Introduction

(This introduction is not part of IEEE PXXXX, Catenary Design Standards)

The Overhead Contact Systems Sub-Committee for Rail Transit Systems was formed in 2001 with the purpose of developing standards governing the design and construction of overhead contact systems for rail transit. The primary concern of the Overhead Contact Systems Sub-Committee Working Group XX was to unify practices and applications for the design and implementation of dc overhead contact systems for rail transit vehicles and electric trolleybuses (ETB). The majority of the present operating DC electrified rail systems use overhead contact system (OCS) or third rail to supply power to the vehicles. Overhead contact systems xxx

This standard specifies:
- definitions pertaining to catenary design used for rail transit vehicles and trolley buses
- Design standards for overhead contact systems
- XXX

This standard does not consider
- to be written

This standard is intended to apply to rail transit vehicles that are electrically powered, which are defined to include Heavy Rail Vehicles (“subway or elevated” cars) and Light Rail Vehicles (streetcars), including units which combine powered and unpowered trucks or axles. This standard does not apply to vehicles which include locomotives and railway electric multiple unit (EMU) cars. Fully-automated, driverless implementations of rail transit vehicles are sometimes included in the mode of transit referred to as Automated Guideway Transit (AGT), and, to the extent that the vehicle does not have other unique requirements, this standard can be applied. It is not intended that this standard be universally required for all AGT systems.

NOTE - Self-propelled railway vehicles operating on trackage of the general railroad system are subject to regulations issued by governmental bodies (e.g. federal, state, and local bodies). In selected jurisdictions this is also true for rail transit vehicles. The user of this Standard should recognize that such regulations always take precedence over a consensus standard.

At the time this standard was completed, the working group had the following membership:

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The following members of the balloting committee voted on this standard. Balloters may have voted for approval, disapproval, or abstention. (To be provided by IEEE editor at time of publication.)
1. Overview
This Overhead Contact Systems Sub-Committee for Rail Transit System was formed in 2001 with the purpose of developing standards governing the design and construction of overhead contact systems for rail transit.

1.1. Scope
This standard (recommended practice) defines the general design parameters of overhead contact system (OCS) design for direct current (dc) transit systems. This standard does not apply to the design of OCS for railroad systems.

The recommendations that follow are intended for new systems and for the expansion of systems where a legacy of design standards does not exist. This standard is not intended to replace or supersede existing design standards but rather to formalize the design process.

1.2. Purpose
This standard (recommended practice) applies to the design of OCS used to power heavy rail vehicles, light rail vehicles, streetcars, and electric trolleybuses (ETB), where traction power is supplied from a direct current, overhead contact system, with a nominal voltage of 600 Vdc and above.

The purpose of this standard is to develop performance requirements and design guidelines for overhead contact systems that provide for the operation of current collectors mounted on transit vehicles, and to control hazards, improve performance and reliability, and reduce life cycle cost. It is consistent with passenger safety, system reliability, mode of operation, type of vehicle to be used, and maintenance.

2. References
This standard shall be used in conjunction with the following publications. If the following publications are superseded by an approved revision, the revision shall apply.
IEEE PXXX, “XXXXXXXXXXX”
IEEE XXX, “XXXXXXXXXXX”
IEEE Std 100-1996, “Standard Dictionary of Electrical and Electronics Terms”

2.1. Applicable Laws, Regulations, Standards and Guidance
In addition to this standard, the design of a OCS must comply with all other applicable engineering codes and standards, including those of the various federal, state, and local jurisdictions.

If codes and/or manuals are specified or referenced herein for the design of an element of a OCS system, then the most recent edition(s) shall be used. Responsibility for design remains with the Design Engineer.

Where design codes conflict with each other, the Design Engineer shall investigate which codes and manuals have priority.

Specific codes and standards include, but are not limited to, the following:

Americans with Disabilities Act (ADA)
3. Definitions

The principle terms and definitions applicable to this standard are specified as follows: for other terms and definitions, see IEEE OCS Dictionary of Terms (under preparation).

Supplier: The manufacturer of the OCS components.

Customer: The entity purchasing or ordering the OCS equipment, which may be either the operating authority or the installing contractor.

Operating Authority: A geographical or political division created specifically for the single purpose of providing transportation service.

OCS supplier: The entity assembling or manufacturing the OCS components

Light Rail Transit: A mode of rail transit characterized by its ability to operate on exclusive rights-of-way, street running, center reservation running, and grade crossings and to board and discharge passengers at track or vehicle floor level

Heavy Rail Transit: A mode of rail rapid transit generally characterized by fully grade-separated construction, operation on exclusive rights of way, and station platforms at the floor level of the vehicles.
Light Rail Vehicle: A vehicle which operates on a light rail transit system, capable of boarding and discharging passengers at track or vehicle floor level.

Heavy Rail Vehicle: A vehicle operating on a heavy rail transit system. Typically, electrically propelled, bi-directional, capable of operating in multiple unit, and designed for rapid, high-level boarding and discharging of passengers.

Nominal Voltage of an Overhead Contact System: Voltage used to describe the line and taken as a reference for certain functional characteristics of the line.

Contact Wire: The wire with which the pantograph or trolley pole makes current collection.

Hanger: Component used to suspend a cross-span, an auxiliary catenary or a contact wire from a headspan or a catenary

Mechanical tensioning equipment: Arrangement enabling the mechanical tension of the conductors to be adjusted.

Automatic tensioning: Device used in tensioning OCS conductors and equipment to automatically maintain constant the mechanical tension within certain temperature limits.

Span: The overhead contact system from one support or suspension to the next.

Supports: Those parts of an overhead contact system which support the conductors and their associated insulators and other equipment

Portal structure: Structure consisting of a transverse beam and poles situated on either side of the tracks.

Head span suspension: An assembly of multiple span wires consisting of a head span, body span and/or steady span.

Foundation: A construction, usually of concrete, completely or partly buried in the ground to which the support is attached, in order to insure stability.

Ground wire: Metal wire connecting supports to earth ground and/or to rail, to protect people and installations in case of installation failure.

Rail joint bond: Conductor ensuring the electrical continuity of rails at a joint.

Stray currents: Portions of the return current which follow paths other than the return circuit (i.e. earth, pipes, metallic structures).

Reserved track: Track (or road) intended solely for railways, tramways, or trolley bus traffic, and forbidden to any other type of traffic.

Gradient (of an OCS): The ratio of the difference measured in height of the contact wire above rail level at two successive rail level at two successive supports to the length of the span.
Design engineer: Individual or organization performing the design. This may include Owner Staff, Consultants, Subconsultants, and others.

Contractor: Refers to the procurement, installation, or construction contractors actually under contract for the construction and implementation of the project.

Creep: The plastic deformation of a material as a function of time while under a constant stress.

4. Technical Requirements
This standard is applicable to electric traction overhead lines (in accordance with the definition given in Sub-clause 1.2.1) for railways, tramways and trolley buses. It is not applicable to feeders remote from the track. It is recommended that these provisions should be applied to electric traction overhead lines of new construction or when complete transformation of existing lines takes place. In the absence of national regulations or standards, this standard shall apply.

5. General Design Requirements for Overhead Contact Systems (OCS)

5.1. General Provisions
The Traction Electrification System (TES) provides electrical power to electric propelled vehicles by the means of Traction Power System 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. LRVs collect current from the contact wire by means of pantographs and return the current to the substations via the running rails. Trolleybuses (ETBs) collect current through a pair of trolley wires one for supplying power and the other acting as the return. Streetcars can either have pantographs or trolley poles, and their overhead traction power distribution system will either be like an LRT OCS or an ETB trolley overhead. Streetcar trolley overhead is described in more detail in Section 14, and ETB overhead in Section 15.

The selection of the OCS Style is dependent upon power demand and application along the route or in their yards. See Table No. 5-1.

<table>
<thead>
<tr>
<th>Application</th>
<th>LRT</th>
<th>Trolley Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Line Dedicated ROW</td>
<td>Simple Catenary</td>
<td>Two trolley wires with underground feeders</td>
</tr>
<tr>
<td>Main Line Cross-overs</td>
<td>Simple Catenary</td>
<td></td>
</tr>
<tr>
<td>Yard Tracks</td>
<td>Single Contact Wire</td>
<td>Two trolley wires with underground feeders</td>
</tr>
<tr>
<td>Yard Leads from mainline</td>
<td>Simple Catenary</td>
<td>Two trolley wires with underground feeders</td>
</tr>
<tr>
<td>In Street running</td>
<td>Single Contact Wire with underground feeder, or Low</td>
<td>Two trolley wires with underground feeders</td>
</tr>
</tbody>
</table>
5.1.1. OCS Line voltage

Standard nominal value of the voltages of the OCS and Trolley Overhead systems are specified in Table No.5-2.

Table No. 5-2

Nominal Voltages for LRV OCS and ETB TOH

<table>
<thead>
<tr>
<th>Type of System</th>
<th>Nominal Voltage (DC)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>LRT OCS</td>
<td>600 750 1,500</td>
<td>It is recommended that new LRT Systems the OCS nominal supply voltage be 750 V or 1,500 V,</td>
</tr>
<tr>
<td>Trolley Overhead</td>
<td>600 750 750</td>
<td></td>
</tr>
</tbody>
</table>

In existing installations voltage may be different from those shown in Table No. 5-2. The values of the “Lowest” and “Highest” limits (in accordance with the definitions in IEC Publication 38) between which the voltage of the traction systems may vary are given in IEC Publication 850. Alternatively Table No. 5-3 is offered (See AREMA 33)

Table No. 5-3

Voltage Supply Range

<table>
<thead>
<tr>
<th>Nominal Voltage</th>
<th>Normal Upper Voltage Limit</th>
<th>Normal Lower Voltage Limit</th>
<th>Emergency Minimum Operating Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>660</td>
<td>480</td>
<td>420</td>
</tr>
<tr>
<td>700</td>
<td>770</td>
<td>560</td>
<td>490</td>
</tr>
<tr>
<td>1500</td>
<td>1650</td>
<td>1200</td>
<td>1050</td>
</tr>
</tbody>
</table>

5.2. Design Life Requirements

The TES shall be designed for a minimum functional life expectancy of thirty (30) years, by:
- careful selection of materials
- detailing of structures
- use of proven components
- catering to corrosion, and
- adequate factors of safety.

5.2.1. Materials

The use of galvanized steel for OCS supports and hardware, copper for conductors, copper alloy for fittings for conductors, galvanized steel wires
for guys, stainless steel for wires ¼ in. and smaller, concrete for foundations and concrete inserts for attachments to civil structures is typical of all recently built LRT systems.

5.2.2. Detailing of Structures
LRT systems are typically not more than two track, so that side poles or center poles are ideal. Although welded lattice poles may have a lower initial cost than solid cross-section such as WF-beams and tubular poles, past experience is that the welded joints can be improperly galvanized which leads to early corrosion, and painting can be an issue in terms of proper surface preparation, and the logistics of doing the work.

5.2.3. Proven Components.
The use of hinged cantilevers with the repetitious use of a small design range of assemblies using a small number of the service proven components, makes for ease of initial construction, a reduced spares inventory for maintenance and flexibility when fitting out maintenance vehicles.

5.2.4. Corrosion Control.
Corrosion control measures are used to prevent premature failures of the OCS and damage to underground structures and facilities caused by atmospheric pollution, corrosive soils and LRT dc. stray currents. These control measures shall be directed towards the following objectives:

- Realize the design life of system facilities by avoiding premature failure caused by corrosion.
- Minimize annual operating and maintenance costs associated with material deterioration.
- Provide continuity of operations by reducing or eliminating corrosion related failures of systems and subsystems.
- Minimize detrimental effects to facilities belonging to others as may be caused by stray earth currents from transit operations.

Corrosion control systems should be economical to install, monitor and maintain.

5.2.5. Factors of Safety
Design Factors of Safety shall be applied as given in Table No. 5-4

<table>
<thead>
<tr>
<th>Device</th>
<th>Factor of Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Messenger Wire</td>
<td>2.0</td>
</tr>
<tr>
<td>Contact Wire (30% worn)</td>
<td>2.0</td>
</tr>
<tr>
<td>Tension Insulators</td>
<td>3.0</td>
</tr>
<tr>
<td>Stand-off Insulators</td>
<td>2.5</td>
</tr>
</tbody>
</table>

5.3. Service Conditions
5.3.1. Environmental Conditions
Temperature, wind, ice and other climatic and environmental (pollution) conditions in which the system must operate will impact the design of the OCS. Extreme weather conditions such as maximum and minimum ambient temperature, build up of ice on the
supports and conductors, and maximum wind speeds, affect conductor tensions and conductor sags, which in turn need to be catered to by careful control of contact wire design heights (which are typically expressed only for NORMAL conditions) and the sizing of poles to cater to worst case conditions as specified in Section 25 of the National Electric Safety Code (NESC).

5.3.2. Environmental parameters to be considered when designing OCS include:

- temperature range
- wind speed
- ice coating thickness
- icicles
- ground topography
- geophysical conditions
- isokeraunic level (lightning strikes)
- elevation
- atmospheric pollution

and any other adverse conditions peculiar to the region where the line shall be installed shall also be considered.

5.3.3. Temperature Range

The loading on an OCS will change as the ambient temperature changes. The temperature range is the range the ambient temperature can change over the course of a year. Typically the limits of the temperature range are defined as the historic low temperature and the historic high temperature as defined by NOAA.

5.3.3.1. Average Ambient Temperature

The average temperature is the average annual ambient temperature. The average annual temperature is typically used to dimension the OCS in the normal position.

5.3.3.2. Maximum temperature

The maximum operating temperature is highest ambient temperature at which the system is expected to operate. The maximum temperature is 50°C (120°F) or the historic high temperature for the area, which ever is greater. OCS design must also consider the effects of current heating on the conductors and the resulting thermal expansion.

5.3.3.3. Minimum Temperature

The minimum temperature is lowest temperature at which the system is expected to operate. The minimum temperature is typically 0°C (32°F) or the historic low temperature for the area, which ever is lower, or as defined in Agency design criteria.

5.3.4. Wind Speed

In order to check the stability of the various parts of the OCS, it is necessary to consider the load caused by wind.
To calculate this load, it is assumed that the wind blows horizontally and exerts its force perpendicular to the surface in question. Wind load is calculated differently for structures than it is for wires, using a different set of factors corresponding to both dimensions and shape.

In accordance with Section 250.C of the NESC the following formulae are to be used to determine the force exerted by wind:

\[
F = D_a \cdot V^2 \cdot k_z \cdot G_{RF} \cdot I \cdot C_d \cdot A
\]

Where

- **F** = wind load
- \(D_a\) = Ambient Air Density constant 0.61, metric (0.00256, english) at 15°C (59°F) at sea level 760 mm HG (29.92 in HG)
- \(V\) = Basic Wind Speed m/s at 10 m (mph at 33 ft) above ground
- \(k_z\) = Velocity Pressure Exposure Coefficient = 1.0 for structures or wires below 10m (33ft). See NESC Rule 250C1, table 250-2 for structures above 10 m (33 ft) above ground
- \(G_{RF}\) = Gust Response Factor 1.02 for structure less then 10 m (33 ft) above the ground and 0.93 for wires span lengths less then or equal to 75m (250 ft) for other structure heights and spans lengths see table 250-3 of the NESC
- \(I\) = Importance Factor 1.0 for structures and their supported facilities
- \(C_d\) = Shape Factor – 1.0 Cylindrical Structures and Wires, 1.6 for Flat surfaces. See Rule 252 B from the NESC for Lattice Structures
- \(A\) = Projected wind area m^2 (ft^2)

5.3.5. Ice Coating Thickness

Ice and snow can accumulate on the OCS. The added weight of the ice and snow will increase the loading conditions on the equipment; increasing tensions and dead loads; increasing the sag of wires, and increase the effective diameter of a wire to wind. In accordance with NESC section 250 A & B the amount of ice loading to be applied to the OCS will fall in three general degrees of loading, light medium and heavy. The location of the OCS system will determine the loadings, Figure 5-5 shows the general loading map pf the United States with respect to loading of Overhead lines from section 250 of the NESC.

Table 5-6 gives the standard combinations of ice, wind and temperature that need to be considered.
Table No.5-6

Ice, Wind and Temperature

<table>
<thead>
<tr>
<th>Loading districts</th>
<th>Extreme wind loading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heavy</td>
</tr>
<tr>
<td>Radial thickness of Ice (mm)</td>
<td>12.5</td>
</tr>
<tr>
<td>Radial thickness of Ice (in)</td>
<td>0.50</td>
</tr>
<tr>
<td>Horizontal wind pressure (Pa)</td>
<td>190</td>
</tr>
<tr>
<td>Horizontal wind pressure (LB/ft²)</td>
<td>4</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>-20</td>
</tr>
<tr>
<td>Temperature (°F)</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: IEEE NESC C2-200?

5.3.6. Icicles. -- Icicles are typically formed by the dripping of water under freezing conditions. Bridge and tunnel soffits should be water tight, but if they are not, special consideration must be made to mitigate the harm the icicles cause, such as coating insulators or impacting pantographs. Ice building up on linings at the mouths of tunnels can be prevented by the application of thermal insulation set marginally away from the lining. The core temperature of rock (normally about 46°F) keeps the water from freezing, so that it can drain away naturally.

5.3.7. Ground Topography – The relationship of the right of way to the surrounding topography can have affects on the performance of the OCS and TES system. Differences in elevation or the presences of large structures can cause excessive wind speeds. On embankments, wind is ‘funneled’ over the tracks thus increasing wind speeds and increasing contact wire blow-off. Additionally, consider special wind regions cited in Section 250C of NESC.

5.3.8. Geophysical Conditions,

5.3.8.1. Soil Resistivity – Soil resistivity will affect the design of the grounding systems. In general, a soil resistivity measurement of 25 ohms or less should be used for general grounding. A resistivity measurement of 5 ohms or less should be used for lightning protection. Reference IEEE Std 81- The IEEE Guide for Measuring Earth Resistivity, Ground Impedance and Earth Surface Potentials of a ground Systems

5.3.8.2. Seismic Considerations – follow local building codes for seismic considerations.
5.3.8.3. Corrosive Soils -- Deterioration of concrete foundations due to corrosive soils must be addressed.

5.3.8.4. Soil Strength – poor soils require special attention to the pole foundation design and may require special installation methods.

5.3.8.5. Rock – ‘Ledge’ which is a highly fractured rock requires special foundations, as it is unreliable as a structural mass for the direct embedment of anchor bolts.

5.3.9. Lightning Strikes, characterized by Isokeraunic Level – The amount and intensity of lightning will affect the durability of components of the OCS and may cause insulator failure if not safeguarded. Careful consideration to the isokeraunic level shall be given when designing lightning protection and basic insulation levels.

5.3.10. Elevation - The air dielectric strength is reduced with increases in elevation. Depending on the operating voltage of the system, increases in clearances are required for installation operating over 3000 feet above mean sea level. See NESC latest addition.

5.3.11. Pollution – Atmospheric pollution can decrease the effectiveness of insulators, cause corrosive conditions, and decrease the life of the OCS. The sources of air pollution include diesel locomotives, exhaust stacks from coal plants. If pollution sources are present, special consideration should be given to areas where the pollutant may be able to concentrate, such as in tunnels.

5.3.12. Other Environmental Considerations -- As may be determined.

5.4. OCS Conductors
The OCS transmits power along the rail line to the train via conductors that provide a continuous contact line for pantographs. There are one or more conductors in an OCS system. Single wire systems consist of a single contact wire, simple catenary systems consist of a contact and messenger system. Other conductor styles are not usually selected for new LRT systems.

Trolley buses use two trolley wires a positive and a negative.

5.4.1. Conductor Selection.
Based upon the required conductor cross-sectional area determined from Traction Power Analysis as supplied by the Traction Power Staff, OCS conductors are selected that provide the best economy-commutation performance. For a simple catenary system this selection typically combines a 500kcmil messenger with a 350kcmil contact wire. The larger the contact wire, the longer the life. Also the greater the tension the less the wind blow-off and therefore the greater the possible maximum span, for a given pantograph width and track parameters. Higher tension and greater mass improve commutation, and result in less pantograph uplift. Other messenger/contact wire combinations are installed in existing LRT systems, but although 4/0 AWG and 300kcmil contact wires were installed on starter systems, later extensions have typically been the 500 kcmil messenger/350kcmil contact wire combination.

5.4.2. Conductor Characteristics
5.4.2.1. Contact Wires
It is recommended that grooved trolley wire be used of sufficient size and strength for the intended application. Applicable agency standards (Design Criteria) shall apply.
5.4.2.2. Messengers
It is recommended that a stranded messenger wire be used of sufficient size and strength for the intended application. Applicable agency standards shall apply.

5.4.2.3. Ancillary Wires and Cables
The types and characteristics of other wires and cables on OCS shall be chosen to satisfy the use for which they are intended.

5.4.3. Mechanical Design of Conductors

5.4.3.1. Factors of Safety.
The suitability of the basic material and its compatibility with the imposed mechanical stress shall be checked using the following loading hypothesis:

Hypothesis (a). Average ambient temperature and absence of wind
Hypothesis (b). Conditions resulting from the most onerous values of the environmental parameters considered in section x that can be anticipated.

The load caused by wind shall be calculated in accordance with section xx. The tensile working load of conductors shall not exceed:
• In the case of hypothesis (a), 30% of their ultimate breaking load
• In the case of hypothesis (b) 40% of their ultimate breaking load.
For copper, silver bronze or cadmium bronze conductors whose mechanical tension is automatically regulated, it is accepted that load in service shall not exceed, under any circumstances, 50% of their ultimate breaking loads.
For contact wires, all the above checks shall be undertaken using the minimum cross-sectional area permitted in relation to the maximum wear allowed.

5.4.3.2. Conductor Tension Calculations
Conductor tension calculations and resulting factors of safety, shall be made for various equivalent spans based upon the following:

5.4.3.2.1. Conductor normal tension at the average ambient temperature

5.4.3.2.2. Minimum ambient temperature
Operational ice loading conditions. See Table No.5-6
• Full radial ice on the messenger (if present)
• Reduced radial ice on the contact

5.4.3.2.3. Maximum ambient temperature

5.4.3.2.4. Non-operational ice loading conditions
• Full radial ice on the messenger (if present)
• Full radial ice on the contact

5.4.4. OCS Styles for LRT.
5.4.4.1. OCS style refers to the general configuration of a type of OCS, whether it is a single conductor contact wire/trolley system or a 2-conductor catenary system, and the way in which the wires are supported. Typical supports include cantilevers, bracket arms, cross-spans, bridles and headspans.

5.4.4.2. Relative Costs of OCS Styles for mainlines:
• Simple catenary with center poles............1.0
• Simple catenary with outside poles...........1.6
• Low profile simple catenary with outside poles...........2.5
• Single contact wire, with underground feeder cables.............10.0
5.4.4.3. Aesthetics, practicality and economy factor into OCS style selection. For instance, a balance shall be struck to minimize the cost of the OCS by only selecting single contact wire system for the most sensitive architectural sections of downtown.

For OCS Styles for Streetcars see SECTION 13

5.4.5. OCS Style Selection for LRT.

Typically there are four situations on a project that are sufficiently different in character and need to each warrant a different OCS style. Each of these OCS Styles will have its own discrete parameters, many of which may not be shared with other styles.

These are shown below with the choice of OCS styles typically used:

5.4.5.1. City Streets - Single Contact Wire with underground parallel feeder or Low Profile Simple Catenary; side poles with or without streetlights, fixed terminated to avoid balance weight assemblies on sidewalks.

5.4.5.2. Medians of two way roads/segregated ROW, - Simple Catenary, auto-tensioned with center poles.

5.4.5.3. Storage Yard – Single Contact Wire, fixed terminated, without feeders.

5.4.5.4. Maintenance Shop. - Single Contact Wire, low fixed tension or untensioned Conductor Rail.

5.5. Insulator Electrical Creepage Distance.

5.5.1. Definition.

IEEE Dictionary, (Ref # 21), defines creepage distance as: “The shortest distance between two conducting parts measured along the surface or joints of the insulating material between them”.

5.5.2. Creepage Dimension.

All insulators have a creepage dimension, and the value indirectly rates the suitability of each insulator for a defined voltage. These creepage distances are ascribed individual dimensional values usually given in ASTM and Electrical Standards, AREMA recommendations, Agency Design Criteria, etc.

5.5.3. Insulator Voltage Rating.

The actual rating of the insulator will be conditional upon the environment in which it is placed. Creepage distances may be increased above the nominal value for ‘clean’ atmospheric conditions. In worst case conditions of high atmospheric contamination, such as industrial areas polluted by smoke or particulates, icicles and ice build-up, salt spray along coast lines road spray associated with chemicals for treating roads in winter, altitude correction values, lightning, basic impulse level (BIL).etc. creepage paths shall be increased as required.

In some environments such as salt spray or spray, creepage paths may be required to be even longer than normally specified for ‘polluted’ areas.

5.6. Insulation and Insulator Placement

Transit Rail (LRV and Streetcar) and Trolleybus systems. A distinction must be made between the design requirements for transit rail where there is a positive energized OCS above the track rails which provide a return path for the current, and
Trolleybus Overhead using a pair of overhead trolley wires for supply and return. Trolleybus overhead design is described in Section 15

5.6.1.1. Live Line Maintenance.
Light rail OCS is characterized by the fact that it can be maintained safely while it is energized, without the specialized manipulation equipment such as hot-sticks, that is used by Utilities for live-line maintenance. To achieve a safe working situation, (Safe Working Zone) all the equipment around the maintainer on the insulated work platform that is within immediate reach must be either:

• Energized,
• Energized and floating (floating meaning neither energized nor grounded)
• Floating and grounded, or
• Grounded

This is practical by the proper placement of two levels of insulation (double insulation) and the screening of grounded equipment such as steelwork of overbridges, canopies etc.

5.6.2. Safe Working Zones. (not applicable to Trolleybus Overhead) Safe working Zones are created by the use of Double Insulation in the OCS support system, and the use of insulating screens around the OCS to prevent the maintainer contacting grounded equipment.

5.6.2.1. Double Insulation. Double insulation is required in all supports, whether they be cantilevers, pull-offs, headspans, cross-spans or steady spans, supports from portals, bridge supports, roof and tunnel supports, wall brackets etc. Double insulation is the provision of two levels of insulation (two insulators) in the OCS. Each level of insulation shall be at the full rating for the selected voltage.

Spacing of the two insulators shall be in such a way that a maintainer’s hands cannot bridge between live equipment and conductive grounded equipment, which would be fatal. This is achieved by providing floating sections in all parts of the OCS support system, such as a wire strand or a pipe installed between two insulators that is too long for the maintainer to reach across. Typically this would be more than a person’s span between finger tips, say 7 feet. With 12 inch-long insulators, the insulator centerline dimension must therefore be more than 6 feet. This separation of insulators defines ‘Double Insulation’.

The same design condition as double insulation can be provided by the use of a single insulator 7 feet long, or by using synthetic non-conductive fiber rope such as Philistran or Kevlar of similar length.

All OCS support insulators must be carefully located to achieve a safe working zone for maintainers.

The PRECISE placement of support insulators in OCS for transit rail is therefore a very important part of OCS design.

5.6.2.2. Insulating Screens.
Safe working conditions for maintaining energized OCS can also be achieved by screening around all GROUNDED equipment within reach of the energized OCS, using insulated sheeting. Insulated sheeting such as Fiberglass Thermoset Reinforced Plastic (FRTP) sheeting, is interposed between the energized equipment and conductive grounded equipment, such as the deck or beams of a
steel bridge. This insulated sheeting shall be suitably dimensioned so that it cannot be reached around by a maintainer with one hand touching energized equipment. This screen will need to be clear of the pantograph clearance envelope, and sufficiently strong and rigid to withstand the natural elements, such as ice build-up and any likely impact such as a maintainer falling against it or equipment hitting it. This design provision is termed ‘Screening’.

5.6.2.3. Exceptions. If the provision of a safe working zone is impractical, for instance, double insulation or screening cannot be provided at certain specific locations, live-line maintenance work shall NOT be allowed at those locations.

5.6.3. Prevention of Circulating Currents.

Precautions shall be taken in the design of OCS assemblies to prevent circulating currents passing through components not designed to carry current. Examples of insulators being placed to prevent circulating currents include non-conductive thimbles in hangers and spool insulators in steady arms that are attached to a single cross-span wire over tracks in the same electrical section, such as in yards.

5.6.4. Precautions in Station Platforms.

Care shall be taken in OCS assembly design to avoid having energized equipment directly above the station platforms, by locating poles between the tracks or on the opposite side of the track from the platform. If this is not practicable, insulators shall be located in the assemblies directly over the space between the track and the platform edge, but outside of the pantograph clearance envelope. Where possible avoid terminating conductors on poles on platforms.

5.6.5. Precautions in Boat-sections. (Cuts with vertical or nearly vertical sides).

These depressed sections of track between retaining walls may have public walkways along the outside and safety screens may be required if energized equipment are within 10 feet of where people can stand. Preference should always be given to locating the OCS supports on the track side away from the wall and walkway.

5.6.6. Precautions at Overhead bridges.

For bridges with steel beams, if the clearance between the underside of the beams and the OCS is less than 4 feet, a screen of insulated sheeting shall be provided extending at least 4 feet each side of the OCS. This screen shall be designed to withstand the effects of ice build-up.

Bridge decks made of concrete or other non-conductive materials, and conductive decks more than 4 feet above energized equipment do not require screening unless specified by the agency.

5.6.7. Precautions in Tunnels.

Tunnels are not treated any differently to overbridges, except that there could be other systems’ installations such as cabling, pipes, lights, etc. mounted on the soffit, parts or all of which are grounded. Here the OCS designer should persuade the designer of the other system’s equipment to locate his equipment away from the OCS, such as lower on the tunnel wall, or on the opposite side of the tunnel to where the OCS supports are mounted.
5.6.8. Section Insulators
Section insulators are ‘hard spots’ in the contact wire, cause arcing and increased wear, and require continuous inspection and adjustment, and therefore should be used with care.

5.6.8.1. Section insulators should be avoided on revenue tracks and the sectioning performed by using insulated overlaps.

5.6.8.2. Section insulators should be installed on the centerline of tangent tracks.

5.6.8.3. Section Insulators should not be used on tracks with superelevation.

5.6.8.4. Section insulators in turnouts and crossovers must be located such that their skids are outside the pantograph clearance envelopes of adjacent tracks.

System heights at the ends of crossover catenary spans should be designed so that the system height at a mid-span section insulator is at 2 feet or more to support it properly.

5.6.9. Insulated Overlaps
To avoid section insulators in revenue tracks, insulated overlaps should be positioned to perform the required sectioning. Overlap spans should be over 150 feet where practical, and utilize regular stick insulators in the out-of-running contact wire, provided they are installed at least 6 inches clear of the in-running contact wire.

Where track layouts preclude the use of overlaps 150 feet long, shorter overlaps can be used. Insulated overlaps as short as 40 ft are practical, but shall use section insulator bodies in the out-of-running wires since the end fittings of regular stick insulators would be prone to impact by pantographs.

6. Electrical Clearances

6.1. Electrical Clearance Values
OCS conductors require electrical clearances from grounded equipment. The clear distance (air-gap) is dependent upon the voltage of the OCS.

6.2. Electrical Clearance Definitions.
IEEE Dictionary (Ref # 21), defines electrical clearance as:

6.2.1. “The minimum separation between two conductors, between conductors and supports or other objects, or between conductors and ground”.

6.2.2. “The clear distance between two objects measured surface to surface”.

6.3. Operating Clearance Definitions.
Clearance requirements (dimensions) vary according to operating conditions. Operating conditions are described as ‘normal’, ‘desirable minimum’, ‘absolute minimum’, ‘static’, ‘dynamic’ or ‘passing’. These terms are defined in the OCS Glossary of Terms, (Ref # 22.)

These electrical clearances are ascribed individual dimensional values usually given in Codes, Standards, regulations, recommendations, design criteria, etc.

Note 1. Adverse environmental operating conditions increase all electrical clearances.
Note 2. Within each electrical category listed above the horizontal, vertical and radial dimensions are generally the same
6.4. Clearances of OCS to Closely Adjacent Structures

For the electrical clearance between bodies of closely adjacent structures and live OCS, it is recommended that the value should not normally be less than the minimum shown in Table No. 6-1, appropriate to the nominal voltage for static and dynamic clearances, respectively. The dynamic clearances take into account temporary movements of the OCS during the passage of current collectors.

6.4.1. The minimum values in Table No. 6-1 should be increased in areas with high atmospheric pollution.

<table>
<thead>
<tr>
<th>Type of System</th>
<th>Nominal Voltage (V)</th>
<th>Minimum desirable clearance between OCS and structure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Static</td>
</tr>
<tr>
<td>Direct Current</td>
<td>600-750</td>
<td>4 in.</td>
</tr>
<tr>
<td></td>
<td>1,500</td>
<td>5 in.</td>
</tr>
<tr>
<td></td>
<td>3,000</td>
<td>6 in.</td>
</tr>
</tbody>
</table>

Note: For voltages of 600 V and 750 V, the minimum clearances result more from physical phenomena than from electrical considerations.

6.4.2. Alternatively, in exceptional cases, and provided the operating and climatic conditions allow, smaller clearances may be used provided that they are not lower than the absolute minimum dynamic values shown in Table No. 6-2.

<table>
<thead>
<tr>
<th>Type of System</th>
<th>Nominal Voltage (V)</th>
<th>Absolute minimum dynamic clearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Current</td>
<td>600-750</td>
<td>3 in.</td>
</tr>
<tr>
<td></td>
<td>1,500</td>
<td>4 in.</td>
</tr>
<tr>
<td></td>
<td>3,000</td>
<td>5 in.</td>
</tr>
</tbody>
</table>

6.5. Clearances of OCS to Vehicles

For the air clearances between bodies of vehicles and the live OCS or bare feeders, it is recommended that clearances should not normally be less than the minimum static and dynamic values shown in Table No. 6-1 in relation to the nominal voltage. The dynamic clearances take into account temporary movements of the OCS and the vehicles.
The minimum values in Table No. 6-2 shall be increased in zones of particular risk (near the ocean, heavy traffic involving heat from locomotive exhausts, industrial pollution, fog, mountainous and tropical regions, etc.)

In exceptional cases and provided the operating and climatic conditions allow, smaller clearances may be used, provided that they are not less than the absolute minimum dynamic clearances in Table No. 6-2.

6.6. Clearances over Rails and Roads

6.6.1. Contact wire heights are measured from the top of rail or road to the underside of the contact wire at midspan.

6.6.2. The minimum contact wire height depends upon various factors some or all of which can occur together. Clearances between the OCS and rail for LRT and to the road for trolleybuses shall be in accordance with the NESC section 232. Table No. 6-3 is abbreviated from Table 232-1 and gives the typical clearance requirements for the following situations. Per 232.a.3 EXCEPTION The conductor temperature and loading condition for trolley and contact conductors shall be 15°C (60°F), no wind displacement, final unloaded sag, or initial unloaded sag in cases where these facilities are maintained approximately at initial unloaded sags.

6.6.3. When considering contact wire height values, the effects of ice or of high temperatures on the conductors must be calculated. To minimize these effects, span lengths can be shortened or alternatively can be accommodated by raising the contact wire heights at the supports.

6.6.4. Table No. 6-3

<table>
<thead>
<tr>
<th>Type of System</th>
<th>Nominal Voltage (V)</th>
<th>Areas subjected to unrestricted vehicle traffic</th>
<th>Areas with pedestrian or restricted vehicle traffic</th>
<th>Exclusive ROW excluding yards and shops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Current</td>
<td>600</td>
<td>18 ft</td>
<td>16 ft</td>
<td></td>
</tr>
<tr>
<td></td>
<td>750</td>
<td>18 ft</td>
<td>16 ft</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1,500</td>
<td>20 ft</td>
<td>18 ft</td>
<td></td>
</tr>
</tbody>
</table>

Source: Table 232-1 from the NESC

6.7. Clearances between OCS and Overhead Utility and other Wires.

Clearance dimensions between messenger wires or OCS Supports and existing aerial cables must be compared to NESC (Ref #19.) permissible values. For maximum clearance without changing the existing wires, the OCS span can be centered on the aerial cables, or the messenger wire height reduced. If the resulting clearance is inadequate to meet code, the aerial cables themselves can be raised, or possibly undergrounded.


The FAA has multiple horizontal and vertical clearances associated with runways. The horizontal clearances include: the building restriction line and the
runway protection zone. The vertical clearances include the approach surface and the transitional surface. Particular attention needs to be given to OCS clearances. Glide paths at airports may require that OCS poles be reduced in height, with possible reduction in contact wire height, system height and/or span length.

6.9. Clearances at Overbridges

If the clearance to rail exceeds 24 feet, an OCS with 19 ft contact wire height and 23 ft messenger height can be installed without restriction.

With less than 23 feet clearance, the contact wire can be lowered without reducing span length provided minimum clearances of OCS conductors to ground which are regulated by NESC (Ref # 19), are maintained, after allowing for contact wire droop due to ice or reduced messenger tension at elevated temperatures. If lesser clearance is available, span lengths can be reduced allowing for the system height at each end of the span also to be reduced and also reducing the allowance for contact wire droop. Reducing span length increases the cost of the OCS and should be resisted. If the bridge is new and still a design concept, increased clearance may be negotiable.

6.10. Clearance at New Overbridges.

From an OCS point of view the greater the clearance to the underside of the bridge deck the better, but this raises cost for both the bridge and its approaches. A comfortable solution would be to agree on a clearance to track that allows for the OCS poles to be 5 feet outside of the deck, minimum OCS hangers at midspan and the lowest contact wire height permitted by the Agency Design Criteria, allowing for ice and elevated temperatures.

6.11. Clearances at Existing Low Overbridge.

An existing bridge that is too low or impractical to install OCS with the smallest system height, will require OCS, Civil and Structural designers to agree on a suitable design approach.

Options include:

- Remove the bridge
- Raise the bridge
- Replace with a thinner deck to maintain original surface
- Lower the track

A pedestrian bridge can be easily raised, but all others will usually involve relocation of services in the deck. Thinner decks are usually practical and can use T-beams which have space between for the services and for accommodating OCS supports. Lowering the track requires removal of the ballast by undercutting (often with the track in place) before the sub-base can be removed, after which the ballast is replaced. The new grade could take hundreds of feet to run out. This may require relocating underground services and also changing the drainage system.

7. Lateral Clearances to OCS Poles for LRVs and Streetcars.

7.1. Clearance Design

The selection of lateral clearances to OCS poles is a fundamental design task with light rail because the location of poles between tracks and the desire to minimize track centers to reduce right-of-way width require very careful analysis.
The matter is complicated by the fact that there are TWO sets of design criteria to be considered, one with regard to Vehicle Envelopes and one with regard to Pantograph Envelopes. These envelopes are based on different criteria and have separate application, depending upon the individual location along the track, and in terms of track curvature and superelevation.

All OCS poles (and other wayside features such as; civil structural elements, including retaining walls, bridge piers, parapets of viaducts, walkways, station platforms, and handicap ramps; train signals; traffic signals, etc.) must therefore be outside of TWO separate clearance envelopes.

7.2. The TWO Clearance Envelopes
Two types of clearance envelopes are used to verify that wayside structures, overhead structures and the OCS are outside the swath of rail vehicles.

- Structure Clearance Envelopes (SCE or CE) – for clearances to the operating vehicle.
- Pantograph Clearance Envelopes (PCE) – for clearances to the operating pantograph above the vehicle roof.

(Either or both envelopes may determine the minimum clearances to wayside features depending upon the cross-section outline of the feature at a specific location along track.)

7.3. Centerlines of Envelopes
SCE’s and PCE’s typically use DIFFERENT centerlines:

- SCE’s use a VERTICAL centerline through the track rails for all track conditions - tangent, curves with NO superelevation and curves WITH superelevation.
- PCE’s use VERTICAL centerline through the track rails on tangent track, and SUPERELEVATED centerline on superelevated track.

Each clearance envelope is checked separately.

7.3.1. Structure Clearance Envelope (SCE).
This is the space into which, other than the rail vehicle, no physical part of the system may be constructed or may intrude. The clearance envelope is normally referenced to the theoretical vertical centerline of the design track. On curved track there will be a set of SCE’s, although the largest theoretical envelope can be used universally.

7.3.1.1. Definition
TRB Report No.57 gives: “The clearance envelope (CE) is defined as the space occupied by the maximum vehicle dynamic envelope (VDE), plus effects due to curvature and superelevation, construction and maintenance tolerances of the track structure, construction tolerances of adjacent wayside structures, and running tolerances”.

7.3.1.2. Structure Clearance Envelope Variations
Clear distinction must be made between the SCE for tangent tracks and the SCE for curved tracks. There is ONE project-specific tangent track SCE, but a SET of SCE’s for curved tracks. These will be for a family of curve radii each with its own subset of values for superelevation.

7.3.1.3. Structure Clearance Envelope Sets
Sets of SCE's occur because tracks vary in curvature and superelevation. This is because as the vehicle body chords curves it requires increasing lateral clearance to both the inside and the outside of the curve, the tighter the curve. Additionally there is the throw of the vehicle by track superelevation. For a typical light rail vehicle on a minimum curve radius of 82 feet, (see Note 1.) the vehicle center throw is about 12 inches and end throw slightly less. For a 6-inch superelevation, which is common on LRT systems, the vehicle throw at a height of say 12ft 6in due only to superelevation, will be about 16 inches. Therefore compared to the width of the SCE for tangent track, which already includes allowances for vehicle roll and lateral movement, track maintenance tolerances and running clearances (See 5.6. below), an additional clearance of $12 + 11 + 16 = 39$ inches or so is required. Because of superelevation this SCE is not symmetrical about the vertical track centerline, but is skewed towards the inside of the curve.

7.3.1.4. Universal Structure Clearance Envelope

If lateral clearances are not a major concern as on single tracks or when OCS poles are ‘outside’ of tracks with available space, a universal SCE for worst case conditions of minimum curve radius (typically 82 feet) and maximum superelevation (typically 6 inches) can be used. On most light rail systems the application of a universal SCE would require clearances deemed to be excessive for most of the alignment, and hence uneconomic. There is every reason to have a set of smaller SCEs for site-specific application.

7.3.1.5. Typical Structure Clearance Envelope

Some agencies have an empirical formula for calculation required clearances for structures. One such is:

$$\text{Clearance} = 8\text{ft 6 in} + 1\frac{1}{2} \text{ in per degree of track curvature.}$$

While this is convenient and easy to apply, the clearance derived will not necessarily represent the lowest acceptable clearance, and should not be used when space is limited.

7.4. Limited Space Conditions

When space is at a premium, calculations to show there is adequate room to operate vehicles safely may require staff of ALL interested disciplines to meet and agree. This is especially necessary where Agency Design Criteria (ADC) is silent on Structure Clearance Envelopes.

7.4.1. Cross Sections

The ADC may give the physical dimensioning of track cross-sections including provision for OCS poles. These are typically given for TANGENT track only, and include cross-sections through stations and structures such as viaducts. These diagrams provide for all LRT equipment, including minimum dimensions. However they do not normally include vehicle pantographs.

7.4.2. Vehicle Dynamic Envelope

Sometimes the ADC gives a VDE showing the outline of the vehicle with sway. This is only a VDE for TANGENT tracks. Such a diagram is NOT an SCE even for tangent tracks, because it does not include lateral clearance for track tolerances, running clearances and allowance for a construction tolerance on new wayside structures.

7.4.3. Design Precaution for Superelevation
On curves, when the cross-section diagrams are typically NOT given in the ADC, SCE’s must be determined. For convenience of application, a schedule for each track radius on a project should be prepared. Although the width of the SDE will vary according to track superelevation, it has been found prudent to use 6 inches superelevation for all curves less than 3000 feet radius, even though the applied design value is less.

7.4.4. Design Precaution for Track Centers
On properties where tracks are nominally 14ft or less track centers and poles are between tracks, great care is required to meet the SCE criteria. When track curvature is below 2000 ft. radius, it may be necessary to increase track centers to accommodate the center poles, or alternatively, poles will need to be placed outside of tracks, which through the curve will double the number of poles.

7.5. Pantograph Clearance Envelope.

7.5.1. Importance
At the heights above rail where pantographs operate, this envelope is a critically important design parameter in the construction of an OCS, including the placement and configuration of OCS supports, and all other wayside features and equipment that extend above the roof level of the vehicle. These features include tunnels through-bridges and overbridges, and other close-by installations such as cable bridges and platform canopies.

The pantograph clearance envelope may be larger than the Structure clearance envelope at these heights, see below.

7.5.2. Risk
The provision of adequate or more-than-adequate clearance for pantographs costs little extra in terms of materials, but the consequences of inadequate clearance are disruptions to service and major rework if the error is system wide.

7.5.3. Application
Pantograph Clearance Envelopes can be developed for various contact wire heights on tangent tracks. For the same contact wire height the PCE for tangent tracks can be used on curved tracks by centering it on the SUPERELEVATED track centerline.

7.5.4. Lateral Clearance
At high contact wire heights on superelevated tracks the PCE can extend further from the track centerline than the SCE. For instance with a contact wire height of 26ft 0in, the PCE will extend an extra 33 inches, compared to tangent track PCE. At this height, the PCE will likely dictate the minimum structure clearance, not the SCE.

7.5.5. No Vehicle Throw
With PCE’s there is NO vehicle throw due to track curvature because pantographs are invariably mounted over the vehicle trucks and experience negligible vehicle center-throw or end-throw on curves.


7.6.1. Clearances to Vehicles
There are no recognized standard vehicles operating on transit systems, nor are there track design standards on which vehicles operate. By means of their Light Rail Design Criteria, Transit agencies set design parameters
for their own system, to which designers and suppliers of LRT equipment and infrastructure must comply.

7.6.2. Agency Design Criteria

Experience with design criteria on Clearances, suggests that there is a lack of clarity, or ambiguity, or confusion regards the naming of the various Envelopes, Outlines, Gauges, Diagrams and Plates.

7.6.3. Definitions

For EACH project it is necessary to define the various clearances and ‘envelopes’ associated with the vehicles and the spaces within which they operate, because of the possible variations. For this document the following meanings are assigned.

7.6.4. Vehicle Static Clearance Outline or Envelope

7.6.4.1. Vehicle Dynamic Clearance Outline or Envelope (VDE)

The envelope or contoured shape within which all rail vehicles must fit, is typically developed by vehicle suppliers for their own vehicles. This envelope must therefore fit within a similar envelope developed and included in the ADC. Manufacturer’s VDE’s do not replace transit agency developed dynamic clearance envelopes, unless by agreement with the agency, they are larger.

7.6.4.2. Static Outline.

TRB Report 57 states: The static outline of an LRV is its dimensions at rest, including elements such as side view mirrors. The resulting diagram will show the minimum overhang on tangents and curves. The dynamic outline is more significant to the track designer.

7.6.4.3. Dynamic Outline.

TRB report No. 57 states: “The dynamic outline of an LRV describes the maximum space that the vehicle will occupy as it moves down the track. The dynamic outline or “envelope” includes overhang on curves, lean due to the action of the vehicle suspension and track superelevation, track wear, wheel/track spacing and abnormal conditions that may result from failure of suspension elements (e.g. deflation of an air spring”).

“The following items are typically included in the development of the VDE:

• Static vehicle outline
• Dynamic motion (roll) of springs and suspension/bolsters of vehicle trucks
• Vehicle Suspension side play and component wear
• Vehicle wheel flange and radial tread wear
• Maximum truck yaw
• Suspension system failure
• Wheel and track nominal gauge difference
• Wheel back-to-back tolerance
• Rail fastener loosening and gauge widening during revenue service
• Dynamic rail rotation
• Rail cant deficiency

The VDE is usually represented as a series of exterior coordinate points with a reference origin as the track centerline at the top of rail elevation.”

7.6.4.4. Agency Design Criteria.

If the Agency Design Criteria shows a VDE, it should be examined to determine whether track alignment maintenance tolerances have been included.
Note that the VDE defined above does not allow for vehicle ‘throw’ effects on curves, or for superelevation (cant).

7.6.5. Development of a Structure Clearance Envelope for Curved Track.

7.6.5.1. Basis
Structure clearance envelopes for curved tracks are based on the Tangent SCE with additional allowances for vehicle throw and superelevation throw.

7.6.5.1.1. Vehicle Throw
These values are calculated by geometry based on the vehicle overall body dimensions, vehicle truck dimensions and selected track radii.

7.6.5.1.2. Superelevation Throw
These values are independent of track radius, and vary with the value of superelevation applied at any curve, being prorated for vehicle height by geometry.

7.6.5.2. Table of Minimum Lateral Clearance Values
This summary of minimum values is developed in tabular form by applying the combination of vehicle throw values and superelevation throw values to co-ordinates of points on the Tangent SCE, to enable the family of clearance envelopes to be generated for the specific project. In practical terms, 6 inches of superelevation combined with the throw value of a selected few curve radii, will result in a select few SCE’s each of which can be universally applied to curves of larger curve radius.

7.7. Pole Offsets
OCS designers are responsible for determining OCS pole ‘offsets’ for the complete track alignment. Pole offset is the centerline of track to centerline of pole dimension. It is NOT the pole clearance which is half the pole width less. Although OCS Staff do not need to calculate all OCS pole offsets on tangent track when the ADC shows a typical cross-section, there can be need to do so on track curves, especially when OCS poles are between tracks or on tangent tracks at crossovers.

(Note. The ADC may give the preferred ‘offset’ for OCS poles, i.e.7ft 0in. on 14-foot track centers. This may be acceptable on tangent track but not on some curves.)

Project wide spreadsheets showing all OCS pole locations should be produced using the MCV to determine minimum clearance and adding say 7 inches (half pole width) and rounding up where practical. When poles are between tracks BOTH clearances should be given but only one offset -- the one to the designated reference track. These calculation sheets are project records.

7.7.1. Cantilever Frames and other OCS Assemblies
7.7.1.1. Cantilever brackets
When vehicles lean towards poles because of track superelevation, the PCE may determine the minimum clearance between the face of the OCS poles and the track centerline, rather than the SCE. When poles are installed between tracks with 14ft. track centers or less, the setting dimension of bottom brackets of cantilevers is critical to ensure the cantilever frame is outside the PCE.
7.7.1.2. Registration Arms
With converging tracks care must be taken to avoid registrations that have drop-brackets inside the PCE of the ADJACENT track.

7.7.2. Existing and Special Clearances.
One must anticipate that there will be cases when substandard clearances, whether electrical or physical, will need to be considered to achieve the best solution to a clearance problem. Any substandard condition needs careful consideration by the agency, who ultimately assume responsibility for safety and reliability. Substandard conditions shall always be annotated on contract as-built drawings so that in event of an incident, any concern about the reliability of the whole installation is considered in the correct light. The sooner that these special circumstances are recognized, the less delay is caused to development of the track alignment, and therefore, OCS design.

7.7.3. Pantographs and trolley poles can have a wide range of vertical movement and operating heights for contact wires and trolley wires can be selected from 14 feet to 26 feet.

7.7.4. Wire Sag Calculation
Wire sag of a single wire is defined as the vertical distance from average height of the wire at the support to the lowest point in the span.

\[ S = \frac{wL^2}{8T} \]

Where
- \( S \) = Sag
- \( w \) = weight of the wire
- \( L \) = length of the span
- \( T \) = Tension

10. Components
10.1. General design theory: Components used to build electrification for propulsion of Light Rail Vehicles
10.2. Conductors: Typically 350/500 wire size (Trolley 4/0)
10.3. Hangers: Typically 1/8"-1/4" Stainless Steel (Solid or Flexible application)
10.4. Splices: Size based upon the load (Slippage) 90% breaking strength of the Conductor.
10.5. Terminations Variable or Fixed Tension (various applications ie. Balance Weight Assemblies, Fixed Terminations etc.
10.7. OCS hardware and fittings: Used to apply & fit conductor and messenger wire for system electrification.
10.7.1. General
10.7.2. Contact wire clamps: Mechanical Devices
10.7.3. Messenger wire clamps: Mechanical Devices
10.7.4. Miscellaneous fittings: Mechanical Devices
10.7.5. Disconnect Switches – Component (Ampacity, Voltage & Operation)
    Operation: Manual and motor driven (Do not open under load)
11. Wiring and cabling
   11.1. General design theory
   11.2. Tolerances
       11.2.1. Installation
       11.2.2. Maintenance
   11.3. Wire Profiles
       11.3.1. Heights and Gradients
       11.3.2. Span wires
       11.3.3. Contact wires
   11.4. Pole spacing
   11.5. System Heights
   11.6. Staggers
   11.7. Special Catenaries
   11.8. Tensions Lengths
   11.9. Wire tensions
   11.10. Overlaps, Turnouts and Crossovers
       11.10.1. Arrangements
       11.10.2. Support location
       11.10.3. Balance weights
       11.10.4. Construction
   11.11. OCS Support Assemblies
       11.11.1. Arrangements
       11.11.2. Components
       11.11.3. Loading
       11.11.4. Materials

12. Sectioning
   12.1. General design theory
   12.2. Location of sectioning
   12.3. Air breaks
       12.3.1. Full tension
       12.3.2. Split tension
   12.4. Section breaks
       12.4.1. High speed
       12.4.2. Low speed

13. Negative Return System

   The negative return system is an integral component of the traction power electrical circuit. It allows the flow of traction power current from the overhead contact system and through the vehicle to travel back to the power supply source (substation). The negative return system has reference to earth and this relationship must be considered in the design of traction power systems in relation to the OCS. Since this guide must consider both light rail transit systems and street cars/trolley bus type systems, and since these two systems have a different negative return configuration, the discussion on the negative return system is sub-divided to cover both configurations.

13.1. Light Rail

   13.1.1 General design theory
The general circuit path for DC traction power current on light rail systems is for current to flow from the substation positive bus thru the feeder breakers out via underground positive feeder cables that run up a feeder pole, out to the overhead contact system conductors, down thru the light rail vehicle pantograph and traction power motors, via the vehicle wheels onto the running rails and finally via underground negative return cables back to the substation negative bus (See Figure No. xxx)

The main items that make up the negative return system are thus:

- Substation negative bus
- Negative return cables
- Running rails

This guide does not discuss the internal negative bus, as this is more fully presented in other IEEE guides prepared by the Traction Power group.

Discussion on negative return cables are also addressed in IEEE guides prepared by the Traction Power group, however, for the purpose of this guide, refer to the discussion on return cables in sub-paragraph 13.1.7 below.

The design and installation of the running rails and their associated components present the greatest challenges in providing and maintaining a good negative return system. This is due to the various manners in which rails are isolated from ground, how rail joints are bonded, the type of connection between the bonding cables and the rail head and use and connection of impedance bonds to the rails.

13.1.2 Isolation of Running Rails from Earth

To be developed.

13.1.3 Rail Bonding

It is essential for a good return rail system to utilize continuous welded rail (CWR) as much as possible – both to reduce the rail resistance and to mitigate stray current problems. However, at turnouts and crossovers, the use of rail bonds must be used to bridge around the required mechanical joints.

Rail bonds should be sized to create an electrical continuity “bridge” around the mechanical rail joint equal to that of a CWR with no mechanical joint. Standard 115 lb rail is equivalent in steel cross-sections to 1,000 kcmil cable. Thus, the traction “power bonds” should be comprised of 2 each, 500 kcmil copper bonds.

13.1.4 Allowable voltage on rails

To be developed.

13.1.5 Return sectioning
To be developed.

13.1.6 Impedance bonds
The main function of impedance bonds is to block AC signal current and allow DC return current to flow thru the IB.

IB’s are generally located at substations and are typically connected to the substation negative return cables and the tracks running rails as shown in Figure xx.

13.1.7 Return cables
The quantity and size of negative return cables are determined by the traction power simulation program and/or specified in the Transit Agencies Manual of Design Criteria.

On most light rail systems in the US, either six (6) or eight (8) 500 kcmil or 750 kcmil insulated cables are used for the traction power return cables at each substation to the trackside IB’s. Some LRT systems, such as Baltimore, use 1,000 kcmil cables.

13.1.8 Track connections
Cadweld versus Cembre. - to be developed

13.1.9 Stray Currents
Stray current is an inevitable problem associated with the fundamental design of electrified rail transit systems, whereby current is returned to the substation via the running rails. The earth surrounding the rails can be viewed as a parallel conductor to the rails. The magnitude of stray currents vary with the usage of the transit system and the relative position and degree of acceleration of the electrified vehicles. The following factors all have an effect on the severity of stray currents:

- Magnitude of propulsion current
- Substation spacing
- Substation grounding method
- Resistance of running rails
- Usage and location of cross-bonds and isolated joints
- Track-to-earth resistance and the voltage of the traction power system

In modern DC transit system design, stray current problems are catered for with two fundamental measures:
- Decreasing the electrical resistance of the rail return circuit, and
- Increasing the electrical resistance between the rails and ground

The first measure makes current return thru the earth less likely. This includes the use of heavier rail sections, continuously welded rails,
improved rail bonding and reduced spacing between traction power substations.

It is desirable to combine substations with passenger stations. At passenger stations, current flow is the highest due to the acceleration of trains. This combination ensures that the peak currents have a very short return path.

The second measure is dealt with by isolating the return rails from earth by using insulator pads placed between the rails and the tie.

13.2. Street Cars & Trolley Bus Systems

13.2.1 General design theory

The general circuit path for DC traction power current on street cars/trolley bus systems is for current to flow from the substation positive bus thru the positive feeders, thru the shared OCS and through the vehicle back to the power supply via aerial negative cables tapped to the shared OCS.

Only those portions of the negative return system that are above ground and attached to the supporting structures so that they are essentially negative feeder cable or taps are considered herein.

13.2.2 Design Considerations

- All negative return cables and taps shall be insulated to prevent corrosion from weather. The insulation shall protect them from arcing, electrolysis and damage in the event they contact a grounded surface.

- Negative return cables shall be supported on insulators when placed on cross-arms, poles or other structures.

- Negative return aerial cables shall be treated mechanically and electrically in the same manner as positive feeder cables and shall comply to the requirements of the NESC, this guide and any other applicable and required codes and regulations to which a state or municipality may impose on electrical conductors.

- When a negative return cable taps from the OCS to the track rails, it shall be run down the pole with physical protection for itself and, if in an area accessed by the public, for protection to personnel. The cable shall be supported in a manner consistent with good industry practice and run to the track rails in conduit.

- When a negative return tap is run from the OCS to the track in a paved area, the cable shall be run in conduit which shall terminate in a track box. The track box shall be bolted to the track rail and have a suitable cover with bolts for access, inspection and easy replacement.
Attachment of the cable to the rail may be accomplished by varying methods such as exothermic welding, MIG welding, brazing and/or any reasonable method.

- Negative return cables are generally switched at the negative return buss at the substation. Where negative return cables rise to the OCS from either manholes, handholes or paralleling return cables, they should be switched so that the cable can be isolated for testing.

- In trolley bus systems where the negative return is hard wired to the track rails, switching and isolation are not possible as the entire track and negative OCS is common. New lines and systems should have the negative contact wire sectionalized where ever a positive section insulator is used. All riser taps should be switched for isolation capability. Consideration should be given to expanding this to existing portions of systems so that the entire system can be upgraded to a sectionalized system.

- Sectionalizing the negative return OCS allows testing for continuity, insulation resistance testing and prevention of electrolysis when a power section is de-energized and grounded to earth ground and the negative conductor. It also prevents voltage potential on the negative return contact wire from other power sections if a power section is de-energized as would occur with a common bonded system.

- All negative return cables rising from either track tap connections, the substation or paralleling return cables shall have surge arresters attached to them as outlined in IEEE Standard P1627. Surge protection is not required where negative feeder taps act as equalizers between negative contact wires and have no connection to a riser return cable.

- The designer of a particular OCS that uses negative return contact wire and/or aerial negative return cable shall consider them in the electrical design of the traction power system and voltage drops and current magnitudes shall be figured in the design so that voltage profiles are kept within allowable tolerances for the vehicles to be operated on the system.

14. Special Design Requirements for Overhead Contact Systems for Streetcars fitted with Trolley Pole Current Collectors

14.1. System Description
14.1.1. Substations provide electrical power to streetcars by the means of positive feeder cables and a trolley overhead system (TOH), which is a type of overhead traction power distribution system that uses a trolley wire (‘trolley wire’ is the IEEE preferred term to ‘contact wire’ when used in TOH, although the conductor is physically the same).
14.1.2. TOH uses components specially designed for operation with trolley current collector poles (collector poles).
14.1.3. The streetcars collect direct current from the TOH by means of the collector poles and return the current to the substations via the wheels and running rails.

14.1.4. Substation locations along the route are determined by power demand; sources of primary power; availability, suitability and cost of sites (real estate); step and touch voltage on the running rails; substation spacing; economics and local planning ordinances.

14.1.5. Positive feeders connect the substation circuit breakers to the line through disconnect switches. Negative return cables connect from the running rails direct to the substation negative bus.

14.1.6. Typically both the positive and negative feeder cables between the substation and the line are insulated cables installed in underground conduits, although in some existing systems overhead feeder connections are employed.

14.1.7. The overhead line may be a single trolley wire or a catenary system employing a messenger wire supporting a trolley wire. All conductors are bare.

14.1.8. In defining OCS distribution systems in general, the conductor configuration over the track and the way the conductors are tensioned determines the OCS ‘style’. Tensioning can be ‘fixed terminated’ (FT) or ‘auto-tensioned’ (AT). See below.

14.1.9. The conductors of TOH for streetcars are invariably FT because of the inability of the trolley poles to transfer from one conductor tension length to a successive tension length at the ‘overlaps’ required in auto-tensioned OCS.

14.2. TOH Styles for Streetcars

14.2.1. FTSW : Single Trolley Wire with conductor terminations direct onto a pole or wall bracket. Maximum span lengths are typically 125 feet

14.2.2. FTSC: A 2-conductor Simple Catenary with conductor terminations direct onto a pole or wall bracket. FTSC has two variants:

14.2.3. ‘Regular’ FTSC, with span lengths up to 210 feet. For supports this system may use cantilevers and /or headspans. Headspans typically use two poles mounted on opposite sidewalks, and will require a minimum of two span wires on tangent tracks and three span wires on curves.

14.2.4. Low Profile LPFTSC, with span lengths up to 160 feet. This system may use cantilevers and or cross-spans. LPFTSC cross-spans are single wire and are considered more aesthetic than the ‘regular’ style using headspans with two or three span wires.

14.2.5. Conductor Rail. Used in special applications such as under low bridges and in maintenance shops, conductor rail such as ‘Double Lobe Bar’ is an untensioned bar supported from closely spaced (1 to 2 feet) ‘barn’ hangers, which are mounted on the underside of troughing attached to the soffits of low bridges or to roof trusses in shops and barns. (see ‘Troughing’ later)

14.3. Types of Distribution System for Streetcars

14.3.1. There are three main types of streetcar overhead distribution system:
14.3.2. FTSW with an additional along-track parallel feeder which provides electrical power reinforcement. This feeder cable requires jumper connections to the trolley wire at close intervals.

14.3.3. FTSW, but without an along track parallel feeder. This is referred to as a feederless system. It can be used where power demand is low, and/or where substations are closely spaced.

14.3.4. SCFT. In this case an overhead messenger wire provides the electrical reinforcement instead of a parallel feeder cable. At the same time the distances between the support poles can be increased by supporting the trolley wire from the messenger thereby taking out the sag that limits span lengths. Simple catenary is seldom used with streetcar systems because the messenger is considered to be less aesthetic than a single trolley wire. However SCFT has economic advantages since the use of a messenger wire avoids the need for underground parallel feeder cables which are costly, and there can be savings in support poles too.

14.4. TOH Style Selection by Type of Route.

14.4.1. The selection of a system with or without parallel feeders and its associated TOH style is very much dependent upon power demand and aesthetic considerations along the route. Where a streetcar route operates part in streets, part with median running and part in reserved ROW, aesthetic concerns may vary. This means that one or more TOH styles could be used in series along a streetcar route.

14.4.2. City Streets

14.4.2.1. Although FTSW with underground parallel feeders and a maximum span of 125 feet is almost always selected for use in city centers, a low profile (LP) catenary system has recently been used because of the significant cost savings when underground feeder cables and their conduits are not required. Aesthetic concerns regarding headspan construction using multiple span wires can be assuaged with a design style using single cross-span wires instead. Single cross-span supports limit span lengths to 160 feet showing a 25% economy in poles as well, compared to STW. In both cases shorter spans to suit the spacing of street lights on joint-use poles are acceptable and have cost savings compared to the use of independent poles.

14.4.2.2. Median Running.

Economics would drive the preference for FTSC especially if back-to-back cantilevers are practical, but aesthetics could require FTSW with underground feeders. A middle ground choice could be to use LPFTSC, especially if cross-spans are mounted on poles on sidewalks.

14.4.3. Segregated ROW.

14.4.4. FTSC is the economic style when the ROW has long stretches of straight or near straight track, but when tracks are curved and trolley wire registrations are closely spaced (see later) the costs of installing and maintaining the additional supports and back bones may not warrant using...
14.4.5. Storage Yard
   14.4.5.1. FTSW without feeders is universally used in storage yards. Supports are typically cross-spans, although if space is available between tracks, back-to-back poles with cantilevers/bracket arms can be used when access roads are not present.

   14.4.6.1. FTSW with a low fixed tension or a conductor rail such as a double lobe bar are options available.

14.5. Typical Supports for TOH.
   14.5.1. Typical supports are similar to those used for OCS (See Section 5.4.4.?) include hinged cantilevers, bracket arms, cross-spans, bridles, backbones and headspans.

14.6. Relative Costs of OCS Styles for mainlines:

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple catenary with center poles – ATSC/pantograph</td>
<td>1.0</td>
</tr>
<tr>
<td>Simple catenary with center poles – FTSC/straight track/trolley pole</td>
<td>1.2</td>
</tr>
<tr>
<td>Simple catenary with outside poles – FTSC/straight track/trolley pole</td>
<td>2.0</td>
</tr>
<tr>
<td>Low profile simple catenary, outside poles, FTSC/straight track/trolley pole</td>
<td>2.0</td>
</tr>
<tr>
<td>Simple catenary with center poles – FTSC/curved track/trolley pole</td>
<td>1.6 to 2.0</td>
</tr>
<tr>
<td>Simple catenary with outside poles – FTSC/curved track/trolley pole</td>
<td>2.2 to 2.6</td>
</tr>
<tr>
<td>Single trolley wire, FTSW with overhead parallel feeder cables</td>
<td>5.0</td>
</tr>
<tr>
<td>Single trolley wire, FTSW with underground parallel feeder cables</td>
<td>10.0</td>
</tr>
</tbody>
</table>

14.6.1. Note. Aesthetics, practicality and economy factor into OCS style selection. For instance, single trolley wire system with underground parallel feeder should only be used for the more sensitive architectural sections of down town.

14.7. TOH Line voltage
   14.7.1. Standard nominal value of the voltages for Trolley Overhead systems are specified in Table No.14-1.
Table No. 14-1

Nominal Voltages for Streetcar Trolley Overhead

<table>
<thead>
<tr>
<th>Type of System</th>
<th>Nominal Voltage (DC)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trolley Overhead</td>
<td>600</td>
<td>In existing installations or their extensions, voltage different from those shown may be used. For new installations or those undergoing complete renewal, these nominal values are recommended.</td>
</tr>
<tr>
<td></td>
<td>700</td>
<td></td>
</tr>
<tr>
<td></td>
<td>750</td>
<td></td>
</tr>
</tbody>
</table>

The values of the “Lowest” and “Highest” limits (in accordance with the definitions in IEC Publication 38) between which the voltage of the traction systems may vary are given in IEC Publication 850. Alternatively Table No. 14-2 is offered (See AREMA Chapter 33)

Table No. 14-2.

Voltage Supply Range

<table>
<thead>
<tr>
<th>Nominal Voltage</th>
<th>Normal Upper Voltage Limit</th>
<th>Normal Lower Voltage Limit</th>
<th>Emergency Minimum Operating Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>660</td>
<td>480</td>
<td>420</td>
</tr>
<tr>
<td>700</td>
<td>770</td>
<td>560</td>
<td>490</td>
</tr>
<tr>
<td>750</td>
<td>825</td>
<td>600</td>
<td>525</td>
</tr>
</tbody>
</table>

14.8. Similarities of Streetcar Trolley Overhead with LRT OCS

14.8.1. Design life, service conditions, environmental parameters, corrosion control, trackwork, track parameters, track gradients, line voltage, conductor sizes and tensions, lateral and vertical clearance requirements, factors of safety, and installation techniques are the same as for OCS as described in Sections 5, 6 and 7.

14.8.2. Installed equipment such as foundations, poles, cantilevers, bracket arms, conductors fittings are similar except as noted below.

14.9. Differences between Streetcar Trolley Overhead and the LRT OCS

14.9.1. Maximum Span Length.

Maximum spans are typically shorter than for the similar auto-tensioned (AT) styles because ice loading and elevated temperatures adversely affect wire sag and conductor tension and thereby adversely affecting pantograph commutation.

14.9.2. Special Work,

14.9.2.1. The harp current collectors mounted at the tops of the trolley poles necessitate the incorporation into the in-running trolley wires of ‘special work’ (components made of castings, such as frogs, and crossings much like track rails use).
14.9.2.2. Special work effectively precludes the use of pantographs on trolley overhead, because each item is a ‘hard spot’ and is not designed for under-running by pantographs. Like-wise regular OCS is not designed for Trolley pole operation because the contact wire swivel clamps and hanger clamps can be too wide for trolley harps.

14.10. Trolley Wire Alignment.

14.10.1. Because trolley harps are rigidly attached to trolley poles, the trolley wire must be located within a few inches of the projected (superelevated) centerline of the track throughout the route for correct operation. On straight tracks the trolley wire is held on the projected centerline of the track and supported at intervals of up to 100 feet. On curves maintaining the trolley wire to this same condition requires a multiplicity of registrations and as a consequence, elaborate guying networks and backbones. On tight curves registrations may be as close as 7 feet. See Table 14.3.


(Abstracted from ATEA specification D 14)

14.11.1. Maximum Spacing of Supports

14.11.1.1. Maximum spacing of supports (poles) shall be as given in Column D.

14.11.1.2. For Curves less than 1500 ft. radius, the required number of pull-offs between the support poles is as given in Column C, and spacing between pull-offs shall not exceed values given in Column B.

Table 14.3. Trolley Wire Alignment for Streetcars

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
<th>Column C</th>
<th>Column D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius of Curve (ft)</td>
<td>Spacing of pull-offs (ft)</td>
<td>No. of pull-offs between pole supports</td>
<td>Distance apart of pole supports (ft)</td>
</tr>
<tr>
<td>40</td>
<td>7</td>
<td>(a)</td>
<td>50 (b)</td>
</tr>
<tr>
<td>50</td>
<td>8</td>
<td>(a)</td>
<td>50 (b)</td>
</tr>
<tr>
<td>60</td>
<td>9</td>
<td>(a)</td>
<td>50 (b)</td>
</tr>
<tr>
<td>70</td>
<td>10</td>
<td>(a)</td>
<td>50 (b)</td>
</tr>
<tr>
<td>80-90</td>
<td>11</td>
<td>(a)</td>
<td>50 (b)</td>
</tr>
<tr>
<td>100-150</td>
<td>12</td>
<td>(a)</td>
<td>50 (b)</td>
</tr>
<tr>
<td>175-250</td>
<td>16</td>
<td>(2)</td>
<td>50</td>
</tr>
<tr>
<td>300-500</td>
<td>25</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>600-800</td>
<td>37</td>
<td></td>
<td>75</td>
</tr>
<tr>
<td>900-1500</td>
<td>50</td>
<td></td>
<td>100 (c)</td>
</tr>
<tr>
<td>Above 2000</td>
<td>100</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

14.11.1.3. Note a. The number of pull-offs between supports will depend upon the spacing of support poles and the offset of the poles.
from the track. In general, not more than 3 pulloffs shall be attached to any one pole.
Where limited space or other conditions require that poles be set too close to the track to permit the use of individual spans between poles and pull-offs, back bone construction should be used.

14.11.1.4. Note: b. Pole spacing is approximate and will vary according to local conditions.

14.11.1.5. Note: c. For radii of 1000 ft. and over, back bone construction shall be used to insure rigidity of construction.

14.11.2. Guy networks:
On curves the pull-offs in each span shall be held radially to the curve by a lacing strand at least 6 inches away from the trolley wire. With an odd number of pull-offs the middle one shall have a separate span guy to each pole.
Intersections and complicated special work, particularly in city streets, will usually require special site specific design.

14.11.3. Curve Dressing

14.11.3.1. Curves shall be dressed with uniform trolley wire ‘set’ to the inside of curve at each pull-off by an amount given by the expression:

\[ S = \frac{EH}{G} + \sqrt{\frac{R^2 + P^2 - Q^2 - L^2}{R^2}} \]

Where S = ‘set’ of trolley wire toward center of curve.

E = superelevation of outer rail
H = height of trolley wire above rail
G = track gauge
R = radius of curve
P = distance from center of streetcar to pivot of trolley pole base
Q = distance from center of car to center of truck
L = horizontal distance from pivot of trolley pole base to point of contact between collector and trolley wire.
All values are in feet.

14.11.3.2. At the beginnings and ends of curves, the ‘set’ shall be uniformly tapered (eased) from the full value at the curve end to zero over the length of the transition curve of the track. If the track has no transition curve, the set shall be eased over the length of ‘easement’, as given in Table 13.2,

<table>
<thead>
<tr>
<th>Radius of Curve</th>
<th>Length of easement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 100 ft.</td>
<td>20 ft. from end of curve</td>
</tr>
<tr>
<td>100 to 500 ft.</td>
<td>40 ft. from end of curve</td>
</tr>
<tr>
<td>500 to 1000 ft.</td>
<td>60 ft. from end of curve</td>
</tr>
</tbody>
</table>

14.12.1. Whenever the trolley wire passes under a grounded structure such as a steel overbridge or the roof of a car barn, a continuous inverted insulated trough is constructed above the trolley wire to catch a trolley pole should it dewire. This avoids the possibility of the collector pole, which is conductive, from shorting between the trolley wire and ground.

14.13. Insulator Electrical Creepage Distance. See Section 5.5.


14.15. Clearances.


14.15.2. Lateral Clearances to Support Poles. See Section 7.

15. Special Design Requirements for Trolley Overhead Systems for Trolleybuses

15.1. Trolleybus Operations

15.1.1. A significant advantage that electric trolleybuses (ETB) have over LRT, is their ability to operate successfully on gradients in excess of 20%, (LRT < 7%), making them ideal for cities like San Francisco and Seattle which have such steeply graded streets.

15.1.2. Normal operating speed for ETBs is in the range of 35-40 mph.

15.1.3. Being unidirectional, ETBs require turn-around loops at the ends of their routes.

15.1.4. Minimum turning radius is about 40 feet.

15.1.5. With their trolley wires typically located 12 feet from the curb, ETBs can ‘tour’ over several travel lanes during normal operations. Note that ‘trolley wire’ is the IEEE preferred term to ‘contact wire’ when used with trolley collector poles, although the conductor is physically the same.

15.1.6. The normally lowest trolley wire height is 14 feet at the supports, but lower wire heights are possible. Low trolley wire heights create conflicts with road traffic clearances when traffic lanes are shared.

15.1.7. ETBs have operated under low bridges with the trolley wires over the sidewalk, avoiding infringing on headroom available for road vehicles.

15.1.8. ETBs require a special design of overhead power distribution system called a ‘Trolley Overhead’ system (TOH) which is designed for use with trolley collector poles.

15.1.9. A TOH comprising two single trolley wires is the most common style in operation, but a simple catenary system has been used in Europe on at least one occasion and doesn’t need parallel feeder cables to satisfy power demand. See below.

15.1.10. A feature of TOH is the use of ‘special work’ which are assemblies comprised of multiple castings, such as frogs and crossings (much like track rails use), straight and curved rails, spacers and insulators together with electrical switches, which are incorporated into the wiring.

15.1.11. Special work effectively precludes the use of pantographs on trolley overhead because each item is a ‘hard spot’ and is not designed for under-running by pantographs. Like-wise regular OCS is not suited to trolley pole operation because contact wire swivel clamps and hanger clamps for OCS are generally too wide for trolley harps.

15.1.12. Because ETBs require complex ‘special work’ in the TOH for turns and junctions in the trolley wires at intersections, they must take sharp turns at a crawl.
15.1.13. Dual-mode trolleybuses (Diesel/Electric) allow for service beyond the end of the TOH, with speeds in diesel mode up to 65 mph. With dual-mode the transition back to electric mode requires the provision of ‘trolley pole guides’ in the TOH to direct the trolley poles onto the trolley wires automatically, see later.

15.1.14. The need for ‘special work’ in the TOH at street intersections makes joint operations with light rail vehicles with pantographs somewhat impractical. It can be done and is done by the application of under-running skids, but this creates a need for regular maintenance to keep the (untensioned) skids in adjustment to avoid snagging pantographs.

15.2. Trolley Overhead Design.

15.2.1. Design life, service conditions, environmental parameters, line voltage, conductor sizes and tensions, factors of safety, and installation techniques are the same for TOH as they are for LRT OCS (that is, for pantograph operations), as described in Section 5.2, and 5.3.

15.2.2. The trolley wire conductors and feeder cables used with TOH are the same conductors that are available for LRT OCS, including copper alloys. See Section 5.4.

15.2.3. Installed equipment such as foundations, poles, bracket arms, conductor fittings are similar to LRT OCS except as follows:

15.2.4. TOH is a system where the trolley wire components are specially designed for operation with trolley collector poles.

15.2.5. The incorporation into the in-running trolley wires of ‘special work’ is a significant difference between TOH and OCS.

15.2.6. TOH systems use a pair of single trolley wires, which are commonly termed a ‘trolley wire pair’

15.2.7. Each of the single trolley wires has fixed terminations: LRT OCS is more typically simple catenary, auto-tensioned.

15.2.8. Each single trolley wire normally has a parallel feeder cable, (see later).

15.2.9. Without the benefit of a messenger wire to provide a ‘soft’ suspension, other precautions must be made to avoid ‘hard’ spots wherever the trolley wires are supported. See ‘Trolley Wire Suspension’, later.

15.2.10. TOH seldom uses center pole construction which is common on LRT. Instead poles are typically set on sidewalks and use cross-span wires to support the trolley wire pairs.

15.2.11. Typically, every second or third cross-span wire is a combined feeder/support cable for either the positive trolley wire or the negative trolley wire with feeder risers from the underground parallel feeder cables.

15.2.12. Joint occupancy of the transitway with other road vehicles impacts the use of low wire heights at low bridges unless special operating precautions are in place.

15.2.13. The presence of the trolley return wire with only two feet separation from the energized trolley wire presents different maintenance issues than for LRT overhead which has double insulation and no ground/return wire in close proximity.

15.2.14. The use of trolley poles necessitates the provision of special overhead protective ‘troughing’ when trolley wires pass under bridges and for wiring in maintenance shops, see later.

15.3. Power Supply

15.3.1. Substations provide electrical power to ETBs using feeder cables to the TOH system.

15.3.2. Each ETB has a pair of trolley current collector poles (collector poles); one, the positive pole, collects direct current from the positive wire; the other the negative pole returns the current to the substations through the negative wire.

15.3.3. Because the trolley wires have a limited current capacity, they will often be electrically reinforced by parallel feeder cables, positive and negative, with jumper
connections at regular intervals. These positive and negative parallel feeder cables are insulated cables and are usually installed in underground conduits, although in some existing systems they are installed overhead, either on the support poles or inspan. The undergrounding of parallel feeder cables is purely for the benefit of aesthetics. There are no other benefits. Underground feeder cables come with a significant cost premium.

15.3.4. There are two types of traction power supply system: a system with along track parallel feeders and feeder jumpers to the trolley wire as described above or a feederless system. With a feederless system the substations will probably be more closely spaced than a system using parallel feeders. These two types may be used in series along an ETB route. The selection of the system is dependent upon power demand and location along the route. Ultimately substation spacing is determined by power demand, availability of primary power, availability and cost of sites for substations, local ordinances, and economics.

15.4. Line voltage

15.4.1. Standard nominal value of the voltages for TOH systems are specified in Table No.14-1.

<table>
<thead>
<tr>
<th>Type of System</th>
<th>Nominal Voltage (DC)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trolley Overhead</td>
<td>600</td>
<td>In existing installations or their extensions, voltage different from those shown may be used. For new installations or those undergoing complete renewal, these nominal values are recommended.</td>
</tr>
<tr>
<td></td>
<td>700</td>
<td></td>
</tr>
<tr>
<td></td>
<td>750</td>
<td></td>
</tr>
</tbody>
</table>

The values of the “Lowest” and “Highest” limits (in accordance with the definitions in IEC Publication 38) between which the voltage of the traction systems may vary are given in IEC Publication 850. Alternatively Table No. 14-2 is offered (See AREMA 33)

| Voltage Supply Range |
|----------------------|------------------|
| Nominal Voltage      | Normal Upper Voltage Limit | Normal Lower Voltage Limit | Emergency Minimum Operating Voltage |
| 600                  | 660              | 480                        | 420                               |
| 700                  | 770              | 560                        | 490                               |
| 750                  | 825              | 600                        | 525                               |

15.5. TOH Wiring Description

15.5.1. Trolley Wire Configuration

15.5.2. As described above, because there is no rail return path for current, a negative trolley wire is installed along side the positive trolley wire. Both wires are ‘fixed terminated’ by virtue of the practical limitations of transferring collector poles between tension sections of auto-tensioned conductors at overlaps, although it is done. Because of the use of FT conductors all conductor terminations are made directly to anchor poles and anchor brackets.
15.5.3. The two wires run parallel and are mounted on common supports. In the US, trolley wire spacing is 2 ft. 0 in, but elsewhere wire pairs are up to 2 ft. 4 in. apart.

15.6. Trolley Wire Suspension

15.6.1. Special care is taken with the suspension of the trolley wires to avoid hard spots, which would increase wear of both the trolley wire and the trolley shoe carbon inserts. Particularly the direct clamping of the trolley wire ‘hanger’ (clamp) onto a cantilever pipe should be avoided. Various acceptable suspensions are available:

- Cross-span construction
- Bracket arm construction.
- Bridle supports
- Pendulum suspension
- ‘Elastic’ and ‘resilient’ arms

For details of these alternatives refer to suppliers’ catalogs.

15.6.2. Pendulum suspensions have an additional merit of reducing the variation in conductor tension for a given temperature range, because of their ability to compensate for temperature change.

15.7. Maximum Span Length.

Maximum spans for direct suspension single trolley wire are typically limited to 100 feet, although longer spans up to 130 or 140 feet may be required at some intersections because of space limitations for poles. For these longer spans, it is necessary to install insulated spacers midway in span to prevent possible shorting due to clashing.

15.8. Trolley Wire Alignment.

A feature of ETB collector poles which differs from trolley poles on streetcars is that the collector heads (harps) on ETBs are free to swivel whereas on streetcars they are ‘rigid’. This allows the ETB to tour to the left and right of the trolley wire pair by up to 12 feet each side (known as ‘touring range’) and the ETB is free to overtake other road vehicles and also to run alongside the curb and use regular bus stops. Moving away from being directly under their wires places a lateral force on their collector shoes, and creates lateral wear and a risk of dewirement. This cannot be avoided on straightaways as the ETB moves to and from the curb, but measures can be taken on curves to bring the poles into being close to tangent to the wires as the ETB turns thus reducing side forces.

15.8.1. Alignment on Straight Stretches of Roadway.

The trolley wire pair is typically centered about 12 feet from curbs of streets, with the negative wire closer to the curb. On straight roads there is no need for any deviation from straight. However if pendulum suspension is adopted, the supports are offset from side to side and the trolley wire pair will appear to be staggered.

15.8.2. Alignment on Curves.

15.8.2.1. Typically the trolley current collectors (swivel harps) at the tops of the collector poles overhang 2 to 5 feet behind the back of the ETB when operating on wires 18 feet above the road. It can be shown that on street curves the center line of the trolley wire pair needs to be inside the “trolley path” to reduce the lateral forces on the trolley wires. The trolley path is considered to be the centerline of the front axle of the ETB. This is shown on alignment plans, particularly on transitways in tunnels, as the design centerline for the ETB, (since there is no centerline of track). The amount of trolley wire inset from the centerline of the ETB path depends upon:
• the ETB dimensions
• the location of the trolley pole bases (the bases for the collector poles mounted on the roof of the ETB) relative to the ETB, and
• the trolley wire height.

15.8.2.2. An approximate formula for the inset in feet is \( \frac{300}{\text{curvature in feet}} \). On tight curves, such as street intersections, where the trolley bus is close to minimum operating radius (typically about 40 feet) the inset could be as much as 7 feet, putting the trolley wires very nearly over the gutter of an intersection with sharply radiused curbs.

15.9. Long Turn Lanes.

At street intersections ETBs turning into the cross-street could be held up by pedestrians on the cross walk, and so delay other ETBs on the ‘through’ route and not turning. These delays can be avoided by installing ‘long turn lanes’, as follows. Fifty or so feet before the intersection, a directional switch is installed in the trolley wires to connect to a second pair of wires to run parallel to the main wires on the side of the turn direction. Turning ETBs are routed to these wires leaving the ‘through’ wire unobstructed. Long-turn lanes can be to either the right or left of the through wires, or both.

15.10. Special Work,

15.10.1. Curve Segments.

Compared to streetcar operations which use ‘fixed’ harps and continuous close registration around curves, ETBs by virtue of their swivel current collectors can be accommodated using fewer assemblies with larger deviations which reduce the number of overhead guys. These assemblies are called curve segments and consist of lightly radiused runners suitable for the low speeds of operation on corners at intersections supported on a strong rigid mount.

Curve segments are typically of two types:

15.10.1.1. Under-running. These assemblies use ‘tips’ that match onto the trolley wire and deflect the swivel harps downwards from the trolley wire onto the curved runners while the trolley wires themselves run straight through to a sharp registration node where the guys can take the radial load.

15.10.1.2. Clamp-type. In these curve segments the trolley wires are clamped directly to the underside of a reinforced curve rail, and the radial load transferred by the use of strain plates and strain bars to provide the necessary rigidity.

15.10.2. Trolleywire Directional Switches.

There are two types of TOH switches:

15.10.2.1. Under-running. In under-running switches, the switch operation is performed on untensioned special work that is suspended from the two trolley wires, which must be suitably insulated. The trolley wires are not terminated at the switch but pass uncut through and above the special work and are guyed as necessary.

15.10.2.2. Cut-in. In ‘Cut-in’ switches the trolley wires are terminated on each side of the switch, and the special work carries the tension being supported from the side by span guys.

15.11. Operation of Trolleywire Directional Switches
There are several ways that trolleywire switches can be activated:

15.11.1. Power On/Power Off. With these the bus operator takes power when passing through the switch in the 'through' direction, or else it aligns to the turning direction.

15.11.2. Selectric Switch. Separate contactors are installed on each of the trolley wires, not opposite to one another but staggered. For trolley buses on the ‘through’ route, the poles will pass by them in sequence thus not completing the switch activation circuit. When ETBs turn relative to the ‘through’ route, the pole to the outside of the turn advances along the ‘through’ trolley wires relative to the pole on the inside of the turn, and the contactors are bridged. This bridging action operates trolleywire directional switch.

15.11.3. Radio Loop. A small transmitter with very limited range is mounted at the top of one of the collector poles. It is coupled to the ‘Turn Switch’ in the operators cab, which when operated causes a receiver mounted on a support pole to activated a power switch on the trolley directional switch special work.

15.11.4. Other Methods. Some agencies detect the ETB in other ways and use computer techniques and programming to activate the trolley directional switches.

15.12. Trolley Pole Guides.

Trolley pole guides are installed at a support as shown in the picture. Using its diesel engine the ETB positions itself directly in line with the guide at a bus stop using the curb and the ‘bus-stop’ marker for correct alignment. By remote control, the driver releases the trolley poles which then elevate automatically onto the trolley wires using the guides to direct the shoes onto the wires. If the poles ‘hang-up’, the driver inches the bus forward using the diesel engine. On satisfactory re-wirement the diesel engine can be closed down.

15.13. Safety Troughing for ETB Operations.
Overhead troughing constructed of wood or other insulated material is installed over the trolley wires for reasons of safety:
- To avoid short circuits
- To avoid false grounds

15.13.1. Avoiding Short Circuits.
Whenever the trolley wire passes under a grounded structure such as an overbridge, or the roof of a ETB barn, a continuous inverted insulated trough is constructed above the trolley wires to catch a trolley pole should it dewire. This avoids the possibility of the collector pole, which is usually conductive, from shorting between the POSITIVE trolley wire and grounded metalwork.

15.13.2. Avoiding False Grounds.
Were it not for the overhead troughing, it would be possible for the NEGATIVE trolley pole, should it dewire, to contact any overhead grounded metal. This is NOT a short circuit because the ETB equipment, motor, resistances, auxiliaries, etc, are in series between the positive wire and ground, which is no different than normal operations. However having the return current passing through the grounded metal of the bridge or building is potentially dangerous and must be prevented.

   15.14.1. Maintenance of the TOH can be performed live by qualified staff, even though the positive and negative wires are closely spaced.
   15.14.2. Maintenance is often performed with the ETBs continuing to run through the job site.

15.15. TOH Supports
   Typical supports are similar to those used for OCS (See Section 5.4.4.?) and include cantilevers, bracket arms, cross-spans, bridles and headspans.

15.16. Insulator Electrical Creepage Distance. See Section 5.5.

15.17. Insulation and Insulator Placement. See Section 5.6.

15.18. Clearances.
   15.18.2. Lateral Clearances to Support Poles.
   Lateral clearances do not apply to ETBs because they are road vehicles, but there may be minimum values for the set-back of support poles from the face of curbs.