PJM Designated Entity Design Standards - Design and Application of Overhead Transmission Lines 69kV and Above

Purpose

These design criteria have been established as a minimum design standard to assure a minimum level of robustness is provided such that the new competitively-solicited facility would not introduce a weak point in the system in terms of performance. These minimum design standards would not apply to projects for which solutions are not solicited through the PJM window process.

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 "DE" in this document refers to the Designated Entity, the party that will own and be responsible for the maintenance and operation of the subject transmission facility

Comment [TDP1]: Are there enough terms that need defined to group them all in one section up front?

YES – Future action item.

1.2. The design and 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. The Designated Entity shall identify and design to all additional legislated requirements as adopted by state and local jurisdictions.
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Comment [TDP2]: Need to meet the NESC and this document.

ACTION: Work this in. - Dave

1.6. Switch or Underground to Overhead transition structures are not within the scope of this document. If a switch or an Underground to Overhead transition is to be mounted on a transmission structure, the structure design shall have adequate strength and rigidity to ensure the reliable operation of the lines and switch.

Comment [TDP3]: Should they be if they are part of a competitive project?

ACTION: Include in the document, but relocate to the load and strength section.

2.0 CONDUCTORS

The thermal ratings of conductors are outside the scope of this document.

Comment [TDP4]: DE will rate conductor based on their own NERC-filed FRM.

Conductors shall be selected with sufficient thermal capability to meet normal and emergency current ratings required for the project, as specified by PJM in the RFP process (?). Normal operation refers to a continuous operating condition where no loss of conductor strength will occur. Emergency operation refers to a short-duration time period where the normal current rating is exceeded to meet temporary changes in system operating conditions. Conductors shall be selected so they will not lose more than 10% (?) of strength over their life of service due to periodically exceeding normal operating conditions. Conductors shall also be designed to handle the heating induced by the anticipated fault currents it may experience during its service life.

Comment [TDP5]: Do we want to go with the NERC definitions, which are worded slightly different than the SPP definitions? Same for Emergency. For the emergency rating, NERC does not specify the loss of strength permitted. If we want this, we'll have to state that specifically.

ACTION: Propose alternate wording – Dave

Comment [TDP6]: Over what time period.

Comment [TDP7]: How do we determine this? Are we trying to cover for relay misoperations?

Conductors shall be of adequate strength to meet required design loading conditions and sustain mechanical loads as specified in Section “X”, while still meeting the minimum clearance requirements as discussed in Section “X”.

Qualified conductors are those meeting all applicable ASTM standards for the materials included in the construction of the cable. Conductor connectors and accessories shall also meet applicable ANSI/NEMA standards, and shall have thermal capabilities no less than the conductor.

Conductor selection and configuration, including conductor size and the number of sub-conductors, shall take into consideration electrical system performance parameters such as voltage, stability, losses, impedance, corona, electric and magnetic fields, audible noise and TV and Radio interference.

Conductor selection shall consider short and long-term material availability locally and within the industry for purposes of maintenance and circuit restoration. Adequate quantities of material shall be stocked by the Designated Entity to allow restoration of the line in sufficient time (one week?).

Comment [TDP8]: No ANSI standards for high temperature operation.

Comment [TDP9]: Suggest striking. The Respondent must submit their O&M plans in the RFP.

<u>3.2 Galloping Mitigation:</u>

Comment [TDP10]: Is a lot of this design manual material?

ACTION: Group agrees this is too prescriptive and in some cases conservative. Dave to suggest language.

Lines shall be designed to mitigate galloping unless a study is performed demonstrating the line configuration is not prone to galloping. Mitigation shall be by the following methods:

- Providing adequate electrical clearances
- Providing structures designed for additional cyclical stresses of galloping conductors.
- Providing in-span interphase insulators or anti-galloping devices.
- Use T2 conductor

<u>Electrical Clearances:</u>
Single loop galloping shall be used for spans less than 700 feet. Double loop galloping shall be used for spans of 700 feet or greater or any span that has strain connections on both ends.

One of two methods shall be used to model galloping ellipses.

1. A combination of the A.E. Davison method for single loop galloping and the L.W.Toye method for double loop galloping.
2. The CIGRE method per Bulletin 322.

When checked using these methods, galloping ellipses shall not overlap one another. Galloping clearances shall also be checked between the transmission conductors and shield wires.

Comment [TDP11]: Conservative?

The following load cases shall be used for galloping calculations:

1. 32°F, 0.5” Radial ice, 2 PSF wind (For determination of Swing Angle)
2. 32°F, 0.5” Radial ice, No Wind (For determination of sag and conductor motion ellipses)

Long spans over eighteen hundred (1800) feet shall take into account existing line historical operation. If no data is available a study shall be performed to determine the proper mitigation methods.

Further Discussion:

Comment [TDP12]: Seems severe.

1. Clearance between the galloping ellipses.
   a. Use a constant buffer for all voltages. 1ft?
   b. Use a voltage dependent buffer.
      i. 69kV - 6”
      ii. 138kV - 12”
      iii. 230kV - 18”
      iv. 500kV - 42”

Vibration

All spans of conductors and static wires shall be evaluated for susceptibility to aeolian vibration. Where aeolian vibration is of concern, mitigation measures shall be taken to avoid damage to conductors, shield wires, hardware and structures. Mitigation measures may include reduced design tensions, mechanical vibration dampers, spacer dampers for bundled conductors, or specially designed conductors, either singly or together. A vibration analysis should be performed by qualified vibration damper vendors and should include recommendations on the type, quantity and placement of vibration damper hardware.

5.0 ELECTRICAL DESIGN PARAMETERS

5.1 Right-Of-Way Width

At a minimum, sufficient right of way width shall be provided so that NESC clearances (plus a three foot buffer?) are maintained to the edge of the right of way, and to adjacent power lines when they exist. This should be calculated with conductors at rest (no wind), final sag, and at the maximum operating temperature; and also with the conductors displaced due to a 6 psf wind, 60F, no ice, final sag condition. Deflection of flexible structures shall also be included in this calculation.

Other considerations shall be made for vegetation management, maintenance, future development and anything else that may impact the long term reliability, maintenance and safe operation of the line.

EMF and AN at edge of ROW to meet state and local requirements.

Consideration shall be given to acquiring uniform ROW widths.

Live Line

Sufficient space to maintain OSHA minimum approach distances in place at the date of project approval, either with or without tools, shall be provided. When live-line maintenance is anticipated, designs shall be suitable to support the type of work that will be performed (e.g., insulator assembly replacement) and the methods employed (i.e., hot stick, bucket truck, or helicopter work, etc.).

Clearance Requirements

The clearance requirements presented in this section of the standards will be maintained with the reference conductor at maximum sag and after experiencing the maximum loading conditions ("final" conditions). Maximum sag conditions may be experienced at maximum conductor operating temperatures or under heavy ice conditions. For conductor-to-conductor clearances between different circuits, the upper conductor shall be at maximum sag and the lower conductor at "minimum" sag. Minimum Sag is defined as 0 degree F, no wind, no ice, initial conditions. In the absence of the necessary data to perform this analysis, the lower conductor's position may be approximated by a straight line interpolation between the attachment points.

Clearances shall assume maximum operating voltages as defined in PJM Manual 3. Baseline Voltage Limits. Exhibit 3 section 3.3.1. The system transient overvoltage's (TOV) shall then be applied and any elevation factors added as specified in NESC.

Wire to Ground Clearance - based on NESC Rule 232

All clearances over ground shall be set to accommodate vehicle access, plus a 3 foot clearance buffer at maximum sag. 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 shall 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. All terrain points shall be considered vehicle-accessible regardless of terrain changes or the presence of access roads.

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.

Comment [TDP13]: Minimum approach distances based on system-specific TOV.

ACTION: Update. Consult IEEE 516 and OSHA. If you don't know the actual TOV, then use the default. - Dave

Comment [TDP14]: Consider breaker operation (one-shot).

Comment [TDP15]: We stated up front that we meet NESC; can this be shortened?

ACTION: Update this section based on comments. - Dave

Comment [TDP16]: Why not NESC? What size vehicle, 8' or 14'?

Research, but 14' seems to be the consensus.

Comment [TDP17]: May be better to call it a design buffer.

Comment [TDP18]: Repeat of the previous sentence?

Comment [TDP19]: Suggest not calling it a safety buffer.

Comment [TDP20]: Commentary, is it needed? (especially the last sentence.

Comment [TDP21]: What is the requirement? Or should we just state "for the largest anticipated vehicle? How do we determine this.

Comment [TDP22]: Not possible.

Comment [TDP23]: Suggest avoiding.

Comment [TDP24]: Ditto.

Clearances to waterways – Based on NESC Rule 232

Clearances over Waters of the United States shall be based, at a minimum, on the NESC requirements in Rule 232, plus a 3 foot buffer. In the event that the Army Corps of Engineers (ACOE) determines higher clearances are required, the ACOE requirements shall be held, plus a 3 foot buffer.

Comment [TDP25]: Do they typically? If they are larger, why not the larger of NESC + 3 or the ACOE clearance.

Avian Considerations.

Comment [TDP26]: Shorten to just say that the APLIC guidance shall be considered in design?

Design should incorporate considerations for avian affects. The use and/or reference to industry guidelines such as APLIC – Avain Powerline action Committee which contain protection plan guidelines as well as suggested practices should be included in the design of the facilities. Design should determine if there is a need to incorporate avian considerations which could impact structure dimensions in areas where safe perching of birds has been an issue and could therefore materially impact the design of an overhead line.

5.7 Insulation Requirements

Comment [TDP27]: Did we discuss using the SPP paragraph to address this and the next section. Insulation, grounding and structure arrangement all work together to provide targeted performance.

The insulation system for the transmission line shall have values in excess of the leakage distance, 60 Hz wet, and Critical Impulse flashover values 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 or other devices. 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.

Comment [TDP28]: Conservative.

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 DE 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.

Comment [TDP29]: Does this preclude the use of bentonite backfill?

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 55dbA during the daylight hours, and 50 dbA at night.

Comment [TDP30]: This is the only real requirement here. The rest seems to be suggestions or design manual material. EMF, etc are also addressed in the conductor section.

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.

Comment [TDP31]: Is this possible?

Comment [TDP32]: Means and methods; design manual material.

5.10 Inductive Interference

Comment [TDP33]: Seems like design manual material. I don't see a design requirement.

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.

Comment [TDP34]: More definition? Electric utilities only, or gas? Railroad?

Comment [TDP35]: Is this limiting to only steady state conditions? What about fault conditions?

Comment [TDP36]: Could this be more collaborative between the DE and the affected utility.

5.11 Line Transpositions

Comment [TDP37]: Suggest striking; It doesn't offer a design criteria.

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 connect s to. If transpositions structures are required, they shall be designed to provide for easy routine maintenance of the structure.

Comment [TDP38]: Phasing?

5.12 Line Crossings

Comment [TDP39]: This is a good practice, but is it more appropriate in a design manual?

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 structure failure must be avoided. The line shall be designed so that a cascading event does not result in failure or severe damage to structures extending beyond a distance of "X" miles from the point of origin. Preventative measures may include, but are not limited to, routine placement of deadend structures, longitudinal guying, etc., along the alignment. Documentation shall be provided upon request by the line designer proving the design meets these requirements. Line restoration strategy should be considered when selecting the appropriate interval for line cascading mitigation.

Comment [TDP40]: The AESO (Alberta ISO) suggests that if tangents have a defined (and they do, albeit more stringent than ours) longitudinal strength, then anti-cascading structures are required.

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.

Comment [TDP41]: I think we decided to strike; design manual material.

6.3

Climbing Devices

Comment [TDP42]: I think we decided to strike; design manual material.

6.3.1

Steel pole structures shall utilize climbing ladders. The DE 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

Comment [TDP43]: Suggest striking this section, if it still is one.