

V.A

PJM Design and Application of Overhead Transmission Lines 69kV and Above

These design criteria have been established to assure acceptable reliability of the bulk transmission system facilities. These set forth the design and service conditions, and establish insulation levels for transmission lines. Some of these parameters were based on requirements for the Keystone, Conemaugh, Susquehanna Eastern, or LDV EHV projects, and others were developed by consensus of the PJM transmission line owners. Specific component requirements are listed in their own sections (in addition to NESC the proposed IEC 61936 could be a good reference). The criteria listed are requirements for lines rated 230 kV and above, and are guidelines for lines below 230 kV.

PJM DESIGN OF OVERHEAD TRANSMISSION LINES 69 kV AND ABOVE

1.0 SCOPE AND GENERAL REQUIREMENTS

- 1.1. This document sets forth the requirements and recommendations for the design of overhead electric transmission facilities.
 - 1.1.1. Transmission lines, for the purpose of this document, are those with an operating voltage of 69kV or greater.
 - 1.1.2. The term "TO" in this document refers to the Transmission Owner, the party that will own and be responsible for the maintenance of the subject transmission facility.
- 1.2. The design and operation of all transmission lines shall meet the requirements of the National Electrical Safety Code (ANSI/IEEE C-2) [NESC]. The edition of the NESC in effect at the time of the design shall govern.
- 1.3. The electrical and strength requirements of this document shall apply to all new transmission lines; and extensions, taps, or additions to existing transmission lines where the circuit length of the new construction is 1000ft or more.
- 1.4. The design of modifications to existing transmission lines; or extensions, taps, or additions to existing transmission lines where the circuit length of the new construction is less than 1000ft; shall meet the requirements used for the design of the existing line and shall meet the requirements of the latest edition of the NESC.
- 1.5. The designs of existing transmission lines may not in all cases meet these criteria. The existing lines themselves are excluded from the scope of this document. However, taps from or extensions to these existing lines are covered under the scope of this document.
- 1.6. Switch structures are not within the scope of this document. If a switch is to be mounted on a transmission structure, the structure design shall have adequate strength and rigidity to ensure the reliable operation of the line and switch.
- 1.7. Transmission structures supporting non-electric transmission facilities (telecommunications antennas, fiber-optic cables, etc.) shall be capable of resisting the structural loads resulting from these facilities within the strength requirements of this document. The locating of such non-electric facilities on transmission structures shall not jeopardize the operation, maintenance, and reliability of the transmission lines.
- 1.8. While this document provides detailed criteria for the design of transmission lines on the PJM system, these do not represent the only issues to consider in the design of such lines. Other issues must also be considered such as: maintenance, inspection, and repair on both the structures and the wires of these lines. This will ensure the reliability of the line at a minimal cost well into the future.
- 1.9. In some instances, the requirements or recommendations specified in this document may come into conflict with other issues such as permitting or local issues. These specifications may be adjusted and negotiated with the specific and written approval of the TO. The agreed negotiation of a relaxation of any specification for an individual project or circumstance does not automatically result in a subsequent revision in this guide. Subsequent instances must be addressed individually on a case-by-case basis.
- 1.10. The use of structure guys, and wood structures shall be approved by the TO.

2.0 CONDUCTORS

Conductors must be selected with sufficient thermal capability to meet continuous and emergency current ratings. Ratings of conductors applied to the PJM system should be determined using the PJM TSDS “Bare Overhead Transmission Conductor Ratings, November 2000”.

The overhead line conductor and static wire should be chosen from those used by the TO. This provides the ability to quickly repair a section of line with utility stock material should an emergency arise. Standard transmission conductor types are ACSR, ACSR/AW, ACSS, and ACAR. Other conductor types will be reviewed by the TO.

The ambient temperature range listed in Table 1 covers the PJM system and is used for the electrical ratings of the conductors as well as the structural loads upon the towers or poles.

3.0 CONDUCTOR SAG & TENSION CRITERIA

3.1 Alcoa – Sag & Tension Common Point

The maximum tension case shall be allowed to default as the common point between the initial and final sag tables. No other common point shall be allowed. An example would be a common point based upon NESC Heavy conditions when calculated tensions for the 1-1/2” Heavy Ice case exceed those for the NESC case.

4.0 STRENGTH REQUIREMENTS

4.1. **Structure Types** – the following descriptions of structure types shall apply to the provisions for strength requirements

- 4.1.1. Suspension Structure – A structure where the phase conductors and static wires are attached through the use of suspension insulators and hardware or, in the case of the static wire, with a clamp not capable of resisting the full design tension of the wire.
- 4.1.2. Strain Structure – A structure where the phase conductors and static wires are attached to the structure by use of dead-end insulators and hardware but where the ability of the structure to resist a condition where all wires are broken on one side under full loading is not required or desired. Typically, strain structures would be used where the line deflection angle is 45 degrees or less. Structures subject to strain structure requirement shall be as identified by the Utility.
- 4.1.3. Dead-end Structure - A structure where the phase conductors and static wires are attached to the structure by use of dead-end insulators and hardware and where the ability of the structure to resist a condition where all wires are broken on one side under full loading is required or desired. Typically, dead-end structures would be used where the line deflection angle is greater than 45 degrees. Structures subject to dead-end structure requirement shall be as identified by the Utility.
- 4.1.4. Line Termination Structure – A structure where the phase conductors and static wires are to be installed on one side only for the purpose of terminating the line, usually at a substation or switchyard. This permanent dead-end condition is assumed in the application of all applicable loading conditions.

4.2. **Loading Definitions**

- 4.2.1. Wind Pressure – The pressure resulting from the exposure of a surface to wind. The pressure values provided are for wind acting upon objects with circular cross section. Pressure adjustments for other shapes shall be as set forth by the ASCE Guidelines for Electrical Transmission Line Structural Loading (ASCE Publication 74) [ASCE 74].

- 4.2.2. Radial Ice – Radial ice is an equal thickness of ice applied about the circumference of the conductors and static wires. Ice density is assumed to be 57 lbs per cubic foot. For the purpose of transmission line design, ice is not applied to the surface of the structure, insulators, or line hardware.
- 4.2.3. Temperature – Used for calculating conductor and static wire sag and tension.
- 4.2.4. Transverse load – Forces or pressures acting perpendicular to the direction of the line. For angle structures, the transverse direction is parallel to the bisector of the angle of the transmission centerline.
- 4.2.5. Longitudinal load – Forces or pressures acting parallel to the direction of the line. For angle structures, the longitudinal direction is perpendicular to the bisector of the angle of the transmission centerline.
- 4.2.6. All wires intact – A condition where all intended spans of conductors and static wires are assumed to be in place. In the case of a Line Termination Structure, conductor and static wire spans are only on one side of the structure.
- 4.2.7. Broken Conductor or Static Wire – A condition where one or more conductors or static wires are specified as broken. It is assumed that the broken conductor or static wire is in place on one side of the tower, and is removed from the other side. The span length for determination of loads from the conductor or static wire weight, wind pressure, and radial ice shall be not less than 60% of the design span length for the intact condition.
- 4.2.8. Load Factor – A value by which calculated loads are multiplied in order of provide increased structural reliability. For the purpose of structural design, Overload Capacity Factors as specified by NESC shall be considered Load Factors.

4.3. Design Loading Conditions

- 4.3.1. NESC – The provisions of the NESC Heavy Loading District, Class B Construction shall apply to all structure types. All wires intact. The latest NESC edition in effect at the time of line design shall apply. For informational purposes, the 1997 edition of NESC specifies the following requirements. Wind pressure – 4psf. Radial Ice – 0.5in. Temperature - 0°F. For the purpose of calculating conductor or static wire tensions, a load constant of 0.3lbs shall be added to the resultant of the per linear foot weight, wind, and ice loads on the conductor or static wire. For steel structures, the load factor for wind load is 2.50; the load factor for vertical loads (dead weight and ice) is 1.50; and the load factor for conductor and static wire tension is 1.65. The associated factors for wooden transmission line structures shall be obtained from the TO.
- 4.3.2. Extreme Wind Loading Condition – Applies to all structure types. All wires intact.
 - 4.3.2.1. *Line voltage 230kV and greater.* Wind pressure applied to the wires shall be 25psf. The ambient temperature is to be 60°F. The wind pressure applied to the structure shall be 31.25psf. Load factor is 1.00.
 - 4.3.2.2. *Line voltage less than 230kV.* The provisions of the NESC Extreme Wind loading shall be applied, subject to a minimum wind pressure of 17psf. The load factor is 1.00. The provision in NESC permitting exclusion of structures less than 60ft in height from extreme wind criteria shall not apply.
- 4.3.3. Heavy Ice Loading Condition – Applies to all structure types. All wires intact.
 - 4.3.3.1. *Line voltage 230kV and greater.* Radial ice thickness on the wires only is to be 1.50in. No wind pressure. Temperature is 32°F. Load factor is 1.00.
 - 4.3.3.2. *Line voltage less than 230kV.* Heavy ice loading (if any) shall be as specified by the TO. Ice loading will not be more severe than that required for voltages 230kV or greater.

- 4.3.4. Longitudinal Loading Conditions for Suspension Structures (line voltage 230kV or greater) – The TO will specify one or more of the following loading conditions for design of Suspension Structures.
- 4.3.4.1. *One broken conductor or static wire.* Any one phase conductor or static wire is assumed broken. For construction using bundled phase conductors, one subconductor of any one phase bundle shall be assumed broken, the other subconductor(s) of that phase shall be assumed intact. All other conductors and static wires are intact. Loading condition is NESC Heavy. The longitudinal load shall be the tension of the broken static wire or broken conductor or subconductor. Tensions shall not be reduced by assumed insulator swing. For the intact phases and static wires, the wind on the structure, and the structure dead weight, the NESC load factors shall apply. For the broken static wire or the phase with the broken conductor or broken subconductor, the load factor shall be 1.10.
 - 4.3.4.2. *Differential Ice Loading.* All wires intact. No Wind. Temperature 32°F. All conductors and static wires on one side of the structure shall be assumed to have 1.0in radial ice. All conductors and static wires on the other side of the tower shall be assumed to have no ice. The determination of differential tension may include calculated swing of suspension insulator or static wire assemblies. Load factor 1.10.
 - 4.3.4.3. *Bound stringing block* – All wires intact. 2psf wind. No ice. 30°F. Any one static wire or phase conductor (or all subconductors of any one phase) are assumed to bind in a running block during installation. The block is assumed to swing 45° in-line. This swing will result in a longitudinal load equal to the calculated vertical load of the static wire or phase conductor(s) under this loading condition. Load factor is 2.00.
- 4.3.5. Longitudinal Loading Conditions for Strain Structures – The TO will specify one or more of the following loading conditions for design of Strain Structures.
- 4.3.5.1. *One broken conductor or static wire.* Any one phase conductor or static wire is assumed broken. For construction using bundled phase conductors, one subconductor of any one phase bundle shall be assumed broken, the other subconductor(s) of that phase shall be assumed intact. All other conductors and static wires are intact. Loading condition is NESC Heavy. The longitudinal load shall be the tension of the broken static wire or broken conductor or subconductor. For the intact phases and static wires, the wind on the structure, and the structure dead weight, the NESC load factors shall apply. For the broken static wire or the phase with the broken conductor or broken subconductor, the load factor shall be 1.10.
- OR
- 4.3.5.2. *All conductors and static wires broken.* Loading condition is NESC Heavy. Load factor is 1.00.
- 4.3.6. Longitudinal Loading Condition for Dead End Structures – All conductors and static wires are to be intact on one side of the structure only. Loading condition is NESC Heavy. Load factors are those specified by NESC.

- 4.3.7. *Longitudinal Loading Condition for Line Termination Structures* – Conductors and static wires are to be intact on one side of the structure only. All loading conditions and load factors set forth by Section 4.3.1, 4.3.2, and 4.3.3 shall apply.
- 4.3.8. *Foundation Loading* – The ultimate strength of overturning moment and uplift foundations shall be not less than 1.25 times the design factored load reactions of the structure. The ultimate strength of foundations subjected to primarily to compression load shall be not less than 1.10 times the design factored load reactions of the structure. Overturning moment foundations designed by rotation or pier deflection performance criteria shall use unfactored structure reactions for determination of the foundation performance, but shall use factored reactions for the 1.25 time ultimate strength check.
- 4.3.9. *Personnel Support Loading* – Structures shall be designed to support a point load of 350 lb at any point where a construction or maintenance person could stand or otherwise be supported.

5.0 ELECTRICAL DESIGN PARAMETERS

5.1 Right-Of-Way Width

The transmission line is to be designed with adequate right-of-way width to provide access for line maintenance, repair, and vegetation management as shown in Table 1. These widths are based upon the listed number of circuits on the right-of-way. For additional circuits, a wider right-of-way should be utilized.

Vehicle or other means of access to each structure site is required for both construction and maintenance activities.

5.2 Wire to Ground Clearance

The minimum allowed clearance between the lowest transmission line conductor(s) shall meet the required NESC minimum plus a safety envelope of 3 feet. (The safety envelope is required to allow for sag and clearance uncertainties due to: actual conductor operating temperature, conductor sagging error, ground topography accuracy, plotting accuracy and other sources of error. The inclusion of a safety envelope is considered to be prudent). The NESC minimum shall be calculated with the conductor at maximum operating voltage and the maximum operating temperature or maximum conductor loading. The minimum clearances should take into account the limitation of a 5 mA shock current as given in NESC Rule 232D3c. All areas beneath the line shall be assumed to allow vehicle access beneath the line. For agricultural areas that may utilize farming equipment, additional clearance will be provided to assure public safety and line reliability during the periods of farming and harvesting activities.

5.3 Wire to Signs, Structures, etc Under the Wires

The minimum allowed clearance between the lowest transmission line conductor(s) shall meet the required NESC minimum plus a safety envelope of 3 feet. The NESC minimum shall be calculated with the conductor at maximum operating voltage and the maximum operating temperature.

5.4 Wire to Structure Clearances

The minimum clearances between the phase conductors and the supporting tower or pole shall not be less than shown in Table 1. These clearances are to apply for all anticipated conductor positions from an every day condition to a displaced condition due to a 9-psf wind or ice loading. These clearances do not have any adders provided for birds or other animals, but are based upon the switching surge values listed in Table #1.

5.5 Wire-to-Wire Clearances

Clearance between the bottom transmission conductor and any lower wire shall meet the required clearance of NESC Rule 233 and 235 as a minimum. When the lower wire is a non transmission wire, then the clearance should be at least 10 feet for voltages less than or equal to 230 kV, and 20 feet for voltages above 230 kV. This will allow safe personnel access to the non-transmission conductors. These clearances should be calculated with the transmission conductor at maximum operating temperatures or heavy ice, whichever provides greater conductor sag, and the non-transmission conductor at 0°F.

Clearances between transmission conductors should be either the larger of clearances based upon switching surges, or clearances based on the NESC. The per unit switching surges to use for the calculation are shown in Table #1

Using switching surge values, the method used to determine the actual required clearance is given in section 5 of the EPRI Transmission Line Reference Book 115 kV - 138 kV Compact Line Design.

For transmission conductors of different circuits, the clearances should be increased so that any wind induced dynamic conductor movement does not result in any breaker operations and subsequent reduction in transmission circuit reliability.

5.6 Conductor Operating Temperature and Conductor Sag

The conductor will be assumed to operate at or above the minimum temperature shown below, and at temperatures less than the maximum shown below. While the line conductor may be designed to operate at a lower temperature, the line must be sagged assuming the conductor temperature is at or above the minimum shown. For designed operating temperatures above the minimum shown, and still below the maximum, the line sag and clearances will be calculated for that operating temperature after rounding up to the nearest 10°C. In no case will a conductor operating temperature be allowed above the maximum shown in the table. Refer to the PJM “Bare Overhead Transmission Conductor Ratings” for the ampacity and temperatures of conductors.

Conductor Type	Minimum Conductor Operating Temperature for Sagging and Clearance Purposes	Maximum Operating Temperature
ACAR	100°C	140°C
ACSR, ACSS	125°C	180°C

Consult with the local transmission utility for the maximum operating temperature since some companies use slightly different values. Higher values for ACSS conductors may only be used with specific approval from the TO. Studies of the long-term high temperature operation of all conductor-connected hardware must be investigated prior to the request for approval from the local transmission utility.

5.7 Insulation Requirements

The insulation system for the transmission line shall have values in excess of the leakage distance, 60 Hz wet, and Critical Impulse flashover specified in Table 1. These values shown are minimum conditions and may need to be increased in specific locations such as coastal environments, industrial smokestack sites, or high altitudes. (BIL values are not included here as they are associated with substation insulation and not transmission line insulation,)

5.8 **Lightning Performance and Grounding**

All transmission structures will be individually grounded through a dedicated earth driven grounding system composed of ground rods and / or buried counterpoise. This system is to be measured on each individual structure prior to the installation of any overhead conductors or wires. The maximum acceptable resistance measurement of this grounding system for voltages up to and including 230 kV is 25 Ohms, and 15 ohms for voltages 345 kV and greater. The grounding system may include radial counterpoise wires, equipotential rings, or both. The TO must approve all grounding methods, and connections to the grounding system that are below grade. These resistance requirements are to assure acceptable lightning performance on the line as well as provide for the safe grounding of the line by construction and maintenance forces.

Individual tower grounding measurements will be allowed to exceed the 25 or 15 Ohms required only if the average value for the 5 adjacent structures along the line is less than the 25 or 15-Ohm restriction.

To assure acceptable lightning performance, a shield wire is required above each transmission line. The number of shield wires and the maximum shielding angles between the shield wire and phase conductor are shown in Table 1. Each new structure design is to be analyzed using the EPRI MULTIFLASH or equivalent software to determine that the line design and actual grounding design provides the required lightning performance shown in Table 1.

In instances where it is very difficult to provide the required lightning performance, the TO may grant permission to utilize a limited application of transmission lines arresters. In no case will chemical ground treatments be allowed to improve structure grounding.

5.9 **EMF, RFI, TVI, and Audible Noise**

The transmission line system is to be designed so that radio and TV interference is just perceptible at the edge of the right-of-way. This is typically the case with radio signal to noise ratios above 20 db, and TV signal to noise ratios above 40 db. The achievement of this level of performance is more of a problem for lines above 230 kV, so a radio frequency survey and investigation should be performed to measure actual radio and TV signal strength and calculate the signal to noise ratio.

Audible noise at the edge of the right-of-way should be calculated for the designed transmission line using wet conductor as the design condition. The resultant noise level must not exceed the level limited by the state and local authorities. Typically the limitation is 55 dbA during the daylight hours, and 50 dbA at night.

Electric and Magnetic Field (EMF) levels are to be calculated using the EPRI ENVIRO or equivalent software and compared to any state or local limits. Modifications are to be made through phasing, structure height, ground clearance, etc. to assure these limitations are met. If no specific limitations exist, the line should be designed to the level of EMF on and adjacent to the right-of-way. A typical example of such an effort is the appropriate choice of phasing on the right-of-way.

5.10 **Inductive Interference**

A study should be done to determine the inductive impact upon other utilities due to the power flow in the new transmission line. The power flow may induce unusual currents and voltages in magnetic and electrical conductors that run parallel to the transmission line.

When it is determined that the currents or voltages are being induced in nearby utilities or other facilities, the engineer for the new or modified line being constructed must take the appropriate corrective actions to eliminate or lower the currents or voltages to an acceptable level.

5.11 **Line Transpositions**

The transmission line designer may be required to transpose the geometry of a new transmission line if the voltage imbalance exceeds the tolerance of the TO at the substations the line connects to. If transposition structures are required, they shall be designed to provide for easy routine maintenance of the structure.

5.12 **Line Crossings**

Line crossings should be avoided if possible, but when line crossings are unavoidable they should be configured such that the most important circuits to the transmission network are on top. Additionally, crossings must be configured such that a single component failure will not outage more than one other circuit (beyond the circuit with the failed component). This is in accordance with MAAC Criteria.

6.0 OTHER DESIGN PARAMETERS

6.1 Line Cascade Mitigation

Transmission line failures that cascade beyond the original structural failure must be avoided. To accomplish this, the design of a new or modified line shall incorporate dead-end strain structures routinely employed along the line. An alternative is to utilize suspension structures that are longitudinally guyed to resist full line tension if all wires on one side were broken. For wood construction, the strain structures shall also have in-line storm guys utilized to provide the structural strength. The line tensions assumed for this condition are the NESC Heavy loadings on one side of the structure as defined above, and no tension on the other. The structures shall be placed routinely along the line to resist a line cascade, but in no case shall these structures be placed farther than 5 miles apart.

6.2 Corrosion Protection

Corrosion protection will be evaluated for all buried structural steel on transmission structures. This covers buried grillage, driven caissons, etc. The line designer will submit a recommendation to the TO for the corrosion mitigation method to be used for buried structural steel. The proposed method must show at least a 50 year durability before any degradation of structural strength is allowed. It is acceptable to include systems that require some routine maintenance such as cathodic protection using buried sacrificial anodes.

Above grade steel will be protected from corrosion using a coating acceptable to the TO. Typical alternatives that have been used include weathering steel, galvanized steel, or painted steel.

6.3 Climbing Devices

6.3.1 Steel pole structures shall utilize climbing ladders. The TO shall specify the requirements and placement of the climbing ladders.

6.3.2 All steel towers shall be designed with step bolts as the provision for climbing. The TO shall specify the requirements and placement of the step bolts.

7.0 MAINTENANCE

For maintenance see section V.L.2.A

TABLE 1
Transmission Line Design Parameters

Parameter	Requirements			Recommendations		
	500 kV	345 kV	230 kV	138 kV	115 kV	69 kV
Ambient Temperature Range	-30°C to +40°C (from -40°C N & W of Blue Mountain)			-30°C to +40°C (from -40°C N & W of Blue Mountain)		
Minimum Extreme Wind Loading	25 PSF	<u>New Line</u> NESC Figure 250-2 or a minimum wind pressure of 17 psf. <u>Existing Line</u> Larger of: NESC Figure 250-2 OR the original line design parameters		New Line: NESC Figure 250-2 Existing Line: Larger of: NESC Figure 250-2 OR the original line design parameters		
Heavy Ice Load (No Wind)	1½"			Consult the TO for applicable heavy ice loading requirements		
Code Requirements	NESC Grade "B" Heavy			NESC Grade "B" Heavy		
Flood Plain	The line shall meet the applicable Local, State and Federal regulations.			The line shall meet the applicable Local, State and Federal regulations.		
Sag and tension Calculation Method	Alcoa Sag & Tension Software or equivalent			Alcoa Sag & Tension Software or equivalent		
Damper Requirements	<18% RBS (No dampers Required) 18% -20% RBS (Dampers Required)			<18% RBS (No dampers Required) 18% -20% RBS (Dampers Required)		
Galloping Mitigation	Provide adequate clearance so that 12" of clearance exists between wire galloping ellipses to minimize conductor or structure damage. The TO may revise this requirement for areas with significant galloping history.			Provide adequate clearance so that 12" of clearance exists between wire galloping ellipses to minimize conductor or structure damage. The TO may revise this requirement for areas with significant galloping history.		
Spacers	18" spacing - NO Preformed wire spacers allowed.			18" spacing - NO Preformed wire spacers allowed.		
Provisions for Live Line Maintenance	As required by the TO.			As required by the TO.		
Access Requirements	Construction and maintenance access is required to each structure.			Construction and maintenance access is required to each structure.		
Approved conductor sizes for NEW Construction	Match approved conductor sizes and bundle configuration with local utility company			Match approved conductor sizes and bundle configuration with local utility company		

TABLE 1
Transmission Line Design Parameters

Parameter	Requirements			Recommendations		
	500 kV	345 kV	230 kV	138 kV	115 kV	69 kV
Approved static and OPGW wire sizes for NEW Construction	Match approved conductor sizes with the TO.			Match approved conductor sizes with the TO.		
Right-of-way width (Target values)	200 Ft. – 1 ckt. 300 Ft.(min.) – 2 ckts	170 Ft – 1 ckt	150 Ft 1 & 2 ckts	100 Ft 1 & 2 ckts	100 Ft 1& 2 ckts	60 - 100 Ft
Max. Number of circuits per structure	1 unless specifically approved by TO		2 unless specifically approved by TO	2 unless specifically approved by TO		
Min. design ground clearance at Max. Sag	NESC minimum requirements PLUS an additional 3 feet			NESC minimum requirements PLUS an additional 3 feet		
Conductor to structure steel clearance (min.)	125 in.	91 in.	69 in.	52 in.	42 in.	28 in.
Insulation Requirements						
Leakage distance	360 in.	250 in.	167in.	100 in.	83 in.	50 in.
60 Hz WET	950 kV	635 kV	490 kV	375 kV	295 kV	170 kV
Switching Surge	2.2 per unit.	2.4 per unit	2.5 per unit	3.0 per unit	3.0 per unit	3.5 per unit
Critical Impulse Flashover	2145 kV	1440 kV	1105 kV	860 kV	670 kV	440 kV
Maximum Structure Ground Resistance	15 Ohms	15 Ohms	25 Ohms	25 Ohms		
Step & Touch Potential Issues	Provide a structure grounding system that meets the step and touch requirements of the TO.			Provide a structure grounding system that meets the step and touch requirements of the TO.		
Minimum Number of Static Wires Required	Minimum of 1 per circuit			Minimum of 1 per structure		
Isokeraunic Level	40			40		
Maximum Shielding Angle	15°	20°	25°	30°	30°	30°
Target Lightning Outage Performance	1.0 per 100 ckt mi. / yr	1.0 per 100 ckt mi. / yr	2.0 per 100 ckt mi. / yr	3.0 per 100 ckt mi. / yr	3.0 per 100 ckt mi. / yr	4.0 per 100 ckt mi. / yr
EMF Limits	As Required by TO and State Regulatory Agencies			As Required by TO and State Regulatory Agencies		
Radio Interference at edge of right-of-way	300 µV @ 1 MHz (350 kV to gnd)	300 µV @ 1 MHz (230 kV to gnd)	No limits specified	No limits specified		
Audible Noise	Per applicable state laws for noise at edge of right-of-way			Per applicable state laws for noise at edge of right-of-way		