Region of Waterloo
Stage 1 Light Rail Transit Project

Design and Construction Performance Output Specifications
Article 6
Traction Electrification System

Table of Contents

ARTICLE 6 TRACTION ELECTRIFICATION SYSTEMS

6.1 General

(a) The purpose of this Article is to provide design guidelines for the Traction Electrification System (TES). Project Co's solution to the TES shall expand on these guidelines. Project Co shall prepare a Basis of Design Report – TES which explains Project Co's approach to the TES in greater detail and in a site specific manner. The presentation of specific TES requirements within this Article must not be construed to limit or modify in any way Project Co's responsibility to provide a holistic, comprehensive, and fully functional solutions to all TES components and TES related appurtenances. The Basis of Design Report – TES shall address every aspect of the TES design requirements cited in this Article. The rationale for all deviations or variances from any requirement cited this Article must be fully described in the Basis of Design Report – TES.

(b) The Traction Electrification System (TES) provides electrical power to Light Rail Transit (LRT) by the means of Traction Power System (TPS) and the Overhead Contact System (OCS). The TPS consists of the Traction Power Substations (TPSS) and the Traction Power Feeder System (TPFS). The TPFS includes both the positive and negative feeder cables and their respective conduits. The Light Rail Vehicle (LRV) will collect current from the contact wire by means of pantographs and will return the negative current to the substations via the running rails.

(c) The TPSS are located along the LRT lines and receive primary power from the local power utility company. The substations include all the equipment necessary to transform and rectify the primary AC three-phase power to DC traction power. Traction power will be supplied to the OCS via positive underground feeder cables. The negative return underground feeder cables shall be connected to the running rails via impedance bonds or equivalent devices compatible with the track circuit technology.

(d) The TPSS shall provide power to the OCS at sectioning points. The OCS shall normally operate as a dual multi-feed system for the full length of the main lines with each track being electrically separated from the other track. The OCS for the maintenance facility and storage tracks shall operate independently from the main line OCS and shall have its own TPSS. The mainline tracks will be electrically isolated from ground and connected to the negative bus at the TPSS. The yard tracks will be separated from the mainline tracks and shop tracks by insulated rail joints, electrically isolated from ground and connected to the negative bus of the storage track's TPSS. The shop tracks will be grounded and separated from the yard tracks by insulated rail joints.

(e) Portions of the LRT tracks will be shared with railroad freight service. The TES must be designed to de-energize all tracks occupied by railroad freight service, upon request from the railroad, while maintaining traction power to LRT tracks not occupied by railroad freight service. On the tracks designated for railroad freight service, all clearances to OCS poles and other wayside elements must comply with railroad requirements.

6.2 References, Standards, Regulations, Codes, Guidelines

(a) 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. Where requirements of two or more codes apply, the more restrictive shall govern:

(i) Association of American Railways (AAR)

(ii) American Railway Engineering and Maintenance-of-Way Association (AREMA)

(iii) American Institute of Steel Construction (AISC)

(iv) American National Standards Institute (ANSI)

(v) American Society for Testing and Materials (ASTM)

(vi) Institute of Electrical and Electronics Engineers (IEEE)

(vii) National Electrical Manufacturers Association (NEMA)

(viii) Insulated Cable Engineers Association (ICEA)

(ix) American Society of Mechanical Engineers (ASME)

(x) Electric Utility Service Equipment Requirements Committee (EUSERC)

(xi) Underwriters Laboratories (UL) / Underwriters Laboratories Canada (ULC)

(xii) National Fire Protection Association (NFPA)

(xiii) Canadian Standards Association (CSA)

(xiv) Ontario Building Code (OBC)

(xv) Ontario Electrical Safety Code (OESC)

(xvi) Canadian Electrical Manufacturers Association (CEMA)

(xvii) Other Codes and Regulations of Federal, Provincial, or Municipal Agencies having jurisdiction.

6.3 Functional Requirements

(a) The TES shall maintain the OCS voltage above the minimum allowable value. The spacing of the substations shall be verified to prevent the temperature of the OCS conductors from exceeding the limit recommended by the conductor manufacturer. The OCS shall be designed to ensure the LRVs operate with all pantographs in continuous contact with the contact wire up to the maximum allowable track speed. The design shall avoid sudden changes in contact wire height that would cause arcing during current collection. If there conditions that result in unavoidable changes in the contact wire height, Project Co's OCS designer shall inform Project Co of the train speed restriction and the applicable train operating speed due to the unavoidable changes in the contact wire height. Project co shall ensure that all OCS speed restrictions are integrated into the design and operation of the Stage 1 LRT Project.

(b) All traction power and distribution system equipment shall be designed taking into account the effects of the harmonic content of the traction load, the highly fluctuating pattern of traction current, and system faults. The TES shall be designed for a minimum functional life expectancy of thirty (30) years. All traction power substations shall meet the harmonic requirements of IEEE 519.

6.4 Traction Power Systems (TPS) Design Requirements

(a) The TPS includes the TPSS, the pad mounted disconnects located adjacent to the substations from which the underground positive feeder cables run directly to the OCS feeder poles and the underground negative return cables run directly to the track rails in non-signalized territory connecting to the rails through impedance bonds or equivalent devices in signalized territory.

(i) Substation Spacing and Location

A. The Region has identified locations for each Traction Power Substation. The final placement within these approximate locations will be determined by Project Co. The final locations and resultant TPSS spacing shall be verified by Project Co through a system load flow simulation. The substations shall be located so that the distribution system voltage does not drop below the minimum level requirements, the temperature of the distribution system conductors does not exceed the maximum allowable value, and the rail voltages do not exceed the maximum permissible values.

(ii) System Load Flow Simulation

A. The design of the TES shall validated be based on a computer-aided load flow simulation. Operation of the trains along the alignment shall be simulated and all necessary parameters for the electrification system design verified and confirmed. The ultimate train length is a two-car train. All simulations shall use the ultimate train operating at the minimum projected headway of five (5) minutes, under normal and individual substation outage conditions, with the cars loaded to their normal service capacity of 200 passengers. Under normal operating conditions two trains should be able to start simultaneously at any station stop and maintain their rated acceleration. Under contingency conditions of one substation out of service, one ultimate train should be able to start at any passenger station in the affected area and maintain its rated acceleration as if the system was operating with all substations on-line. However, under these same conditions, two ultimate trains shall be able to start simultaneously at a reduced acceleration and operating level. Under these operating conditions the TES design shall be shown to operate successfully within the required design parameters and the voltage at the trains shall not fall below 525 Vdc.

B. The input data shall include track gradients, track speed limits, passenger station locations and station dwell times, as well as the electrical and mechanical characteristics of the trains. Further, the input data shall represent the utility electrical system, the traction power substations, the distribution system and the power return system.

C. Tentatively, 13 traction power substations have been identified – 12 for the main line and one (1) for the maintenance and storage facility. The load flow simulation shall confirm these locations; identify the substation capacities and the need for any additional underground parallel feeders, especially along the sections with single contact wire configuration. To the extent possible, all the substations should have same capacities and their major components/subassemblies, such as transformers, should have identical ratings.

D. The output data shall include train operational data such as speed, distance traveled, power demand and energy consumption for each station-to-station run. For each substation, the results shall include average power output, energy consumption, rectifier current and current for each feeder breaker. For each substation to substation section of the line the results shall include voltage profile and current flow in each OCS section and rail potential. Calculations for maximum substation bus current, feeder cable size, equipment temperature rating and OCS conductor temperature shall be performed.

(iii) Substation Incoming Service

A. Connection points for incoming primary AC power to the TPSS will be identified by the local power utility company at a nominal 13.8 kV, three-phase, four wire, 60 hertz. The substations shall be connected by overhead lines or underground cables to the utility three-phase distribution network. Refer to herein to Section 6.9 (b) for additional requirements with respect to incoming AC service. The AC service and AC protection scheme shall be coordinated with the power supply utility.

B. Each TPSS shall be designed to receive two AC feeders. The feeders will be identified by the utility and will be shared feeders. Project Co elects to provide only one AC feeder at some, or all Traction Power Substations, Project Co shall perform a systemwide traction power simulation which reflects the systemwide impacts of losing a specific feeder which may be providing power to more than one TPSS. The simulation shall indicate where reduced performance for the LRV will occur due to voltage being below 650 Vdc. If two AC feeders are available, Project Co. must demonstrate that any other configuration that does not fully utilize a double feeder approach shall meet the traction power availability requirements and also meet the overall system availability requirements. The loss of a single AC feeder is not an excusing event with respect to Schedule 20.

C. Metering shall be provided on the high voltage (HV) side as per the specifications of the power supply utility.

D. Project Co shall be responsible for all costs required to provide AC power feeders and metering for all traction power substations. Refer to section 6.9(b)(ii) for additional information.

(iv) Substation Types

A. Each mainline substation shall have one transformer/rectifier unit and four DC feeder breakers unless otherwise approved by the Region of Waterloo.

(v) Substation Equipment Rating

A. The continuous rating of the mainline substation equipment such as the traction transformer, rectifier, circuit breakers and cables shall be based on the output from the system load flow simulation.

B. Each mainline substation shall be capable of supplying the following load cycle in accordance with NEMA Standard RI-9 “Extra Heavy Traction Duty Cycle” and ANSI standards:

1. Constant temperature of all equipment shall be reached following operation at 100% rated power for a minimum of 2 hours.
2. Equipment shall then be able to sustain a 150% overload for 2 hours with five evenly spaced periods of one minute each at 300% of rated load and one 5 second period at 450% of rated load, followed by a maximum short circuit current with duration equal to substation protective device clearing time.
3. Equipment shall be capable of sustaining such an overload twice a day, once in AM peak and once in the PM peak periods.
4. All equipment insulation shall be rated at the system maximum rated voltage.

(b) Each maintenance substation shall be capable of supplying the following load cycle in accordance with NEMA Standard RI-9 “Heavy Traction Duty Cycle” and ANSI standards. The maintenance facility substation shall be capable of supplying 100% rated load continuously, 150% rated load for two hours following temperature stabilization at 100% load or 300% load for one minute following temperature stabilization at the 100% load.

6.5 System Voltage Design Requirements

Nominal Contact Wire Voltage:	750 Vdc
Maximum Contact Wire Voltage:	900 Vdc
Vehicle Operating Voltage:	525 Vdc
Maximum Rail to Ground Voltage:	50 Vdc

(a) The vehicles will be equipped with regenerative braking. The system shall be designed for natural receptivity only, no additional means of accepting regenerative power or of feeding regenerative power to the utility will be included.

6.6 TPSS Site Access, Grading, and Drainage Design Requirements

(a) A code compliant access drive or a minimum 3.7 metres (12') wide access drive, whichever is greater, shall be provided to each substation from adjacent roadways. The access drive shall be surfaced with gravel or asphalt and shall not exceed a 6% grade. The surfacing material shall be as recommended by a Geotechnical Engineer or as required by local jurisdictions.

(b) A minimum clearance of 3.0 metres (10') shall be provided around the perimeter of each substation to permit access for maintenance vehicles and equipment. Any additional clearance area needed for installing or repairing TPSS equipment shall also be provided. Clearance width may be reduced along one side of the substation with approval from the Region. Each TPSS shall be located within a secured area. The design for the enclosure shall address security issues as well as providing screening for the TPSS from the general view of the public.

(c) The enclosed area shall be generally flat with finished grade sloping a minimum of 2% away from the building.

(d) The drainage shall be analyzed at the substation and storm-water infrastructure provided as appropriate.

6.7 Traction Power Feeder System (TPFS) Design Requirements

(a) The TPFS shall be an underground feeder cable distribution system comprising positive feeder cables, negative return cables, transfer trip cables and high voltage AC power cables.

(i) Positive Feeder Cables

A. The positive feeder cables shall have single multi-strand flexible copper conductors, EPR insulated with low smoke, flame retardant, ozone resistant, non-shielded, jacket complying with NEMA standard WC 70. The cables shall be suitable for installation in an underground conduit or duct and for use in wet and dry locations. The maximum operating conductor temperature shall be 90°C for normal operation and 110°C for hot spot. The cable construction shall comply with ASTM D 2802 and NEMA Standard WC70. The feeder design shall be coordinated with the OCS pole foundations.

(ii) Negative Return Cables

A. The negative return cables shall meet the same requirements specified for the positive feeder cables and shall be installed from the substation negative bus to the running rails. Wherever possible, the negative return cables connection to the running rail shall be a cadweld connection. The negative return conduit location shall be outside the track, not between two rails and shall be coordinated with the design of the substation foundation.

(iii) Transfer Trip Cables

A. The transfer trip cables shall be fiber optic cables. Material and workmanship of all fiber optic cables shall be of the highest quality assuring durability for a 40 year design life. All cables shall be suitable for both wet and dry installations. The cable shall be suitable for direct field termination with most standard optical connectors. The outer jacket material shall be suitable for long-term exposure to sunlight and weather with a life expectancy in excess of 40 years. Suitability shall be determined in accordance with MIL-STD-810, method 505.

(iv) High Voltage AC Power Cables

A. The high-voltage AC power cables shall comply with all of the local utility requirements.

(v) Duct bank, Manholes and Hand Holes

A. Positive and negative cables shall be run in separate ducts, manholes and handholes.

6.8 Sectioning and Grounding Design Requirements

(a) Sectioning

(i) The system sectioning shall be designed to enable the electrical protective relays to disconnect faulted sections of the distribution system, to permit planned maintenance, and to permit flexible operation during system emergencies.

(ii) The TPSS configuration shall be of the double-end type with electrical continuity between substations. All sections of the distribution system shall obtain power from two adjacent substations.

(iii) Sectioning at the mainline tracks or crossovers used for normal train operations shall be performed by the use of insulated overlaps. Sectioning for emergency crossovers or turnouts, defined as crossovers or turnouts not used during normal revenue service, shall be performed using section insulators or insulated overlaps.

(iv) The primary connection and isolation of the system sections shall be performed by the substation DC feeder circuit breakers and by disconnect switches which shall be located adjacent to substations.

(v) Circuit protection and transfer trip features between substations shall be arranged so that a fault on either track shall remove power from the associated track. Activation of a substation emergency pushbutton shall also deactivate the tracks associated with that pushbutton and leave all other tracks unaffected.

(vi) Refer to Section 6.11 (t) for additional sectioning requirements

(b) Grounding for Stray Current Corrosion Control and Safety

(i) See Schedule 15-2 Article 17 for Corrosion Control and Grounding

(ii) OCS pole grounding resistance shall be less than 25 ohms.

(c) Grounding for Lightning Arresters

(i) All lightning arresters 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 less than 5 ohms. Pole grounds may be connected to lightning arrester grounding devices. Also see Section 6.11(u)

6.9 Traction Power System Product Requirements

(a) Equipment Description

(i) The traction power system shall consist of all equipment between the interface points with the power utility, the distribution system and negative return impedance bonds. The equipment includes AC cables, AC switchgear assemblies, transformer/rectifier units, DC switchgear assemblies, busbars, positive and negative cables, cable ductbanks, conduits and raceways, negative return and drainage assemblies, substation housings, foundations, grounding systems, protective systems, auxiliary power supply systems, HVAC systems, batteries and chargers, fire and intrusion detection systems, lightning arresters, annunciation and control systems, metering equipment, supervisory control equipment, portable fire extinguishers, circuit breaker test cabinet, special tools for maintenance, operating and maintenance manuals and training.

(ii) The electrical equipment shall be housed in TPSS, which shall be of the package type. Exceptions shall require approval from the Region of Waterloo. Each substation shall be factory pre-wired, assembled and tested and housed in a self supporting, transportable enclosure suitable for outdoor installation. Each substation shall be a completely self contained and integrated unit installed on previously prepared foundations which may be designed to accommodate a suitable crawl space, utilize cable trenches or other means that allow for ready replacement of cables or additional cabling to be installed in the future and connected via suitable feeder cables to the utility interface point and to the traction power distribution and return systems.

(iii) Entry doors shall be provided. The entry doors shall be of sufficient size for installation or removal of any piece of equipment if no other access is provided. All equipment shall be designed and arranged such that all repair, maintenance and cable connections can be accomplished from within the substation enclosure or through access panels at the rear of equipment line-ups.

(iv) Substations shall be provided with heating, ventilation, lighting, and AC auxiliary power distribution.

(b) Incoming AC Feeders

(i) The incoming substation service shall be by underground cables unless otherwise approved by the Region. Cable ductbanks, conduits, raceways and manholes inside the substation property line shall be designed from the point of utility interface to the traction power substation. The design shall be fully coordinated with the utility requirements and interfaced with the utility overhead or underground facilities. Project Co shall present to the Region as part of the Design Presentation Meeting process any location which Project Co is intending to use an overhead configuration as part of or for the entire length of the incoming service. The feeder rating shall permit the substations to supply the specified load cycle and short circuits without exceeding the allowable equipment temperatures.

(ii) Project Co is responsible for all costs of providing power and metering for the traction power substations. The hydro utilities can provide information on costs, technical requirements, and timing. Project Co should identify any additional ROW associated with providing service to the TPSS for Region approval as part of the Design Presentation Meeting Process. The Region will be responsible for acquisition of any additional ROW approved for TPSS.

(c) AC Switchgear

(i) The AC switchgear assembly shall provide the means to deliver, control, and measure the substation power requirements. The assembly shall be housed in dead-front enclosures containing AC disconnect switch, AC circuit breaker, metering equipment and auxiliary power supply.

(ii) The equipment shall conform to IEEE/ANSI C37.20.1 "IEEE Standard for Metal Clad and Station Type Cubicle Switchgear", and shall be UL listed and labeled, or certified by an independent accredited testing laboratory to meet ANSI and UL standards. Working space shall be provided to gain access to components from the front and the rear of the switchgear.

(d) Traction Power Transformer

(i) The rectifier transformer shall be self-cooled, dry type with primary voltage to be consistent with utility supply, and equipped with appropriate taps to ensure secondary voltages meet the Design Parameters provided in Section 6.5.

(ii) The transformer/rectifier shall be designed so that the maximum overall regulation rate is not greater than 6% ± 0.5% between 1% rated load and 450% rated load.

(iii) Project Co shall perform a Utility Impact Study that shows that their design meets all utility requirements for harmonic distortion and flicker.

(e) Rectifier

(i) The rectifier shall be silicon diode type, natural convection-cooled. Thyristor rectifiers will be considered, where necessary, to provide improved voltage regulation or reduce overall traction electrification costs. The rectifier shall be a complete operative assembly consisting of the diodes, heat sinks, internal buses, connections, diode fuses and all other necessary components and accessories. It shall consist of fullwave bridges providing 12-pulse rectification.

(ii) The rectifier shall be capable of withstanding the duty cycles specified in Section 6.4(a)(v) without exceeding the manufacturer's allowable diode junction temperature and without damage to any component.

(iii) The rectifier shall also be capable of withstanding the maximum theoretical short circuit current on the rectifier until cleared by the fault clearing devices.

(f) DC Switchgear Assembly

(i) The DC switchgear assembly shall consist of the positive and negative switches, rectifier, bus work, and DC circuit breakers. It shall form a lineup of dead-front metal clad switchgear built to ANSI C37.20.2 "IEEE Standard for Metal Clads and Station Type

Cubicle Switchgear". The DC circuit breakers shall be high-speed, stored energy, draw-out, single-pole units and shall have bottom feeder cable entry.

(g) Negative Return and Drainage Assembly

(i) The negative return assembly shall include negative disconnect switches, negative busbar, terminations for negative return cables and other associated equipment. All equipment shall be rated at the system maximum rated voltage.

(h) Programmable Logic Controller (PLC)

(i) The minimum acceptable requirements for a Programmable Logic Controller (PLC) and associated modules as described below for the specified control, processing, and monitoring system and to interface with the TPSS equipment and the SCADA System shall be met. The design shall provide a full featured, integrated, modular operational PLC system. The modules shall be capable of being inserted at the site, with no factory re-wiring required.

(ii) The design shall include a PLC relay interface system. All functional requirements specified shall be met or be exceeded by the PLC system. PLCs, associated network and interfaces shall be rated to utility standards for substation environment.

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

A. Electronic terminators shall replace the normal auxiliary and interposing relays. These shall be placed at the A/C switchgear cubicle, rectifier unit, rectifier DC disconnect switch unit, at each DC feeder circuit breaker unit and at each remote DC disconnect switch group.

B. A stand alone modular programmable controller, or protective relay, shall be designed to provide the breaker reclosure relay, long time overload relay, frame fault protection relaying and lockout relays. Running rail voltage monitoring shall be furnished at each DC feeder breaker.

C. "Transfer Tripping" of DC breakers adjacent to the section where a fault is detected will be provided by an optical fiber link and associated interface equipment.

D. A local area network providing communication from the feeder breakers modular programmable controllers to the substation master programmable controller shall be furnished.

E. A master PLC designed and programmed to integrate and control all interpanel connections and to provide substation monitoring and data logging shall be furnished at each traction power substation. The master PLC in combination with the above-described local area network shall result in the elimination of majority of the interpanel wiring where applicable.

F. A 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) shall be furnished at each traction power substation.

G. All PLC software shall comply with the requirements in Schedule 15-2 Article 9.15.

(iv) The PLC system and equipment shall be designed to operate in the environment and conditions specified by the requirements of the LRT system. 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/lEEE 281. The presence of transients on the communication interfaces shall not cause misoperation or blocking of any of critical communications. The system shall be failsafe.

(v) The systems shall also be capable of integrating with the SCADA system using Ethernet for communication. A SCADA points list will be submitted that includes alarms, status and supervisory control functions. Alarms will consist of all locally annunciated alarm points discussed in Section 6.9(i). Status points will consist of circuit breaker position, and other necessary points selected to give information about the condition of the remote station to Operations Control Center. The selection of a "local" control mode at the substation shall inhibit remote SCADA control of specific functions, but shall not prevent the monitoring of all substation parameters via the SCADA system.

(i) Local Annunciation

(i) 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 described in Section 6.9(h), if provided. The annunciator shall consist of LED indicating lamps, audible alarm, test, silence, acknowledge and reset switches, as well as other associated equipment.

(ii) It is preferred but not required that a blue light shall be installed on the exterior of the substation, visible to the train operators from the LRT trackway. If Project Co elects not to provide a blue light, Project Co is still responsible for complying with requirements cited in Section 6.11(r)(iii) . The blue light shall be continuously illuminated under normal conditions and shall flash whenever a DC breaker is open or the DC output is not available.

(iii) An electrical alarm "points list" shall be developed listing electrical alarms to be annunciated. These alarms will be annunciated locally and by the blue light which shall be visible from the trackway.

(j) Auxiliary Power

(i) The preferred source of auxiliary power for the substation enclosure is a dry type, single-phase, 25 kVA transformer fed from the incoming utility feed. Each substation shall be furnished with AC and DC distribution panel boards. 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.

(k) Busbars and Bus Connectors

(i) 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.

(ii) 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.

(l) Equipment Arrangement

(i) Substations shall have adequate area to accommodate all the electrical equipment and ancillary components. Relative spacing and positioning of each item of equipment shall permit installation, maintenance, removal and replacement of any unit without the necessity of moving other units. The arrangements of the equipment shall meet codes and 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.

(ii) Wall space for future growth shall be provided. Minimum working clearances will be provided per the NEC/OESC. A minimum of 1.8 metres (6') of space in front of high voltage switchgear shall be provided. Two exit doors with panic hardware, one from each end of the TPSS, shall be provided.

(iii) In the "end-of-line" substations space provisions shall be provided for additional AC and DC switchgear for any future extension of the LRT. The space, conduits, and configuration provisions for additional AC and DC switchgear shall be consistent with the space, conduits, and provisions for a typical mid-line TPSS.

(m) Grounding

(i) Each TPSS shall be furnished with a ground mat and provisions for equipment grounding. The ground mat shall be contained within the substation property lines and shall be designed so that the step and touch potentials at the rated short circuit current do not exceed the recommended safety limits of IEEE Standard 80. All grounding connections shall be capable of carrying the rated short circuit current. All normally non-current carrying metallic AC equipment enclosures, parts of AC equipment, or conductive fences shall be connected to the ground grid.

(ii) All normally non-current carrying metallic DC equipment enclosures or parts of DC equipment shall be installed insulated from ground and connected to the substation ground system through a ground fault detection system. This ground fault detection system shall detect and annunciate a grounded condition on the equipment and in case of an energized enclosure, disconnect the substation from the power sources.

(n) Negative Return System

(i) The substation negative bus shall be connected to the running rails. The rails shall be welded in continuous lengths. Any bolted rail joints shall be electrically bonded. At locations requiring insulated rail joints, the continuity of the negative circuit shall be maintained by the use of impedance bonds or equivalent devices.

(ii) In areas of double track equipped with double-rail AC track circuits, cross bonding between tracks for negative return equalization shall be accomplished by impedance bond center tap connections at each substation negative return connection location at the end of every second track circuit. In areas of double track equipped with single rail AC track circuits, cross bonding between tracks shall be accomplished by direct connections between the negative traction return rails only. Single rail negative return segments shall not exceed 18.3 metres (60') in length. In areas of trackage not equipped with track circuits, cross bonding between tracks shall be provided throughout the system, with a spacing of cross bonds of approximately 304.8 metres (1000').

6.10 Overhead Contact System (OCS)

(a) The OCS consists of the conductors, including the contact wire and supporting messenger wire, in-span fittings, insulation, jumpers, conductor terminations, and associated hardware located over the track and from which the vehicle draws power by means of direct physical contact between the pantograph and contact wire. The OCS shall provide for proper current collection under all operating conditions.

(b) The physical support system consists of foundations, poles, guys, insulators, brackets, cantilevers, and other assemblies and components required to support the OCS in the appropriate overhead configuration. The support system shall support the OCS in accordance with allowable loading, deflection, and clearance requirements. The OCS supports throughout the system shall incorporate double insulation.

(c) Each OCS pole shall have an identifying alpha-numeric designation suitable for use by emergency responders to locate or report a situation in coordination with the CCF.

(d) Full-feeding electrical continuity shall be equal to or greater than the electrical capacity of the OCS circuit ampacity.

(e) The design of the OCS shall be based on technical, economical, operational, and maintenance requirements as well as on the local climatic conditions which are outlined in these criteria.

6.11 Traction Power Distribution System

(a) General Requirements

(i) The traction power distribution system consists of all equipment between the interface with the DC traction power supply equipment at trackside disconnect switches, and the vehicle pantograph. The traction power distribution system consists of an OCS, trackside disconnect switches, plus at certain locations, underground parallel feeders.

(ii) The overhead distribution system shall be designed to be low maintenance and environmentally acceptable. Within the mechanical and structural design constraints, the system structures and associated equipment shall be as lightweight as possible and shall use visually unobtrusive fittings. The suspended bare conductor distribution system shall be double insulated with each level of insulation compatible with the system insulation class.

(iii) The overhead system shall be designed to allow the trains to operate with all pantographs in contact with the conductors at up to the maximum allowable speed without excessive oscillations of the system and permit current collection without pantograph bouncing or arcing.

(b) Distribution System Design Study

(i) The design of the distribution system shall be based on an engineering analysis. The analysis shall include calculations of the distribution system design parameters and include pantograph security analysis, pantograph operations analysis conductor tensions and maximum tension length analysis for 4.9 metres, 5.7 metres, 6.1 metres (16-0", 18'-6" and 20'-0") contact wire heights. It shall take into account all factors that contribute to displacement of the contact wire with respect to the pantograph, including:

A. Climatic data.

B. Conductor data.

C. Pantograph dimensions.

D. Maximum contact wire wear.

E. Pole deflection due to loads imposed.

F. Erection tolerances.

G. Vehicle roll and lateral displacement.

H. Sway of pantograph.

I. Track maintenance tolerances.

J. Static pantograph centerline variation from vehicle centerline.

K. Dynamic pantograph centerline variation from track centerline due to vehicle displacement on curves.

(ii) The result of this study shall define and provide values for the following parameters:

A. Maximum structure spacing as a function of track curvature and track vertical profile

B. Conductor blow-off, stagger effect and allowable static offset

C. Conductor rise and fall under various climatic combinations

D. Conductor along-track movement, stagger variation and wire elongation

E. Conductor tensions, sags and factors of safety under various climatic conditions

F. Contact wire deviation due to movement of hinged cantilevers

G. Conductor profile, hanger lengths and spacing

H. Equipment vertical and radial loads

I. Loss of conductor tension along the system due to wire movement and track gradient

J. Contact wire wear chart

K. Conductor temperature range for auto tensioning

L. Pantograph sweep rate criteria

M. Catenary system height criteria

N. Minimum hanger length criteria

O. Pantograph clearance envelope

(c) Contact Wire Height and Gradient

(i) Maximum contact wire gradients shall, wherever possible, not be more than 1 in 4 times line speed, and normal changes in gradient should not exceed half this value. The contact wire height at supports shall take into consideration the effect of wire sag, due either to temperature rise or to ice loading, and installation tolerance (including track construction and maintenance tolerances).

(ii) At critical locations (restricted clearance under bridges) or fixed track work points (e.g., grade crossings, and embedded or direct fixation track work), no allowance is required in the OCS design for track lift. At non-critical ballasted track locations, the OCS design shall allow for a future track lift of up to 75 mm.

(iii) When changing from one OCS type to another, the contact wire height shall be changed gradually to prevent pantograph bounce and arcing. The maximum gradients for contact wire change in elevation relative to the track elevation shall be in accordance with the AREMA Chapter 33 as follows:

Speed Limit/Location	Maximum Gradient
Yard	2.3%
48 km/h	1.3%
73 km/h	0.8%
96 km/h	0.6%

(iv) Except for the yard, the change of grade from one span to the next shall not exceed one half of the value shown.

(d) Loading:

(i) Loading shall be based on CAN/CSA C22.3 No. 1, combined wind and ice heavy loading conditions:

A. 400 N/m² Wind Pressure

B. 12.5 mm Radial Ice on Conductors

C. -20˚C Temperature

(e) Operating Condition and Non-Operating Condition

(i) The design of the overhead contact system shall include consideration of the effects of the following combinations of climatic conditions:

Load Case	Condition	Temperature		Wind Pressure		Radial Ice		Note
		°C	°F	N/m^2	PSF	mm	in	
OP1	Design	16	60	0	0	0	0	
OP2	No ice	16	60	400	8	0	0	
OP3	Ice and wind	-20	0	400	8	12.5	0.5	For messenger wire (see note in NO1)
	Ice and wind	-20	0	400	8	12.5	0.125	For contact wire (see note in NO1)

Load Case	Condition	Temperature		Wind Pressure		Radial Ice		Note
		°C	°F	N/m^2	PSF	mm	in	
OP4	Low temp, no wind, no ice	-25	-10	0	0	0	0	
NO1	C22.31 No.1	-20	0	400	8	12.5	0.5	CSA-C22.3 No.1, Table 30: Heaving Loading Area
NO2	High wind	16	60	766	16	0	0	
NO3	High temp, no wind	40	105	0	0	0	0	

(f) Overhead Contact System Styles

(i) Simple and Low Profile Catenary Auto Tensioned Style

A. At-grade open route mainline tracks, and associated crossovers, shall utilize simple catenary style wiring, automatically tensioned by balance weight assemblies. A simple catenary style shall consist of a messenger wire supporting a contact wire by the means of hangers. Messenger wire is to be located vertically above the contact wire; "warped" or curvilinear wiring arrangements shall not be used. In areas designated by the Region, a low profile catenary system shall be used.

B. Auto-tensioning shall be accomplished by means of balance weight assemblies, which shall be mounted on anchor poles located at the ends of each tension length. Midpoint anchor arrangements shall be used in the center of each tension length to prevent along-track movement of the overhead catenary system at that point.

(ii) Single Contact Wire Auto Tensioned Style

A. In areas designated by the Region, where the environmental impact of simple or low profile catenary configuration is not desirable, a single contact wire style with parallel underground feeders shall be provided. This single contact wire equipment shall be automatically tensioned, except where certain track junction wires have been designated to have fixed terminations.

B. The system in the streets shall be supported and registered by means of single cross-span head span wires designed to accommodate along track movement or hinged cantilevers. At sharp curves and corners, wire pull-off assemblies may be used. The contact wire shall be staggered.

(iii) Single Contact Wire Fixed Termination Style

A. At operations facilities and designated tracks junctions, single contact wire fixed termination style wiring shall be used.

B. The wiring shall be supported and registered by means of cantilevers or single cross-span head span wires. At sharp curves and corners, wire pulloff assemblies may be used. The contact wire shall be staggered.

(iv) Simple or low profile Catenary Fixed Termination Style

A. Tension lengths shall each be designed to be wholly of a single style. Where two tension lengths of different styles abut at an overlap or cross a turnout, the equipments and fittings shall be designed for smooth operation of pantograph under all possible climatic variations.

(v) OCS Conductors

A. The contact wire shall be solid grooved hard-drawn copper, conforming to ASTM Specification B47 (size: 350 Kcmil).

B. The messenger wire shall be standard hard-drawn copper, conforming to ASTM Specification B189, (size: 500 Kcmil), with stranding conforming to ASTM Specification B8, class B or higher.

C. In the design for conductor tension, a 30% cross-sectional area loss due to wear of contact wire shall be considered

(vi) Electrical Clearances

A. The following clearances shall be maintained between live conductors (including pantograph) and any grounded fixed structures in accordance with the AREMA Manual, Chapter 33, Part 2, as follows:

	Static (CA)	Passing (PA)
Normal Minimum	105 mm	80 mm
Absolute Minimum	80 mm	80 mm

B. Static clearance is the clearance between the OCS, when not subject to pantograph pressure, and any grounded structure.

C. Passing clearance is the clearance between the OCS or pantograph and an overhead structure under actual operating conditions, during the time it takes the train to pass.

D. Mechanical clearance from the pantograph to any fixed item, excluding the steady arm or steady arm or registration pipe of the cantilever, shall not be less than 80 mm. Heel setting shall not be less than 40 mm.

E. LRV related clearances shall include the full dynamic displacement of the vehicle under operating conditions (including track and other installation and maintenance tolerances).

F. Railroad related clearance shall conform to the requirements of the railroad.

(g) Tension Length Design

(i) The overhead system shall consist of a number of tension length sections. Each tension length shall be designed as long as possible considering the mechanical constraints of the system design, such as displacement of contact wire due to swinging cantilevers, balance weight travel and manufacturing limits of conductor length. Further, the tension length design shall take into account the sectioning requirements.

(h) Overlaps, Crossovers and Turnouts

(i) One span overlaps are preferred. Non-insulated one span overlaps shall be designed to permit future installation of insulation. Single point overlaps shall not be designed for use with simple catenary wiring or where train speeds exceed 56 km/h (35 mph). Two span non-insulated overlaps may be located on circular curves. Overlaps shall not be built over track sections with spiral transition curves.

(ii) The overlap, crossover and turnout arrangements shall be designed considering the electrical and mechanical properties of the overhead contact system. The designs shall enable a uniform uplift of the contact wires of each system with no hard spots. A smooth pantograph passage and good current collection without arcing shall be achieved under all operating conditions.

(iii) Electrical and mechanical clearances shall be maintained between adjacent cantilevers and between the cantilever frames and adjacent conductors. Where any wires are auto-tensioned, the clearances shall allow for the cantilevers attached to adjacent tension lengths to move in opposite directions as the temperature changes without causing misalignment of the system.

(iv) The overlap, crossover and turnout arrangements shall be designed using single poles with twin cantilevers. Only where this arrangement is not possible, two poles with one cantilever each may be used. In areas where center poles are used, the overlaps shall be staggered along the track to reduce pole loading.

(i) Structure Spacing

(i) Structure spacing for the overhead system shall be as long as possible. The structure spacing shall be optimized so that the contact wire remains within the pantograph head and maximum wire offset available for the designed contact wire height.

(j) Foundations

(i) The design of foundations for supporting structures and guy anchors shall be based on the structure loading calculations and soil data.

(ii) Load cases; See Section 6.11(g)(i)

(iii) Lateral Deflection Criteria: The lateral and rotational movement of the foundation with respect to the displacement of the contact wire shall be limited to 30 mm of lateral displacement measured at the maximum contact wire height due to 400 N/m^2 wind pressure. This is for wind only and assumes that the pole has been raked to vertical for dead loads and does not include deflection of the foundation itself.

(iv) The supporting structure foundation shall be designed to accept bolted base poles and shall have provision for feeder conduits and structure grounding

(k) Poles and Supporting Hardware

(i) All poles shall be designed as free standing except for guyed termination poles. All poles shall have a base plate drilled to fit the foundation bolt pattern and shall have provision for grounding or bonding conductors.

(ii) For open track the poles may be IPN No. 200 to 360 wide flange beams or tapered steel poles mounted between the tracks except where special conditions require side poles. For operations in paved track or where aesthetics are important, tapered tubular steel poles, multisided, tubes or similar aesthetically pleasing structural shapes ranging from 200 mm to 400 mm depending on the application shall be used. At a minimum, tubular steel poles, multisided, tubes or similar aesthetically pleasing structural shapes shall be used between Conestoga Mall LRT Stop and the Northfield Dr LRT Stop as well as the LRT alignment section between Erb Street and the intersection of Mill Street and Ottawa Street. The tapered tubular steel poles, multisided, tubes or similar aesthetically pleasing structural shapes OCS poles shall be coated or painted in a color selected by the Region.

(iii) Load Cases; See Section 6.11(g)(i)

(iv) Lateral Deflection Criteria: Limited to 30 mm maximum contact wire height due to 400 N/m² wind pressure. This is for wind only and assumes that the pole has been raked to vertical for dead loads. Lateral deflection must be included in the calculations for establishing track centres.

(v) In areas designated by the Region, poles shall be of an ornamental style, to provide for joint use with street lighting or traffic services, and be suitable for internal installation of balance weight assemblies.

(l) Cantilevers

(i) The cantilevers shall be designed for a range of loads, pole-to-track centerline distances, and for a range of contact wire heights, whilst considering the system installation tolerances. In locations where railroad is operating adjacent to a LRT track, or railroad and LRT jointly use the same track, the clearance between pole face and centre line of track shall be a minimum of 2.6 metres (8’6”). This clearance shall be increased as per railroad requirements to account for curvature and track superelevation as applicable

(ii) The cantilever members shall be designed for easy installation and adjustment. Cantilevers shall be designed to be capable of field adjustment of both contact wire and messenger wire stagger values over the range of the affects of track maintenance tolerances, without disturbance of wire height adjustments.

(iii) Direct push contact wire registration arrangements shall not be used.

(m) Underbridge Supports

(i) Underbridge supports shall only be used when the geometry of the bridge (width) prevents the catenary to flow through unattached meeting the electrical clearances. The supports shall be designed to restrict the uplift of the contact wire when subjected to pantograph pressure and shall be capable of providing vertical and across-track adjustment. The supports shall permit the longitudinal movement of the contact wire.

(ii) Components of underbridge support assemblies shall be available as standard spare parts from manufacturers existing catalogs where possible. Custom components and steelwork fittings should be confined as much as possible to those sub-assemblies needed to attach standard parts to the bridge.

(n) Insulators

(i) Insulators shall provide electrical insulation in accordance with the system insulation class. Insulators shall be rated for the dynamic loading of the overhead system and shall have the mechanical safety factors specified. The insulators shall have resistance against deterioration from exposure to sunlight and airborne chemical pollution.

(o) Conductors and Associated Items

(i) All feeder and connecting cables shall be insulated, stranded copper conductors with sufficient flexibility to prevent fatigue failure of the cable due to vibration of the overhead conductors.

(ii) All conductor connections, attachments, hangers and clamps shall be copper or bronze fittings and shall be designed for ease of replacement and maintenance.

(iii) Current continuity and potential equalizing jumpers shall be flexible or braided copper conductors. The spacing of the jumpers shall be determined based on the required current conductivity. However, a minimum of one jumper per span shall be used.

(p) Terminations and Midpoint Anchors

(i) Strain-type termination assemblies shall be lightweight and of aesthetically pleasing appearance. Wire wrap, straight line, cone, or wedge type designs are acceptable. Turnbuckles shall be included as appropriate and be adjustable and lockable.

(ii) A mid-point anchor arrangement shall be used at or near the mid-point of each tension length of auto-tensioned equipment to restrict movement of the conductors at that point. These shall be designed to restrain both messenger wire and contact wire when applied to simple catenary style wiring.

(q) Tensioning Devices

(i) The auto-tensioned system conductors shall be tensioned using cast iron, steel or lead counterweights.

(ii) Balance weights shall be positioned to be as unobtrusive as possible.

(iii) Balance weights shall be equipped with a guide rod to prevent lateral movement. In the LRT alignment section between Erb Street and the intersection of Mill Street and Ottawa Street, balance weights are to be installed inside tubular poles.

(iv) The tensioning devices shall accommodate conductor expansion and contraction and shall be provided with broken wire restraint arrangements. All operating wires shall be of flexible, non-rotating stainless steel wire.

(r) Sectioning Equipment

(i) The mainline electrical sectioning shall be achieved by means of insulated overlaps whenever possible. At crossovers and turnouts, bridging section insulators may be used. Non-bridging section insulators shall be installed where voltage changes occur between adjacent substations, or where staff requires access to the top of rail vehicles, such as at maintenance yards and shops.

(ii) It preferred that Project Co provide no load disconnect switches to electrically connect and disconnect line sections. The disconnect switches shall be rated to withstand the system worst-case overload and short circuit conditions without overheating. If Project Co provides no load disconnect switches, the no load switches shall be interlocked to prevent operation when under a load. If Project Co provides load break switches, the load break switches shall be capable of breaking the maximum load current under emergency conditions without hazard to the person operating the switch.

(iii) In areas where the OCS is de-energized for railroad freight operations, a tagged visual indication that the OCS has been de-energized shall be provided to the railroad train crew.

(s) Surge Arresters

(i) Overvoltage protection for the overhead system shall be provided by surge arresters. The arresters shall be rated to withstand the maximum system voltage and anticipated voltages induced from any paralleling high-voltage transmission lines onto the system conductors. The arresters shall be capable of discharging the energy resulting from lightning strikes. Surge arrester ratings and locations shall be coordinated with TPSS requirements.

(ii) At a minimum, arresters shall be located at each substation feed point and in all areas of reduced clearances, such as at overhead bridges. Distance between surge arresters shall be a maximum 650 metres.

(t) Protective Screening

(i) When the LRT is constructed below bridges, buildings, and structures, screening and fencing shall be erected on the structures and stairs to isolate the overhead contact system wires and fittings from human contact where appropriate.

(ii) Conductive screening and fencing shall be electrically grounded.

(u) Design Parameters

(i) The basic design parameters for the TES are provided below.

Exhibit 6.11-1 - Design Parameters

Climatic Conditions	
Maximum Ambient Temperature:	40°C
Minimum Ambient Temperature:	-25°C
Radial Ice Loading:	12.5 mm
Maximum Wind Pressure:	
Structural design	760 N/m^2
Pantograph Security	400 N/m^2
CS Conductor Sizes and Material	
Messenger Wire: Copper. Alternative sizes require Regional approval	500 Kcmil Hard-drawn Copper
Contact Wire:	350 Kcmil Solid Grooved Hard-Drawn Copper
Factors of Safety -- Conductors and Wires	
Operating:	2.0

Non-operating:	1.6
Contact Wire Wear for Mechanical Design	30%
Factors of Safety – Hardware	
Operating:	2.5
Non-operating:	2.0
Minimum Electrical Clearances	
Static Clearance:	See Section.11(f)(vi)A
Passing Clearance:	See Section.11(f)(vi)A
Maximum Contact Wire Gradients	
Constant Gradient:	See Section 6.11(c)
Gradient Change:	See Section 6.11(c)
Pantograph Security	
Minimum Pantograph Security:	80 mm
Loss or gain of tension within a tension section shall not exceed:	4%
Track maintenance Tolerances	
Ballast Track	
Alignment:	30 mm
Cross level:	30 mm
Embedded Track	
Alignment:	15 mm
Cross level:	15 mm
Track Gauge	
Widening:	16 mm

Vehicle Data	
Maximum Roll (broken springs)	4%
Pantograph Data	(Contractor must verify with vehicle supplier)
Width:	1.9 metres
Separation of Carbons:	304.8 mm-330.2 mm
Length of Carbons:	1.3 metres
Maximum Carbon Wear:	
40 mm x 25 mm Carbons	25.4 mm
75 mm x 15 mm Carbons	15.9 mm
Maximum Operating Height	6400 mm
Normal Operating Height	5485 mm
Minimum Operating Height	3800 mm
Lockdown Height	3635 mm
Contact Wire Height	
Normal Contact Wire Height not above public roadways or driveways	5485 mm
Normal Contact Wire Height Above public roadways or driveways	5640 mm or 5485 mm plus the maximum sag condition for the contact wire, whichever is greater
Minimum Contact Wire Heights Above Top-of-Rail	4000 mm Regional approval is required for any deviation in the minimum contact wire height (e.g. overpasses)