Series K: Protection Against Interference: Management of electromagnetic interference on telecommunication systems due to power systems.

1.4.6 Supervisory Control and Data Acquisition (SCADA)

- Code of Federal Regulations (CFR)
  - Title 47 CFR, Part 15: Class A
  - Title 49 CFR, Part 236 Appendix E: Human-Machine Interface (HMI) Design
- Americans with Disabilities Act
- National Fire Protection Association (NFPA) Codes and Standards
- American National Standards Institute (ANSI) Standards
- Institute of Electrical and Electronics Engineers (IEEE) Standards
  - IEEE 802.1: Bridging and Management
  - IEEE 802.3: Ethernet
  - IEEE 802.11: Wireless LANs
  - IEEE 828: Standard for Software Configuration Management Plans
  - IEEE 1815-2012 - Standard for Electric Power Systems Communications-Distributed Network Protocol (DNP3)
- International Organization for Standardization (ISO) Standards
  - ISO/IEC 12207: Systems and software engineering -- Software life cycle processes
- Electronic Industries Association/Telecommunications Industry Association (EIA/TIA) Standards
  - EIA-310: Cabinets, Racks, Panels, and Associated Equipment
  - EIA 472: Generic Specifications for Fiber-optic cable
  - EIA/TIA-598: Optical Fiber Cable Color Coding
  - TIA-475.0000: Generic Specifications for Fiber Optic Connectors
  - TIA/EIA-455: Standard Test Procedures for Optical Fibers, Cables, Transducers, Sensors, Connecting and Terminating Devices, and other Fiber Optic Components.
  - TIA/EIA 568: Commercial Building Telecommunications Cabling Standards
  - TIA/EIA 569: Commercial Building Standard for Telecommunications Pathways and Spaces
- Underwriters Laboratories Inc. (UL) Publications
- Telcordia [Bellcore]
- Network Equipment-Building System (NEBS) LEVEL 3 requirements
  - GR-20: Generic Requirement for Optical Fiber and Optical Cables
  - GR-63: NEBS Requirements: Physical Protection
  - GR-771: Generic Requirements for Fiber Optic Splice Closures

1.5 Precedence of Conflicting Requirements

1.5.1 Precedence by Jurisdiction

This standard is specifically applicable to Electrification system including all Traction Power facilities and Overhead Contact System within Caltrain Right-Of-Way and on tracks on which Caltrain operates.

Where Caltrain operates within another (Third Party) railroad's or transportation's Right-Of-Way, the design requirements of Caltrain and the Third Party shall apply.

The design of facilities owned by a Third Party located outside Caltrain's Right-Of-Way shall comply with the requirements prescribed by the Third Party.

Where Third Party infrastructure is located within Caltrain's Right-Of-Way, the more stringent of the requirements shall apply as required to achieve concurrence of Caltrain and Third Party. If Caltrain's requirements and the Third-Party conflict, the requirements of the party owning the Right-of-Way shall apply.

1.5.2 Precedence by Type of Requirement

In general, applicable regulations and codes take precedence over standards and guidelines. In the case of differences between the regulations, codes, standards, and guidelines the criterion followed shall be that which results in the satisfaction of all applicable requirements.

1.5.3 Precedence of Requirements

- See General Provisions for precedence of documents.
- See General Provisions for precedence of Design Criteria and Design Standards.

1.6 General Design Parameters

1.6.1 Units of Measurement

Caltrain's system shall be based on U.S. Customary Units, defined by the National Institute of Standards and Technology (NIST). This is consistent with guidelines prepared by Caltrans.

Some of the referenced standards listed herein may be in the metric system. Design and construction drawings shall be developed in accordance with Caltrain's CADD Manual.

1.6.2 Structure Numbering

All OCS structures shall have a unique identification number in accordance with Section 3.15.5 and the Standard Drawings.

1.6.3 Design Variances

Approved design variances are required for design elements that do not meet the limiting (maximum/minimum) design criteria. Requests for variances to design criteria shall follow the process set forth in Caltrain Procedure G-24 "Caltrain Standard Procedure for Design Variances."

Design variances and exceptions to a Third Party's design standards shall follow the Third Party's design exception process.

Where a design variance is required for both Caltrain and Third Party, the design exception process for both entities shall be followed.

1.6.4 Designer Roles and Responsibilities

The Criteria contained in this Document are intended to ensure that the functionality, goals, and objectives of Caltrain are met. The Criteria shall be used in conjunction with sound engineering judgment, experience, and standard industry practices. This document in no way replaces the individual Designer's adherence to the profession's "standard of care" in design.

Caltrain's review or acceptance of any drawings or calculations does not relieve the Designer of their obligations or liability with respect to the adequacy, performance, or safety of the design. The Designer is ultimately responsible for every aspect of the design and its overall integrity.

1.6.5 Professional Licensing Requirement

Documents such as drawings, specifications, and calculations intended for the construction of Caltrain facilities shall be prepared under the supervision and approval of a licensed professional in accordance with the requirements of Title 16 of the CCR and shall be subject to the limitations of the licensing laws of the state of California.

1.6.6 Third Party Facilities

Unless otherwise stated in the contract documents, the design, construction, replacement or alteration of Third-Party facilities shall be done in-kind and in conformance with the published standards of the authority having jurisdiction.

1.7 Environmental Conditions

TES and OCS shall be designed to meet the performance required within this standard, under the environmental conditions outlined in **Table 2: Environmental Conditions**.

- **Table 2: Environmental Conditions**

Maximum Ambient Temperature	145° F
Minimum Ambient Temperature	15° F
Operational Wind Speed	55 mph
Average Annual Rainfall	15" to 20"
Maximum Rainfall	2.0" maximum in 24 hours, 1.5" maximum in 1 hour
Humidity	5% to 95%
Seismic Withstand Criteria	Zone 4 (as per IBC and CBC recommendations)
Wind design loads	As per ASCE
Isokeraunic level	10
Conductor Temperature	Maximum =176°F Minimum = 15°F

1.8 Design Life

Design life for Caltrain's system infrastructure and systems elements are presented in **Table 3: Design Life**.

These values are intended as baseline requirements for use in defining and assessing design and development standards and requirements, alternative materials and designs, and operational and maintenance activities.

- **Table 3: Design Life**

Systems Infrastructure	Design Life (years)
Traction Power Systems, including: Traction power supply system (TPS)	40
Steel Structures	100
Support Equipment, e.g. cantilevers	50
Disconnect Switches	30
Section Insulator-Non-Wearing parts	25
Section Insulator-Wearing parts	10
Other in-span equipment	25
Wires (excluding contact wire)	45
Contact wire	15-20
Overhead Conductor Bar	50
Foundations	100
Equipment and supporting cables Supervisory Control and Data Acquisition Communications wired and wireless data transport systems Communications administrative, control and timing systems Communications safety, security and fire detection systems Communications copper and fiber optic cable infrastructure and associated equipment	30
Other technology-based systems (Future): Equipment and non-safety critical microcontrollers, computers, software and similar commercial off-the-shelf (COTS) equipment	10

NOTE: The design life of the wearing parts, such as the section insulator runners and contact wire, will vary depending on several conditions such as the number of pantographs passes and OCS configuration.

1.9 Standardization

Design shall make every effort to use standard materials and equipment as per Caltrain standard design criteria, standard drawings and specifications. Standardization ensures ease of procurement and inventory management, minimizes staff training, optimizes maintenance, and generally try to avoid long lead times for materials, equipment, and components.

Equipment and materials shall meet industry standards, be available off the shelf, and supplied by established manufacturers with service-proven products for the application. Selection of equipment and materials shall consider long-term costs, ease of construction and maintenance, and readily available technical support.

1.10 Durability

Design shall assess potential for deterioration of materials and assemblies, including deterioration specific to exposure to the environment. Materials and detail assemblies shall be durable with minimal maintenance and repairs throughout their design life. For surface and assembly for which appearance is important, durability shall include maintenance required to preserve appearance.

Design shall consider the following aspects of durability:

- Control of moisture
- Control of corrosion (including material compatibility)
- Control of ultraviolet light exposure
- Control of exposure to industrial and vehicular pollution
- Minimize damage from wear and tear
- Ease of repair
- Minimize risk by using theft deterrent materials and configurations

1.11 Reliability, Availability, Maintainability and Safety

- The developed TES System Configuration shall be demonstrated to have a high level of reliability and availability. The reliability and availability targets need to be coordinated with overall project requirements.
- The developed TES system configuration shall state the maintainability requirements and demonstrate that system maintainability is sufficient to support the claimed system reliability and availability performance. The TES system shall demonstrate that maintenance errors have been considered, and as far as is practicable, the risk of maintenance induced faults has been mitigated by the appropriate design.
- The reliability and availability of the system design shall be demonstrated via simulation and/or practical experience from other railways and shall be demonstrated to offer the most cost-effective solution to achieve the required targets.
- The system design shall identify system failure modes and reliability criteria.
- The equipment to be supplied must be designed for minimum or no maintenance. The maintenance activity required must be capable of being performed with minimum or no impact on the train service.
- Where possible, all components shall be items commonly used and readily available and be interchangeable by design.
- The systems design shall mitigate against bi-metallic corrosion between dissimilar materials.
- The OCS design shall satisfy the requirements for bi-directional operation over all running lines as required.

1.12 Sustainability

1.12.1 Demonstration of High-Performance Design

Traction power facilities shall be designed in accordance with all applicable CalGreen Code mandatory measures and any applicable local Green Building Ordinances. The Designer shall develop a project specific sustainability goal through analysis and submit for Caltrain Engineering review. The goal for traction power facilities is to optimize the design in regard to site design, energy, water, materials use, indoor air quality, construction practices, and management. A means to demonstrate this optimization may be to use the Leadership in Energy and Environmental Design

(LEED), the Living Buildings Challenge, The Institute for Sustainable Infrastructures Envision System or other appropriate assessment methodology.

1.12.2 Energy Conservation

Caltrain Electrification Projects shall incorporate energy conservation and efficiency features and operating procedures in all planning, procurement, design, construction, operations, and maintenance of facilities. Caltrain Electrification Projects shall, at a minimum, use energy conservation and efficiency guidelines in applicable CalGreen Code mandatory measures. The energy conservation efforts shall not be to the detriment of system performance or reliability.

1.13 Construction

The contractor shall prepare and submit the Construction Plan prior to work commencing on site in accordance with the project requirements. This plan shall include all the hazards and risks associated with the construction work and comprehensively document the controls that are to be put in place to mitigate the risks. The TES infrastructure shall be constructed in accordance with the following:

- The requirements mentioned within this standard.
- Approved design and acceptance criteria (including sectioning diagrams, bonding plans, layout plans, system drawings, datasheets, cross-sections, switching cross section data sheets).
- Project specifications.
- Requirements of relevant legislation including the OSH Act and
- The manufacturers' installation instructions.

Staged construction work and final installation work shall ensure:

- Every part of the overhead contact system is connected to earth or energized at 25kV (e.g. no floating sections shall be permitted).
- Live parts of the overhead contact system and feeders or static wires shall not encroach over passenger station platforms in either permanent or temporary conditions.
- Adequate safety clearances, access prevention barriers and mechanical factors of safety.

1.13.1 Non-conformances

Any change to the design during the construction process shall be identified and shall be managed accordingly so that design changes can be monitored and approved. Approval by the designer may be retrospective after the construction stage for minor changes.

All construction work shall be verified by planned inspections and measurements to meet acceptance criteria (e.g. electrical clearances). Construction planning shall include consideration for work involving the decommissioning of redundant existing equipment as required.

1.13.2 Warranty Period and Hand Over

Warranty period shall be included in all construction works as per the project specific requirements.

1.14 Testing and Commissioning

The contractor shall prepare and submit a testing and commissioning plan to Caltrain for approval.

1.14.1 Inspection and Testing of Overhead Contact System

Construction inspections shall be carried out by the Contractor. The Contractor shall ensure that written records are made, and any defects found during these construction inspections are recorded on Punch Lists. Punch Lists shall include (at a minimum):

- Project name, report number, tension length number, date, start and finish location and structure numbers (line, location and track).
- Defects in the construction work requiring corrective action.
- The defect items shall be categorized as “minor” and “major.” Major items are those that affect the safety or operational status of the System.
- The corrective action required for each defect and agreed rectification date.
- Items requiring rectification by others to enable energization of the OCS.
- Date, name and signature of the inspector.
- Attendees

As per the project specific requirements, when all of the “major” defects have been rectified, final inspections completed, then the Punch Lists can be signed off by the Contractor’s responsible officer and accepted by Caltrain. This sign off indicates that constructed OCS is safe and ready for energization.

1.14.2 Construction Compliance Certification

The Qualified Technical Person for the electrical contractor completing the Electrification work shall certify that new and modified work is safe and ready for handover into operation and maintenance. The certificate shall be supported by acceptance records and refer to any approved departures from design.

1.15 Commissioning

Procedures for commissioning activities shall be developed, implemented and include a planned inspection test, commissioning and integration plan suitable for the complexity and type of installation and system concerned. Both the modification works of existing electric traction infrastructure, and the decommissioning and disposal works of existing electric traction infrastructure shall be managed by a suitable commissioning and hand over plan. Staff performing inspection and testing duties shall be competent for the tasks being carried out.

Energization of electric traction infrastructure shall not commence until:

- Adequate safety inspections have been carried out
- All major safety and performance defects have been rectified

Commissioning and integration testing shall be carried out, when required, to validate modifications and enhancements interface adequately with existing systems and networks including:

a) Control, protection and power systems are fit for the intended duty nominated within the project plan (including required traffic task).

b) Adequate interfacing with nominated reference trains (if required) and upstream transmission and distribution networks.

1.15.1 Decommissioning and Demolition

Commissioning plan shall include consideration for work involving decommissioning of redundant equipment where this is relevant. Reclaiming and demolition activities shall be carried out in a safe manner with due consideration to personnel, the operating rail infrastructure and any public hazards.

END OF CHAPTER 1

CHAPTER 2

TRACTION POWER SYSTEM

2.0 Traction Power System (TPS)

2.1 Scope

The scope of this chapter includes the main design requirements for the Traction Power System (TPS) and associated site works for the Caltrain network, which is based on a nominal 25 kilovolt (kV) AC autotransformer feed configuration system.

2.2 Overview and General Design Criteria

2.2.1 Traction Electrification System

Traction Electrification System (TES) is the combination of the TPS, OCS, and the traction power return system, together with appropriate interfaces to the TES-related Supervisory Control and Data Acquisition (SCADA) System. It forms a fully functional 2x25 kV AC, autotransformer-based feeder system to power electrical train set equipment on the railway line.

2.2.2 System Configuration

The TES shall have a 2 x 25 kV AC autotransformer feed type configuration. TES configuration shall utilize Traction Power Substations (TPSS) with main power transformers and Switching Stations (SWS) and Paralleling (Balancing) Stations (PS), both with autotransformers, which provide 25 kV (nominal) voltage to the catenary with respect to ground, and also 25 kV to along-track autotransformer feeders (ATF) with respect to ground. Both of these voltages are 180° out-of-phase with each other; therefore, the voltage between the catenary and the ATF is 50 kV (nominal). In an autotransformer system, the autotransformer feeder (ATF) is a parallel conductor which, together with the OCS conductors, forms a 50kV transmission line along the railway. This parallel ATF conductor is connected, via circuit breakers and disconnect switches to one terminal (X2) of a main power supply transformer secondary winding, and autotransformer windings in the traction power facilities. At these facilities, the other terminal (X1) of the transformers is connected to an OCS section or sections, via circuit breakers and disconnect switches. The center-tap of the 25kV-0-25kV main transformer secondary and autotransformer windings are attached to the running rails, aerial static wires, and buried grounding conductors, together with all bonding and grounding interconnections.

Traction power is supplied to the EMUs from wayside TPF through the catenary, which distributes the power to the pantographs. The pantographs, mounted on the roof of the EMU, collect the traction power from the catenary through mechanical contact by running/sliding under the contact wire. The electrical circuit is completed through EMU wheels connection with the rail and return current goes back to the source TPSS via multiple return paths, including running rails, static wires, ground, and the ATF. From the TPSS—which transforms the PG&E high-voltage (HV) from 115kV network to 2x25 kV single-phase power of the autotransformer feed system—the power for the trains is distributed along the tracks by the OCS. Along the open route, the ATF are bare overhead conductors, one ATF per main track, attached to the catenary structures with brackets and insulators. The catenary consists of a messenger wire and a contact wire. The contact wire is suspended from the messenger wire by means of hangers and tied electrically to the messenger wire by means of jumper wires.

Autotransformers are provided periodically along the line, interconnecting catenary, ATF and rails. The autotransformer turns ratio shall be 2:1 of primary (catenary-to-ATF) to secondary (catenary-to-rails) windings, in order to step down the 50 kV distribution voltage between catenary and ATF and provide 25 kV power for the trains from the OCS/ATF 50kV distribution system. The autotransformers effectively balance the OCS and ATF currents and reduce the rail return current in adjacent supply segments between autotransformer installations. This configuration increases the traction energy transmitted at 50kV, thereby maintaining a higher load voltage at the pantograph and permitting longer feeding distances from supply stations.

2.2.3 TPS Performance Requirements

The TPS, in conjunction with the OCS, shall be designed to meet the following performance requirements within the safety parameters listed below:

The current maximum allowable speed of EMUs is 79 mph. Any future design must accommodate the California High Speed Rail's (CHSRA) trains operating at 110 mph depending upon the allowable track speed and designer's assessment.

The design peak frequency of trains is envisioned as 8 (eight) 7-car Caltrain Trains operating at 79 mph and 4 (four) 16-car High Speed Rail trains operating at 110 mph, which shall be 12 trains per hour in each direction.

There shall be no degradation of train performance in case of single electrical contingency conditions and there shall be no stranding of trains in case of double electrical contingency conditions. See Section 2.5.1, for further details.

The system will support the maximum train current, the tractive effort and braking effort available/permissible at different speeds, the train acceleration/deceleration/adhesion characteristics, and other relevant parameters of a typical modern high-speed train (Caltrain) system. (This information shall be coordinated with Rolling Stock.)

The rail potential shall comply with EN 50122-1, with the maximum permissible touch voltages and their durations listed in **Table 12: Duration of Maximum Permissible Touch Voltages**.

In areas where the Union Pacific Railroad operates on an adjacent non-electrified track, the maximum permissible voltage shall not exceed 50 Volts.

2.2.4 General Design Requirements

Safety Design – The design of the TPS and associated site works shall incorporate the following principles:

a. Avoiding, eliminating, or reducing hazards identified by engineering hazard analysis, through design choices, material selection, or substitution.
b. Incorporating fail-safe principles where failures could disable the system, cause human injury, damage to equipment, or inadvertent operation of critical equipment.
c. Locating equipment components so that access to them by the required personnel during operation, maintenance, repair, or adjustment shall not require exposure to hazards such as entrapment, traffic hazard, chemical burns, electrical shock, cutting edges, sharp points, or toxic atmospheres.
d. Providing measures designed to prevent or discourage unauthorized people from entering hazardous areas. See the Electromagnetic Interference and Compatibility chapter for additional requirements.

e. All components containing or generating obnoxious, flammable, and harmful gases shall be vented to the outside.
f. Cables and wires of different systems and/or high- and low-voltage conductors shall be physically segregated / separated from each other and rated in accordance with the requirements specified in CEC, NEC and IEEE 1100, as applicable.

Product Selection – All prescribed equipment, materials, cables and appurtenances shall be either certified by a nationally recognized testing laboratory, or compliant with relevant ANSI/IEEE, EN or local standards.

a. All prescribed equipment, materials, cables and appurtenances shall be designed, constructed and have a "proven track record" of operating within the intended application and operating environment.
b. All equipment, materials, cables and appurtenances shall be produced by manufacturers that are regularly engaged (i.e., at least 5 consecutive years) in the production of such products.
c. All prescribed equipment, materials, cables and appurtenances shall adhere to applicable practices recommended by AREMA.

Uniformity – Equipment enclosures, assemblies, sub-assemblies, and/or components that do not differ in operational, functional, and/or performance characteristics shall be designed so that all components are positioned in the same location and internal wiring is routed between components in a like manner.

Where identical installations exist, the following requirements shall be adhered to (unless site conditions prevent it):

a. Equipment enclosures shall be mounted and installed in a like manner.
b. Penetrations for conduit, grounding, and access panels shall be in the same place.
c. The location of equipment relative to adjacent equipment shall not differ.
d. The routing of conduit, cable tray, and cables between equipment enclosures shall not differ.
e. Termination hardware shall be located in like manner.
f. Cables and wire terminations shall be located in like manner.

Accessibility and Equipment Arrangement – Working clearances on all sides of equipment shall be provided (per the equipment manufacturer's recommendations, power utility requirements, CEC, NEC and/or NESC); as well as horizontal and vertical clearance for equipment removal, replacement and/or maintenance (without impacting other energized equipment), and door openings/hatches.

a. Each prefabricated enclosure for 25-kV indoor switchgear shall have adequate area to accommodate the electrical equipment, raceways/cable trays and ancillary components, and personnel, and allow for easy removal and replacement of any equipment item.
b. All switchgear enclosures shall have front- and rear- access doors. The enclosures with removable panels shall not be used in future modifications and projects as they pose mechanical handling hazard to the maintainers.

2.3 TPS Design

2.3.1 Traction Power Substations

There are two Traction Power Substations to provide traction power, TPSS-1 located at mile post 9.04 in South San Francisco and TPSS-2 at mile post 45.24 in San Jose. The TPSS locations have been determined in consideration of the results of the load simulation analysis, proximity to high-voltage transmission facilities and feasibility of drawing the required HV power, and availability of real estate.

HV Connection Scheme – At each TPSS, 2 separate 115kV feeders are drawn from the power utility network. Each utility supply feeder consists of two phases, to provide the single-phase power required for the traction power system. These circuits originate from different utility substations or from different bus systems. Two 60MVA HV traction power transformers are provided at each TPSS, with each transformer supplied from a separate incoming circuit. Both transformers are energized under normal TES configuration—one of them supplying power to the feed section north of the TPSS and the other to the section to the south—with the two feed sections separated by a phase-break at the TPSS. Both HV power transformers are individually capable of supplying the full normal load of the TPSS.

a. The HV MPT's shall be single-phase, with their primary windings connected to two phases of the utility 115kV 3-phase system. The secondary winding of the HV transformer shall either be a single winding with a grounded midpoint connected also to the running rails or comprise two separate counter-phase secondary windings connected in series, with the common point grounded and connected to the running rails.
b. For HV MPT details refer to Section 2.6.3.

The TPS design shall address power quality issues, such as voltage imbalance, voltage flicker, and harmonic distortion caused by the railway load on the HV supply system, arising from operation of the Caltrain and high-speed rail trains. The measures shall be subject to approval/concurrence by Caltrain.

The TPS system design shall consider rolling stock harmonic spectrum and avoid possible harmonic resonances in the traction power system.

The power factor at the TPS infeed shall be as per PG&E power quality requirements (PG&E Transmission Interconnection Latest Handbook).

Configuration and Operational Flexibility – The traction power substation's single-line diagram and reconfiguration capabilities shall be such that in the event of a power loss to one of the incoming 115kV feeder lines, or temporary outage of one of the transformers, or transformer-related equipment, or outage of a 25 kV bus section, the remaining transformer shall be able to supply power to the feed sections north and south of the TPSS.

The catenary bus of the TPSS (the bus supplying power to the OCS) is split into two sections interconnected via a normally open (N.O.) motorized tie circuit breaker, with each bus section supplied by a different transformer under normal conditions. Each section of the positive bus feeds two different catenary electrical sections in normal TES configuration for two main tracks. The autotransformer feeder bus of the TPSS (the bus supplying power to the along-track ATF) is sectionalized likewise. Tie-breakers of the catenary and the ATF buses are double-pole circuit breakers. The tie-breakers are also interlocked with their associated disconnect switches and the main transformer circuit breakers to prevent inadvertent bridging of 2 incoming supplies.

The outer terminals of the secondary winding of each HV MPT are connected to the catenary feeder and autotransformer feeder buses (the bus sections corresponding to the particular transformer) through a double-pole circuit breaker. The catenary feeder and autotransformer feeder buses in turn are connected to the catenary and ATF, respectively, through double-pole circuit breakers and in-series connected to no-load motorized disconnect switches.

Jumper-type motorized, N.O., no-load motorized disconnect switches are also be provided, connected between each pair of in-phase, same-side, single-pole circuits to allow for one 25 kV circuit to feed both track sections under emergency conditions in the event of TPSS failure. Furthermore, N.O. trackside, motorized, no-load motor operated switches are installed at the substation's phase break, to provide for electrical continuity in emergency conditions between the catenary and ATF, respectively, to feed either side of the phase break. The flexibility and re-configuration capability of the single line diagram of the TPSS on the 50/25 kV side shall be such that a loss of 1 single-pole circuit breaker, or disconnect switch, or interconnecting cable still allows the TPSS to feed the whole feed zone of the TPSS without having to de-energize one of the main power transformers.

2.3.2 Switching Stations

General – The SWS is a facility interfacing the feeding sections of adjacent TPSS. This is an installation at which electrical energy can be supplied to an adjacent but normally separated electrical section during contingency power supply conditions. SWS is located at milepost 26.10 in Redwood City.

Connection – AC voltages on either side of the phase breaks at SWS are of different phases (or even if these have the same phase sequence, the angular displacement may be different). In normal operations, the phase break disconnect switches and tie breaker located at the gantry structure are open, isolating the 2 feed sections. Autotransformers (ATs) are connected on either side of the phase break, 1 AT per side, serving as the last AT of the respective feed section.

The catenary and ATF buses are connected in turn to the primary winding terminals of the AT via a double-pole circuit breaker. The AT winding center tap shall be connected to a neutral bus, which shall be locally grounded and connected to the running rails of both tracks (through impedance bonds as required) and to the static wires.

Configuration – The SWS equipment includes switchgear (25 kV circuit breakers) and motorized disconnect and bypass switches in a configuration that allows isolation of an AT in case of problems, and as required for maintenance. The SWS design provides for electrical continuity across the phase break in contingency operations, in the event the TPSS on one side is out-of-service. In such instances, the TPSS on the other side of the SWS is used to provide power to the sections normally served by the outaged TPSS. This can be achieved by interconnecting the catenary and ATF on both sides of the SWS, by closing N.O. tie circuit breakers. Furthermore, N.O. trackside, motorized, load-break disconnect switches are installed at the SWS phase break, to provide for electrical continuity in emergency conditions between the OCS and ATF, respectively, on either side of the phase break. Suitable interlocking is provided between the tiebreakers and the phase-break bridging disconnect switches at the SWS with the circuit breakers of adjacent substations to prevent inadvertent bridging of feeds from the two substations.

2.3.3 Paralleling (Balancing) Stations

General – The Paralleling Station (PS) is a facility featuring an Auto Transformer as part of the 2x25 kV TES, and associated switchgear and disconnect switches. The PS helps boost the OCS voltage and reduce the running rail return current by means of the autotransformer feed configuration. The TPSS, the number and locations of the PS have been determined based on the results of a traction power study, and by taking into account environmental and real estate considerations. There are seven Paralleling stations in the Caltrain network at the following locations.

- **Table 4: PS Locations**

Paralleling Station	Mile post	Location
PS-1	1.10	Mariposa St.
PS-2	4.94	Bayshore
PS-3	14.76	Broadway
PS-4	20.20	Hillsdale
PS-5	31.84	West Meadow

PS-6	38.61	Sunnyvale
PS-7	48.99	Pullman

AT Connection – One AT serving all tracks is installed at each PS, along with a line-up of medium voltage switchgear containing separate buses for connections to the catenary and ATF circuits. The switch gear includes double-pole 25 kV catenary circuit breakers and ATF circuit breakers, and double-pole 50 kV AT circuit breaker. The catenary and ATF conductors are connected to the switchgear buses via no-load type motorized disconnect switches and the switchgear. The catenary and ATF buses are connected in turn to the primary winding terminals of the AT via a double-pole circuit breaker. The AT winding center tap is connected to a neutral bus, which shall be locally grounded and connected also to the running rails of both tracks (through impedance bonds as required) and to the static wires.

PS Configuration – The PS shall provide a booster connection to the OCS, without OCS sectionalizing gap. There shall be no sectionalizing of the catenary and ATF circuits at the PS. The catenary of each main track shall be connected via double pole circuit breaker to the catenary bus of the PS. Likewise, the ATF wire of each track shall be connected via tap connection and single-pole circuit breaker to the ATF bus. For a PS serving only 2 main tracks this configuration results in 2 double pole circuit breakers overall—1 for the OCS bus and 1 for the ATF bus.

2.3.4 Electrical Sectioning

Main Tracks – The catenary shall be sectionalized between the tracks and longitudinally on the same track along the route in order to limit the extent of an outage zone due to faults or maintenance. Longitudinal sectionalizing of the catenary shall be provided at the TPSS, SWS, and at all track interlockings and track turnouts. The sectionalizing at the TPSS and SWS shall be of the phase break type; elsewhere it shall be a regular sectioning gap (insulated overlap or air gap type on the main tracks). Section insulators are not permitted on the main tracks but can be installed on the crossovers and turnout tracks.

At TPF, the sectionalizing gaps shall be provided with N.O. no-load type motorized disconnect switches that can be closed during contingency operations if the catenary on both sides of the sectionalizing gap needs to be electrically continuous.

At track interlockings, the longitudinal sectionalizing gaps shall be provided with normally closed (N.C.) circuit breakers and/or motorized disconnect switches, which can be opened during contingency operations to isolate a smaller segment of one track between adjacent interlockings (contained within an electrical section) or within an interlocking and the adjacent TPSS or SWS (contained within an electrical section), and permit single-track operations on the other track. At back-to-back crossovers, the sectionalizing arrangement shall be such that the catenary of any track on either side of the interlocking can be isolated selectively.

Concerning the autotransformer Feeder phase, two parallel along-track ATF shall be provided along the route (1 per main track) regardless of the number of parallel tracks at a given location. Longitudinally, the ATF system shall be sectionalized at the TPSS and SWS.

Power Supply to Sidings and Extra Terminal Tracks – As a rule, the power supply to short segments of track sidings not used for regular train service along the main line shall be derived from the adjacent main track via N.C. no-load type motorized disconnect switch across the sectionalizing gap at the turnout. If the siding has turnouts from the main track at both ends, sectionalizing gaps and switches shall be provided at both ends, with one of the disconnect switches being N.O. and the other N.C. type. Such feeding arrangement shall be used regardless of whether the track siding is close to a TPF or not. At terminals with more than 2 tracks, traction power for the additional tracks shall be derived from the main tracks in similar fashion (i.e., using

N.C. motorized disconnect switches across sectionalizing gaps at the turnouts). Both sidings and extra terminal tracks shall be radially fed from the adjoining main track through a single connection point. Exceptions to the above rule shall be subject to approval by Caltrain.

Overhead Line Switches – The N.O. disconnect switches at sectionalizing gaps at TPF, and the N.C. sectionalizing or power supply switches at track interlockings shall be load-break type, motorized, featuring remote status monitoring and remote-control capabilities. Refer to the Overhead Contact System and Traction Power Return System chapter for additional requirements.

2.4 System Voltage and Frequency

2.4.1 System Voltage

The system voltage (U) shall be the potential at the train's current collector or elsewhere on the catenary, measured between the catenary and the rail return circuit. It shall be the root mean square (rms) value of the fundamental AC voltage, and its values shall be as follows (refer to European Standard EN 50163 – 2004: Railway Applications – Supply Voltages of Traction Systems):

The nominal voltage (Un), (the designated value for the system voltage) shall be 25 kV.

The highest permanent voltage (Umax1) (the maximum value of the voltage likely to be present indefinitely) shall be 27.5 kV.

The highest non-permanent voltage (Umax2) (the maximum value voltage likely to be present for a limited period of time (as defined below) shall be 29.0 kV.

The lowest permanent voltage (Umin1) (the minimum value of voltage likely to be present indefinitely) shall be 19.0 kV.

The lowest non-permanent voltage (Umin2) (the minimum value of voltage likely to be present for a limited period of time (as defined below in Section 2.4.2) shall be 17.5 kV.

2.4.2 Voltage Related Requirements

The following voltage related requirements shall be fulfilled:

- The duration of voltages between Umin1 and Umin2 shall not exceed 2 minutes.
- The duration of voltages between Umax1 and Umax2 shall not exceed 5 minutes. If voltage between Umax1 and Umax2 is reached, it shall be followed by a level below or equal to Umax1 for an unspecified period. Voltages between Umax1 and Umax2 shall only be reached for non-permanent conditions such as regenerative braking.
- The voltage at the busbar of the substation at no-load conditions shall be less than or equal to Umax1.
- Under normal operating conditions, voltages shall be within the range of Umin1 :: U :: Umax2.
- Under abnormal operating conditions, the voltage in the range of Umin2 :: U :: Umin1 shall not cause any damage or failure and shall permit continuing vehicle operation with some significant degradation. Rated vehicle power and performance will not be available, but reduced operation will be possible assuming onboard logic will automatically degrade the performance of the traction system (rolling stock) and auxiliaries. Typical abnormal operating conditions could include substation outage, loss of one or more transformers at the substation, utility supply problems, etc. See 2.5.1 Continuity of Power Supply in Case of Disturbances for details.

- The setting of under-voltage relays in fixed installations or onboard rolling stock should be from 85 percent to 95 percent of Umin2.
- Both the following acceptance criteria for “Quality Index of Power Supply” for AC 2 X 25 kV autotransformer feed configuration shall be satisfied (refer to Section 8 of EN 50388 – Railway Applications: Power Supply and Rolling Stock – Technical Criteria for the coordination between power supply (substations) and rolling stock to achieve interoperability):

Um = > 22.5 kV

Ui => 19 kV (Umin1 – Lowest permanent voltage)

Where

Mean Useful Voltage (Um) is the mean value of all rms voltages analyzed in the system simulation study, and gives an indication of the quality of the power supply for the entire system during the peak traffic period in the timetable, and Um = L. Ui/N where Ui is the rms ac voltage over the ith second during the peak period for all trains in the system, and N is the total number of observations.

The TPS designer shall verify this by a traction power simulation study using the specific Caltrain design parameters.

2.4.3 Frequency

The nominal frequency of the supply voltage shall be 60 Hz.

2.5 System Configuration

2.5.1 Continuity of Power Supply in Case of Disturbances

The TPS and the OCS shall be designed to enable continuity of operation in case of disturbances such as:

- There must be no degradation of train performance in case of single electrical contingency conditions, i.e. isolation of any 1 main power transformer in a substation, 1 auto transformer in a PS/switching station or of ATF for any one electrical section.
- There must be no stranding of trains in case of double electrical contingency conditions (simultaneous occurrence of more than 1 single electrical contingency condition in any electrical section).
- The minimum permanent voltage at the train’s pantograph (both under normal as well as single contingency conditions) is 19 kV.
- The acceptance criteria of Quality Index of Power described in Section 2.4.2 are satisfied.
- The minimum non-permanent voltage at the train’s pantograph (under double electrical contingency conditions) is 17.5 kV.

2.5.2 Electrical Protection Coordination

The protection system for the TES shall be designed for a maximum catenary – rails short-circuit fault current of 15 kA.

Compatibility of protective systems between traction unit (rolling stock) and TPSS shall be verified for the following:

- When any internal fault occurs within the traction units, the TPSS feeder circuit breaker and the traction unit circuit breaker may trip immediately. However, the traction unit circuit breaker should trip in order to avoid the substation circuit breaker tripping.
- After the substation circuit breakers have tripped, these breakers shall be capable of being reclosed either automatically or manually after a lapse of at least 5 seconds.
- The traction unit circuit breakers shall trip automatically within 2 seconds after loss of line voltage.
- On re-energization, the traction unit circuit breaker shall not reclose within 3 seconds of the line being re-energized depending upon location the reclosure shall be between 3 to 5 seconds.

2.5.3 Protective Provisions of Traction Power Facilities

The TES design presupposes running rails electrically insulated from ground, but connected to ground at intervals, at least at TPF locations, through the neutral points of impedance bonds. A part of the return current will flow through the running rails because they are part of the traction return system. Because of the impedance of the rails, this return current flow will cause a voltage with respect to the ground especially at locations away from the ground connections.

Electrical safety of the TPS shall be achieved by the following means:

The installations shall be designed and tested such that the permissible touch voltages caused by the traction system under fault conditions or in operating conditions shall not exceed values specified in **Table 12: Duration of Maximum Permissible Touch Voltages**.

A direct connection shall be made between the return circuit and the grounding system of the TPF (TPSS, SWS, and PS). Each TPF return bus shall be connected to the running rails via impedance bonds by at least two return cables. Each return cable shall be of sufficient size to carry the maximum load current, thereby allowing for the failure of one return cable. The connection to the running rails is through impedance bonds. Connections shall also be provided from the aerial static wire to the return bus. Fuses, non-lockable switches, and joint straps that can be released without a tool are not allowed in the return circuit.

The rated impulse voltage (UNi) and the short-duration power-frequency (AC) test level voltage UA (kV rms) shall be as given in **Table 5: Rated Impulse Voltage and Power Frequency Test Voltage** (Refer to European Standard EN 50124-1: Railway Applications – Insulation Coordination – Part 1: Basic Requirements – Clearances and Creepage Distances for all Electrical and Electronic Equipment.)

- **Table 5: Rated Impulse Voltage and Power Frequency Test Voltage**

	Rated Impulse Voltage UNi (kVcrest) *a	Short-Duration Power- Frequency (AC) Test Level Voltage UA (kV rms) *b
Between Catenary/Autotransformer Feeder and Ground	200	95
Between Catenary and Autotransformer Feeder	250	95

Notes:

*a Based on Table A.2, EN 50124-1 (against Rated Insulation Voltage 27.5 kV – Higher Values for Fixed Installations)
*b Based on Table B.1, EN 50124-1 (against UNi of 200 kV and 250 kV, respectively) TPF site between the TPF and the trackside.

The grounding of TPF shall be integrated into the general grounding system along the route to comply with the requirements for mitigating electric shock as specified above.

2.5.4 Harmonic Distortion Limits

The harmonic distortion limits for individual and total harmonic distortion of voltage and current shall be followed as per IEEE Std 519, "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems," unless the limits imposed by the concerned power supply utility are stricter.

2.5.5 Electromagnetic Compatibility

The TPS installations shall conform to the criteria in Traction Electrification System EMC Design Criteria of the Electromagnetic Interference and Compatibility chapter.

2.6 Traction Power Facilities and Associated Sites

2.6.1 General Site Requirements

Access/Egress – Access to each TPF site shall be required for operation and maintenance purposes. Access roads leading to/from the TPF shall be designed in accordance with the ordinances of the local jurisdiction, in which the TPF are located. Access roads and gates at TPF shall be sized to permit placement and removal of all TPF equipment and access by first responders/fire department vehicles. The design of the access roadways and equipment arrangement within the TPF shall ensure that equipment owned by and/or maintained by the local power utility company is located within a distance from the access roadway, as specified by the relevant power supply utility. Every TPF will have a communications enclosure for locating communications interface equipment relating to TES SCADA and other associated equipment.

Security – The design of the access gates shall include a means to secure the gates and prevent unauthorized access. All equipment enclosures shall have a Caltrain-approved locking device. The doorways at the prefabricated equipment enclosures shall include Caltrain-approved intrusion detection hardware, which shall be remotely monitored.

Parking Spaces – A minimum of 4 parking spaces for operations and maintenance (O&M) personnel shall be incorporated into the design of each TPF site.

Aesthetic Treatments – TPF and their sites shall be designed to minimize the adverse visual impact on the areas in which they are located and to follow the appropriate architectural and environmental guidelines.

Drainage – See the Drainage section in the Caltrain Design Criteria. Drainage shall be provided and ensured that there is no water logging in the TPF yards.

Equipment/Enclosure Safety Signage – Safety signage shall be provided at all TPF in accordance with applicable codes and standards (e.g. Cal/OSHA, NEC, NESC, CPUC GOs, Caltrain Standard drawings etc.).

Protective Barriers – Protective barriers shall be provided at traction installations that are subject to road vehicle damage.

Signage and Asset Identification: Each equipment and enclosure shall be provided with asset ID and signage as per Caltrain assets sign convention.

2.6.2 Equipment Support Steel

Equipment supporting steel shall have a hot-dipped galvanized finish, suitable for the intended working environment. Structural steel shall include a cleat/bracket with 2 holes to permit 2-hole grounding/bonding lug connections. All bolts and lugs shall be torqued as per ANSI/NETA and manufacturer's manual.

2.6.3 High-Voltage Main Power Transformer (MPT)

The existing HV MPT's provided in TPSS-1 and TPSS-2 are outdoor type, mineral-oil insulated, and self-cooled, OLTC transformers with a 60 MVA 115-27.5kV ONAN nominal rating.
The HV MPT's conform to the appropriate duty class as specified in the European Standard EN 50329:2003+A1:2010, corresponding to the load curves based on the traction power load flow study.

2.6.4 Autotransformers

AT are outdoor type, mineral-oil-insulated, and self-cooled, with a 10 MVA ONAN nominal rating.
The AT shall conform to the appropriate duty class as specified in the European Standard EN 50329:2003+A1:2010, corresponding to the load curves based on the traction power load flow study. The AT is single-phase, with the primary winding connected between the catenary and ATF circuits, and the center tap grounded and connected to the running rails (and to the static wires). The nominal voltage of the primary winding shall be 50.0 kV between the winding terminals, and 25.0 kV to ground. Turns ratio between OCS side and center tap to center tap and ATF side shall be 1:1. Autotransformer design shall minimize leakage reactance, and the autotransformer impedance shall be around 1.2 percent.

2.6.5 High-Voltage Switchgear

Each HV MPT is connected to the incoming utility line via outdoor HV switchgear of the same voltage class as the utility supply line (nominal 115 kV). The switch gear shall include a circuit breaker, motorized gang-operated air isolation switches, instrument transformers and other accessories. The basic impulse level rating of the outdoor HV switchgear shall be minimum of 550 kV for 115 kV line. The power circuit breakers are outdoor type, 121 kV rms maximum operating voltage for 115 kV line, 550 kV basic impulse level, double-pole, SF6 insulated, free standing. Short-circuit interrupting current capability shall be 40 kA. The circuit breaker shall be rated for operation on a nominal 115 kV, effectively grounded utility transmission system. It shall be similar to a 3-phase circuit breaker of the same voltage rating, except that one phase/pole will not be used.

2.6.6 Prefabricated Enclosures for 25 kV Indoor Switchgear

The 25 kV phase-to-ground class switchgear and associated control and protection systems of the TPSS, SWS, and PS shall be indoor type. The medium-voltage switchgear and related protection control, and auxiliary systems at each TPF site shall be housed in a prefabricated walk-in, climatized, and transportable metal enclosure (or in 2 separate enclosures). The enclosure shall be fabricated from sheet steel, mounted on structural steel base, and provided with internal and external high durability paint finishes designed to prevent corrosion over the life of the enclosures.

Non-painted steel surfaces shall be hot-dipped galvanized after fabrication. Damage to galvanized areas caused by the fabrication process shall be repaired in accordance with ASTM A780/A780M: Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings.

At least two doorways, located at diametrically opposite ends of the enclosures, shall be provided to permit an unobstructed means of egress in accordance with the California Building Code. One of the doorways shall be sized and located to allow removal or replacement of the largest piece of equipment in the room and shall be located such that the equipment can be moved through the enclosure to the outside for transporting off-site.

The design of the enclosures shall ensure a dry internal environment within the specified temperature and humidity limits. The enclosures shall be designed to withstand the level of structural, wind, and seismic loading as specified in the General, Seismic and Structures sections. The floor and walls of each enclosure shall be designed to support the equipment, raceway, and cable tray systems installed and to provide openings to cable trenches, without buckling, bending, or sagging.

2.6.7 25 kV Single-Phase Switchgear

The 25 kV class single-phase circuit breakers shall be as per applicable European standards for railway applications and suitable for indoor installation and shall have rated for maximum operating voltage to ground of 29 kV. Circuit breakers protecting catenary or ATF circuits shall be single pole. Circuit breakers for the AT or on the secondary side of the HV transformers shall be double pole. Nominal phase-to-ground voltage for both single-pole and double-pole circuit breakers will be 25 kV in all the TPF. The pole-to-pole nominal voltages for the double-pole circuit breakers shall be twice the respective voltages to ground. The circuit breakers shall be sealed vacuum type. The AC switchgear are SF6 gas insulated fixed mounted breakers.

The metal-clad gas insulated switchgear shall have the same voltage rating as the circuit breakers. In metal-clad switch gear the stationary contacts of the circuit breakers can be connected directly to the common bus without a disconnect switch. The basic impulse level of the switchgear shall be 250 kV or higher.

Power connections from the catenary and ATF of each track to the 25-kV buses of TPSS, SWS, and PS are through single-phase circuit breakers (forming part of the indoor switchgear lineups) and outdoor gantry-mounted disconnect switches. The latter are motorized and connected in series with the circuit breakers, to provide visible circuit isolation means between tracks and TPF. The disconnects in series with the circuit breakers are no-load type and are interlocked with the respective circuit breaker so that the switch cannot be operated unless the circuit breaker is open.

Switchgear in the TPF and outdoor mounted disconnect switches are interlocked with the associated circuit breakers to ensure the safety of O&M personnel and equipment for all possible circuit configurations, and to avoid inadvertent paralleling of different electrical sections.
Circuit breakers equipped with protective relaying for catenary and ATF circuit protection have multi-stage auto-reclosing capability. Circuit breakers have physical (padlocking) lockout/tag-out provision when the circuit breaker is in the disconnected position. All circuit breakers and motorized disconnect switches can be locally and remotely controlled. Control means to operate all switchgear remotely from the ROCS, and locally via a mimic annunciation panel, graphical user interface, and/or control switches on the equipment.

All AC switchgear cubicles and control equipment cabinets shall be equipped with equipment space heaters, which are thermostatically and humid-statically controlled.

2.6.8 Electrical Enclosures Painting and Finish

All electrical equipment enclosures, materials, and appurtenances shall have a corrosion resistant finish and shall have protection rating for use in high pollution environments. Outdoor enclosures shall be NEMA 4X rated.

2.6.9 Auxiliary and Control Power

- For all TPFs, Primary Auxiliary Power shall be derived from a single-phase 75kVA, 27.5kV-240/120V pad-mount transformer connected to the substation's AT Feeder Bus. The transformer secondary is connected to the "normal" pole of the automatic transfer switch (ATS) located in the TPF.
- TPF Alternate Auxiliary Power shall be a 120/240V source delivered from a PG&E service drop. The primary auxiliary power shall be connected to the "emergency" pole of the automatic transfer switch located in the TPF.
- The load side of automatic transfer switch shall be connected to the "normal" pole of the manual transfer switch (MLTS).

2.6.10 Relay Protection

The objective of the relay protection system shall be to protect the TES equipment and cables within the TPF and the catenary and ATF against short-circuit faults, overloading, and subcomponent failures. This includes fault location and discrimination capabilities, including automatic circuit breaker reclosing for catenary and ATF circuits, as well as manual local and remote re-closure management. It provides proper coordination and selectivity for rapid fault clearance to the affected area of the system only, preventing as much as possible the loss of power to the healthy sections of the TES. It shall adequately discriminate between short-term high loads and fault conditions.

Each HV MPT and autotransformer shall be provided with the following protective devices:

- Overcurrent relays on the primary side (HV MPT's only)
- Differential relays
- Ground overcurrent relay on the secondary side
- Over-temperature protection
- Oil-level and oil-pressure detection relays and alarms

Typically, the protective relays for catenary and ATF circuits employed shall include, but not be limited to, the following:

- Instantaneous and time delay overcurrent relays (for backup short-circuit protection).
- Multi-zone distance relays (for primary short-circuit protection). The distance relays shall feature at least 3 zones with separately adjustable parameters.
- Undervoltage/overvoltage relay.
- Thermal overload relay, for protection of the downstream catenary or ATF circuit against overheating. This relay shall be thermal replica type and shall include an ambient temperature probe located outside the traction power facility, with a feedback loop to the relay.
- Phase directional overcurrent relay.
- Multi-shot automatic reclosing relay (maximum number of auto-reclosing attempts and pause durations to be determined in coordination with the overall protective relaying scheme).

2.6.11 Protective Relaying Scheme for Catenary and ATF Fault Detection

Circuit breakers equipped with distance relays shall feature multi-stage auto-reclosing capability, and catenary and ATF circuit breakers shall have separate protective relaying. The preferred relay protection scheme shall be based on the following general principles:

The distance relays shall be located in the TPSS. The distance relays shall be set to protect the entire feed section from the TPSS to the SWS, or to the end-of-line (in case of the first and last electrical sections). Upon fault detection by the distance relay, initially both tracks shall be tripped. During the pause before the first auto-reclosing, the circuit breakers that tie electrically the 2 tracks at the PS and SWS in the affected feed section shall open, isolating electrically the 2 tracks. Opening of these circuit breakers shall be by local undervoltage relays.

Upon reclosing of the circuit breakers in the TPSS, if the fault has been transient, both tracks will remain energized. In such case, following time delay (presence of voltage indicating power has been restored), all circuit breakers in the PS and SWS shall reclose, restoring the TES to its normal configuration. If the fault is still present, then power will be restored to the healthy track only, as the breaker feeding the fault will be tripped again.

Auto-reclosing on the faulted track shall be attempted once, and if the circuit breaker is tripped at the last attempt, the conclusion will be that the fault is permanent. The next stage consists of approximately locating the fault between a pair of track interlockings (or between an TPSS and its adjoining SWS, or between a track interlocking and the adjacent TPF [TPSS or SWS], depending on the location of the fault), and isolating the faulted subsection by opening (the N.C.) disconnect switches at the interlockings (or TPSS and the adjoining SWS, or the interlocking and the TPF) bracketing the fault, and then restoring power to the healthy segments of the affected track. The procedure for fault isolation (i.e., limiting the power loss between adjacent interlockings on one track) can be either manual—conducted by operators in the OCC/RCC using remote control of circuit breakers and motorized switches—or it can be automated (driven by PLC-based logic), although, the existing system is manual.

The protective relaying scheme outlined above shall be analyzed for both normal and contingency configurations of the TES. The contingency configurations shall include, at a minimum, the following:

- Operational loss of one HV transformer of any substation (with the second transformer supplying both feed sections of the affected substation)
- Loss of a PS
- Loss of one catenary or ATF circuit breaker in an TPSS, SWS or a PS
- Complete loss of TPSS, with the adjacent healthy TPSS providing feed to the extended feed sections.

2.6.12 Fire and Life Safety

A fire alarm control system shall be installed at each prefabricated 25 kV switchgear room in accordance with NFPA 72 and CFR Title 19. A Fire Detection and Suppression System (FDSS) shall be installed in each TPSS switchgear room (at TPS, SWS and PS locations). Fire alarm devices, initiating devices, notification appliances and signaling line circuits shall be designated as Class A, as defined in NFPA 72. The fire alarm system shall be electrically supervised and shall be furnished with emergency backup power. A portable emergency eye-wash unit shall be provided at a location adjacent to the station battery. A portable fire extinguisher, sized per federal, state, and local code requirements shall be provided at each exit door of the prefabricated 25 kV switchgear building.

2.6.13 Metering Equipment

Metering instrumentation capable of measuring current, voltage, and KWH shall be provided on the primary side of the HV transformers, AT, and on each individual catenary and ATF circuit.

2.7 Electrical Assets

2.7.1 Equipment Identification

All equipment shall be uniquely identified in accordance with Caltrain's requirements to indicate geographical location, function, feeding point (if applicable), and ownership. The equipment identifiers shall be permanent and located on the front and rear (where rear access is provided) of each equipment enclosure.

2.7.2 Equipment Enclosures

Equipment enclosures shall be of NEMA classification suitable for the environment in which the equipment is operating. NEMA 4X rated enclosures shall be used for outdoor environment.

2.7.3 Raceway

Exposed conduits shall be rigid galvanized steel and shall be minimum 3/4-inch trade size. All raceways shall be installed parallel or perpendicular to the building members of the TPF. The number of bends in any one conduit run shall not exceed the limit specified in the CEC and NEC. The bend radius of exposed and/or underground raceway systems shall be sufficient to maintain the cable side pressures within manufacturer's recommendations during cable pulling activities and shall conform to applicable codes/standards.

All exposed raceways shall be supported/secured to the walls and/or ceiling of the prefabricated 25 kV switchgear, and Control and Relay Room equipment enclosures in accordance with standard industry practice and the CEC and NEC. Emergency circuits (e.g., fire detection, emergency power) shall not share the same raceway or enclosures with other systems.

Embedded conduits shall be minimum 1-inch trade size.

All underground raceways shall utilize PVC schedule 40, reinforced thermosetting resin conduit or similar conduits, be encased in steel-reinforced concrete (with red pigment) and comply to the requirements of the CEC, NEC, NESC, CPUC General Order 128, and applicable codes and standards. Underground raceways shall slope away from the TPF and towards manholes, pullboxes, etc., at a minimum rate of 3 inches per 100 feet.

Raceway entrances in manholes, pullboxes, etc. shall be sealed against entry of silt, debris, rodents, etc. into raceways.

Tracer/detectable tape shall be installed in accordance with Caltrain Standard Specifications.

HV, LV and communications raceway sharing the same ductbank shall not be routed through the same manholes, pullboxes, etc., and shall be physically separated as per applicable codes for the entire length of the ductbank. Ductbanks shall run as directly as practicable and shall be located to avoid interference with civil structures and sub-grade utilities. All ductbanks shall be designed and installed conforming to all the applicable codes / standards / guidelines.

2.7.4 Cable Tray Systems

Cable tray systems shall comply with NEMA VE 1. Cable tray systems shall be engineered to comply with the following requirements:

- The cable tray system shall be fully enclosed with metal cable trays hot-dipped galvanized after fabrication, with full system appendages.
- The drop-offs to all different points of utilization shall be conduit. Bushed conduit should be used wherever possible.
- The cable tray system construction shall be secure and prevent inadvertent access by unauthorized parties.
- The cable tray system shall have suitable strength and rigidity to provide adequate support for all the contained cables.
- The cable tray system shall include a means to ventilate the enclosed cables, so the heat generated by the cables can be safely dissipated.
- The cable tray system shall include barriers to segregate cables of different systems and voltage ratings.
- The cable tray system shall provide adequate cross-sectional area to permit neat alignment of the cables and avoid crossing or twisting.

2.7.5 Electrical Manholes and Pullboxes

All manholes and pullboxes shall be designed and installed conforming to all the applicable codes / standards / guidelines.

2.7.6 Cable Trenches for Power Cables

The interface of the 25 kV ductbanks with the prefabricated 25 kV switchgear houses shall be through cable trenches. Cable trenches shall be equipped with sump area for drainage by gravity or application of portable or fixed pumps as required. Cable trenches shall be sized to accommodate the number and size of 25-kV circuits, with “catenary” and “return” cables separated by solid barrier or installed on the opposite sides of the same trench.

At the foundation of the 25 kV switchgear house, the cable trenches shall transition into a cable vault of dimensions depending on the locations of the cable terminations at the switchgear. The cable vault shall have sufficient depth and height to provide for ease of installation and maintenance of the cable terminations and other equipment, such as surge arresters. A staircase, external to the prefabricated 25 kV switchgear equipment enclosures, shall be provided to permit access to the cable vault. The design of the cable trenches shall include removable covers, extending a suitable distance from the edge of the switchgear house.

2.8 Conductors

2.8.1 General

All electrical conductors shall be copper. Conductors and cables interconnecting equipment and/or cabinets shall be enclosed in raceways or cable tray systems.

Insulated traction power cables shall be single conductor, with concentric neutral, shielded, and with external non-metallic jacket that is low smoke and sunlight resistant. The cables shall be suitable for installation in wet or dry locations, in underground conduit or exposed to the weather. The cables shall be rated for 30 kV phase-to-ground and have 133 percent insulation level. See NFPA 130 for requirements of conductors when routed through tunnels and see MIL standard 246431 series.

The cables shall be rated for 90°C continuous conductor temperature; 130°C for emergency short-term operation; and 250°C for short circuit conditions. The conductors shall be copper, with Class C stranding. The shield and concentric neutral shall be grounded at one end only, at the station ground bus, to avoid circulating ground return currents through the shield and neutral wires.

Traction power cables, connecting the 25 kV AC feeder breakers to the catenary and autotransformer along-track feeders, and the running rails to the return bus, shall be sized to carry the maximum rms load currents, with due consideration for the installation environment. Cables shall be derated for installations in common underground duct banks or cable trays.

Catenary and autotransformer 25 kV feeders and neutral return feeders shall be standardized in multiples of a single copper conductor size to achieve the required circuit ampacity, especially if using only one cable requires sizes larger than 500 kcmil. The cables shall have sufficient ampacity to carry the maximum rms current imposed by the worst-case operating scenario on a continuous basis, without exceeding the 90°C conductor temperature limit. Low voltage AC and DC power and control cables shall be copper conductors, rated for 600 V AC, with maximum conductor temperature of 90°C, and shall be suitable for installation in conduits, ducts, cable troughs, and cable trays. Cables exposed to the outdoor environment shall have a weather resistant jacket. Instrumentation cable shall be 600 V insulated, multiple shielded, certified for installation in conduits, ducts, cable troughs, and cable trays. For multi-pair twisted cable, each pair shall be individually shielded, and the cable shall have an overall shield insulated from the individual pair shields. No cable splices shall be permitted.

2.8.2 Segregation

Insulated cables of different voltage classes shall not occupy the same conduit, cable tray, pull box, or manhole. An underground ductbank may contain conduits for LV power and control cables, as well as HV traction power cables. However, separate pullboxes shall be provided for each type of cable. For increased flexibility and system reliability during maintenance, 25 kV catenary feeder conductors, 25 kV autotransformer feeder conductors, and rail return feeder conductors shall not be routed through the same manholes and pullboxes. At TPF, if cables for the catenary, return, and/or neutral circuit need to share an overall common enclosure (such as cable trench), partitions or barriers shall be provided to achieve circuit separation.

2.8.3 Sizes of Low Voltage Power and Control Cables

LV power and control cables shall be sized on the basis of the maximum expected load current and acceptable voltage drop. In addition, conductor size shall not be less than the prescribed minimum, for mechanical integrity purposes. Minimum size of LV power conductors shall be No. 12 AWG. Minimum size of LV control conductors shall be No. 14 AWG. Minimum size of analog indication cables shall be No. 16 AWG.

2.9 Emergency Power

2.9.1 Emergency Electrical Loads

Emergency electrical loads are those AC and DC electrical loads required to be in operation during a disruption in the normal power supply to a TPF. These electrical loads include, but are not limited to, the following:

- Fire Alarm Control System
- Supervisory Control and Data Acquisition System
- Intrusion Detection System
- Control Power

- Emergency Lighting System

2.9.2 Emergency Power Requirements

An emergency power source (i.e., battery and charger system), rated for at least 8 hours connected electrical load, shall be provided for all emergency lighting, exit signs, and other vital equipment located at TPF. In addition to the noted electrical loads, the emergency power source shall be able to support at least three operating cycles (where trip and close operation constitute one cycle) of all circuit breakers simultaneously.

The design of the batteries shall be NiCad or Valve-Regulated Lead-Acid (VRLA) or VLA or approved equivalent and have a life expectancy of at least 15 years and are of low maintenance. Transfer from the normal LV power source to the emergency power source shall be automatic. The design of each TPF shall include a receptacle and associated switching equipment to permit the connection of a portable diesel generator during abnormal operating conditions.

2.10 Wayside Equipment

2.10.1 Wayside Power Control Cubicles

In addition to TPF, Wayside Power Control Cubicles (WPC) are located at railway stations including the universal crossovers at both ends, and on the wayside at universal crossovers, at tunnel portals, at rolling stock maintenance facilities, at wayside infrastructure maintenance facilities, and in tunnels longer than 3 miles. WPC is an enclosure for power supply equipment for operation of motorized disconnect switches and the associated SCADA equipment located at the wayside. WPC at railway stations and wayside universal crossovers will be located in close vicinity of PTC wayside installations with common access roads, parking and drainage facilities and low voltage power supply and will use some common equipment (e.g., duct banks, under-track crossings etc.), hence these should be designed and installed in consultation with the PTC Wayside System Design. The secure mounting of enclosures and equipment along the ROW shall be accomplished in coordination with structural and civil design. The number of WPC at each site will depend upon the site conditions, the layout of track (including crossovers and MODs), the location of the auxiliary power source, and the routing of cables. The requirements and locations of WPC shall be suitably optimized in consultation with the OCS, PTC Wayside, and Communications Systems designers.

The design of each WPC shall include:

- All equipment provided therein
- Its grounding system
- SCADA interface with the communications system
- Auxiliary power and SCADA interface with the OCS system at the operating panel of the MOD Foundations

2.11 New Power Utility Services

2.11.1 115 kV AC, Single-Phase 60 Hz Services

The design of the traction power substations and the associated interfaces to the power utility service provider shall comply with the codes and standards specified in Chapter 1. The following requirements shall apply:

The capacity of each incoming power service shall be sufficient to support the following:

- Full service for the ultimate design headway under normal operation and single electrical contingency mode of operation

- No disruption to (but reduced) services under double contingency mode of operation that includes the outage of an entire substation.

The incoming power services to the TPSS shall meet the following conditions:

- Two reliable HV power services, as independent as practical, supplied from separate utility transformers or buses
- The power services to adjacent TPSS are to be from different transmission lines, supplied from different utility substations

2.12 Auxiliary Power Services

The design of the TPS and the associated interfaces to the power utility shall comply with the latest version of the codes and standards specified in Chapter 1. See Section 2.6.9, Auxiliary and Control Power for additional requirements.

2.13 Spares

All control, signal, and communication installations shall include at least 10 percent spare conductors and/or fiber strands. All panelboards and termination cabinets shall include at least 20 percent spare capacity for future growth. All ductbank systems shall include at least 1 spare conduit or 20 percent spare conduits, whichever is greater. All spares shall be capped with a pull line/rope secured inside. Cable tray systems shall be sized to include 20 percent spare capacity.

END OF CHAPTER 2

CHAPTER 3

OVERHEAD CONTACT SYSTEM

3.0 Overhead Contact System

3.1 Scope

This chapter details the design criteria for the overhead contact system (OCS) and the traction return system including the parallel Autotransformer Feeders (ATF).

3.2 Overhead Contact System (OCS)

The OCS is a system in which electrical conductors are supported aerially above the electrified tracks, generally by means of insulators and appropriate mechanical support arms or brackets, and which supplies electrical energy from the traction power supply facilities to rail mounted, electrically powered vehicles through onboard, roof-mounted current collection equipment (pantographs).

The OCS comprises the following:

- All overhead wiring, including the messenger wires, contact wires, feeder wires, and static wires mounted on OCS support structures or brackets
- The foundations, supporting structures, and any components supporting, registering, terminating or insulating the conductors
- Insulators, neutral-sections, auto-tensioning devices, and other overhead line hardware and fittings
- Equipment mounted on the supports for feeding, switching, detection or protection (including but not limited to hangers, manual and/or motor operated disconnect switches, section insulators, section phase breaks, conductor termination and tensioning devices, downguy, and other overhead line hardware and fittings)
- Overhead Conductor Rail (OCR) in the tunnels

3.3 Traction Return System

The traction return system is the means by which traction current is returned from the wheelsets of the trains back to the traction power facilities of the electrified railway, comprising the ATF (due to the configuration of the autotransformer connections), the grounded running rails, aerial static wires and buried ground conductors together with all return current bonding and grounding interconnections. Grounding and bonding and lightning protection for the electrified railway is covered in the Grounding and Bonding chapter (Chapter 4).

3.4 Overhead Contact System Description and General Performance Requirements

Overhead Contact line is fed by a 2x25 kV, 60 Hz single phase AC autotransformer traction power supply system, utilizing traction power substations (TPSS), a switching station (SWS) and paralleling stations (PS).

The OCS supports voltage variations in accordance with IEC 60850 “Supply Voltages of Traction Systems”, as shown in **Table 6: Traction Power System Voltages**.

- **Table 6: Traction Power System Voltages**

Voltage Condition	Symbol	Voltage
Operating nominal system voltage		25.0 kV
Highest permanent voltage	Umax1	27.5 kV
Highest non-permanent voltage	Umax2	29.0 kV
Lowest permanent voltage	Umin1	19.0 kV
Lowest non-permanent voltage	Umin2	17.5 kV

In addition, the maximum short circuit current is 15 kA for protection measurement purposes and accordingly for specification of the electrical equipment. At all traction power supply stations, the center tap of the respective supply transformer secondary and auto-transformer windings is connected to and referenced to the running rails, which will nominally be at ground potential.

3.4.1 General Description

The OCS provides electric traction power to the pantographs of the EMUs and is configured to 25 kV-0-25 kV arrangement with the catenary at a nominal voltage of 25 kV to ground and the longitudinal parallel ATF also at a nominal voltage of 25 kV to ground, but in phase opposite to the catenary. There is a 180-degree phase difference between the voltages of the parallel ATF's and the OCS, giving a 50 kV phase-to-phase voltage difference between these conductors. This phase difference between the parallel OCS serves to mitigate the EMI from the OCS load current.

Except at Phase Breaks, the OCS provides uninterrupted traction power for current collection at the maximum operating speed of 110 mph. To allow bi-directional working, enabling trains to continue operation under emergency conditions and to facilitate routine OCS maintenance, the OCS is divided into electrical sections and sub-sections as detailed in Section 2.3.4. To facilitate operations and maintenance activities, the OCS is typically equipped with non-load break motor operated disconnect switches at feeding points, which can be operated both locally at the site and remotely through a supervisory control and data acquisition (SCADA) system. The switches are fitted with OCS voltage detection circuitry that will provide remote monitoring of the system.

The OCS phase break arrangements are located at the SWS and at the TPSS's to electrically separate two successive catenary electrical sections fed from different 25 kV AC sources, i.e., not of the same phase. The electric trains shall pass through each phase break arrangement without establishing an electrical connection between the successive electrical sections which are fed from different phases. This shall be achieved at the designated maximum operating speed with the train pantographs raised and in contact with overhead contact wire, but with the pantograph breakers off.

Rail Return shall primarily be through the running rails, but a Static Wire (ground wire) shall be provided that interconnects all OCS support structures (poles, portal structures, wall brackets, tunnel drop pipes, etc.) which shall be connected via impedance bonds to the running rails and to the ground grid at each traction power facility (TPF).

Other cross-bonding connections may be required to minimize rail potential rise and the frequency and location of these connections and of the impedance bonds shall be determined under the TP system design and coordinated with the Signal System design. For details refer to the Grounding and Bonding chapter 4. The parallel ATF effectively carries much of the traction return current and minimizes the amount that flows through the rails and static wires. For a more comprehensive description of the traction power supply system and its associated facilities, refer to the Traction Power System chapter (Chapter 2).

3.4.2 Overhead Conductor Rail (OCR)

Overhead Conductor rail consists of a single contact wire continuously supported by sections of aluminum extruded profile, joined to form a conductor bar. Due to the continuous support of the contact wire provided by the aluminum conductor bar, it is not necessary to apply mechanical tension to the contact wire, and thus, there is no requirement for tensioning equipment to be provided. OCR shall be in accordance with Caltrain OCR specifications and shall be installed in the tunnels as per the project requirements.

3.4.3 Factors of Safety

All OCS components and assemblies shall be designed to achieve safety factors of not less than the following minimum values under all loading conditions defined in this standard:

- **Table 7: Minimum Safety Factors for OCS**

Element of Overhead Contact System	Minimum Safety Factor
Messenger wire and contact wire, and their terminations, splices and fasteners (except tie wires)	2.0
Worn contact wire (maximum 30% worn)	1.6
All other aerial conductors and wires	2.5
Down guys, span guys, balance weight support wires and their terminations	2.5
Glass, porcelain and synthetic insulators	2.5
Pins, shackles, swivels, hinges, brackets, and attachments	2.5
Metallic pipes, struts, rods, clamps and castings	2.5
Poles against bending or twisting	2.0
Pole and down guy foundations against displacement and rotation	2.0

The OCS conductor analysis shall be based on a worst-case assumed contact wire wear of 30%. All structural components, including foundations, poles, guys and other structural components, shall achieve the required safety factors in accordance with CPUC G.O. No. 95 standards, AISC, ACI and NESC guidelines, supplemented by the requirements specified herein.

3.5 Environmental Conditions and Climatic Loading Requirements

The OCS shall be designed on a system-wide basis to provide reliable operation under the following environmental and climatic conditions:

3.5.1 Humidity

The OCS shall operate without failure or deterioration in all humidity conditions found in California. These include 95 percent humidity, rain, heavy fog and salt-laden atmospheres, and 100 percent humidity in tunnels. These conditions prohibit the use of weathering steel (ASTM A588) in poles and other structural elements and hardware.

Some of the tunnels in the ROW have high humidity and pollutants like chlorides and sulphides. The OCS shall be designed to operate without failure in this environment.

3.5.2 Ice

In G.O. No. 95 the Light Loading Condition in the parts of California where the elevation above sea level is 3000 feet or less has no ice loading requirement. OCS design need not consider ice loading.

3.5.3 Wind

Wind speed shall comply to ASCE 7-22 “Minimum Design Loads for Building Structures” with exposure C for state of California. The OCS structures shall be classified under risk category IV.

For OCS structural calculations, loads due to wind shall be multiplied by the load factors given in the NESC.

3.5.4 Atmospheric Pollution

OCS equipment shall be designed for and shall be resistant to polluted atmospheres, such as may occur in highly industrialized areas, salt-laden marine atmospheres near the ocean, and persistent fog. In addition, the OCS equipment shall be resistant to the corrosive atmospheres that may be found in cut-and-cover structures and other tunnels. These conditions prohibit the use of weathering steel (ASTM A588) in poles and other structural elements and hardware.

3.5.5 Ambient Temperatures Range

In developing the settings for the auto-tensioning devices (balance weight, spring tensioner anchor arrangements), the designer shall take into consideration the typical and extreme ambient temperatures, i.e. 19°F to 145°F.

3.5.6 Conductor Wire Temperature Range

The messenger, contact wires and the parallel feeder conductors shall be designed to operate at maximum temperature of 176˚F.

3.5.7 Conductor Tensioning

The mechanical tensions in the messenger and contact wires shall be maintained automatically throughout the temperature ranges specified above.

3.6 Overhead Contact Line Design

The OCS design shall be based on Caltrain’s standard system design assemblies with required design life that is capable of sustaining satisfactory current collection for train operations.

The OCS Designer shall ensure the proposed placement of OCS poles and/or supporting structures and wayside equipment enclosures will not block existing access roads, passenger circulations on the platforms and/or trackside equipment anywhere along the alignment. For the location of Wayside Power Cubicles (WPC) the OCS Designer shall coordinate with the TPS designer.

The catenary system in-span hangers shall be current carrying stranded, copper alloy (bronze) material, configured to provide a flexible, non-rigid method of contact wire support from the messenger wire.

The OCS conductors shall be designed for all wire tensioning modes for the full range of nominal design temperatures. Where F.T. designs are used, suitable tension-adjustment tables or graphs shall be used and provided for erection of cables and wires at ambient temperatures other than the normal design condition.

Messenger-to-contact wire hanger lengths and in-span positions shall be tabulated for the standard span lengths, covering the full range of spans in 5-foot increments, including the maximum and minimum mainline spans and required variations for overlap, anchor and bridge or tunnel approach spans. For minimum system height, rigid hangers should be avoided as far as possible.

As per G.O. No. 95, all overhead trolley contact conductors shall be so supported and arranged that the breaking of a single “suspension” or fastening will not allow the trolley conductor or live span wire or current carrying connections to come within 10 feet from the ground or from any platform or grade crossing accessible to the general public. This practically requires that all catenary constructions meet this requirement.

The pantograph security, current collection, and phase break length shall be determined based on the pantograph characteristics requirements of AREMA Manual for Railway Engineering Chapter 33 Section 8.3. The OCS design shall avoid locating down guys, overlaps, phase breaks, balance weights, motorized disconnect switches and other OCS equipment on station platforms, grade crossings and other areas accessible to the public.

Down guys shall be designed to be parallel to the track.

The OCS Designer shall work with the Signal Designer in locating or relocating signal structures. Signal sighting distances shall be considered when OCS poles and/or supporting structures are designed and located.

Other important aspects of the design are the provision of adequate clearances or provision of protective barriers and screens, together with effective grounding and bonding of the electrical system and wayside metallic objects, which are required to minimize the electrical hazards. The recommended minimum clearances between energized parts and grounded parts are detailed in Section 3.14.9. The location of OCS equipment, including poles and downguys, shall be coordinated with clearances defined in G.O. No. 26-D.

3.6.1 Design Data

The OCS system designer shall be cognizant of and shall incorporate into the OCS design the fundamental design data and performance instructions, as defined in this standard, which include, but are not limited to the following:

- Service and operations information
- Infrastructure characteristics
- Vehicle characteristics
- Pantograph characteristics
- Traction power system design
- Environmental conditions
- External limitations on contact wire height, uplift, system height, and/or clearances
- Life expectancy and desired maintenance/renewal philosophy for all components
- Allowable grooved contact wire wear

- Specification of EMC limitations
- Future track lifting allowance
- Track tolerances
- OCS maintenance and installation tolerances
- Pre-sag

3.6.2 Geometry of the Overhead Contact Line

The OCS shall consist of a simple, auto-tensioned catenary system, using a hard-drawn copper alloy messenger wire supporting a nominally level (no pre-sag), solid hard-drawn copper contact wire by means of copper alloy current carrying hangers. For future modifications and improvements, the designer shall assess the pre-sag requirements for the network with a pantograph dynamic simulation modelling.

In general, the catenary shall be supported by pole mounted cantilever frames which shall be designed to provide the required system height and to register the correct stagger of the wires relative to the track centerline. The messenger wire shall be positioned vertically (plumb) above the contact wire.

Back-to-back cantilevers shall not be used on the mainline tracks but can be used in the station areas with side platforms or areas where site constraints or public safety requirements dictate only after approval from Caltrain.

An aerial Static Wire (ground wire), connected at regular intervals to the track via impedance bonds, shall be run alongside the catenary to interconnect each OCS support structure and bracket, such that all OCS non-live metallic supports are at the same ground (and track) reference potential.

The longitudinal ATF shall be supported near the top of the OCS poles, preferably on the track side, but may be positioned on the field side where the right-of-way width or overhead structure configuration shown on the OCS layout drawings dictates. Live bare AT feeders or conductors are not allowed above the public platforms. The aerial parallel ATFs, and the aerial static/ground wires which connect all OCS supporting structures, shall both be fixed termination bare ACSR (Aluminum Conductor Steel Reinforced) conductors, except where local site conditions (reduced clearances, public safety etc.) dictate the need to use insulated cables for the ATFs.

The method of auto-tensioning the messenger wire and contact wire shall be by balance weight and pulley tensioning or spring tensioner devices. The tensions shall be applied to the contact and messenger wires using a yoke plate and balance weights, tensioning devices and anchoring positions.

The designer shall evaluate overlap arrangements. Maximum tension lengths from anchor to anchor shall not exceed 5,600 feet in open route sections and adjacent to traction power substations and switching stations. Insulated overlaps shall not be located at stations, under the bridges, in front of signals or train stopping locations.

At approximately mid-distance between auto-tension terminations, mid-point anchor arrangements shall be installed, such that the maximum half tension lengths do not exceed 3116 feet in open route sections and at power supply stations and switching stations. The 3116 ft is from fixed anchor or midpoint to the last in-running registration.

The maximum permissible span length between supports that are shown on the Standard Drawings shall take into consideration the permissible working range of the pantograph and allowable lateral displacement of the contact wire under the designated operating conditions, including dynamic movement of the vehicle and pantograph.

At overlap locations where sectionalizing is not required, uninsulated mechanical overlaps shall be installed that will permit the pantographs to transition smoothly from one tension length to the next under power. Section Insulators shall not be permitted in the mainline unless approved by Caltrain.

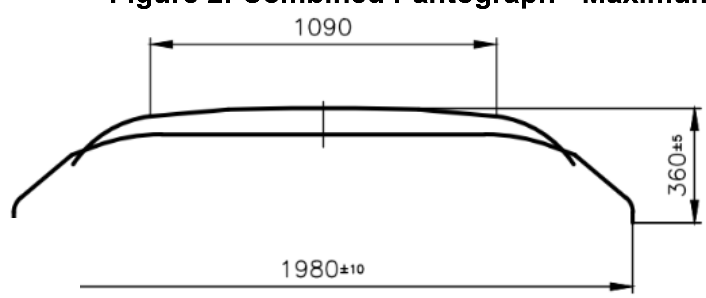
Wherever practicable, the OCS shall be free running under overhead bridges, i.e., no OCS or feeder support are attached to the bridge structure. The designer shall secure permits for attachments to any third party owned bridges or structures where it is determined that OCS support, registration or termination attachments are required.

In limited clearance locations, particularly at low headroom bridges, resilient or insulated arms supporting both messenger and contact wires, may be used. At locations under the overhead bridges, where normal electrical clearances are not able to be met, the Designer may elect to use a contenary system where the messenger wire is changed to a contact wire and run side-by-side with the adjacent in-running contact wire.

3.6.3 Geometry of the Pantographs

The current collector (pantograph) is a hinged frame that is spring loaded to maintain pressure under the contact wire and to accommodate variations in the vertical height of the contact wire. This pressure creates uplift of the contact wire and can result in movement of the messenger wire. At higher operating speeds, aerodynamic forces can be exerted on the pantograph frame, which might result in further uplift of the contact and messenger wires. The design analysis shall identify values of uplift. Mechanical clearance from the pantograph to any fixed item, excluding the steady arm or registration pipe of the cantilever, shall be not less than 3 inches. The Overhead Contact Line shall be designed to accommodate pantographs with an indicative pantograph head profile, as shown in **Figure 2: Combined Pantograph - Maximum Static Geometry**.

- **Figure 2: Combined Pantograph - Maximum Static Geometry**



Pantograph heads are fitted with contact strips, have independent suspensions and have nominal static uplift contact force of 18.66 lbf (83 N) applied to the middle of the head. The Designer shall confirm the pantograph profile in use at the project site.

3.6.4 Wire Heights and Gradients

The contact wire shall be installed and maintained at a nominal constant height of 22 feet above mean top of rail level at the supports; the maximum vehicle load gauge height will vary depending on the segment to be compatible with current Caltrain vehicles and freight traffic and shall also accommodate future CHSRA vehicles.

Exceptions shall be addressed on a site-specific basis, and subject to Caltrain's approval. The contact wire installation height at supports shall take into consideration the effect of wire sag, due to either the temperature rise and installation tolerances (including track construction and maintenance tolerances).

For restricted clearance sections of the route (such as at overpasses) in "double-stack" territory, the support height for the contact wire may be reduced to a minimum value of 21'- 3" AMTOR, provided short-span support arrangements supported from the structure are employed and subject to concurrence by Caltrain, and by the CPUC and the owner of the structure.

For restricted clearance sections of the route (such as in the San Francisco tunnels), where the trains are operating solely over dedicated ROW, the support height for the contact wire may be reduced to a minimum value of 17'- 0" AMTOR.

For unrestricted sections of the route north of Bayshore, where the trains are operating solely over dedicated ROW, the support height for the contact wire may be reduced to 19'- 0" AMTOR. This shall be considered the normal contact wire height (CWH) for dedicated Caltrain-only operation. To assure continuity of current collection by a fully extended pantograph, the OCS design shall be checked to ensure that, under the most adverse operating condition, the contact wire height does not exceed 24'- 0".
The maximum permissible contact wire gradients and the corresponding maximum gradient changes shall not exceed the following values according to the maximum speed:

- **Table 8: Maximum Permissible Contact Wire Gradient versus Operating Speed**

Maximum Speed (mph)	Maximum Contact Wire Gradient	Maximum Contact Wire Gradient Change
125	2/1000	1/1000
110	3/1000	1.5/1000
100	3.3/1000	1.7/1000
75	4/1000	2/1000
60	6/1000	3/1000
45	8/1000	4/1000
30	13/1000	6.5/1000
15 (in yards)	16/1000	8/1000

On tangent track (straight track), the contact wire shall be staggered at each location to alternate sides of the pantograph center line, and the stagger shall normally be set at 9 inches.

On curved track, the staggers shall be calculated on a case-by-case basis considering the track superelevation, radius of curvature, and wind speed, but shall not exceed 9 inches.

3.6.5 Compliance of the Overhead Contact Line System with the Infrastructure Gauge

OCS design shall comply with the static and dynamic envelopes. The dimensions of tunnels and other structures shall be mutually compatible with the geometry of OCS and the dynamic envelope of the pantograph, the static profile of which is shown in Caltrain Standard Drawing SD-W6007.

3.6.6 Fabrication and Erection

The OCS designs and arrangements shall provide for ease of shop fabrication, on-site assembly, field erection, and construction. Catenary components and assemblies, such as cantilevers, steady arms, suspension devices, and related hardware shall be standardized. To the extent that it is economically feasible, key dimensions, weights, mounting points, heights and interface tolerances shall be patterned to provide interchangeable, multi-use designs. The design of the equipment and component parts shall be suitable for pre-assembly and for subsequent assembly shipment. They shall afford final on-site assembly and field erection of the units with a minimum of preparation and equipment adjustment.

All components shall be specifically manufactured for use as electrical products and shall be designed to conform to the requirements set forth in these criteria. The engineering final design shall determine the exact material specification(s) and identify these requirements within each relevant specification section.

Design loadings shall be fully considered in cantilever, bracket, and cross-span arrangements, as defined in the previous sections of these criteria.

The design shall require that all OCS cable, wire, strand, rod, and other equipment, produced in ferrous, non-ferrous, and related materials, shall be manufactured in accordance with the applicable ASTM or other referenced industry standards. The manufacturing methods and materials shall be proven for use on and compatible with an electrified catenary system.

Typically, all catenary assemblies, components, hardware and related equipment shall be designed using Caltrain's existing system design range and Caltrain specifications. All OCS designs shall be subject to Shop Drawing submittals and review by Caltrain.

3.6.7 Overlap, Turnouts and Crossovers

The overlaps in the OCS shall provide for a mechanically smooth passage of the pantograph. Uninsulated overlaps shall be equipped with full electrical continuity jumpers. Insulated overlaps shall be used to the greatest extent practicable for sectionalizing purposes. Turnouts and crossovers shall be fitted with the same style of OCS as the mainline A.T. system. Section insulators shall not be used on the mainline but can be used on crossovers and turnouts. For multi-track applications, the preferred support arrangement is the portal. Headspans shall not be permitted in the mainline for any future works however, at other locations like in yards, prior approval shall be obtained from Caltrain.

3.7 Conductor Tensions

For fixed termination wiring including but not limited to static wire, ATF, mid-point tie wire, the installation tension with respect to the ambient temperature shall comply with the related standard design drawings.

The Messenger and Contact wires shall be automatically tensioned as per the Caltrain standard system design. Calculations shall be performed to confirm that design tension drag of contact wire runs impacted by project work does not exceed ±5%.

3.8 Conductors

The following conductors and cable types and sizes shall be used throughout the system:

3.8.1 Contact Wire

The contact wire shall be grooved hard-drawn copper silver wire, of the requirements shown on the Standard Drawings (SD-W6001) and as set out in EN 50149. The use of cadmium copper is not permitted. The mechanical design of contact wire loads shall be in accordance with EN 50119:2020, Section 5.3.

3.8.2 Messenger Wire

The messenger wire is stranded bronze wire of the requirements shown on the Standard Drawings (SD-W6001) regarding the material designation and composition, conductor appearance and condition, tensile strength and percentage elongation after fracture, breaking load, and mass of the wire.

3.8.3 Hanger Wire

The current carrying flexible conductor for the hanger wire as shown on the Standard Drawings (SD-W6001) which, together with the messenger wire and contact wire clips, shall provide an electrical connection between the messenger and contact wires.

3.8.4 Alternate Conductors

No alternative conductors shall be allowed without prior approval from Caltrain.

3.9 Other Overhead Conductors and Cables

3.9.1 Aerial Conductors

Aerial conductors shall be mounted and spaced on the OCS support structures in accordance with the more stringent requirements of the CPUC General Order No. 95 rules, as they apply to each system classification. Mounting arrangements shall provide for the safety of maintenance personnel. These cables and conductors shall be mounted and profiled in such a manner as to avoid the Overhead Contact Line Zone and Pantograph Zone **Figure 7**, to the greatest extent practicable. Loading calculations and structural designs for the support of these cables and conductors shall comply with the design criteria.

3.9.2 Other Insulated cables and bare conductors

Insulated cables and bare conductors, other than the catenary conductors identified above, that are associated with the OCS may parallel or cross Caltrain's right-of-way, including the parallel ATFs, and static (ground) wires.

Parallel ATF
In general, the parallel ATF shall be a bare stranded ACSR conductor for use throughout the system, as shown on the Standard Drawings. Since the mainline will generally be two-track, with platform tracks at intermediate stations, two ATFs are to be installed; one on each side of Caltrain's right-of-way. At locations where a bare conductor cannot be installed, appropriately sized insulated 25 kV cables, as shown on the Standard Drawings, with appropriate sealing ends, shall be substituted and spliced into the bare conductor, which may or may not have to be terminated on a dead-end anchor pole. Bare feeders shall not be allowed above the public platforms.

Static (Ground) Wire
In general, the static wire shall be a bare stranded ACSR for use throughout the system, as shown on the Standard Drawings. Two static wires are to be installed - one on each side of Caltrain's right-of-way –interconnecting all metallic OCS support structures, including OCS poles and bridge drop pipes and wall brackets to provide a continuous ground connection.

Shunt Wire
At utility crossings, the electrification design shall include the installation of a Shunt Wire, which shall be ACSR, as shown on the Standard Drawings, to shunt the utility crossing span to ground to protect the safety of the public and rail or utility workers in case the utility conductors in the crossing span fail. The Shunt Wire installed above the feeder wire, must be consistent with the GO 95 strength requirements for a 50 kV system (GO 95 Section IV).

Insulated 25 kV Cable
Power feeder cables, where used shall be insulated with a black, low-smoke, flame-retardant, ozone-resistant, ethylene-propylene compound jacket and the aluminum conductor shall be covered with a double-wrapped separator tape or extruded semi-conducting Ethylene propylene rubber (EPR) screen, as shown on the Standard Drawings.
Return cables, where used, shall be insulated with a black, low-smoke, flame-retardant, ozone-resistant, ethylene-propylene compound jacket and the conductor shall be coated, soft-drawn stranded copper, covered with a double-wrapped separator tape or extruded semi-conducting, EPR screen, as shown on Standard Drawing SD-W6001.

3.9.3 Other Disciplines and Third-party Utility Crossings

Cables and wires required by other disciplines, such as signal cable, signal-power cables, control wires and communications cables shall not be allowed to cross above the OCS conductors. Attachment to OCS poles other than TES are not allowed. All third-party utilities power lines less than 33kV shall not be allowed to cross over the OCS conductors and shall be routed underground. The overhead power lines with voltage above 33kV shall follow CPUC GO 95 clearance requirements.

3.10 Dynamic Behavior and Quality of Current Collection

Good quality interactive dynamic performance with minimum wear can be assured by consideration of the quality of current collection, which has a fundamental impact on the life of the contact wire and pantograph components. Compliance with several measurable parameters, as detailed below, shall be achieved.

3.10.1 Requirements

The number of pantographs in service per train is limited to one per trainset. This allows the Phase Breaks to be of short length. The Phase break will have at a minimum a 17' neutral section, with the neutral section grounded.

3.10.2 Contact Wire Uplift or Vertical Movement of the Contact Point

The contact point is the point of mechanical contact between the pantograph contact strip and the contact wire. The vertical height of the contact point above the track shall be as uniform as possible along the span length; this is essential for high-quality current collection. The maximum difference between the highest and the lowest dynamic contact point height within one span shall be less than 3 inches at the maximum operating speed of 110 mph.

In order to maximize safety under all operating conditions (including strong wind conditions and slight misadjustments of the pantographs), the dynamic pantograph envelope at the maximum operating speed shall consider twice the value of the estimated or simulated uplift at the support point. The design of the OCS cantilever and registration shall allow the uplifted steady arm to clear the dynamic pantograph envelope with uplift not more than 9 inches.

3.10.3 Current Collection Quality

To check the performance capability of the current collection system, the following data, as a minimum, shall be measured:

- The contact force.
- The contact wire uplift at the support as the pantograph passes.

In addition to the measured values, the operating conditions (train speed, location, etc.) shall be recorded continuously and the environmental conditions (rain, temperature, wind, tunnel, etc.) and details of the test configuration (parameters and arrangement of pantographs, type of OCS, etc.) during the measurement tests shall be recorded in the test report. In order to maintain the contact wire on the pantograph head, the design factors to be considered shall include OCS conductor blow-off, contact wire height, contact wire stagger, contact wire midspan offset, contact wire stagger effect on tangent, contact wire deviation due to movement of hinged cantilevers, mast deflection due to imposed operational loads, vehicle roll and lateral displacement, width and sway of pantograph, track tolerances, OCS erection tolerances, pantograph shape effect, and a pantograph security factor.

The design shall consider the effects of environment, track geometry, track maintenance clearance tolerances, vehicle and pantograph sway, and installation and maintenance tolerances. Vehicle roll into the wind shall be taken equal to be 50% of the maximum dynamic roll value, in accordance with the AREMA Manual for Railway Engineering. The dynamic behavior and quality of current collection assessment criteria shall be in accordance with EN 50367.

3.11 Current Capacity of Overhead Contact System

The OCS, including parallel feeders, return circuit conductors and feeder connections, shall be designed to cater to the electrical current loading under steady state peak period operating and fault conditions, as defined by the system design, under the environmental and climatic conditions defined in Section 3.5.

In addition, the OCS system shall be capable of meeting the current heating effects of short circuit faults and durations, resulting from automated circuit breaker closure sequences, which occur during peak operations.

The maximum temperature rise in the conductors, caused by the load currents, shall not lead to conductor temperatures at which the mechanical properties are impaired. The maximum permissible temperatures for bare conductors are given in the following table:

- **Table 9: Maximum Permissible Bare Conductor Temperatures**

Conductor Material	Max. Temperature (°F)	Max. Temperature (°C)
Normal and high strength, high conductivity Copper	176°F	80°C
Silver Copper alloys	212°F	100°C
Cadmium Copper alloys	176°F	80°C
ACSR	212°F	100°C

The melting point of any grease used in the strands of the conductors shall be higher than the temperature limits specified above.

3.12 Sectionalizing and Switching

The OCS and related traction power distribution system shall be sectionalized in accordance with Caltrain's operating requirements and shall facilitate and support revenue operations of Caltrain. Arrangement providing continuity and flexibility in operation of the system during contingency modes of operation shall be incorporated. In addition to sectionalizing the traction power facilities, the OCS shall be sectionalized at crossovers or other special trackwork (i.e., turnouts) locations, and in the yard to provide for OCS section isolation and operation around out-of-service tracks.
To allow bi-directional running, enabling trains to continue operation under emergency conditions and to facilitate routine OCS maintenance, the OCS shall be divided into electrical sections and sub-sections. On the main tracks, only insulated overlaps shall be used for power supply sectionalizing purposes, whereas neutral sections shall be used for phase breaks at the traction substations and Switching station. Section insulators shall not be permitted in the main lines but can be used in the slow speed track turnouts, crossovers and in the yard and shop areas.

To form the insulated overlaps, insulation shall be cut into the out-of-running sections of the messenger wire and contact wires of the two overlapping catenaries, having between them a limited air gap electrical clearance. The insulated overlap thus provides a sectionalizing point in the OCS as required for operational and maintenance reasons but allows pantographs to transition smoothly from one energized electrical sub-section to the next under power.

The design of section breaks shall utilize an insulated air-break or insulated overlap. At double-track locations, the air-break/overlap shall be applied to both tracks on adjacent locations.
The overall length of the short neutral section design shall be less than the shortest distance between pantographs. Long neutral section design with two insulated overlaps or air-breaks for phase breaks shall not be used.

Jumper cables shall maintain electrical continuity at special trackwork locations where it is necessary to have physical separation in the OCS. At locations where jumper cables are used to provide full-feeding electrical continuity, they shall equal the electrical capacity of the OCS circuit.

3.12.1 Pantograph Spacing for Design of the Overhead Contact Line

The overhead contact line design shall be based on rolling stock operating only one raised pantograph.

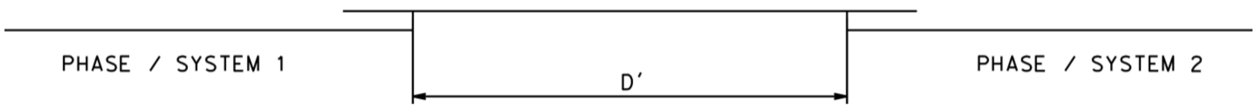
3.12.2 Phase Breaks

The design of the OCS phase breaks shall permit approved trains to move at all speeds up to the designated maximum operating speeds from one electrical section to an adjacent electrical section without bridging between two electrical phases. Trains shall traverse the entire phase break with pantographs raised and in contact with overhead contact wire, but with the pantograph breakers open. The phase break shall be configured such that it can be connected to and energized from either of the adjacent electrical sections by remotely controlled disconnect switches with the provision of appropriate interlocks to ensure the different phases cannot be inter-connected under any circumstances.

The geometry of the phase break elements shall prevent pantographs short-circuiting or bridging between power systems. Provision shall be made in the rolling stock design to avoid bridging of adjacent power supply systems should opening of the onboard circuit breaker(s) fail. Phase breaks shall be avoided near the stations and where train is accelerating or decelerating or stopping.

Short Phase Break (**Figure 3: The Short Phase Break**) with length of the phase break at least 17 feet shall be used.

- **Figure 3: The Short Phase Break**



Conditions: D' > 17 ft

3.12.3 Switching

To facilitate maintenance work and emergency operations, the OCS shall be equipped with disconnect switches at all primary feeding and bypass feeding locations. Where feasible, the OCS disconnect switches shall be pole-mounted at trackside and shall be single pole motorized switches capable of remote operation and also of local motorized or manual operation. The disconnects are also to provide for bypass feeding arrangements that can be implemented during emergency conditions to permit contingency modes of operation.

Remote operations shall be performed from the ROCS and shall be accomplished using the SCADA system. Disconnect switches shall be of the load-break type and shall be rated for the system voltage and anticipated current loads and be designed to carry worst-case overload and short circuit currents without overheating.

As a safety precaution, the switch operating mechanism shall be fitted with a locking bar that will permit the attachment of maintainer locks. In general, all disconnect switches shall be SCADA operated motorized load break switches unless specified by Caltrain.

For locations where solid grounding of the OCS is required, such as working platforms or mezzanines in the depot, the OCS disconnect switches shall be of the three-position type, providing for Closed, Open, and Closed to Ground connections.

Where motorized disconnect switches are located in the vicinity of a traction power facility, the 125 VDC motor power shall be supplied from that facility. At remote locations, such as interlockings, the 125 VDC motor power shall be supplied from a wayside power cubicle (WPC).

While the disconnect switches are within the OCS Designers responsibility, the wayside power facilities supporting them are covered under the Traction Power System Chapter.

3.12.4 Surge Arresters

Over-voltage protection of the OCS shall be provided by means of surge arresters, which shall be rated to withstand the maximum system voltage and anticipated induced voltages from any paralleling high voltage transmission lines. A sufficient number of arresters shall be installed to discharge the energy resulting from lightning strikes without failure of the units. As a minimum, the design shall require arresters to be installed at feeder disconnect switches and at all traction power facilities to assure protection of the feeder cables and upstream equipment. In addition, arresters shall be provided at points of reduced clearance such as restricted clearance overhead bridges and tunnel portals.

3.13 Insulation Coordination Requirements for OCS Installations

Insulation coordination implies selection of the electrical insulation characteristic of the equipment with regard to its application and in relation to its surroundings. Insulation coordination can only be achieved if the design of the equipment is based on the stresses to which it is likely to be subjected during its anticipated lifetime.

The OCS shall be designed with insulated catenary support arrangements. All insulating components shall be electrically rated to withstand a nominal voltage of 25.0 kV and a maximum operating voltage of 29 kV and shall have a Basic Insulation Level (BIL) of 250 kV. The flashover rating shall conform to the minimum requirements as indicated in CPUC G.O. 95. The insulator also has an impulse voltage withstand level of 250 kV. Insulator units and devices shall also be capable of power-frequency withstand wet voltage of no less than 125 kV AC without surface flashover or damage and shall be capable of operating with these types of occurrences on a regular basis.

All insulation assemblies and components shall be designed for high pollution category, to safely carry the mechanical and electrical loads to which they shall be subjected. Insulation properties and methods of manufacture shall conform to all applicable ANSI, ASTM and related industry standards. Pollution categories and associated creepage distances are in accordance with EN 50124-1.

3.14 Electrical Safety

At all authorized places of direct public or staff access to electrified lines or electrical equipment locations and enclosures, signs giving suitable warning of the dangers from live electrical equipment shall be displayed.

Overhead equipment structures and supports shall be of a design, which cannot easily be climbed. Where this is not achieved and/or there is public access to the structure or trespass is likely, anti-climbing protection shall be provided.

3.14.1 Protection by clearance

Live equipment shall not extend over non-electrified lines, behind any buffer stop, over the platforms or any other public part of a station. Wherever practicable, the designer shall provide protection against direct contact by clearance, in accordance with EN 50122-1, Section 5.2.

When modifying, renewing or installing new railway subsystems that affect the clearance from the OCS or live parts of the pantographs to a standing surface, the design of the subsystems shall maximize the clearance so far as reasonably practicable.

The electrical clearances shall be assessed from a standing surface to the exposed live parts of the OCS and exposed live parts mounted on vehicles.

3.14.2 Protection by electrically protective obstacles

Where protection by clearance cannot be achieved, protection by electrically protective obstacles shall be provided in accordance with EN 50122-1, Section 5.3 and GO-95 where applicable.

3.14.3 Overhead Contact Line Zone and Pantograph Zone

Structures and equipment may accidentally come into contact with a live broken contact line, or with the live parts of broken or de-wired pantograph or energized fragments. **Figure 7: Overhead Contact Line Zone and Pantograph Zone** defines the zone inside which such contact is considered probable and which limits are unlikely to be exceeded by a broken overhead contact line or damaged energized pantograph, or energized fragments thereof.

Note: The damaged pantograph may be live, even though it is not in contact with the overhead line, because it is inter-connected with other energized pantographs or because the train is in regenerative braking mode.

The limits of the overhead contact line zone below top of rail extend vertically down to the earth surface, except where the tracks are located on an aerial structure where they extend down to the deck of the aerial structure. In the case of out of running OCS conductors or live feeder wires, the overhead contact line zone shall be extended accordingly.

3.14.4 Protective Screening and Barriers for Standing Surfaces in Public Areas

The requirements for protective screening and barriers for use in public areas for protection against direct contact with adjacent live parts on the outside of vehicles or adjacent live parts of an overhead contact line system for normal voltages up to 25 kV AC to ground, where clearances are less than those shown in
Figure 4 and are summarized as follows:

Where the energized parts are located below the standing surface, protection of the standing surface shall be by means of a solid barrier.

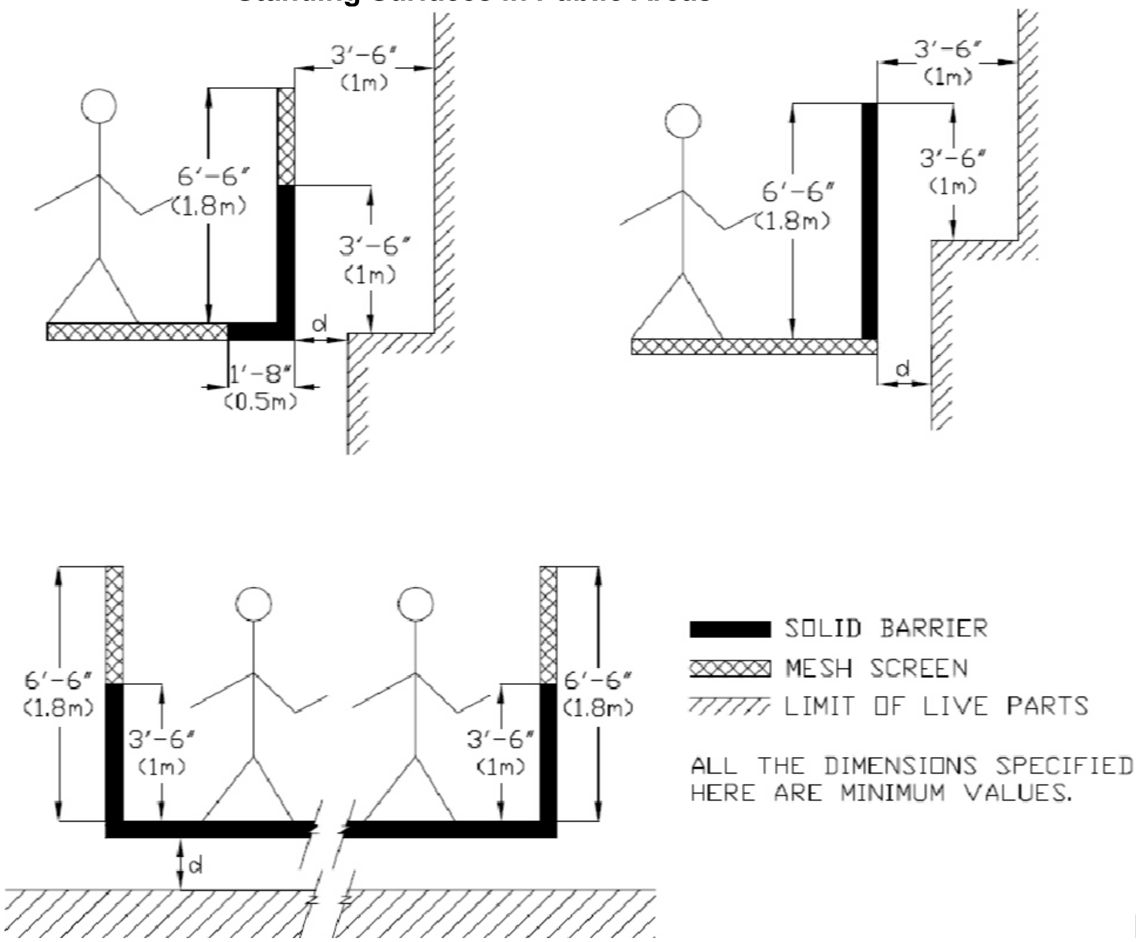
The minimum height of the protective barrier – solid barrier or a combination of solid barrier plus mesh screen, as shown in
Figure 4 shall be 6'- 6".

For Caltrain Electrification Projects protective barriers of greater height are required. The minimum height of the protective barrier for any Caltrain Project shall be 9'-6", with the top 3'-0" being a curved towards public where pedestrians are expected. Where pedestrians are not expected the top 3'-0" shall be straight.

The value of Dimension "d" between the protective screen or barrier and live parts shall be determined from **Table 10** . Where mesh screens are used, 4 inches shall be added to the value of Dimension "d" and where buckling or warping of solid barriers is likely, 1.25 inches shall be added.

The length of the protective screening and/or barrier on structures that cross over the electrified railroad, which protect publicly accessible standing surfaces, shall be extended laterally beyond and normal to the live parts of the overhead contact line by at least 10 feet (3.05 m) on each side. In the case of energized conductors not being used for current collection (e.g., line feeders, reinforcing feeders, out of running overhead contact lines), the barrier shall extend for a width of at least 10 feet (3.05 m) on each side of the conductor, with the provision that movements due to dynamic and thermal effects shall be considered.

- **Figure 4: Clearances from Protective Screens and Barriers for Standing Surfaces in Public Areas**



3.14.5 Protective Screening and Barriers for Standing Surfaces in Restricted Areas

The requirements for clearances from protective screening and barriers for standing surfaces in the restricted areas (areas for authorized personnel only) for protection against direct contact with adjacent live parts on the outside of vehicles or adjacent live parts of an overhead contact line system for normal voltages up to 25 kV AC to ground, where clearances are less than those shown in **Figure 5: Clearances from Protective Screenings and Barriers for Standing Surfaces in Restricted Areas** and are summarized as follows:

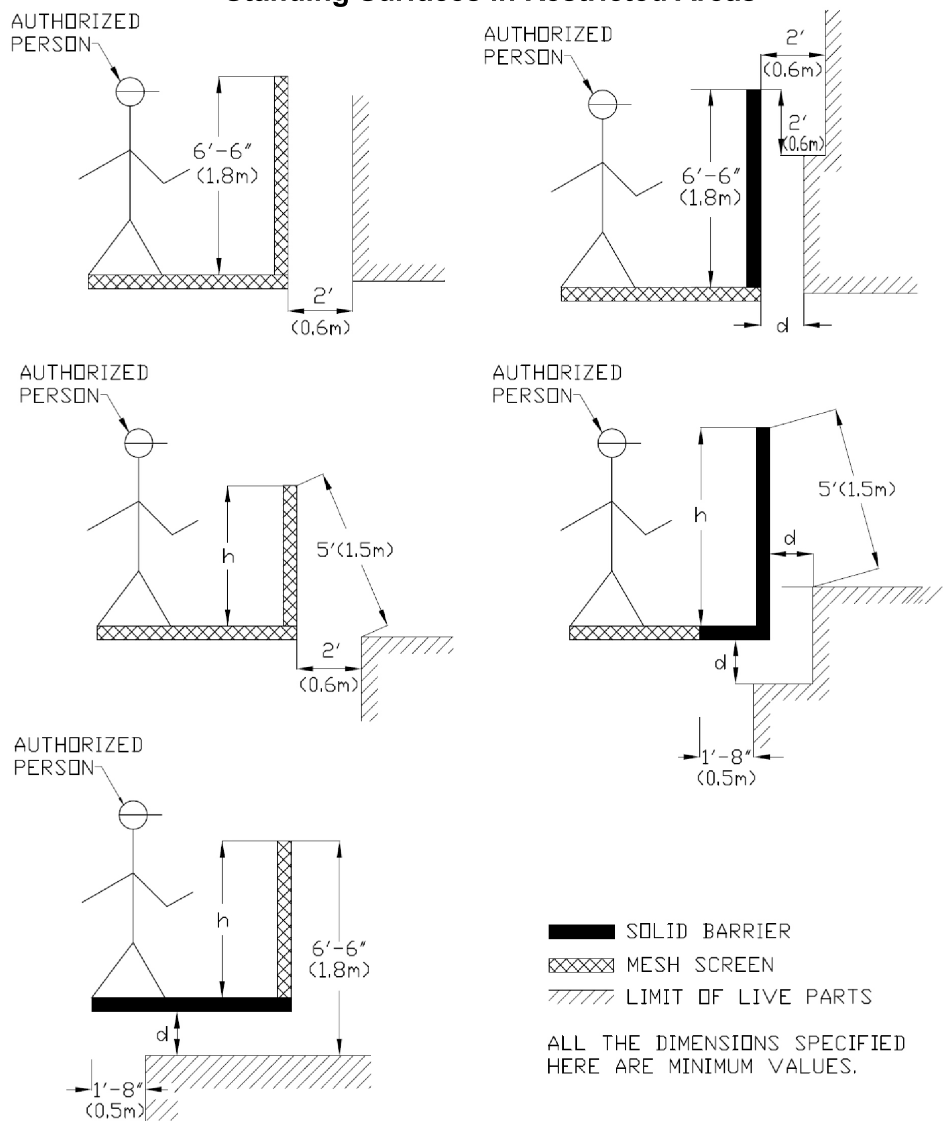
For standing surfaces above live parts on the outside of vehicles or above live parts of an overhead contact line system, the protection shall be of solid barrier construction.
The length of the solid barrier, protecting the standing surface, shall correspond to the pantograph zone and shall extend beyond the live parts of an overhead contact line by at least 1 foot 8 inches.
In the case of energized conductors not being used for current collection (e.g., line feeders, reinforcing feeders, out of running overhead contact lines), the barrier shall extend for a width of at least 1 foot 8 inches on each side of the conductor, with the provision that movements due to dynamic and thermal effects shall be considered.

The height “h” of the protective screening and barrier shall be such that a clearance of 5 feet from the top of the protective screening and barrier shall be maintained (see **Figure 5**).

The height of the side protective screenings and barriers shall correspond to the height of the required safety railing but should be a minimum of 3 feet 6 inches.

The value of Dimension “d” between the protective screen or barrier and live parts shall be determined from **Table 10.** Where mesh screens are used, 4 inches shall be added to the value of Dimension “d” and where buckling or warping of solid barriers is likely, 1.25 inches shall be added.

- **Figure 5: Clearances from Protective Screenings and Barriers for Standing Surfaces in Restricted Areas**



3.14.6 Additional Requirements for Protection Barriers and Screens

Protection barriers or screens shall be of sufficient strength and shall be supported rigidly and securely enough to prevent them from being displaced or dangerously deflected by a person slipping or falling against them. Barriers and screens shall be permanently fixed and shall be removable only with tools. Barriers in public areas shall employ non-removable, captive fasteners.

Barriers shall be of solid construction and fabricated from either conductive or non-conductive materials. Conductive barriers shall be bonded and grounded by inter-connection with the traction system ground, at not less than two locations.

Screens shall be of grounded, conductive, open mesh materials, and shall be grounded by inter-connection with the traction system ground, preferably at not less than two locations. Non-conductive mesh or plastic-coated metal mesh shall NOT be used. Conductive mesh screens shall be constructed such that a cylinder greater than ½ inch (13 mm) in diameter, cannot be pushed through the mesh. Mesh screen construction shall be such that required clearances to energized parts are maintained.

The style of barrier to be employed is dependent upon type of standing surface and its proximity to the energized parts and whether the surface provides for public or restricted access, as detailed above. The size of the barrier or screen shall be such that energized parts cannot be touched in a straight line by persons on a standing surface. The design of the protective screens and barriers shall minimize the loading on the existing structures and the adverse visual impact.
The metallic parts of overhead bridge screens and barriers shall be bonded to the static wires. Other metallic items under overhead bridges within a lateral distance of 10 feet (3.05 m) of any energized and uninsulated equipment below the structure shall be directly or indirectly bonded to the static wires.

3.14.7 Protection Against Climbing

Where there is public access or trespass is likely, anti-climbing protection shall be provided at the buildings and other structures supporting energized parts of the OCS. The anti-climbing protection shall include signs warning of the dangers of high voltage.

Access to fixed ladders, particularly at signal poles and signal gantries, and the means of access to any roof or other place, which could allow non-authorized persons to approach energized parts, shall be secured or otherwise protected.

3.14.8 Clearances for Utility Lines Crossing over the Electrified Railroad

The minimum clearance for overhead power, existing communications or other utility lines, which are not part of the Traction Electrification System (TES), shall be in accordance with CPUC General Order No. 95 Rule 38 Table 2 and shall be measured from the highest energized point on the TES.

For any crossing of the high-speed lines, the utility shall comply with the requirements of CPUC General Order No. 95 with regard to the conductor’s suspension arrangements and strength of the structures immediately adjacent to the crossing point.

3.14.9 Electrical Clearances for Rail Vehicles and Structures

Electrical clearances are classified as either Static or dynamic.

Static Clearance is the physical air clearance between energized parts of a vehicle or OCS when not subjected to dynamic conditions or climatic influences or pantograph pressure, and an adjacent fixed structure or the grounded parts of a vehicle, while the vehicle is stationary.

Dynamic (or Passing) Clearance occurs under dynamic operating conditions that exist during the passage of a train, or when the OCS is affected by extreme climatic conditions, such as wind loading. Dynamic Clearance is the physical air clearance between energized parts of either the vehicle or OCS and the grounded vehicle, or between energized parts of either the vehicle or OCS and an adjacent fixed structure under dynamic conditions.

For all new works the minimum electrical clearance (phase to ground) shall as given in **Table 10**. These clearances shall be applied between all electric traction infrastructure and all earthed structures including airspace development and bridges.

- **Table 10: 25 kV AC Minimum Electrical Clearances**

Minimum Electrical Clearance	Type of Clearance
20" (508 mm)	Static
12" (305 mm)	Dynamic

These electrical clearances shall be adopted at all locations. This is required to avoid short circuits due to bird strikes, animals and vandalism. Where it can be demonstrated that it is not practicable to provide these clearances, permission shall be obtained from Caltrain. However, prior to any reduced electrical clearance, the following factors shall be evaluated by the designer:

- Fault current resulting from a breakdown of the electrical clearance.
- Vulnerability of the OCS and railroad infrastructure to damage, if a breakdown of the electrical clearance occurs.
- Consequences for the safety of persons if a breakdown of the electrical clearance occurs.
- Application and maintenance of tolerances of the OCS and railroad infrastructure
- Economic and technical considerations.

In a 2x25 kV AC system, there is a 180˚ phase difference between parts common to the energized ATF and parts common to the energized catenary system. The preferred clearance between phase to phase shall be 30" (762 mm) in static conditions, whereas the minimum clearance between these elements shall be 22" (560 mm) under worst case conditions.

3.14.10 Clearance Envelope at Fixed Structures

In determining the minimum vertical clearance envelope at fixed structures, including OCS support structures and signal bridges, the provisions in AREMA Chapter 33 shall be followed. In addition, the following factors shall be assessed.

The dynamic vehicle outline, which shall take into consideration the dynamic swept envelope, track position and maintenance tolerances, including railhead side wear, and the effects of vertical and horizontal curvature, including track super-elevation.
The position of energized parts on the rail vehicles, including the dynamic pantograph envelope allowing for pantograph carbon wear and dynamic movements and deflections of the pantograph frame, and vehicle construction and maintenance tolerances. The pantograph envelope shall include an allowance for chording effects, if the pantograph is offset longitudinally on the vehicle from a truck centerline.
The position and size of energized parts of the OCS allowing for installation and maintenance tolerances, uplift and other dynamic movements, including those due to wind, temperature and loading conditions. In assessing the minimum vertical clearance of the overhead structure, the vertical clearance between the overhead structure and the energized bare ATF cable shall also be considered.
The minimum lateral clearance at fixed structures, including OCS poles and other OCS support structures and signal bridges, shall comply with the clearance requirements as given in Section 3.14.9.

3.14.11 Vehicle Clearances

Most railroads, including the commuter lines, adopt one or more of the standard Plate Diagrams issued by the Association of American Railroads (AAR) Mechanical Division in their Manual of Standards and Recommended Practice. For the purposes of these criteria, Caltrain's operating requirements and conditions have been assessed.

Passage of rail traffic over the Caltrain-owned right-of-way is governed by three Load Gauges:

- AAR Plate 'E' Height = 15' 11" MP 0.2 – MP 3.1 (San Francisco to UP's Quint Street Lead)
- AAR Plate 'F' Height = 17'- 0" MP 3.1 – MP 5.1 (UP's Quint Street Lead to Bayshore)
- AAR Plate 'H' Height = 20'- 3" MP 5.1 - MP 51 (Bayshore to Tamien)

Restrictions on the usage of Plate 'E & F' vehicles for the northern portion of the Caltrain ROW is mandated by the limited clearances in the four San Francisco Tunnels. Restrictions on the usage of Plate 'H' on the main portion of the route is mandated by the limited clearance at the San Francisquito Creek Bridge in the city of Palo Alto.

3.14.12 Clearance to Buildings and Signs

Clearance to buildings and signs adjacent to right of way shall be as required by GO 95 rules 54.4H and 37 and Tables 1 & 2A.

3.15 OCS Structural Requirements

3.15.1 General

The OCS poles shall be either galvanized H-section wide flange beams, square tubes or galvanized round, tapered tubular steel sections. In designated areas and at passenger stations round, tapered tubular steel poles or square tube poles shall be used. All poles shall be of the bolted base type and shall be designed and manufactured to relevant U.S. steel standards and G.O. No. 95 strength requirements.

Where multiple items of OCS equipment are to be supported, such as overlaps and turnouts, multiple cantilevers may be attached to a single structure, which shall be of a heavier section such that the applied loads shall not cause twisting of the structure by more than 5 degrees.

In double-track sections, the OCS poles shall be located outside the tracks with cantilever for support of the OCS. Center poles shall be avoided wherever possible but may be used in track areas where site constraints do not permit and adequate track center clearance is available, and it is desirable to avoid property take issues or station platforms with approval from Caltrain.

For multi-track areas where independent poles cannot be installed between tracks, portal structures with bolted base support poles and with drop tubes to support the OCS equipment related to individual tracks shall be used, thereby providing for mechanical independence of the individual equipment. Headspans shall not be permitted.

OCS poles in the station areas shall be located away from the platforms. For situations where OCS poles have to be placed on station platforms, they must be placed in a manner that minimizes the visual impact, obstruction to passengers, shall not impede ADA access or ramps and shall be integrated with platform architecture design by being fully recessed. The minimum distance from platform edge to face of poles shall be 7 feet. Counterpoise grounding derived from
local "drain bonds" or nearby impedance bond pairs shall be used within passenger stations, and the aerial static wire shall be electrically isolated from the OCS structures and components connected thereto.

The design of all OCS steel structures, poles and supports shall conform to the Caltrain standard system design, including relevant seismic requirements. The pole style shall be generally consistent through the project with Caltrain's approval. Poles shall be designed as free-standing structures, except for poles carrying wire terminations, which shall be back-guyed, typically in the along track direction.

Balance weights shall not be placed on the passenger stations. The structures shall be designed to carry the OCS loads as outlined in these criteria, including additional imposed loading resulting from seismic events, without experiencing failure.

All structures, poles and brackets shall be capable of withstanding a broken-wire failure, including breakage of both the static wire and parallel feeder conductor in any one span, without exhibiting major damage that will allow the OCS to fall to the ground. The support structures shall be capable of handling the loads due to breakage of other parts of the OCS. Provisions shall be made in the designs to prevent overloading as a result of temporary construction loads imposed during catenary assembly and wire installation.

The pole length for each pole type shall be as uniform as it is practical, to limit the number of required spares. Exceptions shall be considered on a case-by-case basis only when a standard pole length is deemed to be perceptibly inappropriate. All steel materials, related processes and manufacturing methods shall be specified in accordance with ASTM standards, wherever applicable and deemed appropriate, including requirements for hot dip galvanizing of steelwork and hardware. Painted poles shall not be precluded for poles on the passenger stations, within any urban design area, or in other special circumstances. Anchor bolt patterns shall be selected to provide coordinated relationships between poles and foundations. The coordination shall be based on matching strength and minimizing the number of required configurations.

3.15.2 OCS Pole and Foundation Requirements

The pole and foundation locations shall be designed in a manner that avoids conflicts with existing or planned overhead or underground obstructions. The OCS foundations shall be constructed in a manner that does not disturb the existing tracks under revenue service.

3.15.3 Loading Requirements

Structures shall be detailed to accommodate Caltrain's OCS hardware. Load cases to be considered whilst undertaking structural calculations for OCS shall include (but not be limited to):

- Load Case 1: Static loads applied from all equipment
- Load Case 2: Dynamic loads applied from all equipment including maintenance and installation loads.
- Load Case 3: Applied loads due to conductors (radial, tension and seismic)
- Load Case 4: Across track wind loads applied to conductors
- Load Case 5: Across track wind loads applied to the structure and support equipment
- Load Case 6: Diagonally (45°) applied wind load to the structure and support equipment
- Load Case 7: Along track wind loads applied to the structure and support equipment

Combinations of the above load cases shall be considered when assessing OCS support equipment.

Loads shall be applied to generate the worst case for the structure under consideration, with beneficial loads/actions omitted during the assessment. Examples include:

- Back-to-back cantilever structures, where a single equipment is not attached.
- Structures with ancillary wiring may be subject to a worse loading condition if the ancillary wires are removed.
- Twin cantilevers with a single equipment removed.
- Back-to-back anchor structures must be capable of supporting a single termination, with the other removed.

Wire Break Condition: Portal structures shall be designed to resist the unbalanced forces in the direction of the line resulting from broken wires. Two such wire break loads of not less than 1,000 pounds each (per conductor deadend) shall be assumed as acting on any pole or one wire break load of not less than 2,000 pounds shall be assumed as acting at any set of catenary deadend attachments point to a steel member of a supporting structure. Both conditions shall be checked individually. Wire break loadings need not to be considered as acting in conjunction with longitudinal wind forces.

Arms and arm/column connections need not be designed to resist wire break conditions. However, columns shall be designed to resist wire break loads applied to the section at the messenger wire height. Large deflection and non-elastic deformation to the arm is to be expected, however, overall structural failure shall be prohibited.

The loading assumptions and strength requirements shall meet or exceed the requirements of G.O. No. 95 rules. The general design loads include dead load, live loads - wind and earthquake load. However, as noted in NESC Rule 250A4, the structural capacity provided by meeting the loading and strength requirements of NESC Section 25 and 26 will provide sufficient capability to resist earthquake ground motions.

In addition to the load conditions indicated in G.O. No. 95 and the NESC, a 100-mph wind plus 10 percent gust allowance shall be evaluated to prove no structure failure.

All structures, poles, brackets, foundations and anchors shall be capable of handling construction loads imposed during erection and during catenary assembly and wire installation, and of withstanding a broken-wire failure, including breakage of both the static wire and parallel feeder conductor in any one span, without exhibiting major, catastrophic damage. These support structures shall also be capable of handling the loads due to breakage of other parts of the OCS. Pole and foundation loadings and structural designs shall be developed in accordance with the criteria defined herein.

The design of bolted steelwork connections shall conform to AISC requirements and shall specify materials and methods in accordance with ASTM standards. Anchor bolts (hold-down bolts) shall be galvanized.

OCS foundations and structures shall be designed so that their deflection under the loads imposed during normal operating conditions shall not cause a contact wire displacement that could prejudice acceptable tracking and performance of the pantograph current collector. To this end, the maximum allowable live-load operating deflection of the pole and foundation structure together shall be limited to 2 inches at the normal design contact wire height. For the purposes of structural design, this live loading shall be considered a dynamic operating condition, and the structure shall fully recover from its displacement due to the live loading.

For all non-operating loading conditions, excluding seismic conditions, the maximum total deflection of the pole and foundation together (measured at the pole top) shall not exceed 2.5 percent of the total pole length due to both static (dead) loads and live loads combined.

The foundation and steel pole, or vertical members of the support structure, shall be designed to enable the pole to be raked during installation. This rake shall allow for the static dead loads that are imposed on the structure by the cantilevers, equipment and along-track conductors. Rake installation shall provide for a visually plumb and vertical pole after application of the full static loading. This position shall serve as the design reference datum for the calculation of the live-load operating deflection. All OCS alignment and wire layout designs shall utilize this static, plumb, dead load position as the true pole-face reference datum.

The OCS foundations and poles shall be designed in a manner to minimize the number of types and sizes to simplify constructability to avoid disturbing existing adjacent structures, to provide flexibility for pole rake adjustment, and to minimize future maintenance inventory and costs.
Anchor bolt patterns shall be selected to provide coordinated relationships between poles and foundations. The coordination shall be based on matching strengths and minimizing the number of required configurations.

Particular attention shall be given to the provision of a high level of protection against atmospheric pollution and contamination to maintain the design life without frequent maintenance cycles.

OCS support locations shall be individually numbered for ease of identification on site as given in Section 3.15.5. Structure number plates shall be fitted to the structure at a height of 6 feet 6 inches (1.98 m) approximately above rail level.

3.15.4 OCS Poles

Poles shall be designed as free-standing structures, except for poles carrying wire terminations, which shall be down-guyed, typically in the along track direction. Minimum pole offset from Center of track to face of pole in open line track shall be as per Caltrain standard drawing SD-2002, latest issue. For areas where UP Railroad clearances govern, clearance shall be in accordance with UPRR Standard Drawing 0038K, latest issue. For stations, see Caltrain Design Criteria Chapter 3 – Stations and Facilities. Any variances from the standard spacing between the centerline of track and the face of pole shall be submitted to Caltrain for approval.

Aerial structures will be designed in a manner such that OCS poles can be located at any position along the structure. Alternatively, working in close coordination with the OCS Designer, aerial structures can be designed to provide site-specific locations for OCS pole installations.

The OCS supporting structures shall be calculated in accordance with relevant American standards. The allowance for a one-third increase in allowable stress for wind combined loading shall be waived.

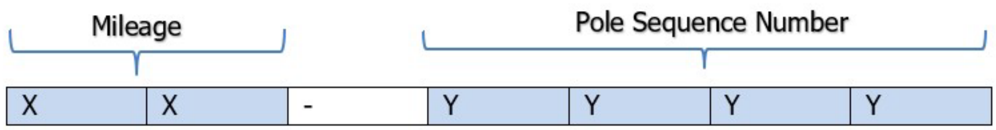
The design of structural and fabrication welding shall conform to the AWS, Standard D.1.1, “Structural Welding Code.”

OCS poles shall be painted in some areas as per OCS specification 34 30 46. The Painted Poles shall be hot-dip galvanized and have the proper surface preparation to receive a two-coat powder finish. The Prime Coat shall provide corrosion resistance, chip resistance and adhesion. The Exterior Coating shall meet color, gloss and color requirements, and the coating system shall meet the OCS specifications.

3.15.5 OCS Pole Numbering

OCS pole identification plates shall be attached to structures on the mast face, facing the on-coming rail vehicle, operating in the normal direction of movement. For masts located between tracks with opposing normal directions of movement, structure number plates shall be affixed to alternate mast faces viewable from the driver of on-coming rail vehicles. Structure numbering shall be as detailed on approved overhead layout plans. Portal structures shall be regarded as one structure and shall carry the same characters for each leg.

- **Figure 6: OCS Pole numbering system**



For details refer to Caltrain Standard Drawings SD-W5187 and SD-W5188.

3.15.6 OCS Foundations

The OCS foundations shall be capable of meeting the structural loading requirements and shall be designed for each individual location. The structural dimensions will be dependent on:

- Loads on the poles due to the OCS conductors, feeder cables, tensioning equipment, insulators, mid-point anchor ties, and all other necessary equipment.
- Wind loads on the poles and associated OCS conductors and equipment.
- Soil conditions.
- Earthquake loads.

OCS foundation designs shall be in accordance with ACI, AISC, and ASTM standards, other applicable codes, and proven foundation engineering and anchoring methods. Foundation designs shall consider buoyancy effects where applicable.

Augered, cast-in-place concrete foundations with a nominal diameter of 3 feet, 3 feet 6 inches and 4 feet, as shown on the Standard Drawings, shall be adopted for all normal situations. Site-specific conditions or unusual loading combinations may dictate the adoption of other types or sizes of foundations. The permissible increase in soil resistance values, as defined in the CBC as being applicable to free-standing structures, shall be taken into consideration in the design of OCS foundations, in accordance with the CBC formulae.

The OCS foundations shall be designed to exceed the capacity of the pole or structure, being supported by the foundation by not less than 25 percent to ensure the foundation will not experience failure under the specified operating and non-operating conditions. The overturning moment shall not exceed 85 percent of the stability moment.

The foundation design shall incorporate the railroad E-80 freight load in any sheeting, shoring and foundation sizing as needed. The Contractor shall perform geotechnical investigations and investigate soil characteristics. The Contractor shall design the slurry backfill to be used to suit the soil characteristics and drilling conditions to be encountered prior to starting installation of OCS foundations. The slurry design shall be modified, as necessary, to maintain adequate performance in various soil conditions.

The Contractor shall provide structural calculations for the proposed installation method showing that such a method of installation does not adversely affect the structural integrity of the tracks. The calculations and installation method will need to be reviewed per the provisions of the Contract by Caltrain.

The Contractor shall provide a set of installation procedures for review prior to construction. The procedures shall include the following details:

a. Step by step process from drilling through concrete placement, including procedures for slurry management and disposal.

b. Procedures for treatment of open holes at the end of a shift, including use of the specified temporary steel casings and caps for covering the tops of these casings.
c. Availability of spare temporary casings on site for use in case of unstable soil conditions and, when required, at the completion of shifts.
d. Adequate availability of equipment to preclude delay to operations resulting from Contractor installation delays.

Where fragmented rock is encountered, excavation shall be required for the installation of standard foundations. Where solid rock is encountered below grade (i.e., with soil cover), epoxy-grouted dowels shall be anchored to the rock (with appropriate pull-out tests being performed as required by the Contractor’s engineer of record), and the upper portion of a standard anchor-bolt foundation cast into the soil. Where solid rock is encountered at-grade (no soil cover), the anchor bolts shall be epoxy-grouted into the rock (with appropriate pull-out tests being performed) as required by the Contractor’s engineer of record) and with a small foundation-top cast around the bolts, primarily for corrosion protection and aesthetic effects.

Foundation height should be level with the top of high rail. The design of OCS pole foundations at station platforms shall be coordinated with the designers of any active station re-designs and shall be approved by Caltrain. When the OCS pole foundations are on platforms, the anchor bolts and base plate shall be fully recessed below platform level, and the void filled with grout as shown on the Standard Drawings. Special foundation heights may be employed in the railway cut sections and embankments to ensure foundations remain above the surrounding grade.

Existing geotechnical conditions shall be established by reviewing the existing soil data, local field testing, sampling and soils investigations. Information suitable for the design of foundations including any sheeting, shoring and foundation size, shall be obtained regarding the soil strata conditions, state, uniformity, water content, weights and densities. Specific descriptions of the uniform layers, and their unique compositions, shall be provided at regular intervals along the ROW. These investigations shall also identify the sand and rock types encountered.

3.16 Traction Power Rail Return System

The Rail Return System comprises the running rails, impedance bonds, static or ground wires, return cables, and the earth, each of which provides a part of the electrically continuous return path for the traction currents. The Rail Return System together with the Parallel ATF’s comprise the Traction Power Return System, through which the whole traction current is returned from the wheel sets of the traction units to the substations.

The whole traction load current of a train operating between any two adjacent autotransformers flows through the rail return system within the bounds of these two autotransformers. These autotransformers, however, redirect a major portion of the traction load current into the ATF’s, thereby minimizing the flow of return current in the rails in sections away from the train operating section. This is a safety related benefit of the autotransformer feed system; the other benefit being reduced electro-magnetic interference produced in this system as compared to the direct feed system.

3.17 OCS Interfaces with Other Disciplines

To achieve satisfactory performance of the OCS and current collection by the electrically powered Caltrain vehicles, it is essential that the OCS Designer works closely with other disciplines. The following is not a totally inclusive listing but provides guidance to the OCS Designer and indicates some of the major issues that must be addressed during the final design process.

3.17.1 Traction Power Supply System

Traction power facility locations particularly of the TPSS and SWS where phase breaks are located, Traction power requirements. Coordinate wayside power requirements and locations.

3.17.2 Rolling Stock

Confirmation of pantograph location on train consists and Freight Clearance Plates.

3.17.3 Train Control System

Coordinate locations of impedance bonds.

3.17.4 Signaling

Coordinate signal sighting requirements. Where reasonably practicable structures and tie foundations shall not be designed to be less than 16.50 feet (5m) from signals, block markers or lineside signage. Structures shall be positioned such that they do not obstruct the driver's view of signals, block markers or lineside signage. Insulated overlaps shall not be positioned on the approach to train stopping points to prevent the pantograph(s) bridging an insulated overlap.

3.17.5 Communications System

Coordinate wayside power cubicle requirements and locations.
Coordinate OCS disconnect switch RTU (Remote Terminal Unit) and interface requirements.

3.17.6 Overhead and Undergrade Bridges, Elevated Structures

Coordinate location of OCS poles and pole loadings. Where the OCS design necessitates mounting structures and/or materials to grade separated structures, elevated structures and/or tunnels; the OCS Designer shall be responsible for:

1. Coordinating directly with the structure's / tunnel's owner and obtain formal permission.
2. Obtaining as-built design information from the structure's / tunnel's owner.
3. Generating OCS designs and submitting them for review and approval to the structure's / tunnel's owner
4. Providing OCS loading requirements to structural/tunnel engineer.

3.17.7 Trackwork

The OCS geometry shall be designed to be in line with the parameters of the track layout and alignment. The parameters to be considered shall include, but are not limited to:

- Track gradient profile and location of the route, including turnouts and transitions.
- Types of turnouts.
- Track gauge.
- Track design speed.
- Locations of impedance bonds.

3.18 Typical design outputs / deliverables

OCS system designs shall be developed and may include the following, for example: conductor particulars, assembly general arrangement drawings, assembly drawings, etc.

OCS project design deliverables shall be determined by the project, and they may include but are not limited to the those outlined below in:

- **Table 11: Project Design Outputs and deliverables**

Deliverable	Description
OCS layout plans	To identify new, modified, redundant and future installations as part of the proposed scheme. Staged drawings to be submitted, as required. *NOTE: For complex areas, the plans are to be drawn on a scale of 1:60 and for open route 1:40.*
OCS cross sections / allocation schedules	As a minimum, OCS cross sections are for: Complex areas where a 1:60 layout plan is produced. Discrete features. New structures. Allocation schedules accompanied by a generic cross section are acceptable for simple open-route areas where the project design is repetitive. Staged revisions to be submitted as required.
Section diagram	For designs introducing a new electrification system or amending the existing electrical sectioning on an existing electrified area.
Bonding plan	To record where structures are bonded to the track.
Wire run schematic	Recommended schemes in complex areas to accompany the 1:60 layout plan.
Schedule of limited clearances	To provide details of limited clearance locations, i.e. overbridges, tunnels, station platforms, signal gantries, where applicable and to provide the design clearance and any risk mitigation.
Foundation schedule	To provide details of new and existing OCS foundations.
Hangers table	To provide details of droppers within a contact and catenary system.
Structural calculations	Structural loading calculations, verified by structural engineer
Design report	To detail the OCS design methodology and notable features of the OCS design. May include any of the above deliverables. May also include, but is not limited to, the following additional information: Design log Designer's risk assessment New OCS basic design drawings

END OF CHAPTER 3

CHAPTER 4

GROUNDING AND BONDING

4.0 Grounding and Bonding

4.1 Introduction

Grounding, Bonding, and Lightning Protection shall be designed to address three purposes: (1) personal safety; (2) equipment, cabling and building protection; and (3) equipment noise reduction. The objective is to achieve a safe operating environment regarding maximum accessible step and touch potentials.

4.2 Scope

This chapter addresses the first two items, i.e personal safety and equipment protection, whereas equipment noise reduction is addressed in the Electromagnetic Interference and Compatibility chapter. Grounding and bonding design shall be compatible with the requirements of the Electromagnetic Interference and Compatibility chapter. This chapter also provides criteria for the electrical separation of outside utility lines from the traction return and grounding systems.

Grounding is the establishment of a common reference voltage (typically 0 V) between power sources and/or electrical equipment. Electrical ground faults, short circuits, lightning, and transients can occur in electrical power supply and distribution systems or the facilities power systems. These design criteria specify requirements for the protective provisions relating to electrical safety in structures associated with the alternating current (AC) traction system and to any structures that may be endangered by the traction power supply and distribution systems or the facilities power system, and to any Positive Train Control (PTC), communications, or other electronic equipment that must be protected from electrical shocks. The grounding of PTC, communications, and other electronic equipment sensitive to high currents and/or voltages is also covered in this chapter. Grounding systems are intended to help clear faults in the quickest possible manner by providing a low impedance path for fault currents.

Grounding, Bonding, and Lightning Protection is multi-disciplinary in nature. The design shall consider and mitigate the negative effects of lightning, ground potential rise, contact with electrical power circuits and induction. The various discipline designers must collaborate with one another to coordinate the overall grounding and bonding design, so that a consistent approach is used and applied by each discipline in the development of the electrical power and structural grounding and bonding and lightning protection.
Where multiple codes address the same issue, but specify differing approaches or values, the most stringent requirement shall be met.

In addition, this chapter provides criteria for designs that will minimize the touch voltage and ground return currents created by the electrification system for the safety of passengers and operating personnel and minimize the hazards of electrical shock. The grounding and bonding system designs shall provide the means to carry electric currents into the earth under both normal and fault conditions without exceeding any operating and equipment limits or adversely affecting continuity of service.

For AC traction systems, grounding is the preferred method for reducing potentials of the electrical system both during normal operations and under fault conditions to protect equipment and to provide safety for employees and the general public. Adequate bonding shall be designed and installed throughout the entire electrified system to provide proper return circuits for the normal traction power currents and fault currents, with grounding connections as detailed in this chapter.

In principle, to assure the integrity of the grounding and bonding systems and the longevity of the system components particularly for buried or encased elements, the bonding and grounding designs shall create duplicate electrical continuity paths and provide for redundancy in jumpers and bonds.

Design documents shall identify each type of ground connection, consistent with the ground categories identified in the Electromagnetic Compatibility and Interference chapter and as indicated in the following sections.

4.3 General Grounding and Bonding Requirements

A uniform/standardized grounding and bonding system design shall be adopted to provide for protection of personnel and equipment. All grounding and bonding designs shall be coordinated with the various discipline designers, including civil, architectural, electrical and electronic, mechanical, plumbing and systems such as traction power supply and distribution, communications, PTC, etc. Refer to respective sections of this Design Criteria for specific grounding and bonding requirements. All grounding and bonding designs shall be coordinated with the stray current and corrosion control measures, along with electromagnetic compatibility and interference requirements, so that the respective designs do not conflict and render other systems ineffective.

Exposed non-current carrying conductive parts within the Overhead Contact Line Zone (OCLZ), such as conduit, cable trays, handrails, trackside fencing, etc. shall be electrically bonded to provide a continuous electrical path and shall be permanently and effectively grounded. Grounding system designs may include the grounding of individual items and/or dividing the length of non-current-carrying conductive entities into sections with each section grounded at only one point. Grounding and bonding conductor sizes shall be selected in accordance with the latest version of the applicable code. For the specific ground resistance at each grounding location, apply the requirements in respective sections of this document.

An electrical safety analysis shall be undertaken to assess which metallic parts need to be grounded and bonded, and the appropriate methodology for implementation identified. Non-current carrying parts that are used as part of the existing utility electrical distribution system, such as conduits, cable trays, manholes are assumed to have grounding in accordance with the National Electrical Code.

Grounding/Bonding requirements for wayside electrical equipment (in addition to fences and other metallic objects) within the OCLZ are generally equalized with the traction return system in addition to earth ground. There shall only be one connection to the traction return system via use of a buried counterpoise conductor(s) and a single connection to an impedance bond for equalization to the traction return network.

Grounding/Bonding requirements for wayside electrical equipment and other metallic items (fences, etc.) outside the OCLZ shall not be connected to the traction return system but be grounded to earth in accordance with Caltrain’s standards and as described herein.

4.3.1 General Facility Grounding

The design of each large facility/building shall include a ground grid. Wayside houses shall be grounded by means of one or more interconnected ground rods. Where ground grids are used, the design shall adhere to the following requirements:

Ground grid design shall be based on local soil resistivity, and the calculations shall be in compliance with IEEE standards (e.g., 80, 142, and 1100) and the CEC/NEC/GO 95/NESC rules as applicable.

Ground grids shall be constructed from an assembly of driven ground rods and bare copper conductors, installed adjacent to but not under the building, and shall achieve a ground resistance of not more than 5 ohms. A continuous loop of the grounding conductor(s) shall surround the perimeter of each facility/building, to which the perimeter fence and gates (where provided) shall be effectively bonded at frequent intervals, and within this loop the conductors should be laid in the form of a grid. At the cross-connections, the conductors should be securely bonded together by means of exothermic welds or Caltrain approved compression connections.

Ground rods shall be installed at grid corners, at junction points along the perimeter, and at major equipment locations with the ground rods being driven vertically into the ground to not less than the minimum depth specified in NESC (2007) Rule 094B2a.

Horizontal ground rod configurations may be required where subsurface rock or other obstructions interfere with the placement of vertical ground rods.

The ground conductors may be made of copper or other metals/alloys that will not corrode excessively during the expected service life.

Ground rods may be of zinc coated steel, stainless steel, copper-clad or stainless steel-clad steel.

The ground conductors shall be securely bonded to the ground rods and to the equipment (including busbars) to be grounded. Joints shall be exothermically welded.

- The ground rods shall be driven to stable soil where constant conductivity properties apply.
- At least 2 ground test stations shall be provided at each ground grid.
- Ground test stations shall be incorporated into the design of the ground grids. Each ground test station shall be connected to the ground grid by at least two grounding conductors.
- Ground test stations shall be located so that they are accessible to Operations and Maintenance (O&M) personnel. Locations shall be chosen that minimize the bonding conductor length.
- Supplemental electrodes (at equipment) shall not be permitted.
- The ground grid shall be bonded to the AC service ground electrode and the structural steel of the building structure.
- Ground grid locations shall be coordinated with landscaping plans to avoid conflicts with tree roots, and with underground utilities and sewer installations to avoid any direct electrical connection to these systems.
- Ground grids shall be designed to allow up to 50 percent additional ground rods to be driven and attached to the grid in the future.

4.3.2 Ground Busbars

Unless otherwise specified, a single ground busbar shall be provided in each equipment room and pre-engineered enclosure (e.g. traction power facility (TPF) equipment houses, communications rooms, PTC /signal houses, and wayside power control cubicles).

Ground busbars shall comprise a solid copper grounding busbar with insulated standoffs, and each ground busbar shall be drilled with rows of holes according to National Electrical Manufacturers Association (NEMA) standards, for attachment of bolted compression fittings.

Additional ground busbars for equipment shall be provided such that no potential equipment location within an auxiliary space (housing the equipment) is more than 30 feet from the nearest ground busbar.

Ground conductors at ground busbars shall be identified as to which system they are connected.

The ground busbars shall be connected to the ground electrodes or ground grids as detailed in Section 4.5.

4.3.3 Non-buried Grounding Conductors

Non-buried conductors between the ground grid or ground busbar and the grounded equipment shall be insulated copper wire or cable in non-metallic conduit. Grounding and bonding conductors shall be sized in accordance with the applicable code, so they can pass the maximum ground fault current without melting or fusing before the circuit breakers or protective relays disconnect the source of the fault current.

Non-buried grounding conductors shall be protected against physical damage and accordingly routed in conduit, cable tray systems, cable troughs, and/or ductbank systems under the following scenarios:

- Between buried ground grids and ground test stations.
- Between ground test stations.
- Between ground test stations and ground busbars.
- Between equipment enclosures and grounding busbars.
- Between equipment enclosures.
- Along the trackside.

Non-buried grounding conductors shall be antitheft approved by Caltrain.

4.3.4 Publicly Accessible Locations

For locations that are accessible to the public, the following constraints shall apply to the grounding and bonding design:

- Anchor bolts and ground lugs shall not protrude in a manner that could result in injury or property damage.
- Materials shall be concealed wherever possible.
- Ground test stations in public areas shall be avoided.
- Tamper proof hardware shall be used.

4.3.5 Grounding Connections

Exposed grounding and bonding connections at equipment, enclosures, ground busbars, ground test stations, and so forth shall be visible and accessible. Two-hole compression-type termination lugs shall be used to connect bonding conductors to equipment enclosures.

Buried/underground joints in grounding conductors and connections shall be exothermically welded. Connections to reinforcement steel shall be exothermically welded.

Epoxy coated rebar cannot be used as a grounding conductor. Where epoxy coated rebar is used as the only type of reinforcement, alternate grounding measures, such as connecting grounding plates directly to a series of buried ground rods or a ground grid, shall be adopted to achieve the required ground resistance.

The required ground resistance shall be achieved, if necessary, by connecting the grounding plate(s) directly to buried ground electrodes. Splices in grounding conductors will not be permitted.

Equipment enclosure doors shall be bonded with flexible metal bonding straps, instead of reliance on hinges for electrical continuity.

Where identical installations exist, the following requirements apply wherever practicable:

- The routing of conduit and conductors between structures and enclosures shall not differ.
- Conductor terminations shall be located in like manner.

Prescribed materials, cables and appurtenances shall be compliant with Underwriters Laboratories' (UL) standards.

Water, gas or other piping shall not be utilized as a ground electrode or ground conductor.

4.3.6 Electromagnetic Compatibility

For electromagnetic compatibility considerations, provide:

- Proper grounding and bonding of apparatus, conductor shields, and raceways to maximize shielding and to minimize circulating currents in shields.
- Surge protection against lightning and other natural sources of Electromagnetic Interference (EMI).
- Additional requirements are specified in the Electromagnetic Compatibility and Interference chapter.

4.4 Maximum Permissible Step and Touch Potential

Step and touch potential at the traction power facilities and facility power electrical rooms and/or yards shall be governed by the requirements of IEEE 80: Guide for Safety in AC Substation Grounding.

The bonding and grounding of current carrying equipment, enclosures and associated structures, including the Overhead Contact System (OCS), rails, and other trackside equipment, shall be designed such that the touch voltages do not exceed the values indicated in **Table 12: Duration of Maximum Permissible Touch Voltages**, which has been derived from EN 50122-1: 2022 Section 9.2.2:

- **Table 12: Duration of Maximum Permissible Touch Voltages**

Duration of Current Flow (sec)	Permissible Voltage in V
0.02	865
0.05	835
0.1	785
0.2	645
0.3	480
0.4	295
0.5	220
0.6	180
< 0.7	155
0.7	90
0.8	85
0.9	80
1.0	75
300	65
> 300 (where accessible to the public under all power supply feeding conditions)	60
> 300 (in workshops and similar locations)	25

In areas where the Union Pacific Railroad operates on an adjacent non-electrified track, the maximum permissible voltage shall not exceed 50 Volts (rms).

4.5 Grounding and Bonding Requirements for Facilities/Buildings and Structures

4.5.1 General Requirements

Structure grounding and bonding shall create a conductive path that will achieve potential equalization of the grounded elements of the railway system. The grounding system provides grounding connections for:

- High/medium-voltage protective ground.
- Low-voltage protective ground.
- Communication and signaling systems.
- Lightning protection ground.

Any non-energized component of structures within the OCLZ and pantograph zone (see section 4.6.3) shall be either directly grounded or be bonded to running rails via an impedance bond pair or “drain bond” to provide personnel safety. Bonding to pre-stressed steel tendons, within structures, is prohibited.

4.5.2 Facilities/Buildings

4.5.2.1 Service Entrance and Building Grounding

The AC grounding electrode system (otherwise known as “building ground”, “service entrance ground”) shall be designed to:

- Establish a common reference voltage for AC electrical power systems
- Provide a safe dissipation path for lightning and/or accidental high-voltage contact
- Provide a safe dissipation path for electrostatic discharge.

The components that make up the AC grounding electrode system include:

- Grounding electrode system (ground rod or ground grid)
- Grounding electrode conductor
- Bonding Conductor connects equipment grounding systems to the AC grounding electrode

A ground grid (see Section 4.3.1 for requirements), in direct contact with the earth at a depth below the earth surface of at least 3 feet, shall be provided at each building. The ground grid shall extend at least 2 feet beyond the foundation footer and at least 1 foot 6 inches outside the roof drip line.

The metal frame of buildings shall be bonded to the ground grid. Connections to the ground grid shall be exothermically welded. Where exothermic welding is impractical, UL listed connection hardware may be used.

For steel-frame buildings, alternate vertical columns shall be bonded to the ground grid.

4.5.2.2 Building Exterior and Interior Bonding and Grounding

Wherever a grounding conductor passes through a structure, foundation or wall, waterstops shall be provided. Multiple separate grounding systems are not permitted within the same building. Where a building is supplied by two or more services, the grounding electrodes for the two services shall be bonded together.

In multi-floor buildings, the grounding conductor shall be extended to each floor.
Provide a grounding electrode conductor sized in accordance with the applicable code between the service equipment ground bus and metallic water and gas pipe systems, building steel, and supplemental or made electrodes. Jumper insulated joints and bolted (non-welded) joints in the metallic piping.

Bond the steel columns to the reinforced steel within the building foundation.
Conductive piping systems shall be bonded to the building grounding system. Bonding connections shall be made as close as practical to the equipment ground bus.
Within a building, the grounding cable shall, where possible, be embedded in or underneath the floor slabs. Attach and bond the grounding electrode system to non-current-carrying conductive entities within the building.

4.5.3 Raised Floor Systems

A Signal Reference Grid (SRG) shall be provided for raised floor systems in compliance with IEEE 1100 and with the requirements of the Electromagnetic Compatibility and Interference chapter. Connect the SRG to the facility grounding electrode system. Where raised floor systems are of bolted metal stringer construction and are electrically continuous, two connections only to facility grounding electrode system shall be required.

4.5.4 Grounding and Bonding of Structures - General

Except for passenger station and service siding platforms, metallic items on structures crossing over, under or immediately adjacent to the electrified tracks shall be bonded either directly or indirectly to a static wire or to the traction return rail of the adjacent track through an impedance bond for personnel safety and lightning protection. Epoxy coated rebar cannot be used as a grounding conductor. Where epoxy coated rebar is used as the only type of reinforcement, alternate grounding measures, such as connecting grounding plates directly to a series of buried ground rods or a ground grid, shall be adopted to achieve the required ground resistance. Where epoxy coated rebar is used in combination with black rebar, the black rebar shall be interconnected to provide an

electrically continuous path, with connection(s) to grounding plate(s), but with no connection to the epoxy bar. The required ground resistance shall be achieved, if necessary, by connecting the grounding plate(s) directly to buried ground electrodes. The grounding and bonding of the emergency walkway area and other publicly accessible areas, as well as grounding and bonding of the track structure (where appropriate), shall be designed to avoid inadmissible touch and step voltages and also to meet the requirements of the signaling system.

4.5.5 Passenger Station and Service Siding Platforms

4.5.5.1 Passenger Stations and Service Siding Platforms in At-grade, Cut-and-Cover Tunnel, or Trench Locations

For at-grade platform grounding, a counterpoise shall be installed along the entire length of each platform with the conductor buried in earth and extending a minimum of 50 feet beyond the ends of the platform. Within station platforms and other public accessible areas, bond all metallic objects, structures, railings, ramps, enclosures and miscellaneous items that:

- are located within the Overhead Contact Line Zone (OCLZ) or Current Collector Zone (CCZ), including all live conductors, as defined in EN 50122-1, or
- are within 8 ft (2.5m) of the platform edge, or
- are within 8 ft (2.5m) of any grounded metallic object, or
- are electrically continuous metallic items capable of carrying induced or fault current in a manner that could create hazardous touch or step potential,
- to the station platform counterpoise connected to the traction return circuit.

Exception: Metallic objects smaller than 6ft (2.0m) in length perpendicular to the track and 8 ft (2.5m) in length parallel to the track need not be bonded to the counterpoise, in accordance with EN 50122-1.
The platform steel reinforcement shall be interconnected electrically by means of exothermic welds and shall be electrically continuous. The catenary columns in the passenger station shall be electrically insulated from the static wire.

In addition, for cut-and-cover tunnel or trench located platform grounding, where the structure is protected by waterproof membranes, an in-ground counterpoise cannot be installed. For these locations, a bare grounding conductor shall be installed along the entire

length of each platform with intermediate connections to the platform reinforcement at not more than 200-foot intervals. The ends of this conductor shall extend a minimum of 50 feet beyond the ends of the structure buried in earth and connected to driven ground rods. The grounding conductor shall be a minimum size of 4/0 AWG copper, but alternate materials, such as aluminum angle of comparable electrical capacity, may be adopted. Appropriate measures shall be adopted where dissimilar metals are interconnected.
In all station platform types (at-grade, cut-and-cover tunnel or trench located platforms) one end of the counterpoise or grounding conductor shall be terminated in a handhole, which will permit the counterpoise or grounding conductor to be connected to the rails via an impedance bond, with the location being coordinated with the PTC System designer. The counterpoise or grounding-conductor-bonded metallic items shall be isolated from steel building grounds and particularly from utility grounds.

The grounding design shall ensure the maximum permissible touch voltages, as specified in **Table 12: Duration of Maximum Permissible Touch Voltages** are not exceeded and without exception, the resistance to ground shall not exceed 5 ohms. Subject to field testing during construction, it may be necessary to install supplemental ground rods at the ends of the counterpoise to achieve the 5-ohm value, and the designer shall incorporate this requirement in the design.

See Sections 4.5.2.1 and 4.5.2.2 for the Grounding and Bonding requirements for facility power installations in passenger stations.

4.5.6 Existing Overpasses

If components of existing overpasses, as detailed below, lie within the OCLZ and pantograph zone, the following special grounding provisions may be required to afford protection to adjacent third-party installations:

- Abutments or Piers – galvanized steel strip on each bridge wall or attached to columns or piers.
- Bridge Face – galvanized steel strip or angle section above the overhead line at each bridge face, if the bridge soffit is within the pantograph zone.

The above measures shall be provided at existing structures if an analysis determines the need for them.

When the vertical clearance between OCS conductors and concrete overpasses is less than or equal to 3 feet, protection panels (flash plates) shall be installed above the OCS, attached to the underside of the structure, and interconnected to the static wire at not less than two locations. For steel overpasses, the steel girders shall be interconnected and bonded to the static wire at not less than two locations.

Publicly accessible overpasses shall be protected by screening and/or barriers which shall be at least 9'-6" high and extend laterally beyond, and normal to the live parts of the Overhead Contact System by at least 10 feet on each side. The metallic portion of the screening and barriers shall be bonded to the static wire at not less than two locations. All other metallic items on the overpass, within the lateral range of not less than 10 feet beyond any energized and uninsulated equipment passing below the structure, shall be directly or indirectly bonded to the static wire.

4.5.7 Screen/Noise/Wind/Safety Barriers

The metallic portions of screen, noise, wind and/or safety barriers shall be electrically connected in a similar manner to that detailed above for aerial structures. Safety barriers shall be electrically bonded to the static wire at not fewer than 2 locations.

4.5.8 Fence and Gate Grounding

The designer shall evaluate touch voltages on metallic fences and/or gates, including inter-track fences, which lie within the Overhead Contact Line and Pantograph Zone (**Figure 7**). Ground electrodes shall be installed on either side of a gate or other opening in the fence. Fence posts at openings in the fence shall be bonded to form a continuous path, and gates shall be bonded to support posts with flexible metal bonding straps to eliminate reliance on hinges for electrical continuity. Fences shall be made electrically continuous and grounding conductors shall be exothermically welded/ Caltrain approved compression clamps to fence posts and to any fence material support members (top and bottom) between posts. Ground rods shall be applied at regular intervals to metallic fences for their entire length. The distance between ground rods shall be dependent on the step-and-touch potential as measured.

Metallic fences outside the Overhead Contact Line and Pantograph Zone (**Figure 7**), up to a distance of 45 feet from an outside track centerline, shall be bonded to form a continuous path in the same manner as detailed above. An insulated section shall be inserted in the fence, where the fence departs this zone and bonding to traction earth is no longer required. Ground electrodes shall be installed on either side of a gate or other opening in the fence, and at intermediate locations, based on local soil resistivity and worst-case projected potentials. Grounding conductors shall be exothermically welded or connected with Caltrain approved irreversible compression connections to the fence posts and to the driven ground electrodes.

4.5.9 Third-Party Grounding Interface

Due to the danger of voltage propagation, third-party grounding installations in the vicinity of the ROW shall not be connected to the railway grounding system. For third-party pipework, non-conducting materials shall be used, or an insulation segment or insulated joint shall be inserted at the site boundary. Where the public network grounding system cannot be separated from the railway grounding system due to lack of space for separation, the traction power return circuit shall be interconnected with the neighboring grounding system of the public network.

To minimize the possibility of shock hazards outside the fence line, the systems designer shall evaluate touch potentials on third-party metallic fences/gates and/or pipelines that parallel the ROW, or other metallic structures. The systems designer shall provide designs for grounding and/or segmenting the conductive feature using insulating measures for these elements, such that touch potentials are controlled to levels that do not exceed the limits detailed in **Table 12**. Fences, and/or segments shall be made electrically continuous, but shall not be connected to railway ground grids, grounding conductors, static wires, or the rails, and shall be independently grounded by means of driven ground rods. Grounding conductors shall be exothermically welded or Caltrain approved compression clamp to fence posts and to driven ground electrodes.

In cases where fences are purposely electrified to inhibit livestock or wildlife from crossing the fence, site-specific insulating measures shall be designed and implemented.
Connections to third-party infrastructure shall be coordinated and approved by the third party.

4.6 Grounding and Bonding Systems for the Traction Electrification System Equipment and Structures

4.6.1 General

The rail return path of the 2x25 kV AC autotransformer feed Traction Electrification System (TES) consists of the static wires, the running rails, cable connections from static wires/running traction return rails to the TPF (all of which are grounded as detailed below) and the earth. The static wire is connected at regular intervals to the running traction return rails, via impedance bonds, to help reduce step-and-touch potentials, but must be coordinated with the signal system to ensure that broken rail protection is not compromised. The static wire runs alongside the catenary to interconnect the OCS supporting structures (except at station platform areas), signal bridges and masts, overhead bridges and is connected to the Traction Power Facilities ground busses.

The traction return current causes a voltage rise in the running rails and static wires, due to the impedance of these conductors for both normal operations as well as under short circuit conditions, thereby resulting in a voltage between the running rails and static wires and the surrounding ground or other grounded metallic parts (touch voltage). These touch voltages shall be limited to acceptable values. Hazards due to touch voltages shall be minimized by means of adequate grounding and bonding measures, and as required, mitigation measures.

For a more detailed description of the TES, refer to the Traction Power System and Overhead Contact System chapters.

The overall grounding and bonding protection for the TES shall consist of the OCS aerial static (ground) conductors, connections from the aerial ground conductors to any buried ground conductor/ground rods and the impedance bonds connected to the track, with connections between these elements and each TPF ground grid. In addition to the impedance bond connections at the TPF's, additional connections between the static wires and the rails through impedance bonds may be needed, based on the traction power load flow simulation results and the step and touch analysis. The designer shall determine the required spacing of the impedance bonds and interconnections to the rails, which must be coordinated with the operating requirements of the PTC System.

Where insulated cables are used within the TES, they shall be specified and manufactured in accordance with the appropriate electrical standards that are applicable to the working environment—voltages, operating and fault currents—to which they will be subjected.

The OCS grounding and bonding system shall interconnect all OCS's normally non-current-carrying metallic parts and shall bond metallic components of overhead bridges, tunnels and other structures.

The grounding and bonding system for the TES shall not be electrically connected to any non-traction power facility electrical grounding system.

4.6.2 Traction Power Facilities

The ground grid for each TPF shall be in direct contact with earth at a depth of 12 to 18 inches below grade, as stipulated in IEEE-80: 2000, Section 9.2. The ground grid shall be extended at least 2 feet beyond the fence of the TPF. The ground grid for each TPF shall be designed as per the specifications of IEEE-80, NESC, CEC and NEC.

The metal fence of the TPF shall be bonded to the TPF ground grid as specified in the applicable code.

A layer (3 to 6 inches thick) of high resistivity material, such as gravel, shall be spread on the earth's surface above the ground grid to increase the contact resistance between the soil and the feet of persons in the TPF. The grounding system shall be designed so that the step and touch potentials under fault conditions are within the designated limits.

In areas where soil resistivity is high or the TPF space is limited, alternative methods shall be considered for obtaining low impedance grounding, such as connections to remote ground grids or wire mesh, deep-driven ground rods or drilled ground wells, plus the use of various additives and soil treatment methods, etc. The effects of transferred potentials, which can result from interconnection to remote ground grids, shall be considered.

4.6.2.1 Wayside Power Cubicles (WPC)

Wayside Power Cubicles in at-grade locations shall be grounded by separately driven ground rods at opposite corners, which are to be connected to grounding pads on the enclosure. For aerial locations and in tunnels, trenches, retaining wall and retained fill structures, the WPC shall be grounded by two interconnections to a grounding plate (as detailed above for the aerial structures).

4.6.3 Overhead Contact System

OCS structure grounding and bonding should create a conductive path that will achieve potential equalization of the grounded elements of the railway system. Grounding connections provide for tying wayside metallic parts to the return circuit and for the electrical interconnection of reinforcing rods in concrete structures, and in case of other modes of construction, the conductive interconnection of the metallic parts. The structure grounding system provides grounding connections for the following:

- High/medium-voltage protective ground
- Low-voltage protective ground
- Grounding of telecommunication and signaling systems
- Lightning protection ground

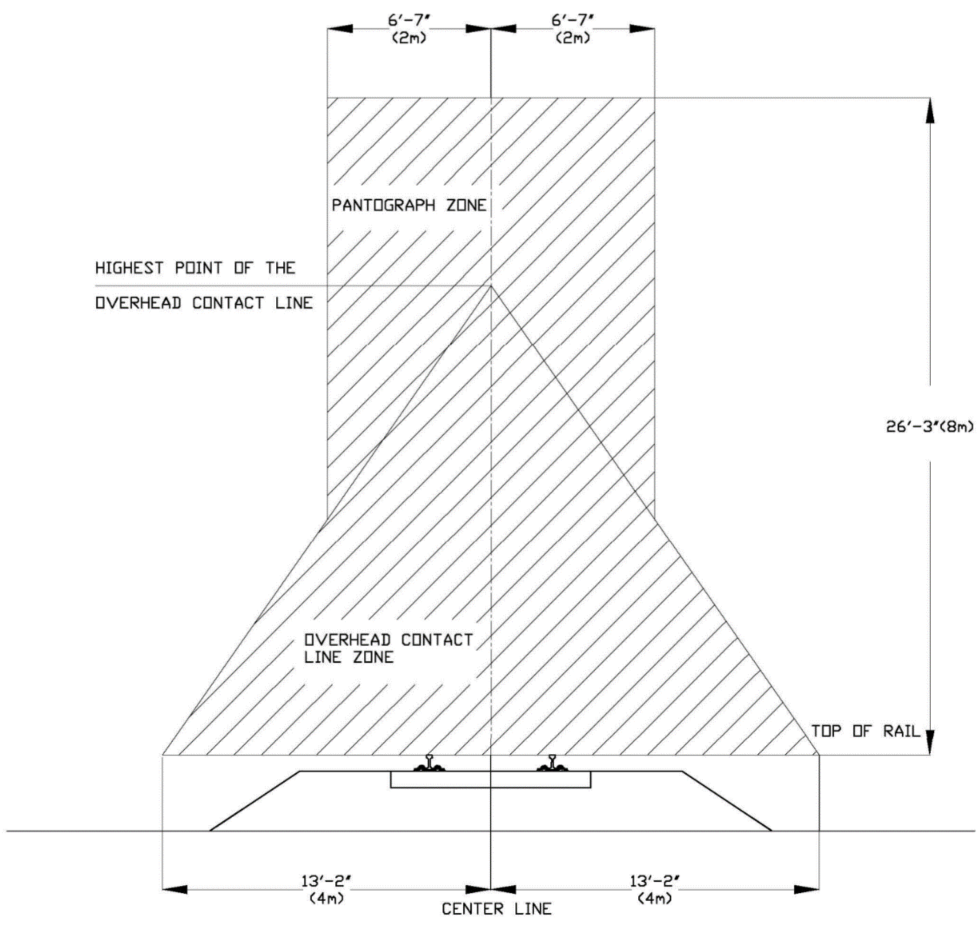
Except at Station Platform areas the OCS poles shall be grounded through interconnection of the pole to the static wire so that the ground resistance of the interconnected poles is kept low. Reinforced concrete and anchor bolt foundations, where the concrete is in good contact with the adjacent soil, are recognized as being good earth electrodes. Where the ground resistance of individual OCS poles exceeds 25 ohms, individual ground rods or other grounding solutions shall be applied. All other OCS structural supports—wall brackets, drop pipes, feeder wire brackets, etc.—shall be interconnected to the static wire.

Ground connections to disconnect switches and ground leads from surge arresters shall have a maximum ground resistance of 5 ohms. Ground rods or a ground mat may be utilized to obtain the required ground resistance. See section 4.7 for additional requirements.

A live broken contact line, or live parts of a broken or de-wired pantograph or energized fragments, may accidentally come into contact with wayside structures and equipment. **Figure 7: Overhead Contact Line Zone and Pantograph Zone** defines the zone inside which such contact is considered probable and which limits are unlikely to be exceeded, in general, by a broken overhead contact line or damaged energized pantograph, or energized fragments.

The limits of the overhead contact line zone below top of rail extend vertically down to the earth surface, except where the tracks are located on a viaduct where they extend down to the viaduct deck. In the case of energized out-of-running OCS conductors and live feeder wire, the overhead contact line zone shall be extended accordingly. Permanent, non-current-carrying metallic components that lie within the overhead contact line and pantograph zone shall be either directly grounded or bonded to the static wire to provide for personnel safety.

- **Figure 7: Overhead Contact Line Zone and Pantograph Zone**



4.6.4 Return System

The ground grid at each traction power facility, and the center tap of the secondary of main power transformers and the center tap of autotransformers, shall be connected to the traction power facility ground bus. The ground bus shall be connected to the traction return

rails through impedance bonds, and to both static wires through two independent connections. The return cable shall be sized to carry the maximum load current. Two connections are to provide redundancy in case there is failure of one return cable. The static wire shall be connected at regular intervals to the traction return rails, via impedance bonds at locations approved by the PTC designer. Additionally, the impedance bonds shall be cross-connected at intervals in both two-track and multi-track areas at a frequency that does not compromise the broken rail detection system.
This aspect of the grounding and bonding system design shall be coordinated between the Traction Power Supply System, OCS and PTC designs.

4.6.5 DC Traction Systems Adjacent to the Caltrain Right-of-Way

Where tracks operated by DC traction power systems are located adjacent to the tracks, a considerable degree of coordination will be required with the DC traction system operator to minimize the possibility of creating DC stray current circuit paths through the AC system traction power return circuits. The design of the TES shall minimize the possibility of creating DC stray current circuit paths through the return system.

The static wire in the area potentially subject to DC stray currents shall be electrically insulated from the OCS poles by supporting the static wire on insulators. The OCS poles shall be grounded through interconnection of the pole, anchor bolts and steel reinforcement of the concrete foundation so that the ground resistance of individual poles is kept low and does not exceed 25 ohms. Where the ground resistance of individual OCS poles exceeds 25 ohms, individual ground rods or other grounding solutions shall be applied.

Fault conditions shall be evaluated, and grounding designs shall be developed such that unsafe touch voltages are not created. The designer shall monitor and document any DC stray current leakage from DC system tracks adjacent to the Caltrain right-of-way/facilities during the design phase to establish baseline levels. Similarly, the contractor shall monitor and document any DC stray current leakage from the DC system tracks during the field testing and commissioning phase, to evaluate any differences and take any necessary remedial action to assure the integrity of the system.

Where passenger platforms and emergency walkways are located adjacent to DC system tracks, the designer shall investigate whether inadmissible touch voltages could occur between the rail and ground, and shall determine whether a voltage-limiting device, such as non-permanent rail to ground connection, should be installed to control touch voltages. If necessary, the designs shall require the contractor to install such devices.

All of the above measures shall be coordinated with the PTC System designer.
Early in the design phase, Caltrain will have to coordinate with the DC electrified railroad operator to obtain assurance that the operator will maintain a high level of insulation between the DC system rails and ground in these sections to minimize the possibility of any DC stray currents leaking into the AC traction return system.

4.7 Grounding and Bonding Protection Systems for the Signaling & Train Control System Equipment and Structures

4.7.1 PTC Houses and PTC Rooms

Ground grid and risers to the PTC rooms in stations shall be included in the facilities design and shall stub out 6 inches above the floor inside the PTC room.

Ground rods or ground grid and risers to the PTC houses and cases shall be provided by the ATC contractor where these units are located at grade.

The grounding system for PTC equipment shall be designed as a single-point ground system. Equipment safety grounding shall be designed to limit touch voltages to safe levels, as specified in **Table 12**, with and without a fault on the AC system.

Solid copper ground busbars designed for mounting on the framework of open or cabinet-enclosed ATC equipment racks shall be provided. Ground bars, within equipment racks, shall be bonded together using solid copper splice plates. All busbars and the metal structure of the houses and cases shall be bonded to the ground conductor, which in turn shall be bonded to the local ground provision (either ground rods or grounding plate integrated into the civil structures).

Bonding conductors shall be continuous and routed in the shortest, straight-line path possible. AC and DC ground detectors shall be provided for each train control room and house, and the sensitivity shall be sufficient to detect a ground leakage resistance of 0 to 2,000 ohms for AC ground and 0 to 10,000 ohms for DC ground.

4.7.2 Trackside PTC Equipment and Structures

Grounding of wayside equipment and metallic structures, including houses and wayside cases, shall be localized as much as practical with ground rods driven into the earth as close to the equipment/structure as possible. Where the structure design prevents the use of ground rods, grounding plates and grounding conductor (as detailed above for the aerial structures, retained fill, trenches, and tunnels) to which the signal equipment shall be grounded, shall be included in the infrastructure design. See Sections 4.3 and 4.5 for further details of facilities, buildings and structure grounding requirements.

The ground resistance shall not exceed 15 ohms as measured from equipment to ground where the ground rods are provided by the Systems contractor and 5 ohms from equipment to the grounding plate connection.

The base of a ground-mounted signal mast or dwarf signal shall be bonded to the traction return system by direct connection to the neutral leads of an impedance bond adjacent to the signal. There shall be no other electrical connections between the signal mast and other structures or other rails or neutral leads unless specifically called for on the plan as part of an “A” point (see below).

Signal bridges or cantilever structures at a location that is not an “A” point (see below) shall not be electrically connected to any neutral leads or any portion of any track structure that is part of the signal system. These structures shall be bonded to the static wire.

4.7.3 Cross Bonding

In signaling systems using track circuits in which the block lengths are defined by insulated joints in the track, impedance bonds are employed to permit the traction return current in the rails to pass through a relatively low impedance on its way back to the substation, while at the same time presenting a very high impedance to the signal circuit. The connections to impedance bonds are configured in a variety of ways, as discussed below, and the bonds are usually installed at the insulated joints.

The preferred locations for all impedance bonds will be identified under the TP system design but must then be coordinated and confirmed by PTC system designer who shall undertake the block design. Once the locations have been confirmed, the Trackwork Contractor, who shall supply the joints, will install the insulated joints at the agreed locations. The ATC Contractor shall supply and install the bonds, and the OCS Contractor will supply and install the center tap bond connections and the exothermically welded rail tap connections. The ATC Contractor shall supply and install the track circuit connections.

4.7.3.1 General Requirements

Impedance Bond arrangements are of 5 different configurations:

- An "A" point is defined as a location where impedance bond neutral leads on all tracks are bonded together, and to one or more OCS support structures which are in turn bonded to the static wires.
- An “A1” point is defined as a location where there are no insulated joints and the “Drain Bond” neutral leads on all tracks are bonded together, to the OCS support structures (which are bonded to the static wire), and in turn bonded directly to the Traction Power Substations, Switching Station and Paralleling Stations rail return bus.
- A "B" point is defined as a location where the impedance bonds neutral leads connect two tracks together, but are not connected to OCS support structures or the static wire.
- A "C" point is defined as a location with no cross bonding. The neutral leads of impedance bonds on either side of a pair of insulated joints on a track are tied together with no connections to adjacent tracks, OCS support structures or static wires.
- A drain bond is an impedance bond installed to connect the rails to traction power facilities, such as substations, switching stations, and paralleling stations, where no insulated joints exist in the tracks in the vicinity of the traction power facility. At such locations, the neutral leads of the drain bonds shall be connected directly to the traction power facility return bus. Drain bonds shall also be used at stations for connecting the platform counterpoise or grounding system to the rails where there is no adjacent “A” or “C” bond to which the platform grounds could be connected. Drain Bond locations on Signal Plans are sometimes referred to as “BC Points.”

The purpose of cross-bond locations ("A” and “B” points) is to minimize step voltages on the rails to values that are less than the limits specified in **Table 12**. Cross-bond locations shall include a minimum of 2 track circuits between them and should, if practical, be located not less than 6,000 feet apart but not more than the permissible potentials will permit. The PTC system designer shall coordinate the cross-bonding locations with the TES designers.

4.7.3.2 Where cross-bonds are more than 6,000 feet apart:

- Distance between cross-bond locations shall be not less than 167 percent of the length of the longest track circuit, any portion of which lies between the cross-bond points.
- Conversely, the total length of any track circuit, any portion of which is between the cross-bond points, shall not exceed 60 percent of the distance between the cross-bond points.
- The ideal arrangement shall be two equal length track circuits between cross-bond points, each 50 percent of the total distance between them.

4.7.3.3 Where the cross-bonds are up to a maximum of 6,000 feet apart:

- There shall be a minimum of 3 track circuits between the “A” and “B” point cross-bond locations.
- Distance between cross-bond locations shall be not less than 250 percent of the length of the longest track circuit, any portion of which lies between the cross-bond points.
- Conversely, the total length of any track circuit, any portion of which is between the cross-bond points, shall not exceed 40 percent of the distance between the cross-bond points.
- The ideal arrangement would be three equal length track circuits between cross-bond points, each 33.33 percent of the total distance between them. Total distance shall be as close to 6,000 feet as possible.
- In no case, a distance of less than 3,000 feet between “A” point cross-bond locations be permitted.

The “percent ratio” shall be calculated for any given section between cross-bond locations as D(XB) divided by D(LTC), where D(XB) is the distance between cross-bond points defining the section and D(LTC) is the length of the longest track circuit in the section.

Where “drain” bonds constitute an “A” point at other than insulated joint locations, the “D(LTC)” shall be the total length of the longest track circuit in the section including any portion of that track circuit outside the limits of the section defined by the cross-bond points.

4.7.3.4 Cross-bonding at Interlockings

Cross-bonding shall be placed as close to interlocking crossovers as practical to reduce the possibility of flashover of insulated joints in crossovers. If possible, an “A” point shall be placed at one of the interlocking home signal locations at each interlocking. This shall be done consistent with these design criteria and the need to place an “A” point at each substation, switching station or paralleling station return bus location.

Only one impedance bond shall be provided at the fouling insulated joints on the turnout track, located on the side of the joints away from the switch points. The neutral leads on this impedance bond shall be tied to the neutral leads between the impedance bonds located at the adjacent insulated joints on the main or straight track.

If there are no insulated joints on the main or straight track within approximately 20 feet of the fouling insulated joints on the turnout track, then a second impedance bond may be used on the turnout track at the fouling insulated joints, located on the switch point side of these joints and the neutral leads of the two impedance bonds at these joints connected in the usual manner. In this case, the neutral leads of the impedance bonds on the turnout track must not be connected to the neutral leads on the main or straight track.

4.7.3.5 Cross-bonding at Single and Twin Single Bore Tunnels

Where an “A” point is required within a single bore tunnel, the neutral leads of the impedance bonds shall be connected to the static wire in that tunnel only. Where an “A” point is required within twin single bore tunnels that incorporate cross passage(s) between bores, cross-bonding between bores shall be accomplished by laying the cables in the cross-passage(s).

4.7.3.6 Connections to Platform Grounding Systems

Counterpoises for at-grade station platforms shall be connected to the rail through the neutral leads of an impedance bond at one end of the platform only. The preference is to connect to the neutral leads of an "A" point. If it is not practicable to attach to an "A" point, the counterpoise shall be connected to the neutral leads of a "C" point. If this is not practicable, a drain bond shall be installed. Each platform shall have an independent counterpoise and impedance bond.

The interconnection between the impedance bond, neutral leads and the counterpoise conductor shall be an exothermic weld or irreversible compression joint which shall be made in a handhole interface box.

Platforms located on aerial structures shall be grounded as identified above and shall be connected to the track through the neutral leads of an impedance bond at one end of the platform only, and with the same order of preference as detailed above. Each platform shall have an independent grounding system and impedance bond. If the impedance bonds used for this purpose are either "C" points or drain bonds, the location becomes a "B" point as the platform counterpoises on structures are attached to the structure and therefore both tracks will be connected together through the neutral leads of the impedance bonds.

4.8 Grounding and Bonding Protection Systems for the Communications System Equipment and Structures

4.8.1 General Requirements

Communications and electronic systems shall be grounded and bonded in accordance with the requirements specified in NFPA 70E, NFPA 75, ANSI/TIA/EIA-607, CEC, IEEE 1100 and ITU standards. The communications designer shall design a communications grounding system to have an impedance from device to ground as per IEEE 1100.

The grounding methods for enclosures, chassis, panels, switch boxes, pull boxes, conduits, terminal boxes, and similar enclosures or structures shall be designed to provide proper terminations for equipment and cable shielding (as necessary) and to avoid conducted coupling, low impedance ground loops, noise, surges from adversely affecting system operation, and hazardous operating conditions—refer to the Electromagnetic Interference and Compatibility chapter for more details.

The AC grounding electrode system is the fundamental grounding element supporting the communications grounding system. The AC grounding electrode system design must be verified to provide a suitable ground resistance for all communications equipment it serves. The communications designer shall use the building structural steel as an additional bonding point for the communications grounding system. The impedance between the structural steel and the AC ground electrode system shall be compliant with IEEE Std. 142.

If the AC grounding electrode system does not supply compliant ground resistance, supplemental grounding electrodes shall be installed to lower ground resistance and shall be connected to the AC grounding electrode system and the ground grid.

The communications grounding system serves to establish a common reference voltage for communications equipment cabinets, enclosures, equipment, and power supplies, and provide an intentional path for fault current to the AC grounding electrode system.

The components that make up the communications grounding system include:

- Supplemental grounding electrodes
- Bonding conductor for communications
- Telecommunications Bonding Backbone (TBB)
- TBB Interconnecting Bonding Conductor (TBBIBC)
- Telecommunications Grounding Busbar (TGB)
- Rack Grounding Busbar (RGB)

Design documents shall clearly articulate details and connectivity of the communications grounding system. The communications designer shall design a separate communications-only or isolated ground system. Bonding conductors shall be sized according to applicable standards and codes. Bonding conductors run for distances less than 100 feet shall be minimum 6 AWG. For distances greater than 100 feet, the communications designer shall size bonding conductors using the more conservative requirements of either the NEC or the CEC.

4.8.2 Communication Equipment within Rooms at Stations and Facilities (located within a Shared PTC and Communications Room and/or Dedicated Communications Room)

See Section 4.5 for ground grid requirements for buildings.

When communications equipment and PTC equipment occupy a shared room, the designer shall coordinate the equipment and shield grounding between the two disciplines.

Telecommunications Bonding Backbone (TBB) within Stations and Facilities Communications room grounding busbars shall be connected together by means of the telecommunications bonding backbone, which shall provide for the interconnection of the grounding busbars, located in each communications room or closet throughout the building, to the telecommunications main grounding busbar.

The telecommunications bonding backbone route and cable size shall be planned to minimize length and eliminate splices.

Wherever two or more vertical telecommunications bonding backbones are used in a building, the grounding busbars shall be interconnected at the top of each riser and at every third floor with a telecommunications bonding backbone interconnecting bonding conductor in accordance with ANSI/TIA/EIA-607 and the CEC and NEC.

4.8.3 Grounding Busbars within Communications Rooms within Stations and Facilities

A grounding busbar shall be provided in every communications room and within every shared PTC and communications room. An entrance facility shall be identified for each building where communications conduit and cable penetrates. The entrance facility shall be provided with a grounding busbar. The grounding busbar shall be located close to the AC ground electrode system. Where a panelboard for telecommunications is located in the same room or space as the grounding busbar, that panel's ground bus or the enclosure shall be bonded to the grounding busbar.

In steel building structures, the telecommunications grounding busbar and telecommunications bonding backbone shall be bonded to the structural steel. The ground resistance between the structural steel and the AC grounding electrode system shall be compliant with IEEE Std. 142.

The communications grounding system in each room shall be bonded to the busbar in each communications room and communications closet. In communications rooms and closets, the busbar shall be bonded to the AC grounding electrode and the nearest structural steel member.

4.8.4 Communications Equipment and Structures

Provide a grounding busbar within all communications interface cabinets (CICs). Within CICs, the equipment grounding system shall bond equipment, rack rails, cabinets and cabinet doors to the telecommunications grounding busbar which shall be bonded to the incoming AC grounding electrode.

4.9 Grounding and Bonding Requirements for Facility Power Systems and Lighting Systems

A bare grounding electrode conductor shall be provided between the HV switchgear/transformer ground bus and the ground grid.

The secondary neutral of pad mounted medium and/or high voltage transformers shall be grounded. Additionally, the pad design shall include the following features:

- Ground grid in accordance with the CEC, or power utility service requirements as applicable.
- The concrete support pad reinforcement steel shall be bonded to the ground grid.

Exterior transformers supplying interior service equipment shall have the neutral grounded at the transformer secondary and a grounding electrode shall be provided at the transformer.

In the case of separately derived systems (i.e., transformers downstream from service equipment) ground the secondary neutral at the transformer to the nearest component of the ground grid.

Lightning arresters on medium and high voltage equipment shall be connected to the equipment ground bus or ground rods as applicable.

For secondary switchgear, switchboards, and motor control centers, the following requirements shall apply:

- The equipment grounding conductors shall be connected to the ground bus in the enclosure with suitable pressure connectors.
- Metallic conduits, which terminate without mechanical connection to the housing, shall include grounding bushings and grounding conductor to the equipment ground bus.
- For service entrance equipment, the grounding electrode conductor, carried in the power supply conduit, shall be connected to the ground bus.

Ground the frames of motors larger than 25 hp by a ground conductor carried in power conduit.

Fixed electrical appliances and equipment shall be provided with a ground lug for termination of the equipment grounding conductor. Ground lugs shall be provided in each box and enclosure for equipment grounding conductor termination.

Panelboards shall contain a ground bus, bolted to the housing, with sufficient lugs to terminate the equipment grounding conductors.

Ground light fixtures to the equipment grounding conductor of the wiring system.

Receptacles shall not be grounded through their mounting screws. Ground with a jumper from the receptacle green ground terminal to the device box ground screw and the branch circuit equipment grounding conductor.

Feeder and branch AC power and lighting circuits shall have a separate insulated equipment grounding conductor.

Bond the equipment grounding conductor to each pullbox, junction box, outlet box, device box, cabinets, and other enclosures through which the conductor passes.

4.10 Grounding Requirements for Raceway, Cable Tray, Underground Duct banks, and Structures

Metallic raceway and cable trays systems shall be bonded together to provide a continuous electrical ground path.

Metallic raceways shall be bonded to other raceway components using insulated grounding bushings. Grounding bushings shall be connected to the grounding system using conductors sized in compliance with the applicable code.

Connect each isolated metallic cable tray system or the entire cable tray system to the building grounding systems with a bare copper conductor in accordance with the CEC, NEC, and NEMA VE 1.

Provide an equipment ground conductor, sized in accordance with the CEC and NEC (but not less than 2 AWG for medium voltage power circuits) in each conduit of an underground ductbank that contains power cables.

Raceways for lighting and power feeders to motor, lighting, and receptacle loads shall contain a separate green insulated safety grounding conductor.

All normally non-current-carrying conductive parts of manholes, handholes, pull boxes, splice boxes, metallic raceway, and/or cable tray systems shall be bonded and grounded. Provide at least one driven ground rod at each underground structure.

4.11 Cables

4.11.1 General

The metallic sheaths, armor or shields of power cables:
- Shall be electrically continuous through troughs, manholes, pull boxes, and splice boxes and any other cable carrying infrastructure.
- Shall be designed and routed in accordance with the requirements detailed in the Electromagnetic Compatibility and Interference chapter.

Conductor splice case grounding and bonding requirements shall comply with the manufacturer's recommendations and CEC and NEC. It shall be ensured that the touch voltages at the non-grounded end of the metallic sheaths, armor or shields of cables do not exceed the maximum permissible touch voltages specified in **Table 12**.

4.11.2 Signaling & Train Control System

The signal designer shall determine as part of its system design and its Electromagnetic Compatibility (EMC) plan, whether to utilize PTC cables with or without metallic shielding. Metallic messenger or duct shall not be used in any way that could cause an electrical interconnection between signals or signal structures and signal equipment housings.

4.11.3 Communications System

Bonding of shielded twisted-pair (STP) cables is necessary to mitigate the effects of unwanted noise signals (antenna effect) on communications cables and to avoid interference with overall network performance.

The shield of STP cables shall be bonded to the connecting hardware in accordance with the manufacturer's instructions. As appropriate, the connecting hardware at the cross-connect shall be bonded to the ground busbar in the PTC room or house, communications equipment shelter or termination room, or communications room.

Grounding at the work area is usually accomplished through the equipment power connection. Shield connections at the work area are accomplished through an STP patch cord. At the work area end of the horizontal cabling, the voltage measured between the shield and the ground wire of the electrical outlet used to supply power to the workstation shall not exceed 1.0 Vrms. Telephone and public address cables at PTC rooms or houses, communications shelters or termination rooms, and communications rooms that originate from the field devices, shall require surge protection.

Bond telephone protector units to the grounding system with at least a No. 6 AWG ground conductor.

4.11.4 Facility Power System and Lighting System

The shields of medium voltage AC power cables shall be grounded at the facility power electrical rooms and/or yards in accordance with the requirements detailed in the Electromagnetic Interference and Compatibility chapter. The shields shall be electrically continuous through manholes, pull boxes, and splice boxes.

The safety grounding conductors for feeder circuits shall each be bonded at one end to the electrical room or yard ground bus and at the other end to the ground bus of a panelboard or a motor control center ground bus. Each branch circuit shall have a safety-insulated grounding conductor extended from the ground bus of the panelboard or motor control center to the device it is serving.

4.11.5 Cable Trough and Outside Plant

Provide an equipment ground conductor, sized in accordance with the CEC (but not less than 2 AWG for medium voltage power circuits), in each conduit of an underground ductbank that contains power cables.

All normally non-current-carrying conductive parts of manholes, handholes, pull boxes, splice boxes, metallic raceway, and/or cable tray systems shall be bonded and grounded.

The communications and signal designer shall coordinate with other disciplines and submit code compliant Outside Plant Cable (OSP) infrastructure bonding system.

4.12 Grounding and Bonding Requirements for Utilities

Non-railway pipes or cable shields should have no connection to the traction return and grounding systems. Metallic utility lines entering or passing through the Caltrain right-of-way shall be fitted with insulated joints to separate the external services and isolate them from the traction return and grounding systems.

Pipes or shielded cables to or from non-railway installations may transfer potentials that could be bridged by persons as step or touch voltages. Additionally, corrosion may be caused by potential differences, if different grounding systems are connected together. For these reasons non-railway grounding systems shall not be connected to railway systems.

Metallic sleeves or casings, installed to permit utility lines to cross the tracks, shall be grounded at one end only, with the grounding electrode having a resistance of 25 ohms or less.

Grounding and bonding for the electrical service shall be provided in accordance with the electric utility company’s requirements.

Unless formally approved by the utility owner there shall be no connection between the grounding system and any utility (including water) outside the dielectric coupling which is used to isolate facilities from utilities outside the building line.

4.13 Lightning Protection

Each facility and exposed structure shall be provided with appropriate lightning protection measures, based on the incidence of strikes in the area local to each facility, which shall be grounded in accordance with the recommendations of the equipment manufacturer, CEC, NEC, NESC, GO 95, and NFPA 780 – Standard for the Installation of Lightning Protection Systems, as applicable.

4.13.1 Insulated Cables Carrying Feeds to the OCS Shall Be Protected With Surge Arresters

The OCS designer shall investigate the incidence of lightning storms on a project section-by-section basis and shall determine appropriate lightning protection measures based upon the incidence of lightning strikes in each area. A static wire shall be positioned at the top of OCS poles to afford protection to the OCS system against lighting strikes. If the cone of protection afforded from this position is insufficient, the static wire shall be mounted on an outrigger cantilever so that shield wire is more closely positioned above and affords protection for all of the OCS conductors. The static wire shall be insulated from the OCS poles in passenger station areas. Additional protection/mitigation measures, e.g., additional grounding conductors/grids, shall be provided as required.

Surge arresters and other circuit protection devices shall be provided as necessary to protect wayside PTC equipment from damage and false operation due to lightning. The surge arresters shall comply with AREMA Signal Manual, for lightning protection.

Trackside antenna towers (e.g. at PTC houses, communication equipment shelters, TPF, etc.) within the Caltrain right-of-way that are specified to be 100 feet tall, shall be protected with appropriate lightning protection measures based on the incidence of strikes in the area local to each antenna tower and/or roof mounted antenna.

Reinforced concrete structures may not be able to take direct lightning strikes without damage. Exposed pre-stressed concrete structures shall be provided with lightning protection, especially in lightning prone areas.

The electrodes—ground rods or ground grids—used to ground lightning protection systems shall not be the same as those used for grounding of either the traction or facility electrical systems, but the electrodes from both systems must be bonded together.

END OF CHAPTER 4

CHAPTER 5

CORROSION CONTROL

5.0 Corrosion Control

5.1 Scope

This chapter describes the requirements for a corrosion control system design which shall prevent premature corrosion failure, and be economical to install, operate, and maintain. Corrosion control provisions shall be required for all facilities, regardless of location or material of construction subject to corrosion, where failure would affect safety or interrupt continuity of operations.

Two major types of corrosion control shall be implemented: soil and water corrosion control, and atmospheric corrosion control.
The design criteria for each of these categories, and their implementation, shall:

- Meet the design life of structures and systems listed in the General chapter:
- Minimize annual operating and maintenance costs associated with material deterioration.
- Provide continuity of operations by reducing or eliminating corrosion related failures.

5.2 Soil and Water Corrosion Control

5.2.1 General

The goal of this section of design criteria is to prevent corrosion of structures due to soil and water. Soil and ground water characteristics shall be determined and documented through boring surveys. Analysis of the data obtained from on-site borings shall be the basis for corrosion control designs. The soil/water samples shall be analyzed for resistivity (or conductivity), pH, chloride and sulfate ion concentrations. Corrosion survey on site, testing soil resistivity, pH, redox potential, and stray current presence shall supplement water/soil samples laboratory analysis.

Normally, affected structures, as in the conditions listed below, shall be protected against the environment by coating, insulation, electrical continuity and/or cathodic protection, whichever is applicable. Water treatment shall be considered to mitigate chemical and microbiologically influenced corrosion inside of pipes and water tanks. Special attention shall be taken to prevent saltwater corrosion on underground metallic structures.

Structures which may be affected by soil and water corrosion typically include, but are not limited to:

- Buried and on-grade reinforced concrete structures
- Pier and piling structures
- Concrete tunnel liner
- Electrical conduits
- Metallic fencing

5.2.2 Materials for Construction

All pressure and non-pressure piping and conduit shall be non-metallic, unless metallic materials are required for specific engineering purposes.

Aluminum and aluminum alloys shall not be used in direct burial applications.

If non-native fill is to be used for backfilling concrete or ferrous structures, then it shall meet the following criteria:

- pH 6 to 8
- Maximum chloride ion concentration of 250 ppm
- Maximum sulfate ion concentration of 200 ppm

Methods to control corrosion of reinforced concrete structures are primarily directed toward preventing or impeding ingress of water and chloride ions into concrete and/or protecting steel rebar after chloride contamination occurs. Based on ACI guidelines, methods in use are the following:

- Control of the concrete mix to obtain low permeable concrete
- Limit chlorides in the original concrete mix ingredients
- Use an inhibitor in the concrete mix
- Increase concrete cover to reinforcement
- Use concrete sealers and coatings
- Use epoxy coated reinforcement
- Apply cathodic protection

5.2.3 Safety and Continuity of Operations

Corrosion control protection shall be required for those facilities where failure caused by corrosion of such facilities may affect safety or interrupt the continuity of operations.

5.2.4 Accessibility of Installations

Where required, permanent test facilities installed with certain corrosion control provisions shall be accessible after installation, allowing for periodic maintenance and monitoring.

5.2.5 Coating

Coatings specified for corrosion control of buried metallic or concrete facilities shall satisfy the following criteria:

- Minimum volume resistivity of 10,000,000,000 ohm-centimeters (10 billion ohm-centimeters)
- Minimum thickness as recommended for the specific system, but not less than 15 mils
- A chemical or mechanical bond to the metal or concrete surface. Pressure-sensitive systems are not acceptable.
- Minimum 5-year performance record for the intended service
- Mill application wherever possible, with field application of a compatible paint or tape system

Mechanical characteristics capable of withstanding coating damage during handling and earth pressure after installation for the design life of the system.

5.2.5.1 Generic Coating Systems

Generic coating systems include but are not limited to the following:

- Extruded polyethylene/butyl based system
- Coal-tar epoxies (two component systems)
- Polyethylene-backed butyl mastic tapes (cold applied)
- Bituminous mastics (airless spray)

5.2.6 Electrical Insulation of Piping

Devices used for electrical insulators for corrosion control shall include non-metallic inserts, insulating flanges, couplings, unions, and/or concentric support spacers. Devices shall meet the following criteria:

- A minimum resistance of 10 megohms prior to installation.
- Sufficient electrical resistance after insertion into the operating piping system such that no more than 2 percent of a test current applied across the device flows through the insulator, including flow through conductive fluids if present.
- Mechanical and temperature ratings equivalent to the structure in which they are installed.
- Internal coating (except complete non-metallic units) with a polyamide epoxy for a distance on each side of the insulator equal to two times the diameter of the pipe in which they are used. Where conductive fluids with a resistivity of less than 2,000 ohm-centimeters are present, internal coating requirements shall be based on separate evaluation.

Devices (except non-metallic units) buried in soils shall be encased in a protective coating.

Devices (except non-metallic units) installed in chambers or otherwise exposed to partial immersion or high humidity shall have a protective coating applied over all components.
Inaccessible insulating devices, such as buried or elevated insulators, shall be equipped with accessible permanent test facilities.

A minimum clearance of 12 inches shall be provided between new and existing metallic structures. When conditions do not allow a 12-inch clearance, the design shall include special provisions to prevent electrical contact with existing structure(s).

5.2.7 Electrical Continuity of Metallic Structures

Electrical continuity shall be provided for all non-welded metallic joints and shall meet the following criteria:

- Use direct burial, insulated, stranded, copper wire with the minimum length necessary to span the joint being bonded.
- Wire size shall be based on the electrical characteristics of the structure and resulting electrical network to minimize attenuation and allow for cathodic protection.
- Use a minimum of two wires per joint for redundancy.

5.2.8 Cathodic Protection

Cathodic protection shall be accomplished by sacrificial galvanic anodes to minimize corrosion interaction with other underground utilities. Impressed current systems shall be used only when the use of sacrificial systems is not technically feasible.

Cathodic protection system design shall be based on theoretical calculations that include the following parameters:

- Estimated percentage of bare surface area (minimum 1 percent)
- Cathodic protection current density (minimum of 1.0 mA/ft2 of bare surface area)
- Estimated current output per anode
- Estimated total number of anodes, size, and spacing Minimum anode life of 25 years (minimum 50 percent efficiency)
- Estimated anode groundbed resistance

Impressed current rectifier systems shall be designed using variable voltage and current output rectifiers. Rectifiers shall be rated at a minimum of 50 percent above calculated operating levels to overcome a higher-than-anticipated anode groundbed resistance, lower-than-anticipated coating resistance, or presence of interference mitigation bonds. Other conditions which may result in increased voltage and current requirements shall be considered.

Test facilities consisting of a minimum of two structure connections, one reference electrode connection, conduits and termination boxes shall be designed to permit initial and periodic testing of cathodic protection levels, interference currents, and system components (anodes, insulating devices, and continuity bonds). By request of the particular utility owner/operator, remotely monitored test facilities could be designed. The designer shall specify the locations and types of test facilities for each cathodic protection system.

5.2.9 Electrical Conduits

Buried metallic conduits shall include the following provisions:

- Galvanized steel with PVC or other coating acceptable for direct burial, including couplings and fittings. The PVC coating is not required when conduits are installed in concrete.
- Electrical continuity through standard threaded joints or bond wires installed across non-threaded joints.

5.2.10 Utility Structures

All piping and conduit shall be non-metallic, unless metallic facilities are required for specific engineering purposes. There are no special provisions required if non-metallic materials are used.

5.2.11 Metallic Facilities (System-wide)

Pressure or non-pressure piping exposed within tunnels or crawl spaces or embedded in concrete inverts shall not require special provisions.

Pressure piping that penetrates tunnel, foundation, or tunnel walls shall be electrically insulated from the external piping to which it connects and from watertight wall sleeves. Electrical insulation of interior piping from external piping shall be made on the inside of the tunnel.

Pressure piping running on the top of the bridge or aerial structure shall be electrically isolated from the underground portion of the piping.

5.3 Atmospheric Corrosion Control

Alternating wet and dry weather together with industrial and chemical pollutants can contribute to increased corrosion rates of exposed metal structures and hardware. The atmospheric corrosion conditions shall be derived from different existing sources. Designs and associated coatings shall be based on recommendations of the reports and shall be used to significantly decrease atmospheric corrosion rates.

The purpose of these criteria is to ensure the function, preservation and appearance of project structures exposed to the environment in the most cost-effective manner. Criteria include the following:
Materials selection – acceptable materials shall have proven past performance records for the service application.
Protective coatings – barrier or sacrificial coatings shall be used on steel.
Design – recess moisture traps and dissimilar metals shall be avoided.
Sealants – accumulation of moisture in crevices shall be prevented by use of sealants.

5.3.1 Scope

Exposed metal surfaces on aerial structures affected by atmospheric corrosion shall be coated. Marine atmosphere shall be considered along the track alignment to develop coating systems. Coating for the catenary poles shall be developed based on local atmospheric conditions.

Coatings shall have established performance records for the intended service and be compatible with the base metal to which they are applied.

Coatings shall be able to demonstrate satisfactory gloss retention, color retention, and resistance to chalking over their minimum life expectancies.

Coatings shall have minimum life expectancies, defined as the time prior to major maintenance or reapplication, of 15 to 20 years.

5.3.2 Metallic-Sacrificial Coatings

Acceptable coatings for carbon and alloy steels for use in crawlspaces, vaults, or above grade are as follows:

- Zinc (hot-dip galvanizing [2 ounces per square feet] or flame sprayed)
- Aluminum (hot-dip galvanizing [2 mil thickness] or flame sprayed)
- Aluminum-zinc
- Inorganic or organic zinc (as a primer)

5.3.3 Organic Coatings

Organic coating systems shall consist of a wash primer (for galvanized and aluminum substrates only), a primer, intermediate coat(s), and a finish coat. Acceptable organic coatings, for exposure to the atmosphere, are as follows:

- Aliphatic polyurethanes
- Vinyl copolymers
- Bonded epoxy polyesters, polyethylenes, and nylons
- Acrylics, where not exposed to direct sunlight
- Alkyds, where not exposed to direct sunlight

Epoxy as a primer where exposed to the atmosphere or as the complete system where sheltered from sunlight

5.3.4 Barrier Coating System

Use one of the following barrier coating systems where corrosion protection is needed but appearance is not a primary concern:

- Near white blast surface according to SSPC-SP 10. Follow with a 3-coat epoxy system
- Commercial blast surface according to SSPC-SP 6. Follow with a 2-coat inorganic zinc and high build epoxy system
- Near white blast surface according to SSPC-SP 10. Follow with a 3-coat epoxy zinc, high build epoxy system

Apply all coatings according to manufacturer's specifications.

Use one of the following barrier coating systems where corrosion protection and good appearance are needed:

- Near white blast surface according to SSPC-SP 10. Follow with a 3-coat inorganic zinc, high build epoxy, polyester urethane system.
- Near white blast surface according to SSPC-SP 10. Follow with a 3-coat vinyl system.
- Commercial blast surface according to SSPC-SP 6. Follow with a 3-coat epoxy zinc, high build epoxy and polyester urethane system.

Commercial blast surface according to SSPC-SP 6. Follow with a 3-coat epoxy zinc, high build epoxy and acrylic urethane system.

Apply all coating according to manufacturer's specifications.

5.3.5 Graffiti-Resistant Coatings

Surfaces which are accessible to graffiti shall be protected with a graffiti-resistant coating. This includes concrete and painted steel surfaces such as walls, columns, and equipment enclosures. All such areas shall be protected up to a height of 10 feet. The coating shall be a urethane-type coating and shall be applied in accordance with the manufacturer’s latest published instructions.

5.4 Stray Current Sources and Protection

DC powered transit systems like BART and VTA could be a source of stray currents for metallic and concrete underground facilities. Welding operations in the industrial areas could be another source of stray currents. Stray current corrosion survey in the vicinity of DC-powered transit lines and in industrial portions of project proposed track alignment shall identify areas with the stray current activity. Local utility companies shall be contacted to obtain information regarding their practice of stray current protection in areas where DC stray currents are present.

Corrosion control requirements for buried utilities installed by the utility owner/operator as part of construction shall be the responsibility of the individual utility owner/operator.

Relocated or replaced utilities, installed by Caltrain as part of contractual agreement between Caltrain and the utility, shall be installed in accordance with the utility owner specifications and shall include the following minimum provisions:

- Electrical continuity through the installation of insulated copper wires across all mechanical joints for which electrical continuity cannot be assured
- Electrical access to the utility structure via test facilities installed at nominal 200 feet intervals
- These provisions are applicable to ferrous and reinforced concrete cylinder piping. Other materials and structures will require individual review.
- The need for additional measures, such as electrical isolation, application of a protective coating system, installation of cathodic protection, or any combination of the preceding, shall be based on the characteristics of the specific structure and shall not adversely affect the existing performance within the environment.
- In the areas with stray current presence in the vicinity of the train tracks, test stations shall be installed to monitor rail-to-ground voltages.

END OF CHAPTER 5

CHAPTER 6

EMI AND EMC

6.0 Electromagnetic Interference and Compatibility

6.1 Scope

The Electromagnetic Compatibility (EMC) scope includes the following:

- Electromagnetic interactions and related design characteristics of equipment and facilities
- Electromagnetic interactions with equipment and facilities of system neighbors

System equipment and facilities shall work with and not interfere with other system equipment and facilities as well as with neighboring equipment and facilities.

The EMC design scope includes the following:

- Design aspects of the equipment and facilities which can electromagnetically interact with themselves, with other equipment and facilities, and with the equipment and facilities of system neighbors, specifically, Communications, PTC, Traction Electrification System (TES), Rolling Stock (RS), and Station and Facility Equipment

Existing neighboring equipment or facilities cannot be changed to resolve EMC issues, unless Caltrain makes a specific agreement with the owner of the equipment or facilities.

EMC interaction scope includes the following:

- Design of equipment and facilities
- Neighbor equipment and facilities
- Electronic devices carried or used by passengers and staff in facilities and trains

Neighbor equipment and facilities include the following:

- Electronic devices of neighbors and of California public safety, government, utility, and industrial staff
- Commercial, residential, and industrial buildings; airports; adjacent and tenant railroads, and adjacent transit agencies, pipelines, and structures; and the industrial and commercial equipment used by the buildings and their occupants; telephone exchanges
- Implanted medical devices in Caltrain passengers, staff and neighboring hospitals

6.2 Description of Electromagnetic Compatibility Program and Electromagnetic Interference

The EMC Program objective is to achieve EMC between all EMC design scope and interaction scope equipment and facilities.

The EMC program shall ensure that Electromagnetic Interference (EMI) does not adversely affect the following:

- The safety or dependability of the system and service
- The health of passengers, staff, and neighbors
- The safety or dependability of neighbor equipment and facilities

To meet the EMC Program objective, the EMC Program specifies the following:

- Activities and deliverables at each project stage and phase
- Design guidelines, criteria, and methods

- EMC design requirements to be included in the procurement specifications of each affected system or piece of equipment and each affected construction contract
- EMC analyses and tests to demonstrate compliance with EMC requirements

6.3 General Design Requirements

Equipment and facilities shall be electromagnetically compatible with one another, with other system equipment and facilities, and with the equipment and facilities of neighbors.

The EMC design criteria shall apply to all equipment, systems, and facilities, including:

- Communications
- PTC Systems
- Traction Electrification System
- Rolling Stock
- Station and Facility Equipment

6.4 Overview of EMC Design Criteria Categories

The EMC design criteria cover equipment, cable, grounding, facilities and high-power motors and controllers, equipment rooms and location, emission and immunity limits, FCC type- accepted radio equipment, and human exposure. The following is an overview of EMC design criteria:

Cable – Cables shall be designed with proper shielding, shield grounding, entry protection, and termination. Each cable should be grouped only with others with similar signal type and energy level. Each cable or group shall be segregated appropriately from other cable groups. Cable runs shall be placed in conduit, raceway, or duct as needed to provide segregation and prevent magnetic or electric coupling from high-energy sources. Fiber optic cable shall be utilized where practical for EMC. Power cables shall be treated according to required practice for their voltage class.

Grounding – Grounding shall conform to the listed standards, provide a suitable safety ground, and signal reference structure ground connections. Long adjacent fences and pipelines shall be regularly grounded or if not grounded, divided into insulated sections to prevent electric shock.

Equipment – Equipment designs shall control emissions and enhance immunity. Design considerations shall include placement, enclosures, filters, modulation methods, interconnect design, and component characteristics.

Facility Power – AC power for equipment shall be properly taken from separate feeder and branch circuits, isolated, regulated, backed up, and protected as required. AC power for remote trackside locations can be taken from the negative feeder by a dedicated transformer and disconnect and filtered to protect supplied equipment. High-current power supply AC cables shall be run twisted together, in metal conduit where possible, to minimize magnetic coupling. Traction power cables shall be run with the smallest feasible separation of supply feed and return cables. Layout shall minimize the loop area of high current cables. Utility power distribution lines shall be routed and carried to system facilities following applicable electromagnetic interference/electromagnetic field (EMI/EMF) regulations and guidelines.

Motors and Controllers – Motor starter or inverters shall be provided with suitable protection and line and load filtering to minimize harmonics, transients, and surges at start and stop. Wiring shall be by twisted and/or shielded cables in conduit as appropriate.

Equipment Rooms and Location – Within physical constraints of planned facilities, equipment shall be located so that high power sources are physically separated as far as practical from the most susceptible equipment. Shielding shall be provided as needed.

Emission and Immunity Limits – Equipment shall be designed and tested to conform to the selected emission and immunity limits. Commercial off-the-shelf (COTS) equipment shall meet the specified standards. Custom equipment shall meet the selected standards, which are FCC Part 15, EN 50121 series, and applicable standards. In cooperation with the adjacent railroads, the design shall mitigate coupling of system 60 Hz power into track circuits of adjacent railroads. The design shall be coordinated with the operator of any airport adjacent the alignment to ensure EMC.

FCC Type-Accepted Radio Equipment – Radio equipment shall be FCC-type approved. Frequencies for licensed radio equipment shall be coordinated within the system and with other California users.

Equipment that transmits or receives on a specific frequency shall be coordinated with the established list of frequencies used by other equipment. Industrial, scientific, and medical device frequency band (ISM) equipment shall be FCC Type Accepted in the 2.4 or 5.8 GHz band. ISM design applications shall operate adequately with interference from other ISM band users.

Human Exposure – Placement of radio transmit antennas shall result in human exposure to fields below limits. Traction electrification facilities shall be posted with signs alerting staff with implanted medical devices such as pacemakers of potentially hazardous electromagnetic field (EMF) levels.

6.5 Communications EMC Design Criteria

6.5.1 Equipment and EMC Considerations

Communications systems equipment consists of the following:

- Wayside communication systems connected by copper wires and by fiber optic cable. Examples include Supervisory Control and Data Acquisition Subsystems (SCADA), Closed Circuit Television (CCTV), data network, intercom and public address, telephone, security and access control, traction power control, and fire and life safety subsystems and functions.
- Wayside and onboard radio systems. Examples include PTC data and voice radio, operations and maintenance radio, voice and data; police, fire, and emergency public safety radio; Wifi and other unlicensed radio; and PTC radio such as 160 MHz, 220 MHz, and Global System for Mobile Communications - Railway.
- Equipment includes cabinets and contents, control panels, displays, cables, conduits, ducts, raceways, enclosures, and antennas.

Communications equipment EMC provisions shall ensure the following:

- Safe and dependable operation
- No interference with or from neighbors
- Compliance with human exposure limits

The following design criteria shall apply to communications systems and to the communication system interfaces with PTC, trains, traction power, and station systems and equipment:

- Cables and cable segregation
- Grounding
- Equipment design
- Facility power
- Motors and controllers

- Equipment rooms, cabinets, and locations
- Equipment emission and immunity limits
- Requirements for radios
- Human exposure limits

The communications systems EMC design criteria are described in the following subsections.

6.5.2 Cable

6.5.2.1 General

The design shall:

- Use optical interconnection cables wherever it is technically feasible and cost-effective. Optical connections between equipment and equipment locations are immune to EMI.
- Utilize electrical cables with proper shielding, shield grounding, conduit or duct protection, entry protection, routing, and termination to control EMI in copper electrical cables as described in this section.
- Electrical cable provisions shall comply with the National Electric Code (NEC) Chapter 2 (Wiring and Protection), Chapter 3 (Wiring Methods and Materials), Chapter 4 (Equipment for General Use), Chapter 7 (Special Conditions) and Chapter 8 (Communication Systems), except to the extent other Design Criteria provisions specify otherwise.

6.5.2.2 Electrical Cable Categories

For EMC purposes, each cable shall be assigned to one of the cable categories in **Table 13**.

- **Table 13: Electromagnetic Compatibility Cable Categories**

Name	Examples, References, Comments
Power at 600 V AC RMS or higher	115 kV feeder.
Traction Power	25 kV AC traction power and return cables.
Power at less than 600 V AC RMS	480 V AC, 120 V AC, Lighting Circuits, heating, ventilation and air conditioning (HVAC) motors, uninterruptible power supplies (UPS), etc.
NEC Class 1 circuits	NEC Class 1 power limited circuits per NEC 725.41 (A), limited to less than 30 V and 1000 VA. NEC Class 1 remote-control and signaling circuits per NEC 725.21 (B), less than 600 V. Includes safety-critical signaling circuits such as fire alarm.
NEC Class 2 and 3 circuits	Power sources for NEC Class 2 and Class 3 circuits per NEC 725.121, shall be limited per Chapter 9 Table 11(a) and Table 11(b).
Unshielded twisted pair signal circuits	Telephone, speaker level audio output, Ethernet.
Shielded signal circuits including shielded twisted pair, coax, and multi-axial cables	CCTV from camera to converter box, microphone and line level audio input, line level audio output.

Leaky coax cable	Distributed communication antenna.
Optical cable	Backbone Network, Local Area Network, CCTV camera feeds from converter box to comm. room.

6.5.2.3 Cable Separation Criteria

Cables in the same cable category may be run together in the same conduit, raceway, duct, trough, manhole, or cable tray, if all cables that are grouped and run together are insulated to the highest voltage level present in the group.

Cables in different cable categories shall not be run together in the same cable assembly, conduit, raceway, duct, or cable tray, without engineering justification documenting the specific cables, signals, and protections against EMI for the proposed combination. However, optical cables (C9) may be run together with any other cable.

Cables running parallel to the track shall be segregated in the cable troughs and duct banks according to cable category.

Wayside cables running parallel to and crossing the track shall be placed in cable troughs and duct banks. These will include communication cables, train control cables, OCS motor operated disconnects (MODs), 480 VAC, 125 VDC and 48 VDC. The cable trough shall not contain C1, power at greater than 600 V, or C2, traction power cable. Cables in the cable trough, manholes, and duct banks shall be separated by cable category, so that a suitable separation is maintained between, for example 480 VAC cables and Ethernet cables. If EMI impact occurs between cables in the cable trough or duct banks, suitable shielding techniques shall be applied to reduce the emission from the EMI source, to increase the immunity of the EMI receiver, or both. Shielding techniques include cable shields and use of metal conduit.

Traction return cables shall be run in troughs, manholes, and ducts separate from other wayside cables. Traction return cables may share a duct bank but not a duct with other cable categories.

Wires carrying circuits belonging to a single cable category, but which use different signal levels shall not be run together in the same cable, without engineering justification documenting the specific cables, signals, and protection against EMI for the proposed combination.

Where cables of dissimilar type, service or signal level cross, the crossing of the cables and their conduits and raceways shall be perpendicular where practical.

Cable separation design shall conform to IEEE Standard 1100-2005, Recommended Practice for Powering and Grounding Electronic Equipment, Section 9.9.

6.5.2.4 Cable Shielding

The design shall use shielded cables and steel conduits and ducts to protect components, circuits, and systems against the effects of undesirable external disturbing EMI sources. A cable shield can:

- Increase immunity and provide additional protection against interference to the enclosed circuits.
- Reduce emissions and provide additional reduction of the level of interference emitted by an enclosed circuit.

Wire and cable shielding and shield grounding design for electronic signals shall conform to IEEE Std 1100-2005, Sections 3.3, 4.9, 9.9, 10.2, and 10.4; and to IEEE Std 1143-2012, Guide on Shielding Practice, Section 7.

6.5.2.5 Cable Shield Grounding

The connections of cable shields and the connection of the shields to the grounding system determine the effectiveness of the shielding in mitigating EMI.

The design shall specify and use a coordinated and consistent method for terminating and connecting cable shields to equipment. The method shall conform to these criteria. The specific provisions for cable shield grounding at the system and detail level shall be documented as part of a Cable EMC Schedule. The Cable EMC Schedule shall be fully implemented across the systems.

The general topology for shield connection to power supply ground shall conform to IEEE Std 1100-2005, Sections 8.5, 9.9, 10.2, and 10.4.

Cable conductors, shield, and drain wire, if used, shall be properly terminated on the connector to prevent the inadvertent grounding of the shield or conductor connection via the connector shell to the equipment enclosure or to another unintended potential.

6.5.2.6 Conduit and Duct

The design shall:

- Run specified cables in trackside ducts. Metal conduits or ducts for cables provide mechanical protection and electrical safety as well as additional electromagnetic isolation compared to physical separation of cables. Metal conduits and ducts increase the immunity of and decrease the emissions from enclosed circuits.
- Use steel conduit and ducts; do not use aluminum.
- Run cables in steel conduit or steel duct on any run that is outside of a single enclosure for any part of its route, except for cables in the trackside ducts and cables for which engineering justification documents the basis for the cables to be run out of conduit.

6.5.2.7 Conduit and Duct Bonding and Grounding

Metal conduit and duct can serve as an overall shield for cables carrying sensitive signals, and for cables carrying signals, which tend to emit EMI. To provide a shielding function, conduit and duct shall be grounded and bonded per the NEC Article 250 where not in conflict with the Grounding and Bonding Requirements chapter.

Hardware listed only by a nationally recognized testing laboratory such as Underwriters Laboratories (UL) shall be used to join and bond conduits and ducts to enclosures, including conduit fittings and EMI gaskets.

Fully coordinate insulated ground (IG) AC circuit conduit routing and connections with the grounding of the systems powered by insulated ground circuits.

6.5.2.8 Entry Protection

The design shall provide the following:

- Room entry EMI impulse protection for wires entering an equipment room
- Enclosure entry EMI impulse protection for wires entering an equipment enclosure

The protection shall consider and be consistent with the cable type, the cable source, and the potential EMI hazards to be protected against. As noted above, cables entering an equipment room shall be enclosed in steel conduit unless the system designer provides specific technical justification for another entry protection method consistent with the above criteria.

Room entry and line entry impulse protection shall consist of line-to-line and/or line-to-ground protection, as appropriate, for each circuit type. Circuit protections on wires include combinations of lightning arrestors, transient suppressors, fuses, spark gaps, filters, ferrite beads and clamshells, etc.

6.5.2.9 Cable Termination

All impedance-controlled cables, such as coax, shall be terminated with the proper impedance.

6.5.2.10 Circuit Loops

The design shall:

- Minimize the area of circuit loops in which magnetic fields can couple.
- For high current circuits, run the feed and return conductors as closely together as feasible and minimize the length over which the feed and return cables are run separated from one another, to reduce the flux generating loop. To improve the immunity of signal circuits, use twisted pair cables.
- To minimize coupling between the flux generating loop and the signal circuit, maximize the distance between power cables and signal cables, and minimize the distance over which the signal cable runs near and parallel to the power cable.
- Ensure that design layout drawings have sufficient detail to show the physical routing of all conduits and cables, so that EMC compatibility can be designed and documented.

6.5.3 Grounding

6.5.3.1 General

The design shall:

- Make equipment grounding provisions so all equipment has a suitable safety ground and so all equipment has suitable EMI-controlling signal ground and return connections.
- Provide a Grounding EMC Schedule and drawings detailing the specific design provisions for each equipment item and its grounding connections.
- Prepare an overall grounding diagram that defines the grounding scheme for each system and subsystem, the AC power (both non-insulated ground and insulated ground) circuits serving these systems, and the interconnection means and interconnection points of the grounding systems.

For safety grounding requirements, refer to the Grounding and Bonding Requirements chapter.

6.5.3.2 Grounding Categories

For EMC purposes, the design shall use the grounding categories in **Table 14** to categorize each ground connection. The design shall apply these grounding categories to:

- Minimize the effects of electrical noise generated by system and neighboring electrical equipment.
- Minimize disturbing effects within directly affected control equipment and propagating effects on associated equipment, which might result from ground currents, fault currents, or nearby lightning strikes.

- Minimize the shock exposure potential which might appear on non-current-carrying equipment or conducting structures, in case an insulation failure energizes the enclosing structure with a dangerous voltage. Proper grounding of equipment and conducting structures will minimize the shock hazard due to a power line insulation failure.
- Provide a discharge path for stray radio frequency (RF) energy.

- **Table 14: Grounding Categories**

Name	Examples, References, Comments
Lightning protection ground	The building lightning protection ground shall connect to the power safety ground, at a single point as per NFPA 780-2023: Standard for the Installation of Lightning Protection Systems.
Power safety ground	Governed by the NEC Article 250
Sensitive electronic equipment ground	The sensitive electronic equipment ground should connect by bonding to the power safety ground at only a single point.
Signal reference structure (SRS) ground	G4 SRS ground configurations include grids and planes which provide a high-frequency common ground reference to which control and communications signals are referenced. A matrix ground mat in or under a sensitive equipment room is a typical SRS implementation. The SRS provides a better reference than a single G3 ground as it provides a lower impedance at high frequencies. If the connection from a G3 sensitive electronic equipment ground to the G2 power safety ground is long, higher impedance in the ground structure results in more electrical noise. A G4 SRS can resolve the problem.
Traction power return	The traction power return and running rails are grounded at each Traction Power Facility (TPF) via a connection from the TPF return bus to the TPF ground grid. The running rails are also connected to the aerial ground wire and to the earth at impedance bond locations at intervals along the track.

The design shall:

- Provide a direct, dedicated ground connection when connecting signal and communication ground circuits to a TPF ground grid.
- Identify, coordinate, keep separate, insulate, and appropriately connect the grounds in each of the ground categories in **Table 14**. Where necessary, identify special provisions for grounds in tunnels, trenches, at-grade ballasted or non-ballasted track, and aerial structures or bridges.
- Integrate and coordinate the lightning protection grounding system with the other grounding system designs.

Optical or other galvanic isolation of signals may be needed to create and maintain the separation of grounds.

6.5.3.3 Traction Power Return

The traction power return circuit shall be connected to the TPF ground grid at each TPF. In addition, the running rails shall be connected via impedance bonds to the earth and to the Aerial Ground Wire at intervals between TPF locations, to control step and touch voltage hazards.

For safety grounding requirements, refer to the Grounding and Bonding Requirements chapter.

6.5.3.4 Industry Standard for Powering and Grounding Electronic Equipment

The designs for powering and grounding electronic equipment shall conform to the applicable portions of the National Electric Code of IEEE Std 1100 and IEEE Std 142, as adapted for the system environment. For equipment designs and connections, the design shall use the specified techniques for powering and grounding electronic equipment.

Note that in the recommended power and grounding schemes, the "grounded conductor" refers to that leg of the circuit (usually the neutral) that is intentionally held at ground potential. The "grounded conductor" is part of the current-carrying circuit. The “grounding conductor” refers to the conductor(s) that connect(s) exposed metal parts of a device to ground, primarily for safety, secondarily for performance. The “grounding conductor” is not part of the current- carrying circuit.

6.5.3.5 Grounding Design Criteria

The design shall:

- Use a safety grounding technique for equipment in racks per IEEE Std 1100-2005, Sections 3.3, 4.9, 8.5, 9.9, 10.2, and 10.4.
- Use a high frequency or RF grounding technique signals per IEEE Std 1100-2005, Sections 3.3, 4.6, 8.5, 9.9, 10.2, and 10.4.

The grounding system shall provide that when electronic equipment has a conducting connection to other devices within a structure that all interconnected devices be referenced at the same lightning protection ground (G1) to minimize possible lightning damage.

6.5.3.6 Insulated Ground Design Criteria

Sensitive equipment may use an NEC-compliant isolated ground to provide basic fault/personnel protection and to protect the equipment. These Design Criteria refer to the NEC-compliant isolated ground using the IEEE Std 1100 nomenclature, which is “insulated ground” (IG).

For IG connections for equipment in racks, modify the safety grounding configuration from that shown in IEEE Std 1100-2005, Figures 8-17 and 8-18, by placing a listed nonmetallic raceway fitting between the equipment rack and the conduit system, as shown in NEC Handbook Exhibit 250.45. The configuration shall ensure that equipment and enclosures served by an IG power circuit are:

- Correctly and safety grounded at the IG location.
- Not inadvertently bonded to unintended non-insulated grounding paths.

6.5.4 Equipment Design

6.5.4.1 General

Equipment and system designs shall control emissions and increase EMI immunity. Design considerations include placement, enclosures, filters, interconnect design, component characteristics, and modulation methods.

The design shall:

- Specify and implement design provisions for equipment placement, enclosures, filters, interconnect design, component characteristics, and modulation methods, for each equipment item, per the following subsections.
- Ensure that plan and elevation drawings show sufficient detail of the layout of equipment in each rack, the layout of racks within a room, and ancillary equipment within a room, so that EMC compatibility can be designed and documented.

6.5.4.2 Placement

High-power potential sources shall be placed as far as practical from sensitive potential susceptible equipment, to minimize magnetic and electric field coupling between nearby pieces of equipment.

6.5.4.3 Enclosures

The design shall:

- Locate electronic equipment in a suitable EMI-Shielded Equipment Rack Cabinet.
- Protect signal and power lines entering enclosures from EMI by using appropriate cable termination techniques as well as proper conduit fittings, gaskets, etc.
- Enclose cables entering or leaving electronic enclosures in steel conduit, unless otherwise specifically justified by engineering documentation.
- A double-wall-shielded equipment enclosure may be necessary for sensitive equipment located near a powerful emissions source. In such cases, the inner enclosure shall be connected to the signal reference structure ground or IG, while the outer enclosure shall be connected to the power safety ground.
- Use shielded enclosures, metal ducts, and metal conduits to control the electromagnetic coupling between and from equipment and wiring.

Within enclosures, the design shall:

- Carefully bundle, twist, shield, protect, route, and properly terminate high current cables such as motor cables, to minimize uncontrolled emissions. The Contractor shall ensure that the cable installation does not exceed the minimum bend radius for the cable.
- Connect low voltage cable shields to the appropriate low voltage ground at the source and, per IEEE Std 1100-2005, Sections 3.3 and 8.5 and IEEE Std 1143-2012, Section 7 to the receiver-end equipment.
- Use twisted pair and shielded cables, coax, or multiax for sensitive signals.
- Place inductive components perpendicularly to nearby susceptible components to minimize the exposure to stray flux.

6.5.4.4 Filters

The design shall:

- Use appropriate low-pass filters on wired connections. Filters minimize conducted emissions from a piece of equipment into other pieces of equipment and improve the immunity of the equipment to conducted emissions on the connecting wires.
- Provide filters on power inputs and outputs to and from AC inverters and converters, transmitters, receivers, and signal circuits.
- Use supply suitable transient suppressors for relay contacts switching inductive loads, including relay and contactor coils.

6.5.4.5 Interconnect Design

The design shall use appropriate techniques to minimize emission and maximize immunity of power and signal conductors, including the following:

- Arrange wires, cables, and conduits to physically separate signals with different signal type, voltage and energy levels.
- Separate and shield circuits carrying power, high level signals, and low level signals.
- Use balanced circuits with coordinated current return paths.
- Minimize the loop area between source and return conductors.
- Use photocouplers or optical fiber to galvanically isolate circuit potentials when needed.
- Shield all sensitive signal conductors in suitable electric and magnetic shielding structures using appropriate combinations of steel conduit and shielded cable.
- Connect shields to appropriate system ground at the high energy end.

The design shall use the following:

- Matching networks to match transmission line and antenna systems to maximize performance and minimize loss and reduce EMI for controlled impedance circuits such as radio frequency signals
- Shielded cables that have shield coverage of at least 90 percent
- Guard shields to improve immunity as required for sensitive electronic circuits
- Optical cables, optically isolated signals, or other galvanic isolation for connection between equipment enclosures, whenever practical
- Isolation transformers, chokes and/or isolators for sensitive audio, video, and data circuits as required

6.5.4.6 Component Characteristics

The design shall utilize appropriate components to reduce EMI. These include the following:

- For power converters, such as UPS, DC-to-AC inverters, and variable speed motor drives, use inductor-capacitor line EMI filters on each power input and output, to reduce power frequency and switching harmonic currents and radiated emissions.
- Ferrite beads and clamshells reduce emissions from signal cables and mitigate line-to-ground (common mode) and line-to-line (differential mode) noise.
- LCD displays for computers. Do not use CRT displays.

6.5.4.7 Modulation Methods

The design shall:

- Use a modulation method, which controls and minimizes the conducted, inductive, and radiated emissions of the equipment for all equipment that converts power from one frequency, voltage, or current level to another.
- For each power converter, the Contractor shall provide a report, manufacturer's data sheet, or other technical data to describe the modulation methods used as well as the mitigation methods used to minimize EMI.

6.5.5 Facility Power

6.5.5.1 General Criteria

The design shall:

- Take power for communication electronic circuits, heating, ventilation and air conditioning (HVAC) equipment, lighting, elevators and escalators, and other systems from separate branch circuits which are isolated, regulated, backed up, and protected as required. Facility power shall comply with the requirements of the NEC Chapter 2 (Wiring and Protection), Chapter 3 (Wiring Methods and Materials), and Chapter 4 (Equipment for General Use).

- Provide a Communications Power EMC Schedule and drawings detailing the specific design provisions for each equipment item and its power and UPS connections.
- Prepare overall power diagrams that define the power distribution scheme for each system and subsystem and show the AC power with both non-insulated ground and insulated ground circuits serving these systems.

6.5.5.2 High Power

The design shall run high-current power AC cables, including phase, ground, and neutral conductors, with minimum loop size and conductor separation, physically separated from sensitive circuits, or if near sensitive circuits, twisted or in steel conduit.

6.5.5.3 Utility Power

The design shall:

- Provide a power distribution design which controls potential effects of EMI generated by high power equipment on sensitive electronic equipment. Use separate transformers and distribution buses to ensure high power loads are separated from sensitive loads.
- Use the physical placement of power distribution equipment to increase the immunity of sensitive electronic equipment to EMI generated by high power equipment.
- Route utility power distribution lines to facilities following applicable EMI/EMF regulations and guidelines.

6.5.5.4 Grounding of Uninterruptible Power Supply Circuits

The design shall follow IEEE Std 142-2007, Recommended Practice for Grounding of Industrial and Commercial Power Systems, Section 1.9.1, for UPS grounding arrangements.

6.5.5.5 Remote Powered Locations

Remote communication locations where utility power is not available may use power supplied from the Overhead Contact System (OCS) negative feeder, from a solar storage system or from another source.

Power at a remote location fed from the negative feeder shall be via a transformer, disconnect, and suitable filtering and power conditioning to protect connected equipment from the transients and harmonics present in the negative feeder.

The selected remote power supply shall make appropriate design provisions for cable, ground, shielding, filtering, and other EMC constraints.

6.5.6 Motors and Controllers

For motors and motor controllers used within the Communication Systems, such as for ventilation equipment, the following criteria shall apply:

- Provide a Motor and Controller EMC Schedule and drawings detailing the specific design provisions for each motor and controller of more than 1 hp.
- Provide each motor starter, controller, or inverter with suitable protection and line and load filtering to minimize transients and surges at start and stop. Provide twisted and/or shielded cables in conduit as appropriate.

- Route input power wires and cables to motors in steel conduit, locate input conductors as far as practical from sensitive equipment, and run wires from the output of any UPS that powers motors in steel conduit.
- Utilize soft-start motor controllers or inverters to minimize conducted line transients caused by motor starts. When multiple motors are in a room, coordinate and delay the starting of the motors in a sequence to avoid the intense transient and line dip effects of all motors starting at once.

6.5.7 Equipment Rooms and Locations

6.5.7.1 Location

The design shall:

- Within the physical constraints of the planned facilities, locate equipment so that high-power sources are physically separated as far as practical from susceptible equipment and cables.
- Where communication equipment, radio, PTC, and similar rooms are near traction power transformers, HVAC motors, or other high current systems, locate the susceptible equipment as far as practical from the stray magnetic fields generated by the transformers, motors, and power cables.
- Preferably, locate high-current equipment and cables in rooms that are not adjacent (either vertically or horizontally) to rooms with sensitive and susceptible equipment. The Contractor shall run all input power cables to high-current equipment in steel conduit.
- Maximize distance between EMI emitter rooms and EMI susceptible receiver rooms. The Contractor shall lay out the equipment rooms with high current equipment at one end of a suite of rooms and susceptible equipment at the other (far) end of the suite of rooms. To the extent practical, for example, the Contractor shall locate rooms so that they start from the left in a hypothetical plan:
- Traction power, HVAC, or other high current rooms would be at the leftmost position (room 1)
- The electrical distribution room (room 2) would be adjacent to and to the right of room 1.
- The UPS room (room 3) would be adjacent to and to the right of room 2.
- The communications rooms would be adjacent to and to the right of room 3.

6.5.7.2 Equipment Room Shielding

When architectural or structural constraints do not allow room locations and cable and equipment placement per Section 6.6.7.1 and when required by the characteristics of sensitive equipment installed in a room, the design shall use architectural shielding in the sensitive room to mitigate the electric and magnetic fields from the high-current equipment.

Architectural shielding materials include steel sheet and steel mesh wall linings; other shielding wall linings such as sheet copper, copper mesh, or conductive polyamide mesh; EMI-shielded doors, windows, access panels, and air ventilation panels; EMI-conductive systems; shielding components; shielding laminates; and EMI-shielded equipment racks.

6.5.7.3 Equipment Emission and Immunity Limits

Typical rail and general-purpose communication systems make broad use of commercial-off-the-shelf (COTS) equipment. COTS equipment shall meet FCC regulations and other EMC standards governing emissions and immunity. Manufacturers of COTS equipment shall guarantee that their equipment meets required regulations and selected published standards, but they will generally not test to confirm or modify their equipment to meet standards other than the required and selected published ones.

All electrical and electronic equipment shall conform to the electromagnetic emission and immunity limits and related requirements in the following subsections.

Each item of electrical or electronic equipment shall be certified and documented to conform to the applicable limits. For equipment that is non-COTS, this documentation shall include a test report, manufacturer's performance data, and acceptance certificates from a qualified test laboratory. Each equipment supplier shall demonstrate and document compliance of each item.

6.5.7.4 Commercial-Off-The-Shelf Communications Equipment Emission Limits

COTS equipment that is not radio transmission equipment shall meet the following conducted and radiated emission requirements of Part 15 of Title 46 of the Code of Federal Regulation (FCC Part 15), sub-part B:

- Section 15.107(b), Conducted Limits, Class A digital devices
- Section 15.109(b), Radiated Limits, Class A digital devices

FCC Part 15.3(h) defines Class A devices as digital devices that are marketed for commercial, industrial, or business use, not for use in general public or home applications. FCC Part 15 does not provide immunity limits.

COTS non-radio equipment shall be proven in similar service and shall have a Certification or a Declaration of Conformity per FCC Part 15, sub-part B, Class A devices. For such equipment, provide documentation of the suitability or test results. Suitability considerations are the following:

- The equipment is COTS.
- The equipment is suited for the planned application.
- The equipment has Certification or a Declaration of Conformity per FCC Part 15, sub-part B, Class A device regulations.

A set of COTS equipment, when installed in a compliant and correct manner in an adequate shielded equipment rack, can be treated as a single item of COTS equipment for the purposes of tests and documentation. However, treatment of a shielded rack of equipment such as COTS does not relieve the supplier of responsibility to achieve and document electromagnetic compatibility for the equipment rack and all the equipment in it.

6.5.7.5 Non-COTS Communications Equipment Emissions and Immunity

Non-COTS communications equipment radiated and conducted immunity limits shall conform to EN 50121-4, Railway applications - Electromagnetic Compatibility, Part 4: Emission and immunity of signaling and telecommunications apparatus.

As per EN 50121-4, the non-COTS communications equipment radiated and conducted emission limits shall conform to EN 61000-6-4, Electromagnetic Compatibility, Part 6-4: Generic Standards - Emission Standard for industrial environments

Each communications equipment supplier shall provide equipment that conforms to the applicable limits, as well as test certification or documentation demonstrating compliance.
In addition, FCC Part 15 governs both COTS and non-COTS communications equipment radiated and conducted emissions, other than for vehicle equipment. FCC limits are more restrictive than EN 50121-4 limits.

Non-COTS communication equipment immunity limits for electrostatic discharge, fast transients, and surges shall conform to EN 50121-4, Railway applications – Electromagnetic Compatibility, Part 4: Emission and immunity of signaling and telecommunications apparatus.

6.5.8 FCC Type Accepted Radio Equipment

Radio equipment, if provided, shall be FCC Type Approved/accepted. Frequencies for licensed radio equipment shall be coordinated with the project needs and as part of the coordination effort with other nearby users.

For FCC Type Accepted radio equipment, the Contractor, if required, shall provide a Radio EMC Schedule and drawings detailing the specific design provisions for each FCC Type Accepted radio.

For radio transmission equipment which has been proven in similar service and which has received Type Acceptance per applicable FCC Part 15 regulations, the suppliers shall document its suitability, demonstrating the following:

- The radio transmission equipment is suited for the planned application.
- The radio transmission equipment has received FCC Part 15 Type Acceptance.

6.5.8.1 Radio Equipment Design Considerations

A detailed frequency and intermodulation analysis and report shall be developed for each radio system, as part of the Radio EMC Schedule. The report shall cover modulation methods and the following:

- Transmission Lines – Use transmission lines, with proper terminating impedances, and matched circuits in RF applications.
- Antenna Placement – Place antennas to consider radio propagation factors for reliable operation, and also human exposure levels for any antennas which share an environment with patrons, staff, and neighbors.
- Intermodulation Suppression – Perform a frequency and interference analysis during the design phase for sites with more than 1 transmitter and receiver. As appropriate, apply the following:
- Use cavity filters to attenuate interfering signals from co-located transmission equipment.
- Use isolators to further suppress intermodulation.
- Properly select antenna combiners and multi-couplers and segregation of high and low power transmission equipment.

6.5.8.2 ISM Equipment

Industrial, scientific and medical device frequency band (ISM) equipment shall be FCC type accepted ISM band equipment in either the 2.4 GHz or 5.8 GHz ISM band. ISM design applications shall provide acceptable performance when interference from other ISM band users is present from many other mobile and fixed sources.

6.5.8.3 Radio System Frequency Coordination

The design shall make the following provisions for radio system frequency coordination:

- Use frequency coordination to minimize EMI. Frequency coordination shall consist of coordinating the transmission or emission frequencies and the reception or susceptible frequencies of all equipment with frequencies already in use in the system and by neighbors.

- Coordinate equipment that transmits or receives on a specific frequency with the list of frequency bands used by other equipment.

6.5.9 Human Exposure to Electromagnetic Fields

If provided, place radio transmit antennas and design the connected radio systems so that human exposure is below the applicable specification limits for EMF in and around the electrified portion of the Caltrain Right-Of-Way (ROW).

The CPUC EMF Policy in Decision 06-01-042 states:
State and federal public health regulatory agencies have determined that setting numeric exposure limits is not appropriate; and existing no-cost and low-cost precautionary-based EMF policy should be continued.

The IEEE developed a set of internationally recognized standards to achieve the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz relative to the potential hazards from exposure of such energy to man, volatile materials, and explosive devices. In compliance to the international practice, the design shall limit EMF exposure levels in and around the system per the IEEE standards:

- IEEE Standard C95.6-2002 – IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz [IEEE Std C95.6]
- IEEE Standard C95.1-2005 – IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz [IEEE Std C95.1]

The IEEE standards and these criteria establish Maximum Permissible Exposure (MPE) limits for the general population and authorized people in controlled environments. Only workers, contractors, and other authorized personnel may be in controlled environments, such as in equipment rooms, or along Caltrain's right-of-way near the tracks. The MPE limits recognize that workers and others in these controlled environments have the knowledge to minimize the duration or extent of exposure to the higher levels that may be present.

6.5.9.1 Maximum Permissible Exposure Limits

The magnetic field MPE limits for general public and controlled environments shall conform to IEEE Std C95.6 Table 2 and IEEE Std C95.1 Tables 2, 8, and 9. The limit for the general public at 60 Hz is 9.0 G (Gauss).

The electric field MPE limits for general public and controlled environments shall conform to the IEEE Std C95.1 Tables 4, 8, and 9 and IEEE Std C95.6 Table 4.

The propagating EMF MPE limits for general public and controlled environments shall conform to the IEEE Std C95.1 Tables 8 and 9.

The MPE limits in the cited revisions of the standards shall apply unless the designer establishes that a newer revision of the Standard is applicable and that the newer revision of the Standard provides adequate protection to people near the tracks.

6.5.9.2 Animal Exposure to Electromagnetic Fields

Pets, Service Animals and farms and ranches may be near radio transmit antennas. Radio transmit antennas and the connected radio systems shall be designed so that animal exposures conform with the same MPE limits as apply to humans.

6.6 Signaling & Train Control EMC Design Criteria

6.6.1 Equipment and EMC Considerations

6.6.1.1 PTC Equipment

PTC equipment consists of the following:

- Wayside PTC systems connected by copper wires and by fiber optic cable. Examples include wayside control units; PTC radio units including Global System for Mobile Communications - Railway, Wifi, 160 MHz, and/or 220 MHz; trackside signals; switches, and hazard detectors; track circuits for train detection, train communication, and/or broken rail detection; transponders; OCC facilities, CTC and SCADA workstations and display units; PTC data network; and support subsystems and functions.
- Onboard systems. Examples include onboard TMC unit, PTC radio unit, Driver's display unit, tachometers and transponder sensors, PTC onboard data radio, and support subsystems and functions.
- Cabinets and contents, control panels, displays, cables, conduits, ducts, raceways, enclosures, and antennas.

Depending on the selected PTC technology, data radio communication between onboard and wayside control units may provide PTC data and functions, or coded track circuits may provide the equivalent function. In either case, the PTC equipment will include track circuits at least to provide broken rail detection. The PTC equipment may include track-mounted transponders, train-mounted transponder interrogators, and track and train auxiliary data radio equipment.

6.6.1.2 EMC Considerations

PTC equipment shall conform to EMC design criteria. PTC equipment EMC provisions shall ensure the following:

- Safe and dependable operation.
- No interference with or from neighbors.
- Compliance with human exposure limits to magnetic and electric fields.

Track circuits shall have specified and demonstrated immunity to train-conducted and inductive emissions. Train-conducted emissions will include 60 Hz power frequency harmonics with significant levels at power harmonics across the audio frequency band. Train propulsion design criteria developed in coordination with the PTC system supplier shall control the amplitude of higher order, higher amplitude 60 Hz power frequency harmonics, and their potential impact on track circuits.

PTC equipment shall conform to electrical safety requirements.

PTC equipment shall provide safety-critical functions with the documented assurance that unsafe failures are controlled to an acceptable limit.

Design and maintenance provisions shall ensure that EMI cannot compromise the safety level of operations achieved by the PTC system.

PTC equipment generally does not use COTS equipment for safety-critical functions. PTC suppliers shall document the achieved level of compliance of their equipment to designated EMC standards.

The following design criteria apply to the PTC system and its interfaces with other systems:

- Cables and cable segregation
- Grounding
- Equipment design
- Facility power
- Motors and controllers
- Equipment, rooms and locations
- Equipment emission and immunity limits
- Requirements for radios
- Human exposure limits

The PTC system EMC design criteria are described in following subsections.

6.6.1.3 EMC with Adjacent Railroads

A freight railroad, the Union Pacific Railroad and electric railroads including Bay Area Rapid Transit and Santa Clara Valley Transportation Authority run adjacent to the alignment for long sections. On the tracks, 60 Hz traction power for high-speed trains will flow in the OCS, running rails, and in the earth, at 750 A or more per train. The EMF of the traction power system will couple some 60 Hz traction power current into the tracks of adjacent railways. High frequency currents may also couple into adjacent railroad communications equipment.

Where an adjacent railroad parallels the alignment for many miles, the induced voltage and current in the adjacent railroad tracks may interfere with the normal operation of the adjacent railroad signaling system, depending on the specific track circuit equipment in service on the adjacent railroad.

Coordinate with the engineering department of adjacent railroads that parallel the alignment, to assess the specific track signal and communication equipment in use on nearby sections, determine potential impacts of EMFs and radio frequency interference on the adjacent railroad equipment, and make suitable design provisions to prevent interference. Design provisions may include replacement of specific track circuit types with other types developed for operation on or near electric railways, providing filters for sensitive communication equipment, and potentially relocation or reorientation of radio antennas.

6.6.2 Cables

6.6.2.1 General

See Section 6.5.2.1

6.6.2.2 PTC System Cables

Equipment-specific EMC design criteria shall apply for specialized PTC system cables, including for the following:
Cables from equipment rooms to wayside track circuit equipment; track switches and signals; transponders and other track mounted apparatus

6.6.2.3 Electrical Cable Categories

For EMC purposes, each cable shall be assigned to one of the cable categories in **Table 13: Electromagnetic Compatibility Cable Categories**.

6.6.2.4 Cable Separation Criteria

See Section 6.5.2.3 for details.

6.6.2.5 Cable Shielding

See Section 6.5.2.4 for details. Special considerations apply to signal control and lighting cables and switch control cables which connect to track signals and switches and run parallel to the track. Shielding and conduit non-continuity for track circuit signal cables shall comply with the guidelines provided in the Grounding and Bonding Requirements chapter, Signal Cables section: “Signal control or lighting cables and switch cables shall not have metallic shielding. Metallic messenger or duct shall not be used in any way that could cause an electrical interconnection between signals or signal structures and signal equipment housings.” This criterion does not apply when otherwise directed by equipment-specific design criteria such as noted.

6.6.2.6 Cable Shield Grounding

See Section 6.5.2.5.

6.6.2.7 Conduit and Duct

See Section 6.5.2.6.

6.6.2.8 Conduit and Duct Bonding and Grounding

See Section 6.5.2.7.

6.6.2.9 Entry Protection

See Section 6.5.2.8.

6.6.2.10 Cable Termination

See Section 6.5.2.9.

6.6.2.11 Circuit Loops

See Section 6.5.2.10.

6.6.3 Grounding

See Section 6.5.3.

6.6.3.1 Traction Power Return

See Section 6.5.3.3 and Chapter 4, Grounding and Bonding.

6.6.3.2 Industry Standard for Powering and Grounding Electronic Equipment

See Section 6.5.3.4.

6.6.3.3 Grounding Design Criteria

See Section 6.5.3.5.

6.6.3.4 Insulated Ground Design Criteria

See Section 6.5.3.6.

6.6.4 Equipment Design

6.6.4.1 General

See Section 6.5.4.1.

6.6.4.2 Power Frequency Track Circuits

Since the system utilizes 60 Hz traction power, the use of power frequency track circuits at 60 Hz or below is not permitted.

6.6.4.3 Placement

See Section 6.5.4.2.

6.6.4.4 Enclosures

See Section 6.5.4.3.

6.6.4.5 Filters

See Section 6.5.4.4.

6.6.4.6 Interconnect Design

See Section 6.5.4.5.

6.6.4.7 Component Characteristics

See Section 6.5.4.6.

6.6.4.8 Modulation Methods

See Section 6.5.4.7.

6.6.5 Facility Power

6.6.5.1 General

The design shall:

- Take power for PTC electronic circuits, HVAC equipment, lighting, elevators and escalators, and other systems from separate branch circuits which are isolated, regulated, backed up, and protected as required. Facility power shall comply with the requirements

of the NEC Chapter 2 (Wiring and Protection), Chapter 3 (Wiring Methods and Materials), and Chapter 4 (Equipment for General Use).
- Provide a PTC Power EMC Schedule and drawings detailing the specific design provisions for each equipment item and its power and UPS connections.
- Prepare overall power diagrams that define the power distribution scheme for each system and subsystem and show the ac power with both non-insulated ground and insulated ground circuits serving these systems.

6.6.5.2 High Power

See Section 6.5.5.2.

6.6.5.3 Utility Power

See Section 6.5.5.3.

6.6.5.4 Grounding of Uninterruptible Power Supply Circuits

See Section 6.5.5.4.

6.6.5.5 Remote Powered Locations

See Section 6.5.5.5.

6.6.6 Motors and Controllers

See Section 6.5.6. Service-proven track switch motors and controllers are governed by signal system design practice.

6.6.7 Equipment Rooms and Locations

6.6.7.1 Location

The design shall make the following provisions for equipment locations:
- Within the physical constraints of the planned facilities, locate equipment so that high power sources are physically separated as far as practical from susceptible equipment and cables.
- Where communication equipment, radio, PTC, and similar rooms are near traction power transformers, HVAC motors, or other high-current systems, locate the susceptible equipment as far as practical from the stray magnetic fields generated by the transformers, motors, and power cables.
- Preferably, locate high-current equipment and cables in rooms that are not adjacent (either vertically or horizontally) to rooms with sensitive and susceptible equipment. All input power cables to high-current equipment shall be run in steel conduit.
- Maximize distance between EMI emitter rooms and EMI susceptible receiver rooms. Equipment rooms with high-current equipment shall be laid out at one end of a suite of rooms and susceptible equipment at the other (far) end of the suite of rooms. To the extent practical, for example, the rooms shall be located so that they start from the left in a hypothetical plan.

6.6.7.2 Equipment Room Shielding

See Section 6.5.7.2.

6.6.8 Equipment Emission and Immunity Limits

6.6.8.1 General

While train control equipment is industrial equipment with similarities to electrical equipment used in other applications, much of it is not COTS equipment. PTC equipment suppliers shall document the achieved level of compliance of their equipment to designated standards.

6.6.8.2 Track Circuit EMC

The PTC equipment and RS suppliers shall jointly establish specific immunity limits to protect PTC equipment; particularly track circuits and track-based data communication circuits, from train-generated interference. These limits shall be implemented by coordinated action by the RS and PTC equipment suppliers during PTC system and RS design, implementation, and qualification testing.

For EMC between RS and track circuits, the PTC equipment supplier shall:

Use procedures to document and convert the electromagnetic immunity characteristics of planned wayside equipment into corresponding emission limits which shall apply to RS. The RS supplier shall ensure that the RS emissions comply with the limits developed by the PTC equipment. If necessary, the suppliers shall modify supplied PTC equipment and RS designs to ensure compatibility.

U.S. Department of Transportation Federal Transit Administration test procedures shall govern testing of the compatibility of trains and track circuits. The RS supplier shall perform field qualification tests to demonstrate that the RS conforms to the emission limits using the following procedures:

- UMTA-MA-06-0153-85-6, Conductive Interference in Rapid Transit Signaling Systems Volume II: Suggested Test Procedures
- UMTA-MA-06-0153-85-8, Inductive Interference in Rapid Transit Signaling Systems-Volume II: Suggested Test Procedures

The PTC equipment supplier shall perform field qualification tests to demonstrate that the susceptibility limits of the track circuits are as documented.

Track circuits and related equipment shall be immune to the effects of traction power currents in the OCS, running rails, and ground, and to the effects of utility power transmission and distribution lines which run parallel to or which cross the Caltrain right-of-way, whether inside or outside the fence line.

6.6.8.3 PTC Radio EMC

For radio transmission equipment which has been proven in similar service, and which has received Type Acceptance via the applicable FCC Part 15 regulations, the supplier shall document its suitability, demonstrating the following:

- The radio transmission equipment is suited for the planned application.
- The radio transmission equipment has received FCC Part 15 type acceptance.

6.6.8.4 PTC EMC Criteria

Specific PTC system EMC design criteria shall apply for PTC equipment. Euro norm standards govern emissions and immunity for wayside and onboard equipment:

- EN 50121-1, Railway applications - Electromagnetic compatibility. General.
- EN 50121-2, Railway applications - Electromagnetic compatibility. Emissions of the whole railway system to the outside world.
- EN 50121-3-2, Railway applications Electromagnetic Compatibility. Rolling stock – Apparatus
- EN 50121-4, Railway applications - Electromagnetic Compatibility, Part 4: Emission and immunity of signaling and telecommunications apparatus

Equipment immunity limits for electrostatic discharge, fast transients, and surges shall conform to EN 50121-3-2 and EN 50121-4.

As noted above, track circuit immunity shall be established per EN 50238-1, Railway applications - Compatibility between RS and train detection Systems; EN 50238-2, Railway applications - Compatibility between rolling stock and train detection systems - Part 3: Compatibility with track circuits; and EN 50238-3, Railway applications - Compatibility between rolling stock and train detection systems - Part 3: Compatibility with axle counters.

Each item of electrical or electronic equipment shall be certified and documented to conform to the applicable limits. For equipment that is non-COTS equipment, this documentation shall include a test report, manufacturer's performance data, and acceptance certificates from a qualified test laboratory. Each equipment supplier shall demonstrate and document compliance of each item.

6.6.8.5 PTC Equipment in Equipment Racks

A set of COTS equipment, when installed in a compliant and correct manner in an adequate shielded equipment rack, can be treated as a single item of equipment for the purposes of tests and documentation. However, treatment of a shielded rack of equipment such as COTS does not relieve the supplier of responsibility to achieve and document electromagnetic compatibility for the equipment rack and all the equipment in it.

6.6.8.6 PTC Equipment Emissions and Immunity

EN 50121-3-2 governs onboard equipment radiated and conductive emissions and immunity. EN 50121-4 governs wayside equipment radiated and conductive emissions and immunity. The PTC equipment supplier shall provide equipment that conforms to these limits, as well as test certification or documentation demonstrating compliance.

The PTC equipment immunity limits for electrostatic discharge, fast transients, and surges shall conform to EN 50121-4, Railway applications - Electromagnetic Compatibility, Part 4: Emission and immunity of signaling and telecommunications apparatus.

6.6.9 FCC Type Accepted Radio Equipment for PTC

See Section 6.5.8.

6.6.9.1 Radio Equipment Design Considerations

If required, develop detailed frequency and intermodulation analysis and report for each radio system, as part of the Radio EMC Schedule. The report shall cover modulation methods and the following:

- Transmission Lines – Use transmission lines, with proper terminating impedances, and matched circuits in RF applications.
- Antenna Placement – Place antennas to consider radio propagation factors for reliable operation, and also human exposure levels for any antennas which share an environment with patrons, staff, and neighbors.
- Intermodulation Suppression – Perform a frequency and interference analysis during the design phase for sites with more than 1 transmitter and receiver. As appropriate, apply:
- Use cavity filters to attenuate interfering signals from co-located transmission equipment.
- Use isolators to further suppress intermodulation.
- Properly select antenna combiners and multi-couplers and segregation of high and low power transmission equipment.

6.6.9.2 ISM Equipment

See Section 6.5.8.2.

6.6.9.3 Radio System Frequency Coordination

See Section 6.5.8.3.

6.6.10 Human Exposure to Electromagnetic Fields

See Section 6.5.9.

6.6.10.1 Maximum Permissible Exposure Limits

See Section 6.5.9.1.

6.6.10.2 Animal Exposure to Electromagnetic Fields

See Section 6.5.9.2.

6.7 Traction Electrification System EMC Design Criteria

6.7.1 Equipment and EMC Considerations

The Traction Electrification System (TES) is described in the Traction Power System chapter and the Overhead Contact System chapter. The TES equipment comprises the following:

- AC power distribution from two independent high voltage (HV) utility supply circuits to traction power substations
- 2x25 kV traction power substations, switching stations, and paralleling stations
- OCS
- Aerial Negative Feeders
- Traction power return system
- Aerial Static/Ground Conductor
- Traction power SCADA, instrumentation, and data network connections
- Equipment includes transformers, cooling equipment, switchgear, overhead contact system hardware, grounding hardware, impedance bonds, cabinets and contents, control panels, monitoring equipment, displays, cables, conduits, ducts, raceways, bus bars, and enclosures.

The 2x25kV configuration reduces propagation of electric and magnetic fields from traction power currents because it minimizes the physical size of the loop in which supply and return currents flow.

Train conducted emissions will include 60 Hz power frequency harmonics with significant levels across the audio frequency band. Train propulsion design criteria developed in coordination with the ATC system supplier shall control the amplitude of higher 60 Hz power frequency harmonics and the susceptibility of ATC equipment to traction power harmonics.

TES equipment EMC provisions shall ensure the following:

- Safe and dependable operation
- No interference with or from neighbors
- Compliance with human exposure limits
- Magnetic and electric fields
- Step and touch potentials

Traction power equipment shall conform to electrical safety requirements.

Design and maintenance provisions shall also ensure that EMI cannot compromise the safety level of operations provided by the traction power system.

The following design criteria apply to the traction power system and its interfaces with other systems:

- Cables and cable segregation
- Grounding
- Equipment design
- Facility Power
- Equipment rooms and locations
- Equipment emission and immunity limits
- Requirements for radios
- Human exposure limits
- Effects on adjacent metallic fences and pipelines

The traction power system EMC design criteria are described in following subsections.

6.7.2 Cable

6.7.2.1 General

Select, install, and connect electrical cables with proper shielding, shield grounding, conduit or duct protection, entry protection, routing, and termination to control EMI in copper electrical cables as described in this section. Treat power cables according to required practice for their voltage class. Electrical cable provisions shall comply with the NEC Chapter 2 (Wiring and Protection), Chapter 3 (Wiring Methods and Materials), Chapter 4 (Equipment for General Use), Chapter 7 (Special Conditions) and Chapter 8 (Communication Systems), wherever the NEC applies, except to the extent other Design Criteria provisions specify otherwise.
Electrical cable provisions shall comply with Section VII of CPUC General Order No. 95.

6.7.2.2 Utility Supply and Overhead Contact System Traction Power Cables

Utility Supply cables shall conform to the applicable CPUC requirements.

OCS cables (Contact Wire, Messenger Wire, plus aerial Negative Feeders, and Static cables) shall conform to CPUC requirements, if any are put into effect.

Utility Supply and OCS traction power cables shall be laid out to minimize the size and asymmetry of the loop formed between power feeders, the aerial traction power feeder, overhead contact wire, return, aerial and buried ground cables. These cables carry high currents and will generate correspondingly high magnetic field levels.

6.7.2.3 Electrical Cable Categories

For EMC purposes, each cable shall be assigned to one of the cable categories in **Table 13: Electromagnetic Compatibility Cable Categories**.

6.7.2.4 Cable Separation Criteria

See Section 6.5.2.3.

6.7.2.5 Cable Shielding

See Section 6.5.2.4.

6.7.2.6 Cable Shield Grounding

See Section 6.5.2.5.

6.7.2.7 Conduit and Duct

See Section 6.5.2.6.

6.7.2.8 Conduit and Duct Bonding and Grounding

See Section 6.5.2.7.

6.7.2.9 Entry Protection

See Section 6.5.2.8.

6.7.2.10 Cable Termination

See Section 6.5.2.9.

6.7.2.11 Circuit Loops

See Section 6.5.2.10.

6.7.3 Grounding

6.7.3.1 General

The design shall make the following grounding provisions:

- Provide each TES equipment item with a suitable safety ground and suitable EMI-controlling TES ground and return connections.
- Provide a TES Grounding EMC Schedule and drawings detailing the specific design provisions for each equipment item and its grounding connections.

- Prepare an overall grounding diagram that defines the grounding scheme for each system and subsystem, the AC power (both non-insulated ground and insulated ground) circuits serving these systems, and the interconnection means and interconnection points of the grounding systems.

For safety grounding requirements, refer to the Grounding and Bonding Requirements chapter.

6.7.3.2 Grounding Categories

See Section 6.5.3.2 and **Table 14** for grounding categories.

6.7.3.3 Running Rails

The running rails shall be connected to earth ground via impedance bonds at all TPF locations, including traction power substations, switching stations, and paralleling stations. The running rails shall also be connected to earth ground via impedance bonds at other wayside locations as necessary to adequately control step and touch potentials.

OCS poles, the static wire, and all other metallic components shall be solidly connected to each other at each location, and the OCS poles shall be grounded through the available path at the OCS pole foundation. However, as noted in the Grounding and Bonding Requirements chapter, where an OCS pole can be touched by a person at a passenger station, the OCS pole shall be grounded to the earth but insulated from the static wire.

Coordinate the grounding configuration of the running rails with the requirements of the ATC system because the running rails will be used for ATC circuits and for broken rail protection. Provide platform touch and step voltage protection, including a counterpoise arrangement to control voltage between train and platform.

Refer to the Grounding and Bonding Requirements chapter for specific criteria for TES grounding and bonding.

6.7.3.4 Traction Power Return

The rail return system connects the running rails to ground via the TPF transformer or autotransformer neutral bushing. The transformer neutral bushing is connected to the TPF return bus, which is directly connected to the TPF ground grid at each TPF.

6.7.3.5 Traction Power Facility Ground and Equipment Safety Ground

Safety ground connection types G1 - G5 in **Table 14**, when connected to a TPF ground grid, shall use a direct, dedicated ground connection.

Specific low-resistance ground resistance criteria may apply to the resistance of the ground grid provided for traction power substations, traction power paralleling stations, and traction power switching stations. Such provisions may be needed to control touch potential along the running rails.

6.7.3.6 Industry Standard for Powering and Grounding Electronic Equipment

See Section 6.5.3.4.

6.7.3.7 Electronic Equipment Grounding Design Criteria

The design shall:

- Use safety grounding technique for electronic equipment in racks per IEEE Std 1100-2005, Sections 3.3, 4.9, 8.5, 9.9, 10.2, and 10.4; and
- Use a high frequency or RF grounding technique for high frequency signals per IEEE Std 1100-2005, Sections 3.3, 4.6, 8.5, 9.9, 10.2, and 10.4.

The grounding system shall provide that when electronic equipment has a conducting connection to other devices within a structure that all interconnected devices be referenced at the same lightning protection ground (G1) to minimize possible lightning damage. This grounding provision does not apply to power cables.

6.7.3.8 Insulated Ground Design Criteria

See Section 6.5.3.6.

6.7.4 Equipment Design

See Section 6.5.4 for details.

6.7.5 Facility Power

6.7.5.1 General Criteria

See Section 6.5.5.1.

6.7.5.2 High Power

See Section 6.5.5.2.

6.7.5.3 Utility Power

Utility power distribution lines shall be routed and carried to facilities according to applicable EMI/EMF regulations and guidelines:

- CPUC General Order 95, Overhead Electric Line Construction
- Pacific Gas & Electric Company, Transmission Line EMF Design Guidelines

The 25 kV OCS lines are not covered by this chapter; however, utility distribution lines to TES power stations are likely to be covered by this chapter.

6.7.5.4 Grounding of Uninterruptible Power Supply Circuits

See Section 6.5.5.4.

6.7.5.5 Remote Powered Locations

See Section 6.5.5.5.

6.7.6 Motors and Controllers

See Section 6.5.6.

6.7.7 Equipment Rooms and Locations

6.7.7.1 Location

See Section 6.5.7.1.

6.7.7.2 Equipment Room Shielding

See Section 6.5.7.2.

6.7.8 Equipment Emission and Immunity Limits

6.7.8.1 General

While traction power equipment is industrial equipment with similarities to electrical equipment broadly used in other applications, it is non-COTS equipment. TES equipment suppliers shall document the achieved level of compliance of their equipment to designated standards.
Other specific criteria below also apply.

6.7.8.2 Current and Voltage Distortion Limits

Harmonic currents or voltages generated by the traction power system and rolling stock can affect the performance of power, communication, and other systems. These effects can be minimized by appropriate placement of feeder, return, and ground conductors on the overhead and track structures, by controlling the phase angle of train power converters to minimize harmonics, and by the appropriate use of onboard filters. Current and voltage distortion limits are provided in IEEE Std 519, Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems. Traction power system current and voltage distortion, including the effects of rolling stock in regular operation, shall conform to the IEEE Std 519 limits in tables 10-3, 10-4 and 11-1, unless the limits imposed by the connected power utility are stricter, in which case the stricter limits shall apply.

6.7.8.3 Traction Power EMC Design and Emission Standards

Traction power equipment shall conform to the following EMC emissions and immunity specifications:

- EN 50121-1, Railway applications - Electromagnetic compatibility. General
- EN 50121-2, Railway applications - Electromagnetic compatibility. Emissions of the whole railway system to the outside world
- EN 50121-5, Railway applications - Electromagnetic compatibility. Emission and immunity of fixed power supply installations and apparatus
- EN 61000-6-4, Electromagnetic Compatibility (EMC) – Part 6-4: Generic Standards – Emission standard for industrial environments

IEEE Standards specify design, safety, and EMC aspects of traction power system equipment:

- Standard 80, Guide for Safety in AC Substation Grounding
- Standard 519, Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems
- Standard 525, Guide for the Design and Installation of Cable Systems in Substations

Because traction power equipment is non-COTS equipment, the suppliers shall certify that their equipment conforms to the limits and standards specified in the following sections:

- EN 50121-2 governs radiated emissions of the system into the environment during train operation.
- For the radiated magnetic field and electric field emission limits for the system including Rolling Stock, track, and OCS during train operation, the "A" curve applies.
- EN 50121-2 shows radiated magnetic and electric field emission limits for substations.
- EN 50121-5 governs TES fixed power supply equipment radiated and conductive emissions and immunity. EN 50121-2 limits in the previous section apply to higher voltage equipment. Each TES equipment supplier shall provide equipment which conforms to these limits, as well as test certification or documentation demonstrating compliance.

The non-COTS TES equipment immunity limits for electrostatic discharge, fast transients, and surges shall conform to EN 50121-5, Railway applications - Electromagnetic Compatibility, Part 5: Emission and immunity of fixed power supply installations and apparatus.

6.7.8.4 Compatibility with Adjacent Airports and Avionic Equipment

The design shall assess whether radiated electric field emissions from the TES could interfere with aviation equipment or operations at commercial and general airports adjacent to the alignment. The assessment shall consider the ambient electromagnetic environment, radiated emissions and other electromagnetic characteristics of the TES, and OCS, as well as potentially sensitive aviation equipment.

6.7.9 FCC Type Accepted Radio Equipment

Radio equipment, if any, shall be FCC Type Accepted. Refer to Section 6.5.8.

6.7.10 Human Exposure to Electromagnetic Fields

The TES and OCS shall be designed so that human exposure is below the applicable specification limits for EMF in and around the system.

The IEEE developed a set of internationally recognized standards to achieve the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz relative to the potential hazards from exposure of such energy to man, volatile materials, and explosive devices. In compliance with international practice, the Contractor shall limit EMF exposure levels in and around the system per the IEEE standards:

- IEEE Standard C95.6-2002 - IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz [IEEE Std C95.6]
- IEEE Standard C95.1-2019 - IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz [IEEE Std C95.1]

The IEEE standards and these criteria establish MPE limits both for the general population and for authorized people in controlled environments. Only workers, contractors, and other authorized personnel may be in controlled environments, such as in equipment rooms, or along Caltrain's right of way near the tracks. The MPE limits recognize that workers and others in these controlled environments have the knowledge to minimize the duration or extent of exposure to the higher levels that may be present.

6.7.10.1 Maximum Permissible Exposure Limits

See Section 6.5.9.1.

6.7.10.2 Implanted Medical Devices

EN standards establish exposure limits for implanted medical devices such as pacemakers, implantable cardioverter defibrillators (ICDs), cochlear implants and brainstem stimulators.

The applicable EN standards follow:

- EN 45502-2-1:2004, Active implantable medical devices - Part 2-1: Particular requirements for active implantable medical devices intended to treat bradyarrhythmia (cardiac pacemakers)
- EN 45502-2-2:2008, Active implantable medical devices - Part 2-2: Particular requirements for active implantable medical devices intended to treat tachyarrhythmia (includes implantable defibrillators)
- EN 45502-2-3:2010, Active implantable medical devices - Part 2-3: Particular requirements for cochlear and auditory brainstem implant systems

The magnetic field MPE for all publicly accessible areas of the electrified portion of the Caltrain Right-Of-Way (ROW) shall be consistent with both the EN limits for medical devices and the IEEE limits for the general public.

EMF levels above the recommended limits may exist inside traction power facilities. TPF sites will be normally unmanned; workers will enter only periodically, for example, to perform routine maintenance. The safety program will disclose health risks to employees who have implanted medical devices and will preclude workers with implanted medical devices from entering any TPF with levels above the recommended limits.

6.7.11 Animal Exposure to Electromagnetic Fields

Passengers may travel with service or pet animals. Farms and ranches may be near the TES and OCS. The EMF exposure limit for animals shall conform to the same limits as for humans.

6.7.12 Effects on Parallel Adjacent Metal Structures

If the right-of-way runs parallel to ungrounded or partially grounded metal irrigation systems, metal fences, pipelines, or other metal structures for significant distances, a person could experience a nuisance shock when touching the metal structure and a grounded metal object.

The system shall include normal project design features to preclude nuisance shocks, which can consist of either: fully grounding the metal structure, fully insulating the metal structure, or segmenting the structure so that the conductive path parallel to the track is interrupted. The project shall protect metal structures within the ROW.

Fences with metal fence posts, buried metal pipelines, and movable irrigation pipes on metal wheels are examples of structures which are already adequately grounded. A metal wire fence with wood fence posts is an example of a structure that may not be adequately grounded. A movable irrigation pipe on rubber wheels is an example of a structure that is probably adequately isolated from ground.

6.8 Rolling Stock EMC Coordination

6.8.1 Equipment and EMC Considerations

The electrification and signal system designs shall be coordinated with the RS equipment, which comprises the following:

Electrical multiple unit (EMU) trainsets with steel wheels on steel rails operating at up to 79 mph on a predominantly at grade alignment.

Passenger train electrical systems will include propulsion; train control; onboard communications; radio, commercial radio and cell phone; Wi-Fi and other unlicensed radio; passenger entertainment and communications; trainline network and data systems; HVAC, auxiliary electric, and lighting equipment; and doors.

Diesel powered passenger and freight trains, including work trains of varying lengths operate on Caltrain tracks, including electrified portions of the ROW.

The RS equipment supplier EMC provisions will ensure the following:

- Safe and dependable operation
- No interference
  - Within the train and with passenger equipment on the train
  - With the PTC system
  - With or from radio communications
  - With or from neighbors
- Compliance with human exposure limits, including for the following:
  - Magnetic and electric fields
  - Step and touch potentials

RS equipment shall conform to electrical safety requirements. Design and maintenance provisions will also ensure that EMI does not compromise the safety level of operations achieved by the train system.

6.9 Station and Facility Equipment EMC Coordination

6.9.1 Equipment and Considerations

There are numerous passenger stations and other facilities along the Caltrain ROW that will have TES and OCS systems and structures installed within or adjacent to them. The Designer shall consider the potential effect of the electrification system on the stations and facilities in its design for the control of EMF. Station and facility equipment are typically comprised of the following:

- Elevators and escalators; HVAC; security equipment; and electrical, lighting, and power equipment
- Communications equipment, and optical, wired, and wireless data networks
- Passenger communications and entertainment equipment including closed circuit television, dynamic message signs and displays, public address systems, intercoms, telephones, wireless networks, and traction power cut stations
- Fare collection
- Vending machines
- Radio
- Equipment includes transformers, inverters, converters, motors and controllers, cabinets and contents, control panels, displays, cables, conduits, ducts, raceways, and enclosures

The electrification design and EMC provisions shall ensure the following for the stations and facilities and their equipment:

- Safe and dependable operation
- No interference with or from the station or facilities systems, with or from radio communications, and with or from neighbors at these locations
- Compliance with human exposure limits

- Magnetic and electric fields
- Step and touch potentials
- Mitigation measures, if any, shall conform to electrical safety requirements

Design and maintenance provisions that are part of any mitigation shall also ensure that EMI does not compromise the safety level of operations achieved by other systems, such as station and facility equipment includes general purpose industrial equipment, specialized transportation equipment, and COTS equipment.

The following design criteria shall apply to stations and facilities, to their equipment systems, and to their interfaces with other systems, if mitigation of existing conditions is required as a result of the electrification system implementation:

- Cables and cable segregation
- Grounding
- Equipment design
- Facility Power
- Motors and controllers
- Equipment rooms and locations
- Equipment emission and immunity limits
- Requirements for radios
- Human exposure limits

The stations and facilities and equipment EMC design criteria are described in following subsections.

6.9.2 Cable

6.9.2.1 General

See Section 6.5.2.1.

6.9.2.2 Electrical Cable Categories

For EMC purposes, each cable shall be assigned to one of the cable categories in **Table 13**.

6.9.2.3 Cable Separation Criteria

See Section 6.5.2.3.

6.9.2.4 Cable Shielding

See Section 6.5.2.4.

6.9.2.5 Cable Shield Grounding

See Section 6.5.2.5.

6.9.2.6 Conduit and Duct

See Section 6.5.2.6.

6.9.2.7 Conduit and Duct Bonding and Grounding

See Section 6.5.2.7.

6.9.2.8 Entry Protection

See Section 6.5.2.8.

6.9.2.9 Cable Termination

See Section 6.5.2.9.

6.9.2.10 Circuit Loops

See Section 6.5.2.10.

6.9.3 Grounding

6.9.3.1 General

See Section 6.5.3.1.

6.9.3.2 Grounding Categories

See Section 6.5.3.2.

6.9.3.3 Traction Power Return

See Section 6.5.3.3.

6.9.3.4 Industry Standard for Powering and Grounding Electronic Equipment

See Section 6.5.3.4.

6.9.3.5 Grounding Design Criteria

See Section 6.5.3.5.

6.9.3.6 Insulated Ground Design Criteria

See Section 6.5.3.6.

6.9.4 Equipment Design

See Section 6.5.4.

6.9.5 Facility Power

See Section 6.5.5.

6.9.6 Equipment Rooms and Locations

6.9.6.1 Location

See Section 6.5.7.1.

6.9.6.2 Equipment Room Shielding

See Section 6.5.7.2.

6.9.6.3 Equipment Emission and Immunity Limits

Rail stations and facilities typically use COTS equipment. COTS equipment shall meet U.S. FCC regulations and other EMC standards governing emissions and immunity. Manufacturers of COTS equipment shall guarantee their equipment meets required regulations and selected published standards, although they will generally not test to or modify their equipment to meet standards other than the required and selected published ones.

All electrical and electronic equipment shall conform to the following electromagnetic emission and immunity limits and related requirements.

Each item of electrical or electronic equipment shall be certified and documented to conform to the applicable limits. For equipment that is non-COTS equipment, this documentation shall include a test report, manufacturer's performance data, and acceptance certificates from a qualified test laboratory. Each equipment supplier shall demonstrate and document compliance of each item.

6.9.6.4 COTS Station and Facility Equipment Emission Limits

See Section 6.5.7.4.

6.9.6.5 Non-COTS Station and Facility Equipment Emissions and Immunity

See Section 6.5.7.5.

6.9.7 FCC Type Accepted Radio Equipment for Stations and Facilities

See Section 6.5.8.

6.9.7.1 Radio Equipment Design Considerations

See Section 6.5.8.1.

6.9.7.2 ISM Equipment

See Section 6.5.8.2.

6.9.7.3 Radio System Frequency Coordination

See Section 6.5.8.3.

6.9.8 Human Exposure to Electromagnetic Fields

Place station and facility radio transmit antennas and design the connected radio systems so that human exposure is below the applicable specification limits for EMF in and around the system.

The IEEE developed a set of internationally recognized standards to achieve the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz relative to the potential hazards from exposure of such energy to man, volatile materials, and explosive devices. In compliance with international practice, limit EMF exposure levels in and around the system per the IEEE standards:

- IEEE Standard C95.6-2002 - IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz [IEEE Std C95.6]
- IEEE Standard C95.1-2005 - IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz [IEEE Std C95.1]

The IEEE standards and these criteria establish MPE limits both for the general population and for authorized people in controlled environments. Only workers, contractors, and other authorized personnel may be in controlled environments, such as in equipment rooms, or along Caltrain's right of way near the tracks. The MPE limits recognize that workers and others in these controlled environments have the knowledge to minimize the duration or extent of exposure to the higher levels that may be present.

6.9.8.1 Maximum Permissible Exposure Limits

The magnetic field MPE limits for general public and controlled environments shall conform to IEEE Std C95.6 Table 2 and IEEE Std C95.1 Tables 2, 8, and 9.

The electric field MPE limits for general public and controlled environments shall conform to the IEEE Std C95.1 Tables 4, 8, and 9 and IEEE Std C95.6 Table 4.

The propagating EMF MPE limits for general public and controlled environments shall conform to the IEEE Std C95.1 Tables 8 and 9.

The MPE limits in the cited revisions of the standards shall apply unless the Contractor establishes that a newer revision of the Standard is applicable and that the newer revision of the Standard provides adequate protection to people near the tracks. In addition, after construction, EMF levels shall be measured to determine whether actual EMF levels exist above the recommended limits at or near the passenger station platform edge, and at locations along the ROW, including TPFs, tunnels, and yards and shops to determine whether passengers or employees with implanted medical devices can be exposed to magnetic fields above the established limits. The measurements shall be made following procedures in EN 50500, Measurement procedures of magnetic field levels generated by electronic and electrical apparatus in the railway environment with respect to human exposure. If the actual EMF levels exceed the established limits, the safety program shall ensure that passengers and employees who have implanted medical devices are informed of the condition by placing suitable warning signs on the passenger station platforms, indicating areas where passengers and employees with pacemakers can stand or sit without exposure to EMF levels above the recommended limits.

6.9.8.2 Implanted Medical Devices

EN standards establish exposure limits for implanted medical devices such as pacemakers, ICDs, cochlear implants and brainstem stimulators.

The applicable EN standards are the following:

- EN 45502-2-1:2004, Active implantable medical devices - Part 2-1: Particular requirements for active implantable medical devices intended to treat bradyarrhythmia (cardiac pacemakers)
- EN 45502-2-2:2008, Active implantable medical devices - Part 2-2: Particular requirements for active implantable medical devices intended to treat tachyarrhythmia (includes implantable defibrillators)
- EN 45502-2-3:2010, Active implantable medical devices - Part 2-3: Particular requirements for cochlear and auditory brainstem implant systems

The magnetic field MPE for all publicly accessible areas of the electrified portion of the Caltrain Right-Of-Way (ROW) shall be consistent with both the EN limits for medical devices and the IEEE limits for the general public. EMF levels above the recommended limits may exist in controlled environments such as facility equipment rooms. Equipment rooms will be normally unmanned; workers will enter only periodically, for example, to perform routine maintenance. The safety program will disclose health risks to employees who have implanted medical devices and will preclude workers with implanted medical devices from entering any controlled environment with levels above the recommended limits.

6.9.8.3 Animal Exposure to Electromagnetic Fields

Passengers may travel with service or pet animals. Farms and ranches may be near the TES and OCS. The EMF exposure limit for animals shall conform to the same limits as for humans.

END OF CHAPTER 6

CHAPTER 7

SCADA

7.0 Supervisory Control and Data Acquisition (SCADA)

7.1 Scope

This chapter on Supervisory Control and Data Acquisition (SCADA) gives the guidelines, principles, and processes that must be followed to successfully design and implement SCADA software, equipment, and support systems for Caltrain. These design criteria govern the design and implementation of SCADA Systems and shall be applied consistently across the Caltrain railroad.

This chapter describes two SCADA Systems:

1. Traction Power (TP) SCADA System.
2. Substation SCADA Systems.

7.2 Traction Power SCADA

The Traction Power SCADA System will carry out data acquisition, processing, alarm management, information presentation, and data archiving functions. Application functions will include monitoring and control of traction power transmission and distribution; load monitoring; energization status; operations reports; information storage and retrieval; and simulation and playback.

The Traction Power SCADA includes the servers, databases, software, and workstations that will present information to the Traction Power Dispatcher and other users, and, when commanded by a user or application program, send commands to power system devices at the substations.

The Traction Power SCADA system shall include the following functions:

A. Data acquisition from substations
B. Data processing
   - Conversion to engineering units.
   - Alarm checking.
   - Presentation of information to users using desktop and wall-mounted video display devices.
C. Supervisory control
   - Commands sent to traction power system devices when initiated by a user or by an application program.
D. Information storage and retrieval
   - Archive information from real-time sources for later review by operating and engineering staff.
   - Provide for replay of traction power system operations on workstations.
E. Network status processor (determination of the energized or de-energized state of traction power devices)
F. Clearances and catenary orders
   - Documenting requests for work on the traction power system devices or the railroad right-of-way.
   - Identifying outages of catenary sections needed to provide a safe work environment.
   - Coordinating planning and execution of the work with Train Dispatchers.
G. Utility supply monitoring.
   - Monitoring electric power supply from utilities.
   - Predicting usage over demand intervals.

- Alerting the user of predicted high-power usage conditions.

In addition to acquiring operating conditions from traction power system devices, the Traction Power SCADA will monitor and control the following substation systems:

- Substation environmental control (HVAC).
- Substation input power, UPS, and batteries.
- Substation fire and security.

7.3 Substation SCADA

Each Traction Power Substation (TPSS), Switching Station (SWS), Paralleling Station (PS) and Wayside Power Cubicle (WPC) shall include a Substation SCADA. The Substation SCADA shall carry out data acquisition, processing, alarm monitoring, and information presentation to maintenance and operations staff within the substation. The Substation SCADA shall also support remote access to the information presentation, as if the remote user were at the substation.

The Substation SCADA shall communicate with the Traction Power SCADA System over the Data Communications System (DCS) using the DNP 3.0 TCP/UDP with secure authentication protocol compliant with IEEE 1815-2012. The Substation SCADA shall communicate with substation devices over a Local Area Network compliant with IEC 61850 standards.

The Substation SCADA shall:

- Be a modern, commercially available platform for the continued monitoring and control of Caltrain power management operations.
- Be based on the latest applications of industry standards, open system design, and system architecture.
- Collect data from smart devices and conventional discrete inputs and outputs at substations and forward the data to the Traction Power SCADA.
- Send supervisory control commands received from the Traction Power SCADA to traction power system devices at substations.
- Be designed with expansion capacity sufficient to support a doubling of the facility in which it is installed. (For example, expansion of a Paralleling Station to two autotransformers and four tracks.) This capacity need not be provisioned, that is it may be necessary to add equipment to the Substation SCADA to achieve the full (expanded) capacity. However, the expansion shall be accommodated within the initially supplied enclosures and racks; it shall also be accommodated without modification to the substation power supply or environmental systems.

The Substation SCADA shall include the following functions:

A. Data acquisition from traction power system devices.
   - The smart devices and local point input/output devices at substations shall be connected over an IEC 61850-compliant LAN.
   - Status (discrete) data state changes shall be time-stamped to a resolution of 1 ms (where supported by the input interface devices – IEDs or other device). The timestamps of simultaneous alarms and events occurring at multiple substations shall be coincident to within 10 ms.
   - Status (discrete) data state changes reported to the Traction Power SCADA shall be current to within 0.5 seconds.
   - Analog measurements reported to the Traction Power SCADA shall be current to within 1.0 seconds.
   - The Substation SCADA shall support periodic polls for data from the Traction Power SCADA:

- All analog data at a substation shall be requested and reported no more frequently than every 2 seconds.
- All status (discrete) data at a substation shall be requested and reported no more frequently than every 1 second.

B. Transmit data to the Traction Power SCADA.
- Support the DNP 3 TCP/UDP protocol compliant with IEEE 1815-2012 for Traction Power SCADA communications.
- Forwarding of supervisory control commands from the Traction Power SCADA to traction power devices.

C. Data processing and presentation to users.
- Support a graphic user interface (also called Human Machine Interface) depicting the traction power devices and their smart controllers.
- Support a secure HTTP (Web) interface for users located outside the substation that provides a graphic presentation similar to the local HMI.

D. Detect connected smart substation devices and configure the devices and the substation controller appropriately.

In addition to acquiring operating conditions from traction power system devices, the Substation SCADA shall monitor and control the following substations systems:

- Environmental control (HVAC).
- Input power and UPS.
- Low and High voltage metering.
- Fire, security and systems.

The Substation SCADA shall:

- Exhibit an availability of 99.99% measured over any 120-day period. If non-redundant architecture is supplied, The Substation SCADA design shall emphasize self-diagnosis, limiting the scope of component failures, and rapid replacement of failed components.
- Be architected commensurate with good industry practices for cyber security.
- Automatically restart the data acquisition and reporting functionality in a safe and secure manner following a power outage of any length without requiring manual intervention. All other functionality shall also restart into a safe mode; but shall not initiate any control actions unless authorized by a user.
- Optimize the operation and maintenance activities for the agency by using standardized hardware in the SCADA panels. The standardized hardware will match the existing infrastructure equipment unless the equipment becomes obsolete. Hardware details can be found be traction power specification 34 31 11.

The Substation SCADA shall be designed for installation and operation in a substation environment and shall:

- Be enclosed in standardized equipment racks and cabinets compatible with the substation racks and cabinets.
- Be designed for the electromagnetic and environmental conditions found at substations.
- Be rated for the seismic environment found at substations and along the right-of-way (ROW).
- Operate from UPS and battery feeds.

END OF CHAPTER 7