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7.0 CHANGES FROM THE 1994 ISSUE OF CHAPTER 33 PART 7 RAIL BONDING

The 1994 version of Part 7 dealt only with the design and specification of rail bonds. It did not deal with the grounding requirements for an electrification system or with the bonding requirements needed to effect satisfactory grounding. The present material represents a major re-write of this Part, and provides recommendations for grounding and bonding of ac and dc powered railroad, light rail, and commuter rail electrification systems.

7.1 INTRODUCTION

The grounding and bonding recommendations for railroad, light rail, and commuter rail electrification contained in this section are intended to achieve the following objectives:

- Safety of employees and the public
- Protection of equipment, cables, and buildings
- Electrical noise reduction
- The correct, efficient, and safe operation of electrical circuits.

Grounding is the establishment of a common reference voltage (typically 0 V) between power sources and/or electrical equipment. Electrical ground faults, short circuits, lightning, and transients can occur in electrical power supply and distribution systems or the facilities power systems. These recommendations identify requirements for the grounding and bonding provisions relating to electrical safety in structures associated with the traction system and any structures that may be adjacent to the electrification power supply and distribution systems, or the facilities power system.

In order to achieve those objectives, a multifaceted approach is required to determine the optimum grounding and bonding guidelines. A number of areas related to the grounding and bonding issue need to be considered. They include:

- Insulation Coordination, including consideration of impulses associated with lightning strikes and switching surges.
- Inductive coordination
- Protective Relay coordination
- Step-and-Touch Potentials
- Rail Potentials
- Railway Equipment (Rolling Stock) Potentials
- Systems design (electric traction power supply and distribution, signals, communications, and track)
- Construction, operations and maintenance
- Corrosion control
- Economics versus performance.

It should be noted that ac and dc traction power systems have different design requirements that are often in conflict and present considerable challenges in the grounding and bonding design. In addition, the staging of modifications to an existing railway electrification system must include modifications to the grounding and bonding system in order to ensure the objectives listed above are met. These objectives must be
maintained throughout each stage of the work, on both existing, and new electrifications. A comprehensive grounding and bonding study is recommended to obtain up-to-date information regarding the current or proposed system and establish the proper criteria that will be required for the design.

The grounding and bonding design should achieve the following:

- A basic impulse insulation level should be established for the electric traction system in order to provide a baseline for insulation coordination of system components and hence for the design and specification of equipment.
- The development of grounding and bonding plans for the system under design.
- Recommendations for the application of cross bonds, supplementary conductors, aerial ground, and static wires for traction current return with consideration of their impact on broken rail protection.
- Recommendations for grounding and bonding in dc territory.
- Recommendations for grounding and bonding in ac territory with the appropriate considerations if the same rails are used for dc return.
- The structures of the Overhead Contact System (OCS) should be solidly grounded to reduce the possibility of step and touch potential, provide a solid ground reference for the protective relays and lightning strikes to the structures.

The objectives, conclusions, and statements that are a part of the grounding and bonding design must be confirmed with the system owner prior to proceeding with the tasks enumerated herein.

At present there are no standards or guide documents in the USA that are directly applicable to the grounding and bonding specifically of electrified rail transit systems. However, there are three foreign standards, available in the English language, which have been developed specifically for the design of electrified railway facility grounding:

- European Standard BS EN 50122-1: 2011, Railway applications – Fixed installations – Electrical safety, earthing and the return circuit, Part 1: Protective provisions against electric shock; and

### 7.2 AC ELECTRIC TRACTION SYSTEM CONSIDERATIONS

The grounding and bonding considerations related to ac electric traction systems are typically based on the following configuration:

- The return circuit consists of the static or aerial ground wire, OCS support structures, the running rails, supplemental return cables where applicable, cable connections to the substations, cross bonding of the running rails, and the earth.
The cross-bonding of the running rails through impedance bonds at intervals compatible with the signal system.

Any metallic components of the surrounding infrastructure, which are not part of the traction return system but are capable of carrying current or picking up induction, should be grounded and bonded to mitigate potential differences with the return circuit.

The electrification infrastructure is bonded and can carry a portion of the return current of the traction power system under both normal and fault conditions. The ac electric traction system may be configured with a supplementary return conductor in addition to an aerial ground wire or static wire. The connection of the aerial ground or static wire or supplementary return conductor in parallel with the running rails can help to reduce the impedance of the return circuit which will in turn reduce the voltage drop across the return rails and increase the voltage delivered to the propulsion system of the train. The efficiency of operation is, therefore, improved via the parallel return paths of the running rails, the supplementary return conductor, aerial ground or static wire, and the earth.

For typical ac electrification systems it must be recognized a portion of the return current will travel through the earth. An analysis of the soil conditions should be conducted to determine that capability. Since the surrounding infrastructure is grounded and bonded it is not unreasonable to observe currents associated with the ac electric traction system return through the infrastructure. However, every effort should be made to avoid relying on the earth or any of the surrounding infrastructure components as part of the normal return path. The distribution of currents for the system can be determined via analytical methods and field measurements.

When designing the ac traction return system considerations must be given to the current or proposed level of service. The return systems must be sized large enough to carry the maximum operating currents from any of the following, while allowing room for future growth:

- A single ac locomotive or electric multiple unit train set
- A pair or more ac locomotives operating separately or in tandem
- Multiple electric trains in a given section
- Multiple light rail vehicles or street cars

7.2.1 AC TRACTION POWER FACILITIES (TPF)

The ground grid for each ac TPF should be in direct contact with earth at a depth of 12-18 inches (300 - 450mm) below grade. The ground grid should extend at least 3 feet (1m) beyond the fence or building of the TPF. Every effort must be made to ensure the entrance gates swing into the TPF. Should that prove unrealistic the ground grid must extend 3 feet (1m) beyond the swing of the entrance gate. The ground grid for each TPF should be designed in accordance with the requirements IEEE-80 Guide for Safety in AC Substation Grounding, and where applicable The National Electrical Safety Code (NESC), The National Electrical Code (NEC), and state or local codes.

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

A layer (3–6 inches (75-150 mm) thick) of high resistivity material, such as gravel, should be spread on the earth’s surface above the ground grid to increase the contact resistance between the soil and the feet of persons in the TPF. The grounding system
must be designed so that the step and touch potentials under fault conditions are within the designated limits.

In areas where soil resistivity is high or the TPF space is limited, alternative methods can be considered for obtaining low impedance grounding, such as connections to remote ground grids or wire mesh, deep-driven ground rods or drilled ground wells, plus the use of various additives and soil treatment methods, etc. The effects of transferred potentials, which can result from interconnection to remote ground grids, should also be considered. See section 7.5.6 for additional information regarding fence bonding.

7.2.2 AC OVERHEAD CONTACT SYSTEM (OCS) SUPPORTS

Grounding connections provide a path for tying the OCS metallic parts to the return circuit and for the electrical interconnection of structures, caissons, and in case of other modes of construction, the conductive interconnection of the metallic parts during fault conditions.

The OCS poles should be grounded through interconnection of the pole to the static /aerial return wire so that the ground resistance of the interconnected poles is kept low. Foundation caissons, where there is good contact with the adjacent soil are recognized as being good earth electrodes. Where the ground resistance of individual OCS poles exceeds 25 ohms, individual ground rods or other grounding solutions should be applied to achieve the 25 ohm value. All other OCS structural supports – wall brackets, drop pipes, feeder wire brackets, etc. – should be grounded.

Ground connections to disconnect switches and ground leads from surge arresters should have a maximum ground resistance of 5 ohms. Ground rods or a ground mat may be utilized to obtain the required ground resistance. If the metallic OCS pole at the disconnect switch location is to be used as part of the grounding system, the pole should be bonded to the steel caisson, or more driven ground rod(s) and/or the ground mat.

7.2.3 AC RETURN SYSTEM

The ground grid at each ac TPF should be connected to the TPF return bus. The return bus should be connected to the rails through impedance bonds through two independent connections. Each return cable should be sized to carry the maximum load and maximum anticipated fault current, thereby allowing for the failure of one return cable. Where signal track circuits are present, the connections to the running rails should be made via impedance bonds at locations approved by the Signal System Designer.

Impedance bonds in both two-track and multi-track areas should be cross-connected at intervals at a frequency that does not compromise the broken rail detection system.

Wherever possible, wayside structures or facilities should not be connected to the traction return system, and should be bonded and grounded independently.

These aspects of the grounding and bonding system design must be coordinated between the Traction Power Supply System, OCS and Signal System designs. Diagrams of an AC Return System are outlined in the AREMA Manual Volume 3, Chapter 33, Part 5.
7.3 DC ELECTRIC TRACTION SYSTEM CONSIDERATIONS

DC traction power substations convert (rectify) three-phase ac utility power to direct current for utilization by rolling stock. The direct current is distributed from the substation rectifiers to the right-of-way by the positive supply system and from the right-of-way back to the rectifiers by the negative return system. The negative return systems of most modern dc rail transit systems are intentionally isolated from earth (ungrounded) under normal operations to prevent stray current corrosion, which can be destructive to nearby metallic infrastructure. After being utilized on some early systems, it has been well established that the solid grounding of substation dc negative buses results in unacceptable damage from stray current corrosion, and this method of system grounding is no longer used on dc systems in the USA.

Intentional isolation of the dc negative return system from earth enables voltage differences to appear on the tracks between running rails and remote earth (rail potential). It also complicates the detection of positive-to-ground faults, since there is no intentional low resistance path back to the rectifiers for fault current flow. Connection of the substation negative buses to ground through power diodes initially appeared to offer improved ground fault detection and reduced stray currents in comparison to solid grounding, but it is being phased out in favor of the isolated type of system grounding. Rail potential with diode-grounded substations has not been found to be significantly reduced, and stray current levels are still unacceptably high.

Some transit systems in the USA use negative grounding devices in substations to temporarily ground the dc negative bus when high bus-to-ground voltages are measured. These devices are also called “automatic grounding switches”, “rail potential control devices”, and “grounding contactors”. These devices are connected between the dc negative bus and the substation grounding grid. In addition to limiting rail potential in the vicinity of the substation, negative grounding devices assist in the detection and clearing of positive-to-earth ground faults external to the switchgear.

During the design phase of new or modified dc electrification systems, the designer should monitor and document any dc stray current leakage from dc-powered systems, such as welding facilities, adjacent to the right-of-way facilities and/or from existing transit operations, to establish baseline stray current levels against which future stray current leakage can be assessed.

7.3.1 DC TRACTION POWER FACILITIES (TPF)

The ground grid for each dc TPF should be in direct contact with earth at a depth of 12-18 inches (300-450 mm) below grade, as stipulated in IEEE-80. The ground grid should extend a minimum of 3 feet (1 m) beyond the fence or building of the TPF where pre-packaged substation houses are employed. Every effort should be made to ensure any entrance gates swing into the facility. Where that is not possible, the ground grid must extend 3 feet (1 m) beyond the swing of the gate or doorway of a pre-packaged substation. The ground grid for each TPF should be designed in accordance with the requirements of IEEE-80 Guide for Safety in AC Substation Grounding, and where applicable the NESC, NEC and state or local codes.

Where the TPF is enclosed by a metal fence, the fence should be bonded to the TPF ground grid as specified in the applicable codes. Where unit substations are employed,
(typical of most LRT systems) the TPF house should be bonded to the TPF ground grid as specified in the applicable codes.

A layer 3–6 inches (75-150mm) thick of high resistivity material, such as gravel, should be spread on the surface of the earth above the ground grid to increase the contact resistance between the soil and the feet of persons in or at the TPF. The grounding system must be designed so that the step and touch potentials under fault conditions are within the designated limits.

7.3.2 DC OVERHEAD CONTACT SYSTEM SUPPORTS

Grounding connections for dc traction systems should minimize the possibility of tying line side metallic parts to the return circuit to minimize the possibility of creating electrical paths for stray currents.

For dc systems that utilize an OCS the poles should be individually grounded through interconnection of the pole to the foundation rebar cage and supplementary ground rods, as needed based on ground resistivity, so that the ground resistance of each pole is less than 25 ohms. Foundation caissons, where there is good contact with the adjacent soil, are recognized as being good earth electrodes. Where the ground resistance of individual OCS poles exceeds 25 ohms, additional or deeper-driven ground rods or other grounding solutions should be applied. Other OCS structural supports, such as wall brackets, drop pipes, feeder wire brackets, etc., should be either insulated from ground to the extent practicable or interconnected to an aerial ground wire that is grounded at one end only, so that the ground resistance is less than 25 ohms.

Ground connections for disconnect switches and ground leads from surge arresters should have a maximum ground resistance of 5 ohms. Ground rods or a ground mat may be utilized to obtain the required ground resistance. If the metallic OCS pole at the disconnect switch location is to be used as part of the grounding system, the pole should be bonded to the steel caisson, or to driven ground rod(s), and/or to the ground mat.

7.3.3 DC RETURN SYSTEM

The ground grid at each traction power facility should not be intentionally connected to the TPF return bus except by voltage limiting devices that make this connection only temporarily. The return bus should be connected to the running rails through impedance bonds by at least two suitably-rated negative return cables. Each return cable should be sized to carry the maximum load and maximum anticipated fault current, thereby allowing for the failure of one return cable. Where signal track circuits are present, the connections to the running rails should be made via impedance bonds at locations approved by the Signal System Designer.

Impedance bonds in both two-track and multi-track areas should be cross-connected at intervals at a frequency that does not compromise the recognition of trains and/or broken rail detection systems.

Wayside structures or facilities should never be connected to the traction return system, and should be bonded and grounded independently.
These aspects of the grounding and bonding system design must be coordinated between the Traction Power Supply System, OCS and Signal System designs. Diagrams of a DC Return System are outlined in the AREMA Manual Volume 3, Chapter 33, Part 5.

7.4 COMBINED AC & DC CONSIDERATIONS

Where both ac and dc railways operate over the same tracks, there are concerns unique to either of the operating systems. In order to accommodate the needs of both systems, the OCS designer must look at the following:

- Impedance bonds, cross-bonding cables and connections, and (if required) rail head bonds must be sized to accommodate the currents from both systems possibly occurring simultaneously. DC saturation of the impedance bonds must also be evaluated, as an impedance bond that becomes saturated may allow other currents to pass that were meant to be contained by the impedance bonds.
- Grounding of OCS poles must be closely evaluated. Poles that are grounded by a static or return conductor should not form closed loops with the rails. This can lead to stray dc currents traveling through the return system via the OCS poles causing deterioration.
- The ac and dc substations should be located sufficiently far enough apart that the rail connections into each substation do not compromise the signal system. If these substations cannot be separated and must share a common rail connection, care must be taken to provide paths back to each ac or dc source that minimize the possibility of creating circulating current paths.
- Insulation of rails, return conductors, static wires, or even structural steel may be necessary to keep the return currents on their preferred electrical path. Care must be taken to still keep all ground resistance values under 25 ohms.
- Stray dc currents should be thoroughly evaluated and appropriate mitigation designed.

The designer should monitor and document any dc stray current leakage from dc system tracks adjacent to the right-of-way facilities during the design phase to establish baseline levels.
7.5 FACILITIES, BUILDINGS, AND STRUCTURES

Grounding and bonding of facilities, buildings, and structures should create a conductive path that will achieve potential equalization of the grounded elements of the railway system. Facilities grounding should be designed in accordance with the requirements IEEE-80 Guide for Safety in AC Substation Grounding, The National Electrical Safety Code (NESC), The National Electrical Code (NEC), and state or local codes as applicable.

In ac electrification systems, grounding connections provide a path to the return circuit from metallic supports and parts, and for the electrical interconnection of steel caissons, and in case of other modes of construction, the conductive interconnection of the metallic parts during fault conditions.

On dc electrification systems, line side metallic parts should be isolated from the return circuit to the greatest extent practicable, and steel poles, caissons, and other metallic parts should be independently grounded.

The structure grounding system provides grounding connections for:

1. High/medium-voltage protective ground.
2. Low-voltage protective ground.
3. Grounding of communication and signaling systems.
4. Lightning protection ground.

Any non-energized metallic component of the OCS within the system should be directly bonded to the static/aerial ground wire for personnel safety.

It is recommended that bonding of pre-stressed steel, or post-stressed tendons, within structures, should be prohibited.

7.5.1 PASSENGER STATION CONSIDERATIONS

Trains powered by either ac or dc traction systems will service passenger stations along the right of way. Rail return connections should be separated from the local ac distribution circuits without eliminating step and touch protection between car bodies and other metallic infrastructure within the station.

Every effort should be made to avoid placing OCS support structures, or other metallic components, in areas of the station where passengers could simultaneously come in contact with such items and rolling stock car bodies.

7.5.1.1 RECOMMENDED GROUNDING PROCEDURES - AC SYSTEMS

Railways use several different methods to mitigate step and touch potentials at passenger stations. Detailed below are two of the most common methods used.

A. The first method of mitigation requires the installation of a station ground wire or counterpoise in an unobtrusive location along the length of the platform. Each end of the station ground wire should have ground rods installed and tested to 25 ohms or less. Additional rods should be installed at 500 feet (150 m) maximum intervals through the entire length of the run. Finally a connection to the closest
catenary structure that is properly bonded to the main static/ground wire must be installed. All OCS structures are connected to the aerial ground or static wire.

All metallic objects, structures, and miscellaneous items within 8 feet (2.5 m) from the edge of the platform or 8 feet (2.5 m) from a grounded item and capable of picking up induction or carrying fault current within the platform area should be bonded to the station ground wire as illustrated in Figure 33-7-1 below.

**Figure 33-7-1**
Method A: Grounding for Mitigation of Stray or Fault Current at Passenger Stations

B. The second method also requires the installation of a station ground wire or counterpoise as detailed in paragraph 7.5.1.1 A. However, under this method all OCS structures and other metallic objects within the station area are bonded to the station ground and, instead of attaching the ground wire to a single OCS structure, the station ground wire is connected to an existing impedance bond within the track bed. In the absence of an impedance bond, a drain-type impedance bond can be installed to the closest electrified track with side leads connected to each running rail. The center tap from the drain bond is then connected to the station ground wire as illustrated in Figure 33-7-2 below.
Figure 33-7-2
Method B: Grounding for Mitigation of Stray or Fault Current at Passenger Stations

The static or aerial ground wires must be disconnected and insulated from the top of each structure within the station area.

When considering this method of station grounding, a Signal System Designer must be consulted.

When sizing the station ground wire or counterpoise for either method, all available information should be used to determine the minimum size. However, it is recommended this wire be a 4/0 AWG or larger conductor to maintain physical integrity.

7.5.1.2 RECOMMENDED GROUNDING PROCEDURES - DC SYSTEMS

Rail potential is the voltage between the running rails and ground, and is an inherent aspect of conventional railway systems, due to the use of the running rails as conductors for rail return current. There are a number of methods by which rail potential can be either controlled or mitigated. These methods are frequently referred to as “rail potential management”. The primary distinction between the various approaches to rail potential management is whether they are passive or active.

Passive methods provide rail potential control through system design by adjusting design parameters such as substation spacing, and rail return circuit longitudinal and track shunt (leakage) resistances. If these measures are not sufficient to keep rail potentials below the desired limits, electrical isolation, sufficient clearances and barriers can also be employed to prevent contact with impermissible voltages.

Active measures involve the control of rail potential through the use of equipment that monitors rail potential on infrastructure, and reduces it when needed by temporarily connecting the infrastructure to the negative return system (“voltage limiting devices”). Active rail potential management methods and the associated devices have been standardized in most regions other than North America and are described in European Standard EN-50122-1.

For dc traction systems, metallic passenger station infrastructure should not be permanently connected to the running rails, since this would result in unacceptable stray current-related damage (signal system operation could also be compromised). This arrangement permits voltage differences to exist between the metallic shells of railcars and metallic platform infrastructure. For reasons of personnel safety, passenger station platforms in the vicinity of train boarding areas should be constructed with electrically-insulating materials or surfaces, and metallic infrastructure should not be permitted within 8 feet (2.5 m) of the platform edge. Metallic platform edge doors are an exception to this practice, and require special treatment (normally some form of voltage limiting device).

In general, railway systems in North America, which utilize dc traction power, employ electrical isolation to manage rail potential. The use of electrical isolation to manage rail potential typically involves one of the following treatments for accessible infrastructure that could be either energized by rail potential, or provide a path to earth for rail potential.
The use of non-metallic materials for structures such as equipment supports, enclosures, platform handrails, and fencing.

The placing of metallic infrastructure sufficiently far from the tracks, 8' 0" (2.5m) to preclude simultaneous contact with energized and grounded surfaces by persons or animals.

Installation of a layer of high-resistance material on standing surfaces such as station platforms.

7.5.2 ROLLING STOCK MAINTENANCE FACILITIES

Where the catenary passes through the rolling stock maintenance buildings, a thorough investigation must be made to evaluate the return system. Every effort should be made to isolate the OCS disconnect switch grounding from the building and associated facility electrical grounding system.

On modern dc systems, insulated rail joints are typically required at each end of the maintenance shop track to isolate them from yard tracks. If this approach is adopted, an independent DC power supply must be provided inside the facility.

7.5.2.1 INSPECTION PLATFORMS IN MAINTENANCE YARDS AND FACILITIES

For ac systems, metallic parts of elevated access platforms for rooftop equipment inspection and maintenance at service sidings should be electrically interconnected and connected to the rails directly in non-signaled territory, or through an impedance bond at one end only in signaled territory, to minimize step and touch potentials between the access platform and the vehicles. Provisions should be incorporated into the platform design such that all metallic structures and miscellaneous metallic items within 8 feet (2.5 m) from the edge of the platform (including any OCS poles) should be isolated from the static wire and should be bonded directly to the platform. The platform-bonded metallic items should be isolated from any facility or utility grounds.

For dc systems, the use of non-metallic materials for structures, such as equipment supports, enclosures, platforms, handrails, and fencing should be considered, together with the placing of metallic infrastructure sufficiently far from the tracks 8 feet (2.5 m) to preclude simultaneous contact with energized and grounded surfaces by persons or animals.

7.5.3 STRUCTURES - GENERAL

In addition to the grounding requirements at passenger stations and service track platforms, any metallic items on structures crossing over, under or immediately adjacent to the electrified tracks should be grounded for personnel safety and lightning protection.

On an ac system, above-mentioned metallic structures should be either directly or indirectly bonded to the static or ground wire and/or to a trackside grounding plate, whereas on dc systems they should be independently grounded. The grounding and bonding of the emergency walkway area and other publicly accessible areas should be designed to mitigate step & touch potentials and also to meet the requirements of the signaling system.
7.5.4 OVERHEAD BRIDGES

Where components of overpasses, as detailed below, are within or over the electrified railway the following special grounding provisions may be required to afford protection to adjacent third party installations:

- Abutments or Piers - galvanized steel strip on each bridge wall or attached to columns of piers.
- Bridge Face - galvanized steel strip or angle section above the overhead line at each bridge face.
- Parapets - Ground wires should be attached to any metallic surface and attached to the bridge grounding or static wire.

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

When the vertical clearance envelope between OCS conductors and pre-stressed or steel reinforced concrete overpasses can be breached by birds, animals, ice, or other obstructions, designers must consider how to protect the bridge from electrical faults. High fault current that commonly occurs during electrical faults of this type may damage the bridge superstructure.

One common method to protect the bridge is the installation of flash plates. These plates are installed on the underside of the bridge across the entire pantograph envelope and bonded to the static/ground wires, as indicated above.

Another common method used to protect a bridge is the installation of insulation panels constructed of fiberglass or some other non-conductive material, which should be installed above the OCS and attached to the underside of the structure. Where insulated panels are used, the fastening system should preferably be non-metallic to ensure that the fasteners do not create an electrical path to the steel reinforcement or post-tensioning strands in the structure.

When choosing a method of protection, designers should also consider any future maintenance issues that may occur using these or any other methods.

For steel overpasses, the steel girders should be interconnected and bonded to the static wire at not less than two locations, as indicated above.

7.5.5 TUNNELS

For tunnel sections, metallic drop pipes or brackets, which support the OCS cantilevers, should be bonded to one or more aerial ground wire(s). On an ac system, dependent on tunnel length and the requirements of the signal system, the aerial ground wire(s) should be connected to rail through impedance bonds in the same manner as for surface sections. On a dc system, these structures should be grounded with ground rods or a ground grid.

For tunnels, particularly those cut into rock, the designer should determine whether additional grounds and/or an additional along-tunnel ground wire(s) may be required to meet the ground resistance requirements and/or to minimize the possibility that rail
potentials may cause unacceptable touch voltages and should incorporate such into the
design as needed. Any required additional ground conductors should be laid at low level – adjacent to the track or along the outer edges of the walkways – so these conductors will supplement the grounding capability of the system and enhance fault detection and control in the event of a broken wire condition. Based on the rail potential analysis and in order to provide a sufficiently low ground resistance, it may be necessary to install a ground grid at or near one or both tunnel portals.

In accordance with the latest edition of the National Fire Prevention Act (NFPA) 130 Standard for Fixed Guide way Transit and Passenger Rail Systems, or as required by local governing standards or requirements, coordination with the tunnel life safety design must be considered for tunnels greater than 1000 feet (305 m) in length. Every effort must be taken to ensure that both fault and return current will not interfere with the operation of the life safety equipment.

7.5.6 FENCES, PIPELINES, GATES, AND OTHER LINE SIDE METAL WORK

The designer should evaluate touch potentials on metallic fences and/or gates, including inter-track fences, which lie within the electrified railway. Ground electrodes should be installed on either side of a gate or other opening in the fence. Fence posts at openings in the fence should be bonded to form a continuous path, and gates should be bonded to support posts with flexible metal bonding straps to eliminate reliance on hinges for electrical continuity. Fences should be made electrically continuous and grounding conductors should be attached to fence posts and to any fence material support members (top and bottom) between posts. Metallic fences should be electrically bonded to the aerial ground or static wire or the return system at a single point.

Vinyl or other such coated chain link fences should not be used in electrified territory.

Metallic fences outside the electrified railway should be examined to determine if they need to be grounded as well.

7.5.7 STEP AND TOUCH POTENTIAL

The following points are noted regarding tolerable step and touch potentials:

- The issue of electrical safety is based on the magnitude and duration of body current.
- The magnitude of body current is based on the step and touch potentials associated with hand-to-hand, hand-to-foot, and foot-to-foot contact with conductive surfaces.
- The duration of body current exposure is based on the clearing time of ground fault circuit interrupting devices which for reasons of conservatism is based on breaker failure and backup clearing.
- In operational systems, measurements of step-and-touch potentials should be obtained with and without railway traffic at locations of concern.

The issue of tolerable 50-60 Hz alternating current is addressed in the latest edition of ANSI/IEEE Std. 80 Guide for Safety in AC Substation Grounding.
The above-mentioned standard does not reference or cover dc systems or areas outside substations for ac systems. Additional information for the permissible level of step-and-touch voltages over time can be found in the European Standards, which are detailed in the latest addition of EN 50122-1: - Railway applications — Fixed installations – Electrical safety, earthing and the return circuit, Part 1: Protective provisions against electric shock.

7.6 SIGNAL SYSTEM CONSIDERATIONS

When designing rail return systems, a Signal System Designer must be consulted.

Recommended practices for rail return and signal system coordination are outlined in The AREMA Manual, Volume 3, Chapter 33, Part 5.

7.7 LIGHTNING PROTECTION

When designing a traction power return system protection against lightning should be considered. The following methods have been adopted and should be considered:

- Static wires can be installed at the top structures and above the OCS to provide shielding of the system from lightning strikes.
- In a dc system the static wire should be isolated from the OCS poles and grounded at the TPFs.
- In an ac system, the static wire should be electrically bonded to the OCS poles since it can be used as a ground or supplemental return wire. In this instance it should be bonded and grounded as part of the return system.
- The static wire will reduce the exposure of the substations of the electric traction system from current surges that can enter the substations as the result of lightning strikes, and is connected to the substation ground bus.
- The static wire may also reduce the exposure of the signal system, which is connected to the structures via the impedance bonds.
- Surge arrestors can be installed on the OCS and the source terminals of the equipment of the signal, communications, and electric traction systems to divert over-voltages and current surges that occur as the result of lightning strikes to ground and hence protect the system from conditions that exceed the ratings of the connected equipment.

Additional guidelines for lightning protection can be found in the following standards:

- NFPA 780: Standard for the Installation of Lightning Protection Systems

7.8 DETERMINING RAIL BOND SIZES

In order to design the bonding of the running rails for an electrified system, certain contributing factors must have already been studied and determined. These factors involve a study of the overall system from an economic and performance standpoint and include as a minimum:

- The spacing and location of the substations
- The maximum allowable voltage drop for safe operation of traction motors.
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- Permissible voltage drop in the overhead system and feeders (involves the cost of copper)
- Permissible voltage drop in the return system (involves electrolysis and stray current)
  - The size and weight of the running rail with an emphasis on the use of continuous welded rail (CWR)
  - The signal system in use or proposed
  - Multiple versus single track territory
  - The use of supplemental return cable(s)
  - The use of materials that may be prone to vandalism and theft.

The size and type of rail bonds is a matter of keeping the allowable voltage drop in the return circuit at or below the prescribed limit, while using bonds that are heavy enough and strong enough to carry the full load current while withstanding normal vibration, fatigue, and mechanical damage.

After sizing the rail bonds for the traction return, confirmation must be obtained from both the Track and Signal Engineering groups as to the type of bonds to be utilized. These considerations must include:

- Signal system requirements for broken rail protection
- Cab Signal, ATC, or PTS requirements
- Track Engineering concerns regarding drilling into or heating of the rail for bond attachments
- Any other applicable track requirements

7.8.1 CALCULATIONS FOR DC SYSTEM BONDS
TO BE DEVELOPED

7.8.2 CALCULATIONS FOR AC SYSTEM BONDS
TO BE DEVELOPED

7.8.3 RAIL BOND SELECTION

After sizing the rail bonds to be utilized for the traction return, recommendations from the Track and Signal Engineering groups must be considered as to the type of bonds allowed. These considerations must include:

- Signal requirements for broken rail protection at joints
- Cab Signal, ATC, or PTS requirements
- Track Engineering concerns about drilling into or heating rail
- Any Applicable Track Requirements

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