Overhead Contact Systems for Modern Streetcar Systems-
Overbuilt, Overpriced and
Overly Obtrusive-An Alternative Design Approach

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ABSTRACT

Current practice for the design of overhead contact lines for modern streetcar systems is to use large contact wires, multiple substations, heavy overhead fittings, close pole spacing and heavy cantilevers. This paper discusses how overhead material can be substantially reduced in mass and weight without compromising strength or safety while providing a visually unobtrusive aerial system with substantially reduced OCS construction costs and future maintenance considerations. Pole spacing can be increased with a standard 4/0 contact wire size for single wire systems and catenary suspension can be replaced with single wire using in track feeder cables. Necessity for increased pole sizes and foundations due to heavy catenary systems can be offset with track slab conduit along-track parallel feeder cables which allow greater substation spacing and reduced visual bulk in the reduction of overall costs for new start systems.

INTRODUCTION

With the advent of the light rail renaissance from the 1980’s to the present, lessons and methods of design from the past have largely been forgotten, ignored or unknown. New traction power and OCS systems use multiple substations without paralleling feeder cables, oversized contact wires, large OCS support poles with deep foundations, a disregard for simple OCS suspensions, and little regard for aesthetics.

Substation design has tended towards low voltage on the primary side without full consideration for operations with substations off line. Designers are using station primary voltage sources of 480 volts which are typically part of the utility company’s secondary circuits. Voltage levels on the contact wire cannot always be sustained with only contact wire as a feeder and time proven design criteria standards of contact wire wear have sometimes been changed to meet requirements.

The design of the traction power system which includes substations, OCS and track structure as an electrical conductor, must be considered as an integral system and the designers should incorporate these in their design of an overhead contact and traction power system. A well designed OCS that is practical, economical and aesthetically sensitive will consider the entire traction power system.

This paper describes a practical, economical and aesthetically sensible approach to overhead contact system (OCS) design for streetcar systems.

BACKGROUND

Streetcars of the past, such as the PCC car, did not draw large amounts of current under full operation. Accelerating currents were up to 500 amps and dropped off to approximately 200 amps while running. Contact wire sizes were either 2/0 or 4/0 trolley wire, usually of bronze and parallel feeder cables kept current in the contact wire to a minimum. As real estate and substation construction were expensive, substations were spaced as far apart as possible and often fed multiple lines.

To keep voltage levels within operational parameters, feeder cables, either aerial or underground emanated from the station and to the various lines with paralleling feeder cable taps. Track rails in city streets were electrically common to each other and all lines had rails tied together, usually at many locations between substations. This added cross-sectional area to the rail conductors to keep voltage drop on the rail portion of the circuit to a minimum.

With the advent of new streetcar installations in the late part of the 20th century, vehicle power demands had changed to more than a two fold increase and OCS and traction power designers conceived the feederless OCS system with frequent small capacity substations. This necessitated using substations at low primary voltage due to their frequency and large conductors for contact wires and messenger cables. It was felt that the use of feederless
systems with frequent small substations and large overhead conductors was more economical than traditional systems.

What was achieved were substations that were susceptible to local power failures, higher power costs, and inability to provide adequate power to the line in the event of an individual substation failure. The overhead system had to have large diameter poles at greater depths to support the increased weight of the overhead conductors for catenary systems and more frequent poles for single contact wire systems. Overhead components had to be larger to withstand high contact wire and messenger wire tensions. Designers changed time proven guy wires to stainless steel wire rope sized with tensile strengths far higher than previously required. Larger components and wire diameters increased ice and wind load further requiring larger poles and deeper foundations, and with a consequential increase in cost.

A more simple and practical OCS and traction power system that is presented herein can alleviate high cost, operational inflexibility and visually obtrusive overhead.

TRACTION POWER SYSTEM

Current Streetcar Traction Power Design

Substations in traditional transit systems are typically fed from either private utilities or the agency’s own power source at medium voltage of 12 kV or higher. With a private utility feed, the medium voltage supply is often a dedicated circuit for industrial customers who are given priority for restoration after power outages. The substation typically has two feeds on different circuits so that the station will continue to operate if one circuit goes down. Costs for power are substantially lower with 12 kV or higher voltage than for a 480 volt supply.

Fluctuations in supply voltage are substantially lower with a medium voltage circuit and large current draw on the substation side does not affect the voltages to other users of the circuit. With a 480 volt supply, large current draw from the substation can affect local customers with brown outs. If the substation is located in an area where the utility doesn’t have a 480 volt network, they often set a dedicated 480 pad mounted supply transformer to supply the substation, requiring dedicated space within the substation site and negating any real estate saving resulting from the lower footprint of a 480 volt supplied substation.

HNTB’s modeling of modern high performance streetcar systems indicated that substation sizing is often determined by rectifier instantaneous currents rather than the RMS current values. This results in a substation being rated for 500 KW or greater where the sizing based only on RMS currents would only be 350 KW. 500 KW is a common transition point for deciding whether a load can be served at 480 volts or medium voltage. When a utility sees a 500 KW rectifier/transformer they often insist on medium voltage supply even though the average load is less than 500 KW.

Substations require maintenance and can have equipment failures. The type of substations being used for new streetcar startups typically use only one rectifier and have no remote control. Local control of the station equipment must be done on sight and in the event of emergencies, fire-fighting companies have to physically go to the station and shut it off to kill power to the catenary.

Typical streetcars substations are not usually designed to have contingency failure so that if one station goes off line, the remaining stations do not have adequate capacity to run the line with a station off line. In city operations, this is critical as the system must continue to operate or it will not be dependable.

Because these systems are feederless, there is no way that a station, even with adequate capacity, can keep the voltage to a sustainable level because it is only feeding through either catenary or contact wire and the resistance is too high to keep the voltage at minimum levels. Further, fault conditions on an overhead conductor will cause all current to flow through that conductor so that it can anneal should it short circuit to ground. The enormous amounts of current that will flow through the conductors, even for short periods of time before the breaker trips, can produce extreme heating to cause the conductor to lose its tensile strength. This especially holds true for conventional use of 350 kcmil copper contact wire which anneals at a lower temperature than bronze contact wire.

Proposed Streetcar Traction Power Design

The authors propose a traction power system that uses paralleling underground feeder cables in track slab construction, frequently spaced feeder taps and 4/0 alloy 80 bronze trolley wire. Design criteria typically requires a contact wire regardless of its size to have a maximum of 30% wear and the load flow calculations are based on the resistance of the worn wire. Voltages for modern streetcar systems typically requires a minimum of 525 volts delivered to the streetcar. Allowances need to be included for the voltage drops caused by the resistance of the feeding cables from the substation, the overhead conductor, the running rails and the return cables.

The authors were designers for two startup modern streetcar systems and did the 30% design. The vehicles to be operated on the lines were the Inkon/USA streetcar which had voltage profiles shown in Table 1 and Table 2.
For system A which was a 3.2 mile double track system, the track rails were tram rail size R52 with a resistance of 0.011 ohms/1000 feet, a 4/0 alloy 80 contact wire with a resistance of 0.052 ohms/1,000 feet, paralleling feeder cables of 500 kcmil with a resistance of 0.026 ohms/1,000 feet. Substations were difficult to locate because of real estate unavailability but three stations were finally located. Once the station locations were established, a load flow analysis was conducted using two scenarios: one with no paralleling feeders and 350 kcmil copper contact wire and one with 500 kcmil paralleling feeder cables and 4/0 alloy 80 contact wire.

### 4/0 Bronze Contact Wire and 500 kcmil Feeders

![Diagram](image)

### Table 1
350 kcmil Single Contact Wire

![Diagram](image)

### Table 2

Using the agencies established design criteria, with one substation off line and the contact wire worn at 30%, the single 350 kcmil without paralleling feeder cables could not keep the voltages within limits. With a 4/0 contact wire and paralleling feeder cables, the voltage was within limits.

**Use of Track Slab Conduit**

System A utilized existing street lighting conduits for the feeder cables as most track had been constructed in advance of the power design. For system B, placing conduits in the reinforced concrete track slab was considered and found to be a very practical and economical method of installing conduit in the street. The street had to be excavated to accommodate the new tracks and a reinforced concrete slab was to contain and support the rails. Each track had its own slab built to a depth of 15.83 inches as shown in Figure 1. This would allow four, 4 inch FRE conduits to be placed in the slab and still have adequate concrete cover and protection. Typical cost for separate in street conduit for a 2 over 2 costs approximately $100/ft while cost for 4 conduits in a track slab costs approximately $24/ft.

![Figure 1](image)

Feeder cables were to be 500 kcmil copper but for additional cost savings, 750 kcmil aluminum cables were chosen as the cost was 1/3 that of copper. New advances in aluminum alloys that have an expansion rate almost identical to copper improve the operating capabilities of the cable so that it becomes comparable to copper. Feeder tap cables were 4/0 copper and had connections in handholes at 400 foot intervals as determined from the load flow study, and branched out to the OCS pole.

A major problem with new system designs using underground feeder cables is that a disconnect switch is not used and the entire OCS network is hard wired from the substation. If a fault on any part of the circuit occurs, the breaker opens and the affected power section remains de-energized until the fault is cleared. The contact wires from adjoining power sections cannot be jumped through the by-pass switches to jump the section insulator as the adjoining power section is faulted.

Use of disconnect switches at the cable taps allows the affected short circuited power section to be isolated from the underground cables so that the contact wires can be jumped from an adjacent section. As current at the feeding point is limited and not full load, smaller type disconnect switches can be used. These switches are mounted at the point where the feeder cable tap exits the OCS pole and is hook stick operated. Its small size of approximately 4” x 6” x 12” makes it unobtrusive yet the capacity of 500 amps is sufficient for feeder taps.

**OVERHEAD CONTACT SYSTEM**

**Current Streetcar OCS Design**

Conventional OCS design for modern streetcar systems has used either a full catenary or a single contact wire system with span wire or cantilever suspension supports. The catenary has consisted of a 500 kcmil messenger cable and a 350 kcmil contact wire, both hard drawn copper. When designed per the requirements of the National Electrical Safety Code [1], the loads on the poles
become substantial and large diameter poles with deep foundations are required. On one transit system, a 1,000 kcmil messenger cable was used requiring excessive pole and cantilever sizes (Figure 2). Pole spacing is usually determined from vehicle and pantograph parameters as well as sag and blowoff of the wire on the pantograph. Use of a catenary with large conductors over city streets creates a visual blight, public abhorrence to overhead wires and is unnecessary.

As an alternative to the visual blight of a full catenary over city streets, designers have reverted to a single contact wire to lessen the burden of visual impact. Typically, a 350 kcmil copper trolley wire has been used in streetcar systems that do not have paralleling feeder cables as designers felt that the increased cross sectional area of this wire is such that voltage levels can be kept at minimum requirements for streetcar operation. The suspension of the wire has typically been suspended with head spans and steady spans to support it if span wire construction is employed. Hinged pipes, referred to as cantilevers, attach to the poles and support the contact wire when cross track span wire is not employed. Suspension from the head span assembly or from the cantilever has usually been done with a “stitch assembly” which utilizes an insulator, trolley clamps, a stitch wire with insulators and a heavy steady arm. This also imparts visual bulk into the OCS and is excessively heavy construction (Figure 3).

Suspension of 350 kcmil contact wire is typically direct suspension either from span wires (or cantilevers) with rigid fixed line insulators and trolley clamps for variable tensioned systems. For constant tensioned systems, the line insulator supports a pulley and a stitch support runs through it and connects to the contact wire. Two span wires are typically used, a head span and a steady span. If cantilevers are used, they are hinged and swing along track to accommodate the contact wire movement and the contact wire is generally supported from them with a stitch. Steady arms are used to align (register) the contact wire further adding to the weight of the assembly.

Use of 350 kcmil single contact wire requires more frequent supports than the traditional 4/0 contact wire suspension system. The 350 kcmil wire must have supports spaced at close intervals so that the maximum span length, typically 80 feet, does not allow the contact wire to sag excessively. Added weight and tension is imparted into the contact wire from ice and wind loading which, in turn, creates high span wire tensions and additional sagging of the wire.

Further, as pointed out in the previous paragraphs for a voltage analysis of a new modern streetcar system which the authors participated in the 30% design, the voltage with one substation off line cannot be sustained at the minimum allowable level with the 350 kcmil wire worn to 30% requiring paralleling feeder cables to keep the voltages to the minimum of 525 volts. Consequently, using the same system with the same scenario, a 4/0 contact wire 30% worn with parallel feeder cables kept the voltages by 17% above the required minimum or 613 volts.

Single contact wire is susceptible to annealing during short circuits as all fault current passes through it. With paralleling feeder cables, the majority of fault current will pass through the feeder cables saving the tensile strength of the contact wire in most cases. Of course, should the substation breaker fail to open, all cables and wires would be adversely affected.

**Span Approach Angle**

The sag of 350 kcmil wire also increases the angle of the contact wire as it approaches and leaves the suspension point. This angle, referred to as the Suspension Point Angle (SPA), is greater with wires having more sag.

By itself, the SPA is not a problem and does not adversely affect the contact wire but it directly affects trolley pole and pantograph current collection at the
suspension point, Figure 4. The greater the sag of the contact wire, the greater the SPA. When the contact wire is tensioned between two points, it has a relationship between weight and tension and a sag results with the shape of the wire closely approximating a parabolic curve. At the mid-point of the span, in between the two suspension points, the line is horizontal. As the contact wire approaches each suspension point, a hypothetical tangential line at any location on the wire changes from horizontal to an increasing angle as each point becomes closer to the suspension at the pole. The greatest deviation from the horizontal is at the immediate vicinity of the suspension point. The increasing slope of the contact wire is dependent upon the distance between the two suspension points and the specific tension of the contact wire with its resulting sag [2].

![Figure 4](image.png)

The pantograph is affected by this angle as it must be accelerated upward corresponding to the steepness of the contact wire curve. The acceleration of the pantograph upward is limited by its mass inertia and the inherent vertical velocity of the pantograph mechanics. This means that the pantograph’s ability to accelerate upward to meet the increasingly steeper contact wire is restricted because the slope of the wire is too great due to the vehicle speed along the tracks. The pantograph therefore jumps off the contact wire just before it approaches the suspension point, then hops under the suspension point and rejoins the contact wire just after the suspension point to the next span length of contact wire. This jump is easily recognized on rigid overhead contact systems by the arcing at the suspension point with subsequent wear. At the same span length, 4/0 contact wire has less sag than 350 kcmil wire and therefore, a smaller SPA providing better pantograph operation (see Table 3).

To control excessive sag when 350 kcmil wire is used, pole spacing is decreased from 100 ft to around 80 feet on tangent construction. When the spacing is decreased from 100 feet to 80 feet, the sag at a 100 foot span is reduced from 17 inches to 11 inches at the highest temperature and lowest wire tension. This excessive sag further compounds SPA at the support where the current collector, such as a pantograph, cannot negotiate without bounce.

### Contact Wire Comparison

<table>
<thead>
<tr>
<th>Wire Type</th>
<th>350</th>
<th>4/0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension 120°F</td>
<td>913 lbs</td>
<td>769 lbs</td>
</tr>
<tr>
<td>Tension 32°F w ⅛” ice-wind</td>
<td>2,917 lbs</td>
<td>2,544 lbs</td>
</tr>
<tr>
<td>Tension 0°F w ⅛” ice-wind</td>
<td>3,877 lbs</td>
<td>3,213 lbs</td>
</tr>
<tr>
<td>Sag 120°F</td>
<td>17.46 in</td>
<td>12 in</td>
</tr>
<tr>
<td>Sag 32°F w ⅛” ice-wind</td>
<td>9.09 in</td>
<td>7.42 in</td>
</tr>
<tr>
<td>SPA 120°F no ice/wind</td>
<td>1.66°</td>
<td>1.19°</td>
</tr>
<tr>
<td>SPA 32°F w ⅛” ice-wind</td>
<td>0.90°</td>
<td>0.70°</td>
</tr>
<tr>
<td>Initial Tension 68°F</td>
<td>1,500 lbs</td>
<td>1,500 lbs</td>
</tr>
</tbody>
</table>

A further drawback with 350 kcmil wire in a variable tension system is the higher tension on it during very cold temperatures. To keep the sag reasonable during warm weather, the wire would have to be at very high tension during cold weather. In doing so, it will put very high tensions on curve pullovers and pulloff wires with consequentially higher pole loadings. To prevent this, the tensions are lowered as illustrated by the tensions in Table 3. If an initial higher tension of 1,000 lbs at 120°F is used, the 350 contact wire will have a tension (no ice/wind) of 4,708 lbs at 0°F which may over-stress pullovers, place higher loads on poles and require wider and deeper pole foundations.

### Constant Tension Devices

Balance weights have been a simple, effective method for ensuring that contact wires are kept at a constant tension throughout the temperature range that they are subjected to. Constant tensioning controls the tension and subsequent sag over the temperature range that the contact wire will experience. Along city streets, they can be placed either outside of the pole or inside it to hide them but inside-the-pole weights must have a pole of large enough diameter to allow the weights to be suspended inside of it, typically 16” diameter. Further, the pole cannot deflect under the wire loadings or it will pinch the weights and they will not travel up and down freely. These poles are back guyed to prevent deflection and the guys consist of large diameter guy wire and typically have insulation in them. The pulley wheels
extend outside of the pole and the back guy presents an obtrusive appearance.

Further, the opening at the top of the pole for the pulleys allows birds to enter and nest. This leads to debris building up inside the pole which can jam the weights. The bird droppings corrode the cables, fittings and weight pieces compromising their integrity. Bird droppings jeopardize the safety of maintenance crews as it is considered a hazardous substance. Droppings on the outside of the pole at the nest entrance are also unsightly.

Outside-the-pole balance weights are usually simple and easy to maintain as shown in Figure 5. A recent innovation that is being used in Europe and Canada, Figure 6, shows a spring tension device (STD) that keeps a constant tension on the contact wire throughout its temperature range. It is aesthetically pleasing, easy to maintain, self-contained and safe for public thoroughfares such as sidewalks. The STD can be mounted on any pole regardless of its diameter (also wall surfaces or tunnel ceilings) so that large poles are unnecessary. The cost of the STD and the labor to install it is considerably less than a balance weight assembly that is inside or outside the pole.

**Semi-constant Tensioning**

Control of contact wire tension can be accomplished not only through tensioning devices but by the use of semi-constant tensioning, also referred to as partial temperature compensation. This is another method for controlling contact wire tension and is done by using inclined suspension at support spans and cantilevers. Partial temperature compensation, over the full temperature range, is produced with minimal tension variation. With this type of system, balance weights or other tensioning devices are not required but can be employed with the inclined system if constant tensioning is warranted for higher speeds of up to 70 mph.

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**Span Wire, Pole and Foundation Loading**

The inclined system, when inclined pendulum suspension hardware is used, is the simplest and most aesthetically pleasing OCS available. It is also the least maintenance intensive and the most economical of the OCS systems when tension and sag control are required.

Design of modern streetcar systems must consider simplicity, economy and aesthetics. OCS designers have put forth designs over city streets using 500 kcmil messenger cable with 350 kcmil contact wire, multiple span construction or cantilever support with large diameter poles. Single contact wire systems are being designed with either direct suspension or a stitch with steady arm hardware (which tends to acts as direct suspension) or constant tension hardware using stitches in pulleys and steady arms with multiple span wire or cantilever support.

Consider a typical modern streetcar design of span wire construction with an 80 foot tangent pole spacing and 60 foot span length across a street for double track using a 350 kcmil contact wire, stitch support, and two span wires of 3/8" diameter. Contact wire height at the span is 19 feet and the system height is 3 feet. The total weight the two poles have to support is 400 lbs. If a span wire slope of 1:8 is used, the tension on the head span wire is 1600 lbs. The steady span has a minimum tension set at a tension of 500 lbs to prevent it from going slack. With the poles 24 feet from the contact wire, height of the head span wire at 25 feet, the steady span wire is 20.5 feet with the resulting bending moment on the pole being 50,250 ft lbs.

Using the previous scenario of a 60 foot wide street but with poles spaced 120 feet rather than 80 feet, and using a 4/0 contact wire, inclined pendulum suspension, and one span wire of 5/16" diameter, the total weight the two poles have to support is 343.25 pounds. Using a span wire slope of 1:8, the tension on the span wire is 1,373 lbs. With the poles 24 feet from the contact wire, height of the span wire will be 24 feet and the bending moment on the pole will be 32,952 ft lbs. The loads for both scenarios do not include NESC ice and wind loads and overload factors for simplicity of illustration.

Pole deflection is given in the American Transit Association manual D11-39 as 6 inches in 24 ft or about 2% of the pole length above the ground line. From the pole loadings above, a typical tapered pole that would meet these loading and deflection criteria would be a Union Metal type A23E-9.5” x 26’ (9-1/2” base diameter with a ½” wall) for the head span with 350 kcmil wire and an A23E-8.5” x 26’ (8-1/2” base diameter with a ½” wall) for the single cross span for 4/0 wire. This results in a net savings in weight of about 151 lbs per pole when the
smaller diameter pole is used equating to approximately $453,00.

Foundation diameter and depth is both project and soil specific so one can only provide an example. The foundation diameter for the 1,373 lb load, using a 13 foot depth foundation in poor soil defined as 1,500 psf, and a safety factor of 1.5 on the load, would be 2.62 feet in diameter as defined by the foundation formula in the American Transit Engineering Association Manual D104-55. For the typical suspension using a head span and steady span with a load of 1,600 lbs and 500 lbs respectively, the foundation size required at 13 ft deep is 4.10 ft diameter.

With simple, light weight OCS, pole sizes and foundations can be reduced to save cost and visual bulk. A comparison between a 350 wire with head span stitch suspension and a 4/0 wire with single span construction shows that with the 4/0 wire, less poles are required, the load on each pole is reduced, the foundation size is decreased, the visual obtrusiveness is negated and the cost is less.

**Alternative Streetcar OCS Design**

**Aesthetics for Overhead Contact Systems**

The OCS put forth by the typical OCS designer specifies the use of large, heavy components, large poles, multiple span wires and in-pole balance weights. A culture exists where alternative solutions are not explored and modern streetcar OCS in the United States is constructed without complete consideration for aesthetics, operation or maintenance. Simple, lightweight systems are easier to install and less costly to maintain and the designer should look at all aspects of the OCS so that every component and assembly of the system is considered.

<table>
<thead>
<tr>
<th>OCS System Comparison-2,500 ft Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire Type</td>
</tr>
<tr>
<td>Ruling Span</td>
</tr>
<tr>
<td>Pole Quantity</td>
</tr>
<tr>
<td>Concrete Cu Yds</td>
</tr>
<tr>
<td>Span Wire ft</td>
</tr>
<tr>
<td>OCS Span Suspension</td>
</tr>
<tr>
<td>Foundation Volume Cu Yds</td>
</tr>
<tr>
<td>Estimated Total Cost ($)</td>
</tr>
</tbody>
</table>

**Table 4**

**Constant Spring Tension Device**

An effective alternative to balance weights is a simple spring tension device for ensuring that contact wires are kept at a constant tension for controlled and reasonable sag. These are mounted to the exterior of the pole and can be painted to conform to the color of the pole. Pole deflection is not a consideration in the operation of the device as it is completely outside the pole. The outside diameter of the pole can be considerably smaller than the typical 16 inch diameter inside-the-pole balance weight pole. With a single contact wire having a constant tension of 2,500 lbs at a height of approximately 20 ft, the bending moment on the pole would be 50,000 ft lbs. A tapered pole having a diameter of 8.50 inches with a wall thickness of 0.50 inches is able to meet the loading and deflection requirements for this load.

Along city streets, where pedestrians pass, there is no danger from weights falling or interfering with pedestrian traffic near the pole as the spring tensioner is completely encased. In the event of a catastrophic failure such as a contact wire break, the unit recoils without any parts falling. Maintenance is minimal so that the device not only is practical and functional, but aesthetically pleasing. (Figure 6). This type of tension device is now utilized extensively on public thoroughfares in Europe [3].

**Direct Embedment Pole Foundation**

Traditional transit systems have historically used direct embedment for pole installations in most locations as it was easier to install and more economical from a labor standpoint. The hole is excavated, the pole is inserted and positioned and then concrete is poured in. This allows for an inexpensive installation without the need for reinforcing cages and anchor bolts. It also allows the sidewalk surface/pole interface to be obstruction free and the pole to be repaired in place if ground line corrosion occurs without affecting attachments to the pole.

Anchor base poles can create a visual and physical obstruction on narrow sidewalks where ornamental bases are not used. They are particularly susceptible to corrosion on their anchor bolts where salt is used for snow and ice melting and they cannot be repaired with the pole in place. Typically, a new foundation is set next to the pole and a new pole set on it and all the spans and attachments transferred to the new pole. Then the old pole is removed and the top of the foundation removed to just below the top of sidewalk with new concrete or other material used to restore the sidewalk.

From an aesthetic viewpoint, exposed anchor bolts and pole base plates can be unsightly (Figure 7). They also can be a tripping hazard unless the pole base is covered with some sort of ornamental or streamlined cover.

It is recommended that either a full depth embedded pole or a partially embedded anchor base pole be utilized.
for protection of the pole at the ground line and for aesthetics when ornamental pole base covers are not used.

**Suspension System**

The recommended OCS put forth by the author’s design specifies that the use of single contact wire with simple, light weight, non- visually obtrusive OCS components, smaller poles, single span wires, constant tension spring tension devices and underground feeder cables be considered (see Figure 8). Stitch assembly suspension with steady arms (Figure 9) is analogous to direct suspension in that the contact wire does not lift as the pantograph approaches due to the weight of the system and there is a tendency for appreciable contact wire wear at the support. Inclined construction, especially with aesthetically appropriate pendulum suspension, allows the contact wire to rise ahead of the pantograph so that frictional resistance on the wire is substantially reduced [2].

Span wires of smaller diameter but with higher strength should be used for suspension of contact wires. For example, a 5/16” extra high strength span wire with similar breaking strength as a 3/8” utilities grade span wire can be used. The use of 3/8” stainless steel wire rope in modern streetcar systems adds significantly to the cost and is unnecessary as 7 strand galvanized guy wire has historically given excellent service in transit and railway systems. Reduction of diameter reduces wind and ice loading as well as visual clutter and further reduces loading on poles and foundations. The fittings used to terminate the span wire are also reduced in size and cost when the smaller size wires are used. The simplest, most economical and least visually obtrusive terminations are crimp sleeves or preformed wrap end fittings.

An alternative to steel span wires is the use of synthetic ropes which are non-conducting and do not need insulators. High strength Kevlar® ropes can provide a similar strength as 3/8” Utilities Grade guy wire with a much lower weight, even with ice load.

**Feeding System**

Feeder cables from the substation to the OCS rise on feeder poles through an initial disconnect switch. Many modern streetcar systems use open face disconnect switches mounted at the top of the pole (Figure 10). These are extremely unsightly but also unsafe in that the energized switch parts are exposed and operation with a load will draw an open arc. This type of switch is typically mounted on a grounded base plate so that if the insulation between the switch body and the plate fails, a short circuit occurs. Figure 11 shows this type of switch in a fault mode. Having this in public thoroughfares is unsightly and very dangerous.

Disconnect switches should be mounted in non-conducting enclosures on poles in a manner where the public cannot access them. Side operated linkages are visually unobtrusive and unnecessary. Simple switches, rated for the current they are to carry are commercially available from manufacturers so that they function properly while maintaining some degree of aesthetics.

For parallel track feeders, the cables would run in track slab conduit to a hand hole where each feeder tap is brought up through the inside of the pole and exits through a feeder spout near the span wire. The cable is
attached to the span wire or cantilever and run out to the contact wire. At each feeder tap, a small enclosed disconnect switch should be attached either to the pole or the span wire/cantilever to allow easy disconnect of the paralleling feeder cable for isolation and power section tying of the contact wire in the event of a fault. Both the cable insulation and the disconnect switch exterior can be produced with a light gray exterior color.

It is important to consider the visual aspects of an overhead contact system as well as its mechanical and operational aspects. An OCS should be fully functional while considering the aesthetics of the surrounding environment as described by John Kupla and Arthur Schwartz [4]. The authors of this publication, (Kupla and Schwartz) encourage other traction power and OCS designers to integrate aesthetically pleasing designs into the OCS. The utilization of higher capacity substations with medium voltage utility supply, track slab parallel feeder cables, inclined pendulum construction, and constant tension spring devices as described by White and Greig, incorporate simplicity, practicality, economy and aesthetics into the OCS design.

CONCLUSION

The typical traction power system and OCS put forth by many TP/OCS designers of modern streetcar systems specifies the use of secondary voltage utility supply substations of small capacity, heavy OCS components, large diameter poles with multiple span wires, in-pole balance weights and they believe this is the only way overhead can be designed. The authors have been involved with the design of modern streetcar systems and have incorporated simplicity, practicality and economy to achieve traction power systems that incorporate the recommendations and aesthetics as put forth in this paper.

Traction power substations for modern streetcar systems can be reduced in number by using higher capacity stations with a medium voltage power supply and parallel feeder cables so that they have adequate power to keep voltage levels within allowable limits.

OCS for modern streetcar systems can have components that are aesthetically pleasing and lightweight so that the pole structures can be reduced in size and their corresponding foundations decreased in volume. Use of 4/0 bronze contact wire with paralleling track slab feeder cables and inclined pendulum suspension allows a savings in cost as well as a less visually obtrusive OCS when compared to a full catenary or single 350 kcmil contact wire system.

OCS wires can be tensioned with simple spring devices that place a constant tension on the line without the use of large, back guyed poles and balance weights. Smaller pole sizes can be used without undue deflection and visual obtrusiveness reduced. Pole foundation sizes will be shallower or smaller in diameter for additional cost savings.

The parallel track slab feeder cable system allows cables to augment the contact wire to keep voltage profiles at minimum allowable levels in the event of a substation outage. The cables also protect the contact wires during fault conditions as the majority of current passes through them. Track slab conduit is less expensive than traditional street conduit and does not interfere with surrounding utilities.

With the incorporation of industry recommended aesthetics coupled with simplicity and economy as recommended herein, a resulting reduced maintenance, and reliable operation can be achieved.

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END NOTES

3. European Standard EN 50019:2004 (revision), Section 7.5 Tensioning Devices, 4th paragraph.

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