V. Design, Application, Maintenance & Operation Technical Requirements

V.A PJM Design & Application of Overhead Transmission Lines 69 kV & Above

These design criteria have been established to assure acceptable reliability of the bulk transmission system facilities. Specific component requirements are listed in their own sections. The criteria listed are requirements or recommendations for lines rated 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. Transmission lines, for the purpose of this document, are those with an operating voltage of 69 kV or greater.

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.

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.

1.2 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 three spans or more.

1.3 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 or equal to two spans; shall meet the requirements used for the design of the existing line and shall meet the requirements of the latest edition of the NESC.

1.4 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.

1.5 Switch structures, while outside the scope of this document, may 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.

1.6 Transmission structures supporting non-electric transmission facilities (telecommunications antennas, distribution under build, 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-transmission facilities on transmission structures shall not jeopardize the operation, maintenance, and reliability of the transmission lines. Prior to installation of non-transmission facilities, the owner of the transmission facilities is responsible for the evaluation to assure adequate loading and clearances are maintained.

1.7 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.

1.8 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 shall be addressed individually on a case-by-case basis.

1.9 The use of structure guys, and wood structures on new lines should be avoided and shall be approved by the TO.

2.0 Conductors

Conductors shall 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 TSS (formerly referred to as TSDS) “Bare Overhead Transmission Conductor Ratings”.

The overhead line conductor, conventional and optical static wire, and associated accessories 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. Contact PJM to determine the types of conductors used in a specific Transmission Owner area.

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

Sag & Tension Calculations 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 Type Definitions

The following descriptions of structure types shall apply to the provisions for strength requirements. The type and location of each structure shall be approved by the Transmission Owner.

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° or less.

4.1.3 Dead-end Structure and Line Termination Structure

Structures 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° . However, both intact and broken conductor conditions shall be evaluated in the design of these structures.

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 Manuals of Practice 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 ft. 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 structure, 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 <u>*Load Factor*</u> - 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 <u>*NESC*</u> - 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. All of the NESC load cases shall be met. In addition the PJM supplemental conditions shall also be met.

4.3.2 <u>*PJM Extreme Wind Loading Condition*</u> - Applies to all structure types. All wires intact.

4.3.2.1 *Line voltage 230 kV and greater.* Wind pressure applied to the wires shall be greater of 25 psf or the NESC wind pressure requirement. The ambient temperature is to be 60° F. The wind pressure applied to the structure shall be 31.25 psf. Load factor is 1.00.

4.3.2.2 *Line voltage less than 230 kV.* The provisions of the NESC Extreme Wind loading shall be applied. The load factor is 1.00. The provision in NESC permitting exclusion of structures less than 60 ft. in height from extreme wind criteria shall not apply.

4.3.3 <u>*PJM Heavy Ice Loading Condition*</u> - Applies to all structure types. All wires intact.

4.3.3.1 *Line voltage 230 kV and greater.* Radial ice thickness on the wires only is to be 1.50 in. No wind pressure. Temperature is 32° F. Load factor is 1.00.

4.3.3.2 *Line voltage less than 230 kV.* Heavy ice loading, if any, shall be as specified by the TO. Ice loading will not be more severe than that required for voltages 230 kV or greater.

4.3.4 <u>*PJM requirement for Longitudinal Loading Conditions for Suspension Structures*</u> – For a line voltage 230 kV or greater, the TO will specify one or more of the following loading conditions for design of Suspension Structures. For a line voltage below 230 kV, the TO may 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 sub-conductor of any one phase bundle shall be assumed broken, the other sub-conductor(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 sub conductor. 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 sub-conductor, the load factor shall be 1.10.

4.3.4.2 *Differential Ice Loading.* Assume all wires intact, no wind and temperature 32° F. All conductors and static wires on one side of the structure shall be assumed to have 1.0 in radial ice. All conductors and static wires on the other side of the structure 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.* Assume all wires intact, 2 psf wind, no ice, and temperature of 30° F. Any one static wire or phase conductor (or all sub-conductors 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 *PJM requirement for 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 sub-conductor of any one phase bundle shall be assumed broken, the other sub-conductor(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 sub-conductor. 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 sub-conductor, 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 *PJM requirement for 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 *PJM requirement for 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. 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 times ultimate strength check.

4.3.8 *PJM requirement for 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. For these analyses, a factor of 2.00 shall be applied concurrently with all load cases.

5.0 Electrical Design Parameters

5.1 Right-Of-Way Width

The transmission line shall 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 on the listed number of circuits on the right-of-way. For additional circuits, a wider right-of-way should be utilized. More compact configurations may be approved at TO's discretion.

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 ft. 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 shall 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 from lowest/nearest phase conductor shall meet the required NESC minimum plus a safety envelope of 3 ft. The NESC minimum shall be calculated with the conductor at maximum operating voltage, the maximum operating temperature, and maximum NESC wind displacement. Only TO approved buildings are permitted in the right of way.

5.4 Wire to Supporting 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 everyday condition to a displaced condition due to a 9 psf wind at 60° F (Based on utility practice) These clearances do not have any adders provided for birds or other animals, but are based upon th**e** switching surge values listed in Table #1. Avian protection must be evaluated and shall be approved by the TO.

5.5 Wire-to-Wire Clearances

5.5.1 Not on the same supporting structure

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.

5.5.2 On the same supporting structure

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 ft for voltages less than or equal to 230 kV, and 20 ft 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.

5.5.3 Line crossings

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 ft for voltages less than or equal to 230 kV, and 20 ft 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 lower conductor at 0° F.

5.6 Conductor Operating Temperature and Conductor Sag

For purposes of clearances to objects under the line, 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 shall 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 ampacityand temperatures of conductors.

Conductor Type*	Minimum Conductor Operating Temperature for Sagging and Clearance Purposes (° C)	Maximum Operating Temperature (° C)
ACAR*	100	140
ACSS	175	250
ACCR	170	240
ACSR*, ACCC	125	180

* For these and other conductor types not listed, contact the local transmission utility.

Consult with the local transmission utility for their operating temperatures, since companies may use different values. Appropriate hardware needs to be selected to coordinate with the chosen operating temperature(s).

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). Ceramic or glass insulators shall be used for suspension and strain applications of 230 kV and above. Non-ceramic insulators may be used for special applications including post/braced post installations and areas of special contamination concern, provided that corona/grading ring application is consistent with TO or manufacturer requirements. Contact TO for insulation system requirements.

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. However, if a TO's resistance requirements are more stringent, then their requirements apply. 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 structure 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. During reconductoring projects, every opportunity should be taken to verify structure grounding resistance. To do this the static wires and other conductors may need to be insulated from the structure.

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. Shielding angle shall be maintained under wind-displaced conductor positions of 60° F and 6 psf wind. Each new structure design is to analyzed using lightning analysis 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 line 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 hrs, and 50 dbA at night.

Electric and Magnetic Field (EMF) levels are to be calculated using EMF software and compared to any state or local limits, where applicable. Modifications are to be made through phasing, structure height, ground clearance, etc. to assure these limitations are met. If no specific limitations exist, contact the local transmission owner for requirements.

5.10 Induced Interference

A study should be done to determine the inductive and capacitive impacts upon other facilities due to current and voltage in the new transmission line. Current and voltage may induce unusual currents and voltages in metallic objects that are in the vicinity of the transmission line.

When it is determined that unacceptable levels of currents or voltages are being induced in nearby 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 to which the lines connect. If transpositions structures are required, they shallbe designed to provide for 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 should be configured such that single component failures will not outage more than one additional transmission circuit beyond the circuit with the failed component. This is in accordance with NERC criteria.

6.0 Other Design Parameters

6.1 Line Cascade Mitigation

Transmission line failures can cascade beyond the original structural. To mitigate against cascade failures, the design of a new or modified line shall incorporate dead-end structures (see Section 4.1.3) . These structures shall be placed along the line to resist a line cascade, but in no case shall these structures be placed farther than five mi apart.

6.2 Corrosion Protection

Corrosion protection shall be evaluated for all buried structural steel on transmission structures. This includes buried grillage, driven/vibratory caissons, etc. The line designer will submit a recommendation to the TO for the corrosion mitigation method to be used for buried structural steel. Direct embedded steel pole structures, shall include a corrosion coated ground sleeve with dimensions approved by the TO. The coating should extend to within 3 in of the ground sleeve and shall be feathered into the pole surface at the upper extreme of its application to prevent water retention.

Above grade steel will be protected from corrosion using a coating acceptable to the TO. Typical alternatives that have been used include weathering, galvanized, painted steel, or other TO approved coating. The use of weathering steel shall take into account the potential for pack-out in areas of standing water and therefore may not be suitable in all locations.

Painted structures and attachments shall be hermetically sealed. Galvanized structures shall be open to allow full coverage of the pole interior. Weathering steel structures can be either hermetically sealed OR open throughout the interior to prevent water accumulation.

6.3 Climbing Devices

6.3.1 Steel pole structures shall be designed to accommodate either portable or permanent climbing ladders. The TO shall specify the requirements and placement of the climbing ladders and associated permanent clips.

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.

6.3.3 Fall protection requirements can be obtained from each TO and shall comply with OSHA 1926.954.

7.0 Maintenance

For maintenance see section V.L.2.A.

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	Larger of 25 psf or NESC rule 250C.			New Line: NESC rule 250C Existing Line: Larger of NESC 250C OR the original line design parameters		
Heavy Ice Load (No Wind)	1.5”			Consult the TO for applicable heavy ice loading requirements		
Code Requirements	NESC Grade “B”, Heavy Loading District			NESC Grade “B”, Heavy Loading District		
Flood Plain	The line shall meet the applicable Local, State and Federal regulations.			The line shall meet the applicable Local, State and Federal regulations.		
Damper Requirements (Tensions at 0° F)	<18% RBS (No dampers Required) ≥18% RBS (Dampers Required) Unless engineering study indicates otherwise			<18% RBS (No dampers Required) ≥18% RBS (Dampers Required) Unless engineering study indicates otherwise		
Galloping Assumptions	Span length ≤ 600 ft use single loop Span length > 600 ft use double loop			Span length ≤ 600 ft use single loop Span length > 600 ft use double loop		
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		
Anti-galloping devices	Acceptable			Acceptable		
Spacers	18” spacing - NO twist-on wire spacers allowed. Spacer-dampers are permitted.			18” spacing – NO twist-on wire spacers allowed. Spacer-dampers are permitted.		
Provisions for Live Line Maintenance	As required by the TO.			As required by the TO.		

Parameter	Requirements			Recommendations		
	500 kV	**345 kV**	**230 kV**	**138 kV**	**115 kV**	**69 kV**
Access Requirements	Construction and maintenance access is required to each structure. Matting may be required to access.			Construction and maintenance access is required to each structure. Matting may be required to access.		
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		
Approved static and OPGW wire sizes for NEW Construction	Match approved sizes with the TO			Match approved sizes with the TO		
Right-of-way width (Target values)	200 ft – 1 circuit. 300 ft (min) – 2 circuits	170 ft – 1 circuit. 270 Ft - 2 circuits	150 ft 1 & 2 circuits	100 ft 1 & 2 circuits		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 ft			NESC minimum requirements PLUS an additional 3 ft		
Conductor to structure steel clearance (min)	125 in	91 in	69 in	52 in	42 in	28 in
Insulation - Leakage distance (min)	360 in	250 in	167 in	100 in	83 in	50 in
Insulation - 60 hz WET (min)	950 kV	635 kV	490 kV	375 kV	295 kV	170 kV
Insulation - Switching Surge	2.2 per unit	2.4 per unit	2.5 per unit	3.0 per unit		3.5 per unit
Insulation - Critical Impulse Flashover (min)	2145 kV	1440 kV	1105 kV	860 kV	670 kV	440 kV
Maximum Structure Ground Resistance	15 Ω		25 Ω	25 Ω		
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.		

Parameter	Requirements			Recommendations		
	500 kV	**345 kV**	**230 kV**	**138 kV**	**115 kV**	**69 kV**
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°		
Target Lightning Outage Performance (new construction)	1 per 100 circuit-miles/yr.		2 per 100 circuit-miles/yr.	3 per 100 circuit-miles/yr.		4 3per 100 circuit-miles/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 (under fair weather conditions)	100 µV at 1 MHz (350 kV to ground)	100 µV at 1 MHz (230 kV to ground)	No limits specified	No limits specified		
Audible Noise	Per applicable state and local laws for noise at edge of right-of-way			Per applicable state and local laws for noise at edge of right-of-way		

Table 1 – Transmission Line Design Parameters (The data in this table is based on Good Utility Practices and is subject to further enhancement. Contact TO for specification if applicable.)