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SECTION 9 - TRACTION ELECTRIFICATION SYSTEM

9.1 GENERAL

Commuter rail corridors shall be electrified at 25kV (nominal), 60 Hz, single phase alternating current, unless otherwise approved by RTD. RTD-owned traction power substations shall receive primary supply from electric power utility company ("Utility") feeders or taps and supply 25kV electrical power to the commuter trains' pantographs via an overhead contact system. Return current from the trains shall reach the substation via the wheels and the traction power return system.

Unless defined within this document, traction electrification system terms are defined in American Railway Engineering and Maintenance-of-Way Association Manual for Railway Engineering (the "AREMA Manual"), Chapter 33.

9.1.1 THE TRACTION ELECTRIFICATION SYSTEM

The Traction Electrification System (TES) shall be comprised of three major electrical systems- Traction Power System (TPS), the Traction Power Distribution System (TPDS), and the corridor-wide Traction Power Return System (TPRS).

The design of the 25kV traction electrification system depends on the type of traction power distribution system actually used. The variations possible for the 25kV power distribution system shall include direct feed system or "1x25kV system", and autotransformer system or "2x25kV system".

These design criteria address both systems but assumes that the autotransformer system will be used for the major part of the route, with extremities and yard facilities supplied by direct feed systems.

For the purposes of this design criteria section, track running rails, impedance bonds and rail bonds are considered part of the TPRS, while covered under the signaling system and trackwork design criteria sections.

9.1.2 THE TRACTION POWER SUPPLY SYSTEM

The Traction Power Supply System shall include Traction Power Substations (TPSS), Autotransformer/Paralleling Stations (APS), and Switching Stations (SWS), and their connections to the Traction Power Distribution System (TPDS) and the Traction Power Return System (TPRS).

The traction power substations shall receive primary power from Utility feeders or taps at transmission levels (115kV or 230kV) and shall include the equipment necessary to step-down the levels to the traction system distribution voltage of 25kV, and the necessary ancillaries and protective systems. Traction power shall be supplied to the traction power distribution system by underground cables or aerial conductors terminated on trackside disconnect switches. Current shall return to substations via permanently connected cables from the running rails.

The autotransformer/paralleling stations shall have switchgear to parallel the Overhead Contact System (OCS) and feeders of multiple tracks, autotransformers (if used), sectionalizing switchgear if the station is located at interlockings, the necessary ancillaries, and protective systems.

The switching stations shall separate the traction power supplies of different phases by phase breaks in the OCS. Switching stations shall have provisions for extending the 25kV supply from one side to the other in the event that supply on one side is not available, such as occurring from a substation failure. The switching station shall have equipment to parallel the OCS of two tracks, autotransformers (if used), and the necessary ancillary and protective systems.

9.1.3 THE TRACTION POWER DISTRIBUTION SYSTEM (TPDS)

The TPDS shall include the OCS and the Autotransformer Feeder System (AFS)

9.1.3.1 THE OVERHEAD CONTACT SYSTEM (OCS)

The OCS shall consist of an arrangement of steel poles, cantilever assemblies and conductors installed over the rail tracks that deliver the 25kV single phase power supplied by the Traction Power Supply System to the pantographs of the trains.

9.1.3.2 THE AUTOTRANSFORMER FEEDER SYSTEM (AFS)

The AFS shall comprise bare aerial conductors installed on the OCS poles to supply power to the autotransformers at paralleling stations.

9.1.3.3 STATIC WIRE

Although part of Traction Power Return System (TPRS), static wires shall be considered part of the TPDS for the purpose of designing structures and assemblies.

9.1.4 TRACTION POWER RETURN SYSTEM (TPRS)

The TPRS shall comprise the track running rails, the rail bonds, the impedance bonds, and the static wires. There shall be no direct connection between OCS poles and track rails except in the areas without track circuits.

Static wires, one for each track, shall be provided from end-to-end to connect all OCS poles, except those installed on passenger station platforms. Only one static wire is required in areas where center poles are used. Static wire shall be electrically connected to the OCS poles by a flexible bond of compatible material. Static wires of the two tracks shall be electrically paralleled at intervals determined by the Grounding and Bonding Study.

Impedance bonds shall be installed at insulated rail joints to allow traction current to flow while blocking signaling currents. Track rails shall be periodically grounded by connection to the static wires at selected impedance bond locations (also known as A-points). Return cables shall connect the running rails to the TPSS return bus at substations and autotransformer/paralleling stations.

Where yard and shop tracks are isolated from mainline tracks, impedance bonds shall be provided at the rail joints for passage of traction return currents.

9.1.5 PROJECTWIDE DESIGN CRITERIA

Design criteria for the development of the TES includes data and criteria from other sections of the design criteria document, such as the following:

9.1.5.1 DESIGN CRITERIA – SECTION 4. TRACKWORK

- Relevant track data including construction and maintenance tolerances, vertical curve data, horizontal curve data, track switch data, maximum track gradients.
- Ballasted-track cross sections, double-track cross sections, retained-track cross sections.
- Structure clearance data. Clearance charts for curvatures in ½” steps of superelevation.

9.1.5.2 DESIGN CRITERIA – SECTION 5. STATIONS

- Side and/or center platform plans
- Side and/or center platform cross-sections
- Details of typical footbridges

9.1.5.3 DESIGN CRITERIA – SECTION 6. BRIDGES AND STRUCTURES

- Catenary Pole Foundations

9.1.5.4 DESIGN CRITERIA – SECTION 12. SYSTEMWIDE ELECTRICAL

- Grounding on passenger platforms
- Grounding of fences

9.1.5.5 DESIGN CRITERIA – SECTION 13. COMMUTER RAIL VEHICLE

- Vehicle dimensional data: Dynamic clearance envelope, spring failure body sway, operational normal body sway, point of sway rotation, lateral shift, wheel wear, etc.

- Pantograph data: Pantograph collector overall width, maximum operating height, minimum operating height range, maximum lockdown height on vehicle, pantograph sway allowance dimension, uplift pressure
- Minimum pantograph spacing in a multiple-car train

9.1.5.6 DESIGN CRITERIA – SECTION 14.7. RIGHT-OF-WAY FENCING AND BARRIERS

- OCS security fencing criteria along the right of way
- Safety barriers on overpasses above and beside the OCS

9.2 FUNCTIONAL REQUIREMENTS

9.2.1 TRACTION POWER

The TES shall be designed to maintain the voltage at the pantographs and the OCS conductor temperatures within limits specified in AREMA Manual or by the conductor manufacturer. The number, location, and rating of the paralleling stations shall be determined by a computerized traction power load flow analysis which shall also determine the territorial limits of the direct feed (25kV) system and, if selected, autotransformer feeder (2x25kV) system.

The TPS shall supply 25kV power to the OCS and to the Autotransformer Feeder System (AFS) via disconnect switches installed at trackside gantries with separate feeds for inbound and outbound tracks.

The TPS shall be designed for full redundancy, such that the loss of any one major item of equipment or feeder will not result in degradation of train schedules in any corridor. There shall be at a minimum, two traction power substations (TPSS), each supplied by different Utility substations such that a complete loss of a TPSS or Utility substation shall not preclude train operations at the specified reduced level of performance in any corridor.

For a 2x25kV system, APS shall each have at least one autotransformer and Switching Station at least two, one for each side of the phase break.

The TES shall be designed for a minimum functional life expectancy of forty (40) years.

9.2.2 POWER DISTRIBUTION

The OCS shall be designed to ensure spark-free current collection by multiple-unit train consists with each train having multiple pantographs in use at any one time. Train consists considered in designs shall include both initial maximum train length and any future maximum train length specified by RTD for the route.

There shall be no high-voltage interconnection between the pantographs.

The design of phase breaks shall permit operation of randomly marshaled train consists with various pantograph separations.

AFS conductors shall be located adjacent and parallel to the OCS to optimize mitigation of their electromagnetic fields and reduce inductive interference in communications lines. Electrical clearance suitable for 50 kV shall be provided between the OCS and feeder.

9.2.3 OCS SECTIONING

The system sectioning shall be designed to allow isolation and de-energization of parts of the TPDS to permit planned maintenance, to isolate faulted sections, and to permit flexible operation during system emergencies.

Where they are installed, OCS conductors and each autotransformer feeder circuit shall form part of a single circuit, and shall be sectionalized together by 2-pole circuit breakers and 2-pole disconnect switches.

Schematic Sectioning Diagrams shall show diagrammatically the relative location of all tracks, interlockings, fixed signals, passenger stations, substations, and switching and paralleling stations. For each track with OCS, a single line shall be shown with its phase breaks and sectioning points. Unwired turnouts shall also be shown and identified as such.

Normal position of the circuit breakers and disconnect switches, open or closed, shall be shown. The normal method of operation of each motorized or hand-operated disconnect switch shall be indicated. All circuit breakers and disconnect switches shall be identified for operating purposes by a serial number unique within the RTD LRT and the CR systems.

9.2.3.1 MAINLINE

OCS sectioning on the mainline shall utilize insulated overlaps suitable for 25kV.

9.2.3.2 CROSSOVERS, TURNOUTS AND YARDS

Bridging section insulators shall be used for:

- Crossovers and turnouts that are not used during normal revenue service
- Main lines when the maximum operating speed is limited to 30 mph
- In yard areas

9.2.3.3 PHASE BREAKS

A design shall be produced that integrates OCS, vehicle and track details to permit commuter rail vehicles to routinely operate through each phase break without impacting train service. Phase breaks are required at substations, switching stations and locations where adjacent sections of the traction power distribution system are supplied by different electrical phases.

Phase breaks shall not be located:

- where trains require high current draw or regeneration capabilities
- in braking or stationary zones on the approach side of signals at interlockings
- on sharp curves and steep gradients

With consideration given to minimum and maximum pantograph spacing, it is preferred that the electrical separation at a phase break be provided by either:

- Long phase break consisting of multiple insulated overlapping spans
- Short phase breaks with grounded center, and with inbuilt vacuum circuit breakers to extinguish arcs caused by current drawn by each commuter rail vehicle

Train operators shall be instructed to reduce power demand before traversing phase breaks. Details of the operating procedures shall be determined during detailed design in coordination with RTD.

9.2.3.4 INTERLOCKED SWITCHING

Yards and shops shall be provided with interlocked arrangements of disconnect switches to protect or warn maintenance staff from approaching or touching ungrounded wiring above rail vehicles. Such design shall be site specific and support the safety procedures, equipment and features developed and approved for such operations.

Typically, interlocked switching equipment may include safety mechanisms preventing access to the OCS unless it has been de-energized and providing audible and visible warning before being energized.

9.2.4 REMOTE OPERATIONS

Substations, switching and paralleling stations, circuit breakers, and motor-operated disconnect switches, shall be designed for remote operation from the Commuter Rail Operations Control Center. Local operation of individual equipment shall be possible via control switches.

9.3 TES DESIGN REQUIREMENTS

For reasons of practical support dimensioning and strength rating, aerial feeder wires, static wires, and pole-mounted disconnect switches shall be considered to be part of the OCS design, specification, and construction.

Impedance bonds and rail bonds shall be considered part of signaling systems and trackwork design and specifications, respectively.

9.3.1 TRACTION POWER SUPPLY SYSTEM

9.3.1.1 LOCATION OF SUBSTATIONS (TPSS), AUTOTRANSFORMER/PARALLELING STATIONS (APS), AND SWITCHING STATIONS (SWS)

TPSSs shall be located close to a Utility transmission substation or transmission line, to minimize the required length of the transmission line interconnections. The number and location of substations, switching stations, and autotransformer/paralleling stations shall be confirmed by the Traction Power Systems Studies and after site surveys determine the site suitability. Sites shall have good vehicular access and availability of real estate.

9.3.1.2 PRIMARY POWER SUPPLY

Primary electrical power supply shall be obtained from the Utility at either 115kV or 230kV, 60 Hz, via two separate circuits for redundancy. Each primary feeder shall be either by overhead connections or underground cables, as agreed upon with the Utility. Each feeder shall utilize a different phase pair unless otherwise agreed by the Utility.

Service details and AC protection scheme shall be coordinated with the Utility.

9.3.1.3 TRACTION POWER SYSTEM DESIGN STUDIES

The TPSS design shall be based on a computer-aided traction power load flow simulation. This study shall simulate peak-hour operation of the trains along each commuter rail corridor under normal and contingency conditions.

Contingency conditions shall include outage of one major item of equipment, such as a transformer or feeder cable, or of an incoming electrical feed, at a substation or outage of one paralleling station at a time or outage of a section of track. Trains consisting of the ultimate consist size shall be simulated to operate on the corridor at the ultimate corridor headways, or as otherwise specified by RTD, with the cars loaded to AW3. In the event of a complete substation outage, the remaining substation(s) shall provide power to all corridors to allow for restricted train operations. The acceptable level of service reduction shall be coordinated with and approved by RTD.

The input data shall include track alignment including interlockings, track gradients, track speed limits, passenger station locations and station dwell times, as well as the electrical and mechanical characteristics of the trains.

The input data shall represent electrically the Utility interconnections, the TPS, autotransformer/paralleling stations, and the OCS and traction return conductors.

The study shall determine voltage at train pantographs, power demand at the substation (both primary and secondary side) and at autotransformers, bus currents at TPSSs, APS, and SWS; equipment ratings, including sizes of feeder cables, autotransformer feeders; and OCS conductor sizes and temperature rises.

The study shall confirm that for the final selected equipment ratings and conductor sizes, the voltage at the pantograph, conductor temperature and rail potential rise remain within the specified design parameters under normal and contingency conditions.

Additionally, the following system studies shall also be performed:

- Utility Impact Study – performed by, or in coordination with, the Utility to determine the impact of single phase traction loads on the utility grid and any necessary corrective measures

- Short Circuit and Protective Relay Study – to determine the requirement and settings of protective relays

- Insulation Coordination Study - to determine the minimum acceptable insulation levels for the equipment, buses, and the surge arresters ratings

- EMI Study - to determine the impact of the single phase AC traction loads on the trackside signaling and communication installations and any necessary corrective measures

- Grounding and Bonding Study - to determine the requirements for grounding and bonding of the system, overhead structures, and trackside installations

9.3.1.4 RESULTS OF DESIGN STUDIES

The output data of the load flow analysis shall provide train operational data such as speed, distance traveled, voltage profile, current in OCS conductors, power demand and energy consumption for each station-to-station run. For the TPSS, the results shall include average power and power factor on the primary and secondary sides, energy consumption, primary current, and current for each feeder and OCS breaker.

9.3.1.5 OCS AND FEEDER CONDUCTOR SELECTION

Minimum sizes for the OCS and feeder wires and cables shall be determined based on the results of the load-flow analysis. The final selection of the messenger wire, contact wire and feeder wire sizes may be marginally larger/stronger than the electrical system design studies determine, and shall be made with consideration of possible mechanical, economic and maintenance impacts.

The selected wire sizes shall be confirmed to be suitable by the OCS mechanical dynamic simulation studies detailed in 9.3.3.3.

9.3.1.6 SUBSTATION EQUIPMENT RATINGS

The continuous rating of the TPS equipment such as the traction transformer, circuit breakers and cables shall be based on the traction power load flow simulation. Transformers and other equipment shall have overload rating per Chapter 33 of the AREMA Manual. Equipment shall be capable of sustaining such an overload twice a day, once in morning peak and once in the evening peak periods.

9.3.1.7 SUBSTATION EQUIPMENT

Each half of a TPSS shall be capable of meeting the power requirements of the entire corridor during contingency operations. Each half shall have a primary supply with HV switchgear, one traction power transformer, one lineup of 25kV switchgear with a normally-open tie circuit breaker, and one station supply transformer.

In the event the maintenance shop is supplied directly from a substation or a switching station, a dedicated circuit breaker with protective relays shall be provided to prevent tripping of the mainline power in the event of fault in the yard and/or shop.

All traction power and distribution system equipment shall be designed taking into account the effects of the harmonic content of the traction loads, fluctuating pattern of the traction currents, and frequent system faults. The traction power substation(s) shall, at a minimum, meet the harmonic requirements of IEEE 519 at the point of common coupling with the Utility.

9.3.1.8 SUBSTATION EQUIPMENT LAYOUT AND LOCATION

High voltage (115kV and 230kV) buses and switchgear, traction transformers, auxiliary power transformers, and harmonic filters (if provided), shall be installed outdoors in a switchyard, wherever not disallowed by site constraints. Location of 25kV switchgear, indoor or outdoor, shall be determined by relative cost and site constraints. Where located indoors, equipment shall be suitable for installation inside buildings with appropriate enclosures or safety barriers. 25kV switchgear shall be metal clad of arc resistant construction per IEEE Std. C37.20.07 with vacuum interrupters. Where located outdoors, 25kV breakers shall be vacuum types, dead tank construction, pole or pedestal mounted. High voltage circuit breakers shall be of the SF-6 type, preferably of dead-tank construction, pedestal mounted.

Equipment layouts for TPSS shall accommodate the equipment necessary for the interconnecting voltage. AT TPSS locations where it is determined that the utility will raise the interconnection voltage in the future, the layout shall identify the additional TPSS space that would be required on site or on an adjacent site.

If 25 kV breakers are located outdoors, control equipment, Remote Terminal Unit (RTU), batteries, and battery chargers shall be installed in a prefabricated building. 25kV disconnect switches shall be installed on track-side gantries.

9.3.1.9 TRANSFER TRIP CABLES

Transfer trip circuits, if required, shall use a pair of fibers on the communication cables.

9.3.1.10 SUBSTATION SITE ACCESS, GRADING AND DRAINAGE

A 15-foot (minimum) wide access road shall be provided to each substation, switching station, and paralleling stations from adjacent roadways, leading to a public roadway. The access road shall be surfaced with gravel or asphalt and shall not exceed 7% grade. The surfacing material shall be as recommended by a Geotechnical Engineer or as required by local jurisdictions.

A minimum clearance of 10 feet shall be provided, where practicable, around the perimeter of each substation to permit access for RTD and maintenance vehicles and equipment. Clearance width may be reduced at one side of the substation with approval from RTD. A 96-inch (minimum) high chain link fence or non-scalable wall shall be provided around the perimeter of the substation with a vehicular gate at the access drive.

The fenced area shall be generally flat with finished grade sloping away by a minimum of 2% from the building. Crushed stone or gravel (1.5 inch minimum) shall be spread in the switchyard and four feet outside the fence to minimize step and touch potentials.

Adequate drainage and infrastructure for handling storm water shall be provided in compliance with local and state requirements. Ductbanks within the substation shall slope downward into a manhole, which shall be the lowest point, to prevent leakage of water in the cable vault of the substation building. Manholes shall be provided with French drains.

Oil filled transformers and autotransformers shall have sumps or other means to collect oil and prevent it from contaminating soils or reaching drains or surface run offs per IEEE Standard 980.

9.3.1.11 LIGHTNING AND SURGE PROTECTION

Traction power substations, switching stations, and autotransformer/paralleling stations shall have adequate protection against lightning by shield wires or lightning masts per IEEE Standard 998. Additionally, surge arresters shall be provided, at a minimum, on the transformers, disconnect switches and cable terminations. Arrester ratings shall be selected from the results of the insulation coordination study.

9.3.1.12 EMERGENCY SHUTDOWN

Emergency shutdown devices shall be provided for quick de-energization of energized equipment for personnel safety at maintenance facilities and, where required by the local fire department, for firemen's use while responding to an emergency.

Traction substations and autotransformer/paralleling stations shall be provided with emergency pushbuttons inside control buildings and outside at one or two conspicuous locations to de-energize the entire site.

Location of the pushbutton and circuits to be de-energized shall be determined during detail design in consultation with RTD.

9.3.1.13 MAINTENANCE FACILITY – POWER SUPPLY

Maintenance facilities shall be powered from one or more feeder breakers at a substation or switching station with an alternate emergency feed, interlocked to prevent simultaneous supply from more than one source.

9.3.1.14 INSULATORS

Solid core porcelain or composite insulators consisting of a Fiberglass Reinforced Epoxy (FRE) core with weather-resistant sheds to applicable ANSI standards shall be used. Disc insulator assemblies shall be used in tension only. Creepage lengths shall be determined during detail design on the basis of environmental conditions.

The insulators shall have resistance against deterioration from exposure to sunlight and airborne chemical pollution, and in particular mist deposits from highway de-iceing chemicals. The insulators shall be a light gray, sky tone in color and their life expectancy shall be compatible with that of the rest of the equipment.

9.3.1.15 PROTECTIVE RELAY SYSTEMS

Protective systems for the OCS and feeders shall be designed to detect and isolate faults on any section, and coordinated to prevent cascading trips. Relays shall be coordinated to open circuit breakers to de-energize the minimum possible OCS length to isolate the fault. Protective relays shall be of the microprocessor type. Protective relays for the transformers and autotransformers shall provide protection against internal and external faults, overloads and short circuits, gassing and sudden pressure in the track, and low oil level.

9.3.2 TRACTION POWER FEEDERS AND RETURN CABLES

9.3.2.1 25KV FEEDERS

25kV power from the TPS shall be delivered to the 25kV disconnect switches installed on trackside gantries or on OCS structures by underground cables or aerial conductors; and from the 25kV disconnect switches to the OCS and to the AFS, by bare overhead feeders.

Overhead bare feeder wires shall be copper or aluminum alloy conductors and sized based on the traction power studies.

9.3.2.2 RETURN CABLES

Return cables installed in ducts shall connect the running rails to the transformer or autotransformer neutral via impedance bonds.

Cable size(s) shall be based on traction power studies and the selected type of raceway.

9.3.3 OVERHEAD CONTACT SYSTEM (OCS)

Refer to Table 9-3 for a summary of design values to be applied.

9.3.3.1 OCS STYLES

The OCS shall be applied from the following styles according to application:

For mainlines, mainline crossovers, and yard lead tracks to mainlines – Auto-tensioned Simple Catenary style (ATSC)

For Yard tracks, inside shop, and shop approach tracks - Fixed Termination Simple Catenary style (FTSC) or Fixed Terminated Single Contact Wire style (FTSCW)

Where a long storage yard track is to function as a test track – Auto-tensioned Simple Catenary style (ATSC)

9.3.3.1.1 AUTO-TENSIONED SIMPLE CATENARY STYLE (ATSC)

ATSC shall consist of a messenger wire supporting a contact wire by the means of hangers. Each messenger wire/contact wire pair shall be arranged into Tension Lengths which overlap at each end with neighboring tension length to provide a continuous, smooth contact path for the vehicle pantograph.

The ATSC wires shall be tensioned by means of suspended weights, called balance weights assemblies, which shall be installed on the anchor poles located at the ends of each tension length. As the wires contract and expand with temperature variation, the balance weight assemblies shall be designed to maintain a constant wire tension throughout the specified temperature range.

Suitable mid-point anchor or fixed end anchor arrangements shall be installed in each tension length to prevent accumulation of along track movement in the tension length.

Along-track movement of the wires due to temperature change shall be facilitated by all support and registration assemblies for ATSC style wiring.

The contact wire profile shall be designed for no ice cover, and the wire temperature within the designed operating temperature range of the balance weight anchor assemblies.

The contact and messenger wires shall be offset or staggered at registration points to provide for even wear of pantograph collector carbons.

This style of OCS wiring shall be designed to provide spark free current collection up to the maximum design train operating speed plus an allowance of 10% for over speed.

On tracks designed to operate with train speed limits of 50 miles per hour or higher, ATSC wiring shall feature a scheme to limit the effects of pantograph uplift variation within each span. Such a feature could be either a contact wire pre-sag factor applied to the wire profile, or a stitch wire messenger wire support arrangement, but not both concurrently.

9.3.3.1.2 FIXED TERMINATED SIMPLE CATENARY STYLE (FTSC)

FTSC wiring shall consist of a messenger wire supporting a contact wire by the means of hangers. The contact wire shall be without sag at the normal temperature of 60°F. The catenary conductors shall be tensioned to anchor poles located at the ends of each tension length. Conductor tensions will vary with change of temperature causing the messenger wire sag to change resulting in the contact wire sagging also. These changes together with ice loading of the conductors will also cause the contact wire to sag or hog in span. In order to limit these height variations, span lengths shall be limited to about 75% of maximum spans allowed for ATSC system. The selected maximum span length for FTSC shall be determined by analysis.

9.3.3.1.3 FIXED TERMINATED SINGLE CONTACT WIRE STYLE (FTSWC)

FTSWC shall be used in the maintenance shop. In this fixed-terminated system, the conductor tension will vary as temperature changes. This arrangement utilizes a single contact wire supported by pole or building mounted assemblies.

9.3.3.2 ENVIRONMENTAL CONDITIONS

In addition to ambient conditions given in Section 1 of these Design Criteria, the following conditions shall apply to the Traction Power Distribution System:

Conductor temperatures:

- Normal 60° F
- Minimum -25°F
- Maximum 125°F for contact wire and messenger wire under all Operating Conditions
- Maximum 160°F for electrical connections and all other wires.

Conductor ice loads:

- Operating Conditions

½ inch ice on the messenger wire
¼ inch ice on the contact wire

- Non-Operating Conditions

½ inch ice on the messenger, feeder and static wires
½ inch ice on the contact wires
Wind:

- For train Operating Conditions – 55 mph wind
- Under Non-Operating Conditions – 90 mph to 120 mph as required by local codes

The RTD operating region traverses into a Special Wind Zone as declared in NESC. The designers shall familiarize themselves with each wind zone declared by local governments having jurisdiction over each segment of route.

Where RTD routes are adjacent to roads, chemicals such as magnesium chloride and salt may be applied to deter ice. In such localities, a polluting spray environment may settle on and adhere to the TPDS equipment. Material selection and insulator creepage path lengths shall be selected appropriately. The region in which RTD operates is frequented by various animal and bird species identified for protection under federal codes. Applicable codes and related guidelines shall be considered when determining requirements in the design, and in installation and maintenance practices.

9.3.3.3 OVERHEAD CONTACT SYSTEM DESIGN STUDIES

The design parameters and values for the OCS shall be based on engineering studies. Basic design, as expressed below, is to provide a set of detailed parameters for application in site specific design of the OCS for the project.

9.3.3.3.1 STUDY CONDITIONS

Two named conditions exist to generally categorize combinations of environment for application to the various study calculations and any subsequent detailed design. Multiple combinations may exist for each named condition.

Operating Conditions describe one or more combinations of ambient temperature, wind and the presence of ice under which the OCS shall be designed to permit the normal operation of trains.

Non-Operating Conditions describe one or more combinations of ambient temperature, wind and the presence of ice, and with no trains operating, under which the OCS, AFS and Static wires, poles and all associated equipment shall remain within their safe working tensions and loads. A typical application for Non-Operating Condition values is for determination of the minimum mechanical strength of OCS equipment and wiring.

9.3.3.3.2 CONDUCTOR SIZES AND TYPES

Contact wire, messenger wire, auto-transformer feeder wire and static wire type determined by the Traction Power System Design Study, and shall be selected to provide a practical and economic configuration of the OCS and AFS suitable for the environmental conditions, the electrical requirements, normal and emergency operations and ease of maintenance.

9.3.3.3.3 CONDUCTOR TENSIONS

Conductor tensions for each style of OCS shall be determined to meet requirements of minimum strength and factors of safety suitable for the Non-Operation Conditions, and NESC.

The OCS, AFS and Static Wires are to be considered as NESC Grade C construction for these purposes.

Maximum conductor tensions shall comply with NESC Rules 261H and referenced Rules 250 and 251. Selection of conductor tensions shall include consideration of the effect of Aeolian vibrations.

Maximum and minimum wire tension calculations shall be made for the expected range of equivalent span lengths within the Commuter Rail System.

Normal wire tension shall be at 60°F for each wire type for calculation purposes.

Tensions for normal and worst case conditions shall be documented in tabular form in the project drawings.

9.3.3.3.4 MAXIMUM TENSION LENGTH

The maximum tension length shall be determined based on:

- Along-track movement of in-running cantilevers
- Stagger change
- Balance weight travel
- Tension variation
- Manufacturing limits on conductor length
- Number of cantilevers in one tension length

The results of this study shall be given in basic design charts included in the project drawings, providing the maximum distance from mid-point or fixed termination to the last in-running cantilever and to the balance weight anchor pole.

Normally, the tension length shall not exceed one mile.

9.3.3.3.5 SPAN LENGTH AND MID SPAN OFFSET

The OCS design study shall include calculations that take into account all factors that contribute to horizontal and vertical displacement of the contact wire with respect to the pantograph.

This study is required for each OCS style for each normal and maximum contact wire height as shall be applied to the project.

The study shall include calculations for the following:

- Maximum structure spacing as a function of track curvature
- Conductor blow-off
- Permissible midspan static offset for contact wire spans over tangent tracks
- Permissible midspan static offset for contact wire spans over curved tracks
- Conductor along-track movement with temperature variation, and resulting stagger variation
- Pantograph security analyses for selected contact wire heights

The results of each study shall be given in basic design charts and graphs included in the project drawings.

9.3.3.3.6 ATSC DYNAMIC PERFORMANCE STUDY

An OCS/pantograph dynamic study to verify the suitability and stability of the specific combination of wires types, tensions, span lengths, hanger arrangements and pantograph dynamic properties to be used for ATSC style equipment.

Any report arising from such a study shall be submitted to RTD for review.

9.3.3.3.7 CATENARY HANGERS

Hanger spacing schemes shall be prepared for:

- Standard spans
- Overlap spans
- Anchor spans
- Spans with section insulators

Where appropriate ATSC spans shall be designed to account of contact wire presag or messenger wire stitch features.

Results shall be provided in tabular form in the project drawings.

9.3.3.3.8 MINIMUM STRUCTURAL LOADS ON LIVE FITTINGS

A minimum mechanical load criteria shall be determined for assemblies energized at 25kV or higher, to mitigate the effects of charging sparks being generated by loose joints. The criteria shall consider the effects of permanent loads and reverse direction wind loads.

9.3.3.3.9 CONTACT WIRE STAGGERS

Maximum stagger calculations shall be prepared using 50% of all allowances made for pantograph security calculations. Maximum stagger shall be determined by subtracting the 50% allowance total from the half width of the pantograph carbons.

Maximum stagger values shall be calculated for curved track and for tangent track for both normal contact wire height, and for maximum contact wires height.

9.3.3.3.10 PANTOGRAPH CLEARANCE ENVELOPE

A pantograph clearance envelope shall be developed for application on all tracks including super elevation, for the worst case track conditions and full vehicle roll plus a 3-inch mechanical running clearance.

No live 25kV equipment, except OCS steady arms attached to the contact wire, shall intrude into the pantograph clearance envelope.

No grounded equipment or 25kV equipment of another circuit shall intrude within Passing Clearance distance of the pantograph clearance envelope.

9.3.3.3.11 CONDUCTOR CLEARANCES

Minimum clearance dimensions shall be determined between each type of conductor or live fitting and adjacent equipment.

Clearances shall be developed in accordance with NESC, and consider the following:

- Relative differences in sag at mid span where one conductor is vertically above the other.
- Sufficient clearance for circuit of one track to be alive while maintenance is being performed on an adjacent circuit.
- Position of static wire to provide shielding of wiring below.

9.3.4 OCS ROUTE DESIGN

A route design shall be prepared to show at a low level of detail, the arrangement of each tension length of OCS to be built or altered.

The route design shall take into consideration fixed locations for phase breaks, insulated overlaps, station crossovers, low clearance buildings and bridges, and any infrastructure features preventing the placement of wiring terminations.

Live conductors shall not be installed above passenger platforms or buildings.

To improve operational options following wiring damage incidents, the OCS wires of individual mainline tracks should be routed to service only one track of that route. Tension lengths servicing crossover tracks or yard leads should be independent of mainline wiring.

The results of the OCS route design shall be documented on a Master Overlap Chart. Refer to 9.3.16.2.1.

9.3.5 OCS WIRING ARRANGEMENTS AT OVERLAPS, TURNOUTS AND PHASE BREAKS

For ATSC and FTSC, the OCS shall consist of a number of tension lengths with overlapping ends where the two catenaries are parallel and share a common span, called an ‘overlap’ or ‘overlap span’.

Individual tension lengths of catenary shall be terminated at each end by balance weights or by fixed terminations, as necessary. A ‘full tension length’ has a balance weight assembly (BWA) at each end of the tension length and a midpoint anchor assembly (MP) midway between the two tensioning devices. A ‘half tension length’ has a fixed termination assembly (FT) at one end and a BWA at the other.

For auto tensioned style wiring, if the track has an average continuous gradient exceeding 2%, the wiring shall be arranged into ‘half tension lengths’ with the BWA located on the lower end.

The contact wire heights at overlaps, turnouts and phase breaks shall be designed considering the mechanical properties of the OCS and pantographs. The design shall enable a smooth transition between adjacent contact wires without hard spots, by equalizing the contact wire heights over approximately 10 to 15 feet of track.

The two catenaries at overlaps and turnouts shall be configured using pairs of poles each with one cantilever carrying one catenary and spaced 10 feet apart.

9.3.6 CLEARANCE BETWEEN BRIDGES OR BUILDINGS AND OCS

Where a bridge or building structure exists or is to be built over a track that is to be wired, normal minimum clearance requirements shall be determined from Figures 9.1 or 9.2 based on the maximum rail vehicle type authorized to travel on that track, and on the permission or otherwise of the structure owner, for the OCS, AT Feeder wires or Static Wire to be attached to the bridge or building.

Should the structure designer require smaller clearances than shown these diagrams, then the OCS designer shall prepare a detailed design for the OCS, feeder wires and static wire in collaboration with the structure designer.

Should the OCS designer require OCS, AT Feeders or static wires to be located outside the clearance outline described by these diagrams, or within electrical clearance of the outline, then the OCS designer shall prepare a detailed design for the OCS, feeder wires and static wire in collaboration with the structure designer.

9.3.7 BRIDGES AND BUILDINGS OVER THE TRACK

A clearance study, showing plan and profile of OCS and feeders, shall be made for each overhead bridge and structure. The study shall document the minimum clearances between OCS conductors and the structure under worst conditions. Such studies shall consider clearance requirements due to adjacent grade crossings, public pedestrian crossings, and other features requiring high contact wire heights.

9.3.8 CONTACT WIRE DIMENSIONING

9.3.8.1 CONTACT WIRE HEIGHT

Limits on contact wire height are affected by a very wide variety of values for track tolerances, weather, vehicle size and local conditions at along each route.

Table 9-1 below provides minimum contact wire height values for input into OCS designs based on safe clearance of energized ice covered wires. Minimum heights shown do not include the vertical effects of track superelevation.

These values are to be utilized by an OCS designer for development of site specific design height for contact wire for installation and for coordination with other design elements such as bridges and grade crossings.

TABLE 9-1
CONTACT WIRE HEIGHT

Condition	Minimum Permissible As built Contact Wire Height anywhere in span, with ½" Ice, above designed rail level.
Exclusive use ROW, RTD Commuter Rail vehicles only, ballasted track	17'-2" ***"
Exclusive use ROW, over Amtrak Code D vehicles and RTD Commuter Rail vehicles only, ballasted track.	20'-9"**
Tracks shared with freight railroad	23'-7"*** ++
Under bridges or buildings, RTD Commuter Rail vehicles only	16'-3"**
Under bridges or buildings, over Amtrak Code D vehicles and RTD Commuter Rail vehicles only	20'-8"**
Under bridges or buildings, tracks shared with freight railroad	22'-8"**
Station Platforms, RTD Commuter Rail vehicles only	16'-0"*
Crossing at-grade with a public road	21'-7"***
Public Pedestrian Crossing at-grade	19'-7"***
Maintenance Building	22' - 0" ++
Storage tracks	21'-7"***

** Includes provision for restricted track construction and maintenance tolerances totaling up to 1.5 inches*

*** Includes provision for restricted track construction and maintenance tolerances plus allowances for track surface limit and cross level deviation effects totaling 5 inches*

**** Includes provision for future track level raising maintenance tolerance plus allowances for track surface limit and cross level deviation totaling 15.4 inches.*

++ Reduced value may be permitted on a location specific basis. RTD approval is required for any deviation in the minimum contact wire height shown based on a documented Safety Case.

Under no circumstances shall the as-built contact wire height exceed 25 feet 7 inches relative to the design track level. This value results in a maximum pantograph operating height of at least 25 feet 11.5 inches above actual rail level, and is derived from assumed track level construction and maintenance tolerances of -2.5 inches and vehicle dynamic bounce downward of 2 inches

Only authorized persons shall be permitted in locations where contact wire is less than 19 feet 7 inches with or without ice cover.

For open route mainlines the preferred design height for contact wire is in the range 21 feet 0 inches to 23 feet 10 inches.

9.3.8.2 CONTACT WIRE GRADIENT

The pantograph shall track smoothly under the contact wire at all times. Where the contact wire height needs to be changed, the change shall not cause bouncing and arcing of the pantograph.

Table 9-2 provides recommendations from the AREMA Manual for Railway Engineering for the maximum wire gradient versus train speed ranges. Contact wire gradient values are to be applied relative to the track plane.

TABLE 9-2
MAXIMUM WIRE GRADIENT VERSUS LINE SPEED

Speed Range (mph)	Maximum Gradient (%)
1-15	2.3
15-30	1.3
30-45	0.8
45-55	0.6
55-65	0.5
65-79	0.4

9.3.8.3 CHANGE OF CONTACT WIRE GRADIENT

The maximum change of contact wire gradient shall be equal to one-half the maximum gradient, from one span to the next.

9.3.8.4 CONTACT WIRE STAGGER

The contact wire shall be staggered except in the maintenance shop where no stagger is needed.

The largest acceptable stagger shall be selected at each contact wire registration, with the proviso that the maximum midspan offset for the specific span is not exceeded. Additionally maximum stagger values shall be in accordance with 9.3.3.3.9.

The angle of contact wire deviation on a single steady arm shall not exceed 7 degrees.

On tracks designed to operate with trains speed limits of 50 miles per hour or higher, span lengths and stagger values shall be selected to provide a Stagger Sweep Rate of between 0.24% and 0.80% of span length.

9.3.9 FOUNDATIONS

The design of foundations for supporting structures and guy anchors shall be based on the structure loading calculations and soil data. The supporting structure foundations shall be designed to accept bolted base poles. Refer also to the requirements of Section 6, Bridges and Structures.

The size and placement of the OCS foundation anchor bolts shall be in accordance with RTD's previously installed OCS foundation designs. Deviation from the existing designs will require prior approval from RTD.

9.3.10 POLES AND PORTALS

The OCS along mainline route and in the yards shall preferably be supported and registered by means of poles with cantilever assemblies, and where poles are not appropriate, by use of portal structures. In the shop, the OCS shall be attached to the building structure.

All poles shall be designed as free standing except for those anchoring OCS, static wires or feeder wires. All poles shall have provision for securely connecting grounding or bonding conductors near their base plate.

Pole and portal column base plates shall be designed and drilled to prevent a high strength type of pole being inadvertently erected onto a foundation designed for a weaker pole or column.

Structures shall be designed so that the normal operating across-track live load deflection of any structure shall not exceed 2 inches at contact wire height, i.e. one inch in either direction laterally.

OCS poles shall be designed and with a size range selected to minimize the spare quantities required to be held in maintenance stock.

OCS portals shall, if practical, use portal columns of the same steel sections as OCS poles.

9.3.11 CLEARANCE OF POLES AND FOUNDATIONS FROM TRACK

Poles shall be horizontally clear of superelevated track centerline as required by Design Criteria Section 4. OCS poles and columns shall be considered non structural objects for clearance purposes.

Designed pole face horizontal offset dimensions shall include additional allowances for foundation bolt construction tolerances, across track live load pole deflection, pole rake and encroachment of assemblies attached to the pole. Tolerances and allowances shall be considered up to contact wire level.

Typically for 14 inch wide poles constructed between tracks, 20 inches of gap will be required between the minimum trackway clearance lines. Reference Section 4.2.5 Clearances.

OCS foundations shall be designed to be horizontally and vertically clear of minimum trackway clearances by the applicable foundation construction tolerances.

Reduced clearance values may be permitted on a location specific basis. Written RTD approval is required for any deviation from the minimum clearances.

9.3.12 OCS SUPPORT REQUIREMENTS

9.3.12.1 MAINLINE

For mainlines, a principle of independent registration shall be applied whereby a single failure of OCS wiring on one mainline track shall not prevent a parallel mainline from being operated. This generally requires that each OCS wire be supported from cantilever assemblies only, and that pulloff assemblies or span wires service one track only.

Auto tensioned OCS shall be supported on hinged cantilevers in turn supported by poles or by portal structures with grounded drop pipes between each track.

Headspan construction shall not be employed without the express site-specific approval of RTD.

9.3.12.2 YARD

The FTSC shall be supported on cantilevers mounted on galvanized steel tubular or wide-flange poles installed clear of access paths, between tracks where feasible.

Where poles are not feasible, galvanized portal structures shall be installed to carry cantilever frames on grounded drop pipes.

Headspan construction shall not be employed without the express site-specific approval of RTD.

9.3.12.3 MAINTENANCE SHOP

The FTSCW shall be supported from and anchored to the shop structure.

9.3.12.4 SUPPORT SPACING

Spacing for the OCS supports shall be as large as possible consistent with the required system height, ice-loading criteria and maximum permissible midspan offset values.

For mainline wiring, where adjacent wire span lengths differ, the larger span length shall not exceed 150% of the length of either adjacent spans, except with written site-specific approval of RTD.

9.3.13 TYPES OF OCS SUPPORTS

9.3.13.1 CANTILEVER SUPPORTS

Cantilevers mounted on poles or portals shall be designed for a range of loads, various cantilever reaches, and for a range of system heights. The permissible range of loads, heights and reaches shall be shown on the relevant assembly drawings.

9.3.13.2 CROSS SPAN WIRES

Cross-span wires may only be used between grounded drop-pipes and portal columns, where the catenaries are in the same electrical section.

Span wire insulation shall be installed between tracks supplied from the same electrical section.

9.3.13.3 PULLEY SUPPORTS

Pulleys may be used to indirectly support an auto-tensioned messenger wire by including of an intermediate supporting bridle wire assembly support from the pulley suspension. Due to the effects of abrasion and work hardening, copper wire shall not be run over a pulley.

9.3.13.4 SUPPORTS UNDER BRIDGES AND BUILDINGS

Where tracks pass under bridges and buildings, preferably OCS and ATF under bridge support assemblies shall be mounted on poles erected under the bridge or building. Special support assemblies mounted on short poles shall be used where there is insufficient clearance to accommodate an open route cantilever-type assembly. The supports shall be designed to restrict the uplift of the contact wire when subjected to pantograph pressure. They shall be capable of providing vertical and across-track adjustment of wiring position.

Support assemblies shall permit the full range of along track movement of auto tensioned contact wire and messenger wire.

When a pole is impractical, under bridge supports may be attached to the soffit of the bridge or building by drop pipe assemblies, on a site-specific basis approved by RTD and with written approval of the bridge owner.

Grounded flash plates shall be installed above each wired track under each bridge or building. Refer to 9.4.9.

AT Feeder support assemblies shall be arranged to provide maintenance and operational clearances to structures, vehicles and adjacent wiring.

9.3.13.5 SUPPORT CLEARANCES

Sufficient electrical and mechanical clearances shall be maintained between adjacent cantilevers and between the cantilever frames and adjacent conductors of the auto-tensioned catenaries at all temperatures.

9.3.14 CONTACT WIRE REGISTRATIONS

The designer shall develop contact wire registration sub-assemblies to suit the required loading range and dynamic performance requirements of each OCS style.

Direct push steady arms or assemblies that push the contact wire shall not be applied to in-running ATSC style OCS.

Steady arm shapes and dimensions shall be designed to clear the pantograph over the full range of dynamic movement and track superelevation. The application of light weight high strength materials to sub-assemblies shall be considered.

For registrations where the permanent radial load is less than the reverse direction wind load, wind stay sub-assemblies shall be considered for application to steady arms.

Application rules and dimensions shall be developed for setting the heel height of steady arms that consider the style of OCS and loads being applied to the contact wire.

For design purposes of the various sub assemblies, the designer shall develop an assembly type grouping scheme based on a common parameter such as radial load.

9.3.15 INSULATION

All OCS support and registration equipment, span wire and termination assemblies shall be single insulated, except where additional insulation is required at stations and certain overbridge attachments.

Where span wires are utilized, span wire insulation shall be installed between all tracks even if supplied from the same electrical section.

Where OCS or feeder wires are adjacent to a passenger platform, OCS and ATF support assemblies shall have their high voltage insulators placed with live components horizontally off the platform. Additionally, where the static wire is required to be insulated from the pole, assemblies shall have an additional level of insulation installed between the assemblies and the poles. Such insulation shall be 5kV rated. The metallic equipment between the two levels of insulation shall be grounded to the static wire.

9.3.16 OCS PROJECT DOCUMENTATION

9.3.16.1 BASIC DESIGN DRAWINGS

Basic design drawings are general across the project and not specific to an individual site. They comprise of technical sheet drawings and a group of standard drawings.

9.3.16.1.1 TECHNICAL SHEET DRAWINGS

Based on OCS basic design studies, technical sheet drawings shall be prepared giving design parameters, conductor characteristics, loading tables, tension charts, clearance envelopes, OCS acceptance criteria, application charts and other data.

9.3.16.1.2 GENERAL ARRANGEMENT DRAWINGS

General arrangement drawings shall be used to show major groups of assemblies of multiple structures and spans. Installation rules and principal dimensions shall be given.

General arrangement drawings for OCS overlaps shall be prepared for the detail design of overlaps. Drawings shall include both insulated and uninsulated overlaps, for tangent and curved tracks and to include feeding and switching arrangements and minimum clearances.

General arrangement drawings for OCS turnouts and crossovers shall be prepared for track special work locations where trains change tracks at crossovers and where they leave or enter the mainline.

General arrangement drawings shall be prepared for phase breaks to suit all pantograph configurations to be utilized by RTD.

9.3.16.1.3 ASSEMBLY DRAWINGS

OCS assembly drawings shall be prepared for every required assembly. More than one similar assembly may be defined on a single assembly drawing. Individual assembly references shall be nominated for every discrete set and discrete count of components. It is acceptable for items such as pipes and wires that may vary in length in any assembly to be included showing quantity ‘as-required’ in any OCS assembly, without affecting the assembly reference number.

A Bill of Materials table shall appear on each assembly drawing that identifies parts by descriptive name and part number.

9.3.16.2 SITE-SPECIFIC DESIGN DRAWINGS

For reasons of site safety, electrical connections and circuit identifications shall only be shown on sectioning drawings.

9.3.16.2.1 OCS MASTER OVERLAP CHART

A Master Overlap Chart shall be drawn to express the route design of the physical wires relative to each other and related design features.

The proposed location of insulated overlaps shall be based on the requirements of the sectionalizing diagram. Uninsulated overlaps, balance weight terminations, fixed terminations and OCS midpoint anchors shall be shown overlaying the tracks.

9.3.16.2.2 WIRING LAYOUT DRAWINGS

Site-specific OCS wiring layout drawings shall be prepared showing the layout of the OCS poles and other supports, with the civil track plans as background. Each pole/support shall be assigned an OCS structure number unique within the RTD Commuter Rail and Light Rail systems.

The line of the OCS conductors shall overlay the pole/support layout, and the staggers at each pole/support, and the string line for each span on curved track, shall be given. OCS conductor heights above top-of-rail at each support shall be included.

The line of the autotransformer feeder wire and its mounting height shall also be shown on the OCS wiring layouts.

The OCS wiring layouts shall identify the OCS and feeder assemblies by reference number required at each OCS support location, unless specified on a separate drawing. OCS and feeder wire assemblies to be installed ‘in span’ shall be referenced on the wiring layout plans.

9.3.16.2.3 GROUND AND BONDING LAYOUT DRAWINGS

Site-specific Grounding and Bonding layout drawings shall be prepared showing the layout of the static wires, OCS poles and other supports, with a two rail representation of track plans as background.

All grounding connections to each static wire and impedance bonds, and bonding connections to all metallic items shall be shown.

9.3.16.2.4 MATERIALS ALLOCATIONS

Each assembly defined in the basic design drawings shall have a unique assembly reference number assigned.

Using the assembly reference numbers given in the basic design drawings, each pole support shall be allocated the OCS and feeder assemblies that altogether define the materials required to be installed at that particular support stationing. These allocations of assemblies shall occur on either the wiring layout plans, or if produced, structure specific cross section drawings.

9.4 GROUNDING

This Section specifies requirements for the following:

- Traction Power Return System (TPRS)
- Traction power substation (TPSS), switching station (SWS), and autotransformer/paralleling station (AT/PS) grounding systems
- Grounding and bonding requirements for the Overhead Contact System (OCS)
- Grounding and bonding for structures, such as TPSS, SWS, APS, fences, bridges, bridge barriers, and passenger stations.

9.4.1 TRACTION POWER RETURN SYSTEM

The Traction Power Return System consists of track rails, impedance bonds, drain bonds, static wires, and ground. The system shall be designed to provide a low impedance path for the return currents to the substation under normal and fault conditions and to limit rail-to-ground voltages to safe value.

Rail bonds shall be provided across rail joints, at crossovers, turnouts, and expansion joints.

Track rails shall be connected in parallel with each other at impedance bond locations.

Adjacent tracks shall be connected in parallel using crossbonds and connect to the static wires. The design shall be coordinated with the signal designer for location of impedance bonds and crossbonds to be paralleled, so that broken-rail protection is not compromised.

Crossbonds shall be provided to parallel all rails at all traction power substations, autotransformer/paralleling stations and switching stations, and connect to the facility ground grid and neutral of autotransformers (for AT system). Coordinate the interface between traction return cables and the impedance bonds with the signaling design.

Return current ground buses shall be connected to rails through impedance bonds and to the substation ground grid.

Impedance or drain bonds shall be provided at all passenger stations for connection of all track rails to the platform grounding system to equalize potentials from trains. Refer to 9.4.11.

9.4.2 TRACTION POWER SYSTEM GROUNDING

Step and touch potentials of rails, equipment, structures and trackside facilities shall be within IEEE Standard 80 limits under fault conditions.

At each TPSS, PS, and SWS provide a ground grid to maintain safe step and touch potentials, in compliance with IEEE Standard 80 for the expected maximum short circuit level. Connect all metallic objects within the site, including the security fence, to the ground grid. Extend the grid a minimum of 4 feet outside of the fence, including gate swings. Determine soil resistivities and grid resistance in compliance with IEEE Standard 81.

Below ground connections shall comply with the requirements in IEEE Standard 837.

Ground conductors shall be stranded copper and grid conductor size shall be a minimum of 4/0 AWG. Ground rods shall be copper clad steel with a minimum diameter of 3/4 inches.

Connect surge arrester ground leads directly to the nearest ground electrode, such as ground rod or ground grid, with a ground resistance than 5 ohms or less.

Grounding of Traction Transformer and Autotransformer (for AT System) Bushings:

- Ground the neutral bushing of traction power transformers and autotransformers directly to the ground grid with a 4/0 AWG (minimum) stranded copper conductor riser near the bushings.
- Additionally, ground the neutral bushings to the return current ground bus.

Provide grounding and bonding and test provisions for all TPS and associated equipment in TPSS, APS, and SWS or where adjacent to the tracks or other properties to ensure the proper working of the railroad and the safety of the public, passengers, and personnel.

9.4.3 OCS POLES

Pole grounding resistance shall be 25 Ohms or less.

9.4.4 OCS SURGE ARRESTERS

Surge arresters installed on the OCS shall be grounded by an independent ground cable directly attached to a grounding device such as ground rod(s) or ground mat with a ground resistance of 5 Ohms or less. Pole grounds may be connected to surge arrester grounding devices.

The surge arrester type installed on the OCS and AFS shall be coordinated with those determined for the Traction Power System.

9.4.5 UN-ENERGIZED COMPONENTS

All OCS metallic fittings and equipment not intentionally energized shall be effectively grounded. There shall be no electrically floating wire or component.

9.4.6 GROUNDING OF METALLIC OCS POLES AND STRUCTURES

Electrically connect all OCS poles, portals, structures, and supports attached to bridges and tunnels directly to the static wire except as required in 9.4.11.

All connections shall be firm and solid and shall be achieved by means of a flexible stranded copper bonding jumper equivalent in size to the static wire. Any contact point between the static wire and the OCS pole/structure susceptible to movement shall be considered a not-acceptable connection for grounding purposes.

Connect the OCS poles/structures to impedance bonds where possible, ground grids, and to the along-track counterpoise conductor.

All grounding connections shall be by 4/0 AWG, minimum, stranded copper wire. Below ground connections shall be exothermically welded.

9.4.7 GROUNDING OF GANTRIES AND GANTRY EQUIPMENT

All gantry structures associated with substations, autotransformer/paralleling stations and switching stations shall be connected to the facility ground grid by two independent conductors connected between each outer support column of the gantry and the station ground grid.

Bare stranded 4/0 AWG copper grounding conductor shall be looped along the gantry members to provide a ground bus for equipment installed on the gantry. The loop grounding conductor shall be connected, at their extremities, to the two grounding conductors connected to the gantry support columns.

9.4.8 GROUNDING FOR STEEL OVER RAIL BRIDGES

Grounding at the overhead bridges shall provide path for passage of traction short circuit currents to the static wire and prevent the short circuit currents from entering the bridge steelwork.

Ground steel bridges with a grounding loop of 4/0 AWG, minimum, stranded copper conductor on all four sides, exothermically welded.

Connect the grounding loop to static wires at a minimum of two locations.

Bond steel support beams and all metallic equipment on the bridge, bridge protective barriers, fences, signs, traffic rails, communication devices, handholes, pull boxes, and poles to the grounding loop.

In locations where the overhead contact wire system is connected to the bridge by drop tubes or other devices, bond the connecting member to the grounding loop.

9.4.9 GROUNDING FOR CONCRETE OVER RAIL BRIDGE

Grounding at the overhead bridges shall provide path for passage of traction short circuit currents to the static wire and prevent the short circuit currents from entering the bridge reinforcing steel.

Provide a grounding loop of 4/0 AWG, minimum, stranded copper over all four sides of the bridge.

Install 1/4-inch minimum thickness, copper or stainless steel, metallic flash plates equal to pantograph width, on the bridge soffit to prevent damage due to arcing between the pantograph and the bridge concrete. Flash plates shall be insulated to 5kV from the bridge structure. Flash plates may be omitted where pantograph and live wires are 6 feet from the soffit.

Interconnect adjacent flash plate sections over each track with a bare 4/0 AWG, minimum, stranded copper conductor to form an electrically continuous grid for the full length of the bridge.

Bond steel support beams and all metallic equipment on the bridge, including flash plates, bridge protective barriers, fences, signs, traffic rails, communication devices, handholes, pull boxes, and poles to the grounding loop.

9.4.10 UTILITIES ATTACHED TO BRIDGES

Utilities attached to the bridges shall be insulated, grounded and bonded, as required to prevent the short circuit currents from entering utility pipes or conduits. Details shall be determined by the Grounding and Bonding Study during the detailed design phase.

9.4.11 GROUNDING AT PASSENGER STATIONS

The static wire shall not be connected electrically to the OCS poles or supports located on the station platforms or station structures. Static wires shall be installed on 5 kV insulators at these support points.

Insulation and grounding connections required for OCS and ATF support assemblies mounted on poles on platforms are described in Paragraph 9.3.15.

All metallic structures and miscellaneous items installed on passenger platforms shall be isolated from the static wire and connected to the platform grounding system as required for Systems Grounding on Platforms shown in Section 12, System-Wide Electrical Design.

All below ground connections shall be exothermically welded.

9.4.12 PERSONNEL GROUND GRIDS

Personnel ground grids 6 feet long by 4 feet wide shall be installed at all disconnect switch locations. The grid shall be installed on the operator's side of the switch, 6 inches below finished grade, and shall be connected to the switch support structure by a flexible 4/0 AWG copper conductor or braid. The grid shall be exothermically welded to two different conductors of the ground grid and to the switch support.

9.4.13 PERSONNEL GROUNDING PLATFORMS

Grounding platforms 6 feet long and 4 feet wide shall be installed where the installation of a buried personnel grounding grid is not feasible. Platforms shall be constructed of galvanized steel members sized to safely support operating personnel. Hand rails and access steps shall be provided for elevated platforms where appropriate.

Platforms, hand rails and steps shall be bonded and connected to the switch support structure and to the main ground grid by a 4/0 AWG bare copper conductor exothermic welded to two different sections of the platform.

9.5 STANDARDS AND CODES

All design work and material selection shall conform to or exceed the requirements of the latest editions of standards and codes issued by the following organizations:

- Association of American Railroads (AAR)
- American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual For Railway Engineering
- American National Standards Institute (ANSI)
- American Society for Testing & Materials (ASTM)
- Institute of Electrical & Electronics Engineers (IEEE)
- National Electrical Manufacturers Association (NEMA)
- Insulated Cable Engineers Association (ICEA)
- American Society of Civil Engineers (ASCE)
- American Society of Mechanical Engineers (ASME)
- Underwriters Laboratories (UL)
- National Fire Protection Association (NFPA)
- National Electrical Testing Association (NETA)
- National Electrical Code (NEC), where applicable

- National Electrical Safety Code (NESC)
- Applicable state, local, and county codes and regulations
- Applicable federal and state statutes

9.6 PRODUCT REQUIREMENTS

9.6.1 TRACTION POWER SUPPLY SYSTEM

9.6.1.1 EQUIPMENT DESCRIPTION

The traction power supply system shall consist of equipment between the interface points with the Utility and connection to the feeder and OCS disconnect switches, autotransformer/paralleling stations, and return current circuits. The systems shall include all the necessary equipment and ancillaries, such as:

- High voltage buses, cables, and conductors
- High voltage disconnect switches and switchgear
- Traction transformers (and autotransformers for 2x25kV systems)
- 25kV switchgear assemblies, busbars, and associated protective relays
- Auxiliary power supply transformers with associated AC and DC control power gear including battery and battery chargers
- Harmonic filters, if required
- Cable ductbanks, conduits and raceways within the substation and paralleling stations
- Return cables and connections to impedance bonds
- Equipment foundations
- Grounding system
- HVAC system for buildings
- Surge arresters
- Local annunciation, monitoring and control systems
- Utility metering equipment
- Supervisory Control and Data Acquisition (SCADA) equipment
- Safety equipment e.g., portable fire extinguishers, eye wash and other mandated requirements
- Spare parts for normal maintenance for three years
- Circuit breaker test cabinet, special tools for maintenance
- Comprehensive Operating and Maintenance (O&M) manuals and training of personnel

High voltage equipment, transformers, harmonic filters (if provided) and disconnect switches shall be installed outdoor in switchyards. 25kV switchgear shall be installed indoor or outdoor based on relative cost. Auxiliary supply and control gear shall be installed in a building. Prefabricated and pre-wired assemblies shall be utilized where economically feasible.

9.6.1.2 INCOMING AC FEEDERS

The incoming primary supply shall be by overhead lines (preferred) or underground cables as agreed with the Utility terminating on gantries or other support structures. Cable ductbanks, conduits, raceways and manholes inside the substation property line shall be designed per applicable codes. Interconnection designs shall be fully coordinated, and in compliance, with the Utility requirements and interfaced with the Utility overhead or underground facilities. The incoming feeder ratings shall permit the substations to supply the required load cycles and withstand the expected short circuit levels without exceeding the allowable equipment temperatures.

9.6.1.3 HIGH VOLTAGE CIRCUIT BREAKERS AND DISCONNECT SWITCHES

High voltage (115kV and 230kV) circuit breakers and disconnect switches shall be outdoor 2-pole type. The breakers shall be dead tank SF6 type with spring charged or permanent magnet actuators. Disconnect switches shall be motor operated with remote and local operation capabilities and rated for no-load operation.

9.6.1.4 TRACTION TRANSFORMER

Transformers shall be oil filled natural cooled (ONAN) rated, with appropriate overload capability, per paragraph 9.3.1.6, conforming to ANSI C57.12 shall be used. Maximum temperature rise for 100% full load shall not exceed 55°C. Off-load tap changers shall be provided.

The transformers shall be capable of withstanding fluctuating traction load, repeated short circuits (typically as many as 300 per year), and harmonic currents associated with traction loads.

9.6.1.5 25KV FEEDER CABLES

Cables for use on 25kV system shall be of 46kV class, 250kV BIL, suitable for use in continuous and emergency operation. The cables shall be single conductor, stranded copper of the size determined during detail design, EPR insulated, shielded, rated for 90ºC in normal operation, 130ºC in emergency operation and 250ºC in short circuit condition. The cables shall have an overall black jacket of high molecular polyethylene to ASTM D1248 suitable for outdoor and indoor application.

9.6.1.6 25KV SWITCHGEAR

25kV switchgear shall be single-pole if 1x25kV system is used or two-pole if 2x25kV system is used. The switchgear shall be outdoor or indoor depending upon the relative cost.

Indoor switchgear, if used, shall be metal-clad dead-front conforming to ANSI C37.20.2 IEEE Standard for Metal Clad and Station Type Cubicle Switchgear. Adequate working space, per NEC shall be provided for maintenance from the front and the rear of the switchgear. The switchgear shall be trip-free, horizontal drawout type with arc resistant construction to IEEE Std. C37.20 with proven track record in traction duty. The switchgear shall be rated at 200kV BIL to ground (250kV across open contacts).

Outdoor switchgear, if used, shall be dead tank type, rated at 250kV BIL and installed on free standing steel structures with horizontal and vertical clearances per NESC.

Busbars and bus connections shall be designed to withstand, without damage to the bus or enclosure, the thermal and mechanical stresses occurring during the specified weather and load cycle and the rated short circuit currents.

Busbars shall be made of rigid high electrical conductivity copper. Indoor busbars shall be adequately insulated and braced with high-strength insulators. Bus connections shall be bolted and furnished with silver-plated surfaces. Each joint shall have conductivity at least equal to that of the busbar.

9.6.1.7 25KV DISCONNECT SWITCHES

25kV disconnect switches shall be installed on track-side structures. The disconnect switches shall be motor-operated with remote operation capability, 250kV BIL, 125 V DC operated, capable of operation under icing conditions. Disconnect switches shall be fitted with arc horns or momentary charge/discharge devices to prevent long term damage to the contact surfaces. Disconnect switches on 2x25kV system shall be 2-pole.

9.6.1.8 POTENTIAL TRANSFORMERS (PT)

Potential Transformers (PT) shall be suitable for traction duty. PT units which are directly connected to the catenary shall be ferroresonance resistant and comply with EN 50152-3-3. All PT units shall have high resistance primary windings.

9.6.1.9 LOCAL CONTROL AND ANNUNCIATION PROGRAMMABLE LOGIC CONTROLLER (PLC)

The substations, paralleling stations and switching stations shall be unattended and normally controlled from the control center via SCADA. However, local control switches shall be provided for all equipment for operation in the event of failure of SCADA or the communication link. Use of PLC units and intelligent electronic devices (IED), suitable for service inside Utility substations, is allowed for all functions. Devices and subsystems performing interlocking functions shall be hard wired to provide Safety Integrity Levels (SIL) appropriate for the hazard. Protective relays shall trip the circuit breakers independent of the PLC.

The PLC system, if used, shall be full featured, integrated, modular, using non-proprietary off-the-shelf software. The modules shall be capable of being inserted at the site, with no factory re-wiring required. It shall include a relay interface system. All functional requirements specified shall be met or be exceeded by the PLC system. PLC, associated network and interfaces shall be rated to Utility standards for substation environments.

The substations shall be equipped with an internal annunciation system. The annunciator shall be of modular design, programmable, and may be integrated with the PLC. The annunciator shall consist of touch screens, indicating light emitting diode (LED) lamps, audible alarm, test, silence, acknowledge and reset switches, as well as other associated equipment. Switches and controls may be implemented in software.

An electrical alarm "points list" shall be developed listing electrical alarms to be annunciated. These alarms shall be annunciated remotely and locally.

At a minimum, the PLC system shall consist of the following components:

- Electronic terminators, capable of handling 130 V dc, to replace the normal auxiliary and interposing relays for the AC switchgear cubicles, high voltage circuit breakers, disconnect switches, etc.
- Transfer trip module, if transfer trip is provided
- Master PLC with dual CPUs , one working as hot standby, designed and programmed to integrate and control all inter-panel connections and to provide substation monitoring and data logging that is easily downloadable
- Man/machine interface (operator panel) capable of providing substation status annunciation and local/remote control of substation operations (e.g. opening and closing of circuit breakers)

The PLC system and equipment shall be designed to operate in an electric utility environment. All electrical interfaces, including relaying, voice, and data shall meet ANSI/IEEE surge withstand requirements. The system shall be immune to Radio Frequency Interference and shall be designed to meet the requirements of ANSI/IEEE C37.90.2 and ANSI/IEEE 281. The presence of transients on the communication interfaces shall not cause mis-operation or blocking of any of critical communications. The system shall be failsafe. Interface with SCADA system shall not require an RTU.

9.6.1.10 CONTROL POWER

Control power supply shall consist of 120V AC (and 240/480V AC if required for HVAC) and 125V DC for breaker and other critical controls. Redundant battery chargers shall be provided. AC and DC distribution panel boards shall be NEC compliant. The AC panel board shall supply the substation lighting, HVAC, convenience receptacles and battery charger. The DC panel board shall supply circuit breaker and other control power and annunciation. External outlets shall be provided for providing auxiliary power from external sources if required.

9.6.1.11 BUSBARS AND BUS CONNECTORS

Busbars and bus connections shall be designed to withstand, without damage to the bus or enclosure, the thermal and mechanical stresses occurring during the specified load cycle and the rated short circuit currents.

Busbars shall be made of rigid high electrical conductivity copper and shall be adequately insulated and braced with high strength insulators. Bus connections shall be bolted and furnished with silver-plated surfaces. Each joint shall have conductivity at least equal to that of the busbar.

9.6.1.12 EQUIPMENT LAYOUT

Substation (TPS, SWS, and APS) layouts shall allow working on one half of the substation while the other is energized and feeding the OCS. Adequate clearance shall be provided between the bays to achieve this. High voltage areas shall not be placed near entrance gates.

Relative spacing and positioning of each item of equipment shall permit maintenance, removal and replacement of any unit without the necessity of moving other units. The arrangements of the equipment in the building shall permit doors to be opened, panels to be removed, and switchgear to be withdrawn without interference to other units. Ceiling heights and structural openings shall permit entry and removal of the largest components installed in the housing. Minimum working clearances shall be provided per the NEC. Two exit doors with panic hardware, one from each end of the switchgear, shall be provided.

Circulating area, either inside or outside the site, shall permit turn around of tractor trailers.

9.6.1.13 RETURN CABLES

Medium voltage feeder cables, 2kV class, shall be low smoke, flame retardant, ozone resistant, non-shielded, Ethylene Propylene (EP) rubber insulated and provided with a heavy-duty Chlorosulfonated Polyethylene

(CP) jacket. The cables shall be suitable for installation in an underground conduit or duct, for use in wet and dry locations. The maximum operating conductor temperature shall be 90ºC for normal operation, 130°C for hot spot, and 250°C for short circuits. The cable construction shall comply with ASTM D2802 and ANSI/ICEA Std. S-93-639.

9.6.1.14 AUXILIARY POWER SUPPLY AT INTERLOCKINGS

Auxiliary power supply for operation of disconnect switches at interlockings shall be obtained from the OCS via step-down transformers. Backup power to signal houses may be provided from an auxiliary power supply distribution panel powered from the step-down transformers. The transformers shall be ferroresonance resistant. Power supply for train stations, other facilities, and primary power to signal houses shall not be obtained from the 25kV system.

9.6.1.15 OPERATIONS FACILITY ELECTRIFICATION

See Section 11 of the Design Criteria.

9.6.2 OVERHEAD CONTACT SYSTEM (OCS)

The OCS consists of all equipment between and excluding traction power disconnect switches (mounted on OCS trackside switching/feeder gantries) and the vehicle pantograph. The OCS equipment shall include foundations, poles, portals, gantries, cantilevers, under bridge arms, shop building supports, system conductors, feeders, hangers, jumpers, terminations, tensioning devices, sectioning equipment and all other necessary equipment.

The OCS shall be designed to be environmentally acceptable. Within the economic, electrical, mechanical and structural design constraints, the OCS structures and associated equipment shall be as lightweight as possible and shall use visually unobtrusive fittings.

Refer to Table 9.3 for a summary of design values and factors of safety to be applied to OCS equipment.

9.6.2.1 FOUNDATIONS

Each foundation shall be designed to suit the bearing strength and conditions of the ground into which it is to be built.

Foundation location, lateral offset and foundation top level shall not cause the foundation to encroach on required horizontal and vertical clearances from rail vehicles and track. Refer to 9.3.9 and 9.3.11.

All exposed steelwork shall be galvanized.

9.6.2.2 POLES, PORTALS, AND GANTRIES

All poles, portal columns, and gantry columns shall be steel of solid cross-section to discourage unauthorized climbing. All poles, portal columns, and gantry columns shall be hot-dip galvanized after fabrication.

9.6.2.3 CANTILEVERS ASSEMBLIES

Cantilever Assemblies shall be easy to install and field adjust to account for the effects of future track settlement or movement. All steel or cast iron components shall be galvanized.

9.6.2.4 CONDUCTORS AND IN-SPAN ITEMS

Contact wire shall be solid, grooved, copper conductor. The messenger wire shall be stranded, hard-drawn copper conductor.

All conductor connections, attachments, hangers and clamps shall be corrosion resistant and compatible with conductor material. They shall be suitable for high levels of wiring vibration, and designed for ease of replacement and maintenance.

Continuity and equalizing jumpers shall be flexible copper conductors. The spacing of the jumpers shall be determined based on the local current demands. A minimum of two equalizing jumpers per half tension length shall be installed.

9.6.2.5 TERMINATIONS AND MIDPOINT ANCHORS

Strain-type termination assemblies shall be light weight. Wire wrap, straight line, cone or wedge type designs are acceptable.

Turnbuckles shall be included as appropriate and shall have adequate adjustability. All turnbuckles shall include locking devices. Where yoke plates are utilized, these shall be positioned horizontally outside the pantograph security envelope irrespective of height.

A mid-point anchor arrangement shall utilize a span-guy of sufficient strength to withstand full line tension of both messenger and contact wires.

Auto tensioned, mid-point anchor arrangement shall include contact wire restraint sub assemblies if:

Pulleys at the balance weight anchor location are provided to share messenger wire and contact wire tensions, or

The messenger wire and contact wire have independent balance weight anchor assemblies.

9.6.2.6 TENSIONING DEVICES

The auto-tensioned system conductors shall be tensioned using cast iron or steel balance weights. The tensioning devices shall accommodate conductor expansion and contraction due to temperature and long term wire creep, while maintaining wire tension within the designed range. They shall be provided with broken wire restraint arrangements.

Balance weights shall be positioned in the pole web to be as unobtrusive as possible. The poles with balance weights shall be fitted with guides that will prevent the balance weights from binding or jamming. The guide shall prevent the weights from falling away from the anchor pole should a wire break.

All operating wires shall be of flexible stainless steel wire.

Where yoke plates are utilized, these shall be positioned horizontally outside the pantograph security envelope irrespective of height.

Balance weight anchor assemblies shall not be installed in areas frequented by passengers or pedestrians.

Pneumatic or hydraulic tensioning devices shall not be used.

9.6.2.7 SECTIONING EQUIPMENT

High-speed section insulators may be used in crossovers, yard leads and in yards. All section insulators shall be of an overlapping runner style, and be fitted with arc horns designed to protect tensioned components. Messenger wire shall be sufficiently higher than the contact wire to mitigate arc damage, and increase dynamic stability.

9.6.2.8 SURGE ARRESTERS

Over-voltage protection for the OCS and equipment shall be provided by surge arresters. The arresters shall be rated to withstand the maximum operating voltage and anticipated voltages induced from any paralleling high-voltage transmission lines onto the system conductors, and shall be explosion proof. The arresters shall be spaced to satisfactorily discharge the energy from lightning strikes to the ground.

All transformers, cable terminations and cable-to-overhead transitions shall be protected by surge arresters in addition to the substation and autotransformer/paralleling station gantries. Additional arresters shall be provided on the OCS at spacings determined during detailed design. The installation of arresters shall prevent grounding of the energized circuit during catastrophic failure of the arrester.

9.6.2.9 PROTECTIVE SCREENING

When the OCS and/or feeder wire is constructed below a bridge, building, or structure, screening and fencing shall be erected to physically separate the catenary wires from human reach. The overpass screening and/or fencing shall be constructed to protect rail vehicles and wiring from vandals dropping objects from above.

Horizontal screens shall have a smooth upper surface sheet, and be shaped to allow falling objects to slide towards trackside. Horizontal screens shall be designed to support the weight of a trespasser. Vertical screen shall be designed and placed to discourage trespassers gaining hand hold or foot holds. The design of the overpass screening and/or fencing shall be compatible with the local architecture and landscaping.

At a minimum, all fencing passing over the tracks and within 25 feet parallel to the track shall be grounded. Fence grounding resistance shall be less than 25 ohms to ground or as determined during grounding design study. Grounding requirements of parallel fences over 15 feet from the tracks shall be determined during grounding design study. Grounding shall be consistent with Section 12.8 of the Design Criteria.

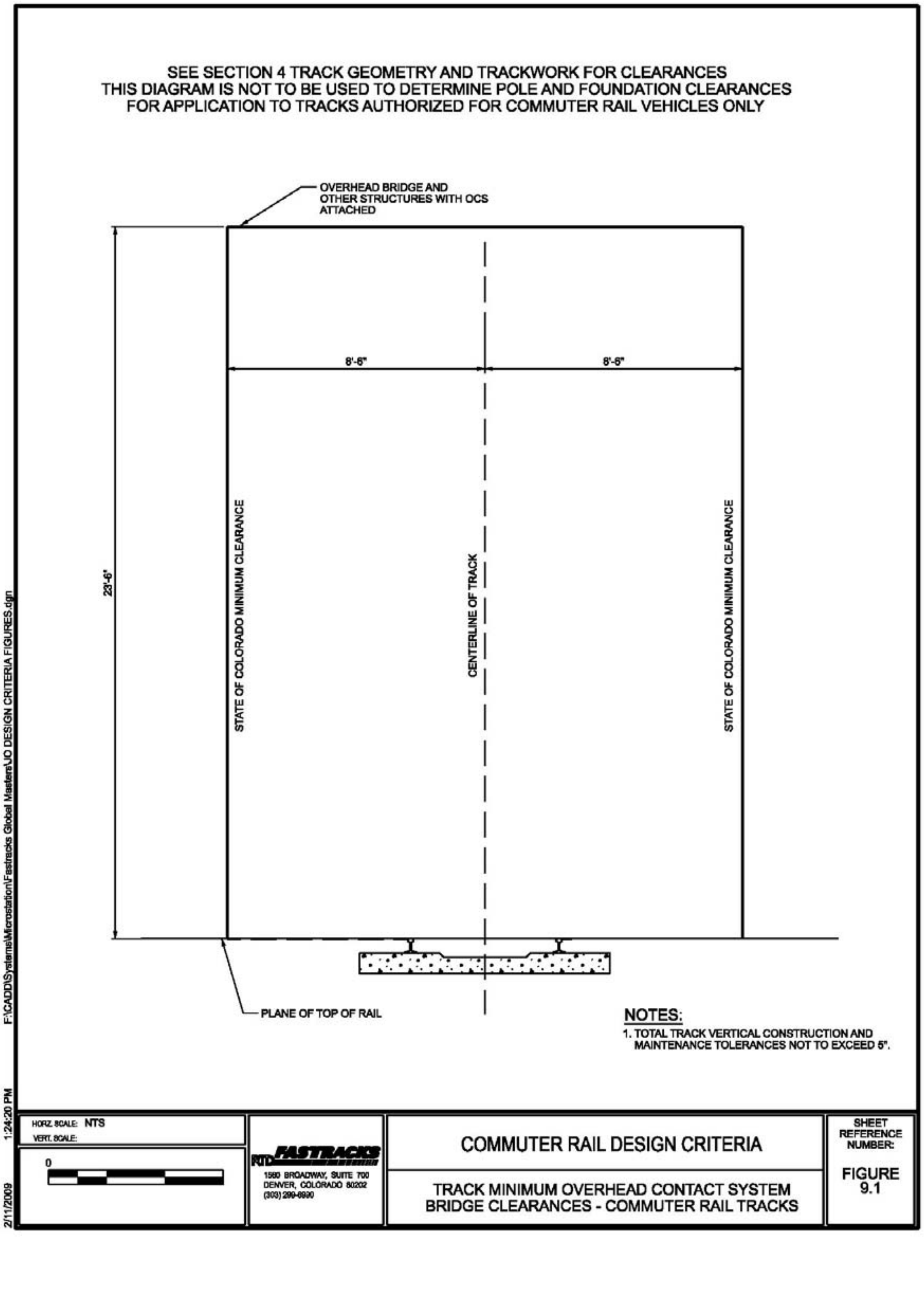
In cases where any energized OCS component has less than 10 feet separation from pedestrian access, a solid barrier or panel shall be placed alongside or over the OCS between the energized component and pedestrian access to deter access to the energized component, and to prevent vandalism.

9.7 OCS DESIGN PARAMETERS

TABLE 9-3

DESIGN PARAMETER SUMMARY

Climatic Conditions	
Ambient Conditions	See Section 1 for common parameters
Environmental Conditions	See Paragraph 9.3.3.2
NESC Grade of Construction	Grade C
OCS Conductor Sizes and Material	
Messenger Wire:	Hard Drawn Copper Size and class shall be based on systems simulation
Contact Wire:	Solid Grooved Hard Drawn Copper Size shall be based on systems simulation
Minimum Factors of Safety - Conductors and Wires	
- Under Operating Conditions	2.0
- Under Non-operating Conditions	1.6; determined in accordance with NESC Rule 261H and other referenced rules.
Contact Wire Wear for Mechanical Design	30%
Minimum Factors of Safety – Strain Insulators	
- Under Operating Conditions	4.0
- Under Non-operating Conditions	3.2
Minimum Factors of Safety – Hardware	
- Under Operating Conditions	2.5
- Under Non-operating Conditions	2.0
Minimum Electrical Clearances	
Static Clearance:	12 in
Passing Clearance:	10 in
Pantograph	
- Dynamic uplift allowance	3 in
- Minimum Pantograph Security:	3 in


SEE SECTION 4 TRACK GEOMETRY AND TRACKWORK FOR CLEARANCES
THIS DIAGRAM IS NOT TO BE USED TO DETERMINE POLE AND FOUNDATION CLEARANCES
FOR APPLICATION TO TRACKS AUTHORIZED FOR COMMUTER RAIL VEHICLES ONLY
OVERHEAD BRIDGE AND OTHER STRUCTURES WITH OCS ATTACHED
8'-6"
8'-6"
23'-6"
STATE OF COLORADO MINIMUM CLEARANCE
CENTERLINE OF TRACK
STATE OF COLORADO MINIMUM CLEARANCE
PLANE OF TOP OF RAIL
NOTES:
1. TOTAL TRACK VERTICAL CONSTRUCTION AND MAINTENANCE TOLERANCES NOT TO EXCEED 5".
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HORZ. SCALE: NTS
VERT. SCALE:
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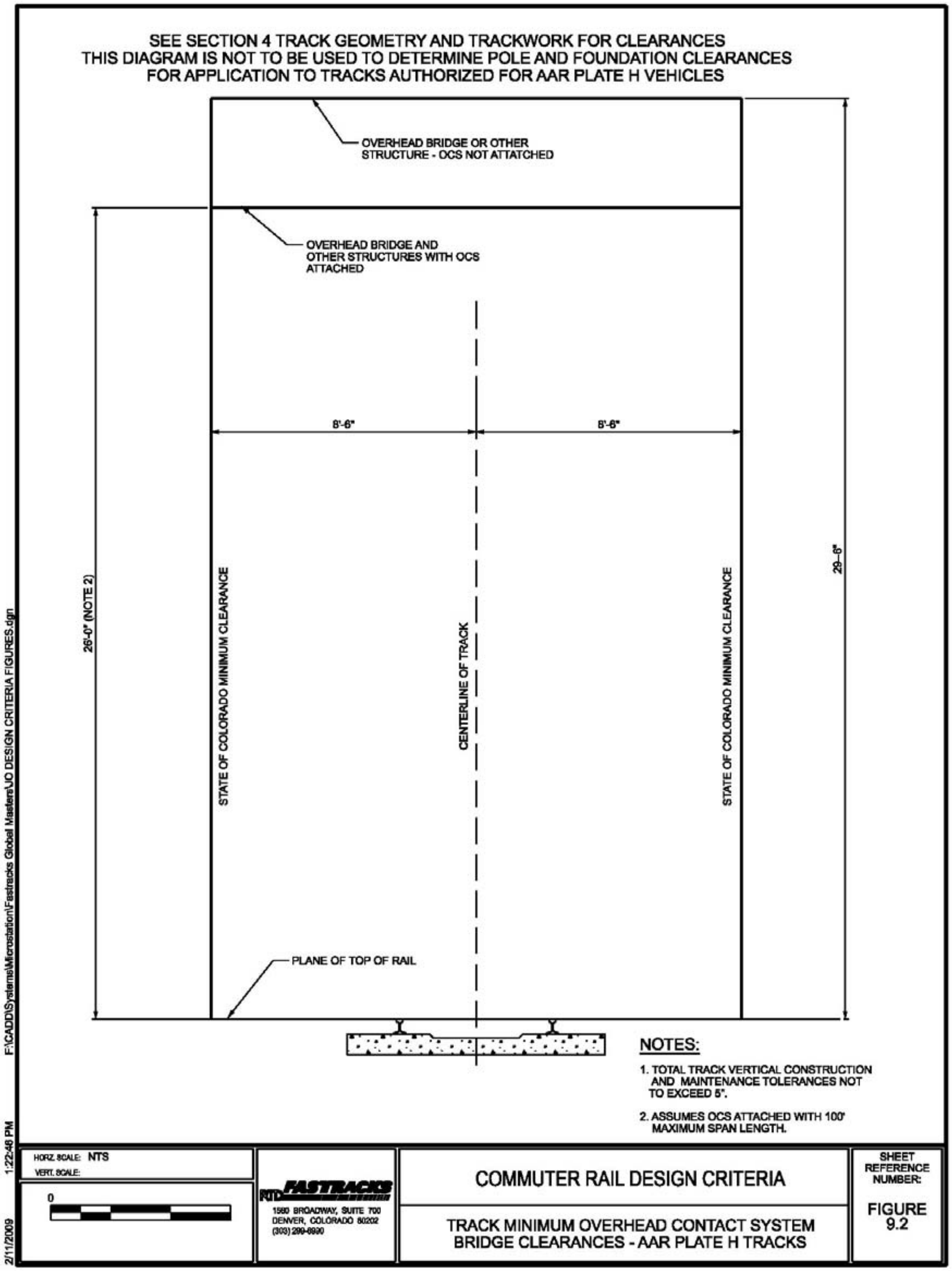
RTD FASTRACKS
1560 BROADWAY, SUITE 700
DENVER, COLORADO 80202
(303) 299-6990
COMMUTER RAIL DESIGN CRITERIA
TRACK MINIMUM OVERHEAD CONTACT SYSTEM BRIDGE CLEARANCES - COMMUTER RAIL TRACKS
SHEET REFERENCE NUMBER:
FIGURE 9.1



SEE SECTION 4 TRACK GEOMETRY AND TRACKWORK FOR CLEARANCES
THIS DIAGRAM IS NOT TO BE USED TO DETERMINE POLE AND FOUNDATION CLEARANCES
FOR APPLICATION TO TRACKS AUTHORIZED FOR AAR PLATE H VEHICLES
OVERHEAD BRIDGE OR OTHER STRUCTURE - OCS NOT ATTATCHED
OVERHEAD BRIDGE AND OTHER STRUCTURES WITH OCS ATTACHED
8'-6"
8'-6"
26'-0" (NOTE 2)
29'-6"
STATE OF COLORADO MINIMUM CLEARANCE
CENTERLINE OF TRACK
STATE OF COLORADO MINIMUM CLEARANCE
PLANE OF TOP OF RAIL
NOTES:
1. TOTAL TRACK VERTICAL CONSTRUCTION AND MAINTENANCE TOLERANCES NOT TO EXCEED 5".
2. ASSUMES OCS ATTACHED WITH 100' MAXIMUM SPAN LENGTH.
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HORZ. SCALE: NTS
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RTD FASTRACKS
1560 BROADWAY, SUITE 700
DENVER, COLORADO 80202
(303) 299-6900
COMMUTER RAIL DESIGN CRITERIA
TRACK MINIMUM OVERHEAD CONTACT SYSTEM BRIDGE CLEARANCES - AAR PLATE H TRACKS
SHEET REFERENCE NUMBER:
FIGURE 9.2