For the ~~As of~~ 5/16~~0~~/2017 meeting review

PJM DESIGNATED ENTITY DESIGN STANDARDS – UNDERGROUND LINES

1.0 PURPOSE

These standards represent the minimum criteria by which a competitively solicited facility must be designed by the Designated Entity unless more stringent requirements are specified in the Problem Statement and Requirements Document (PSRD). These standards facilitate the design of transmission line facilities in a manner that is compliant with NERC requirements and PJM criteria; are consistent with Good Utility Practice, as defined in the PJM Tariff; and are consistent with current industry standards specified herein, such as NESC, IEEE, AEIC, ASCE, CIGRE, and ANSI, at the time the PSRD is issued.

2.0 SCOPE

This document sets forth the minimum requirements for the design of AC underground electric transmission line facilities rated 69kV and above for projects solicited through the PJM competitive process. These minimum design standards do not apply to projects that are not associated with the PJM competitive process.

3.0 GENERAL REQUIREMENTS

The design of all underground transmission lines shall meet or exceed the requirements of this document, the National Electrical Safety Code (ANSI/IEEE C-2) [NESC] in effect at the time of the project design, and all additional legislated requirements as adopted by governmental jurisdictions. It shall be the responsibility of the Designated Entity to identify all additional legislated requirements. In the event of conflicts between documents, the most stringent requirement shall apply.

4.0 UNDERGROUND TRANSMISSION DEFINITIONS

1. **Thermal Resistivity** is a heat transfer property used to evaluate current soil conditions and to grade thermal backfill in underground transmission line construction. This property is a measurement of a temperature difference by which a material resists heat flow.

2. **Pipe-Type Cables**, also known as High Pressure Fluid Filled (HPFF), have three phases insulated with tapes of kraft paper or laminated paper polypropylene (LPP) installed in a steel pipe pressurized with dielectric fluid. High Pressure Gas Filled (HPGF) cables have three phases insulated with tapes of kraft paper or laminated paper polypropylene installed in a steel pipe pressurized with nitrogen.

3. **Self-Contained Cables**, also known as Self-Contained Fluid Filled Cables (SCFF), up to three phases, each phase consisting of a hollow core conductor, paper insulation, a lead or metallic sheath, and a protective outer jacket. The hollow core conductor may be wrapped around a steel tube that houses a low viscosity dielectric fluid.

4. **Solid Dielectric Cables** is a type of cable where the insulation material is extruded over the conductor shield and then cross-linked for cross-linked polyethylene or ethylene-propylene rubber. Three types of solid dielectric cable are XLPE (Cross-linked Polyethylene), EPR (Cross-linked Ethylene Propylene Rubber), and PE (Thermoplastic Polyethylene).

5. **Load Factor** is the ratio of the average loading to the peak loading over a 24 hour period.

6. **Loss Factor** is the ratio of the square of the maximum hourly reading to the sum of squares of the hourly current ratings over a 24 hour period.

7. **Conductor Maximum Temperature** is defined by industry standards that are based on damage limits for the insulating material adjacent to cable conductor. There are industry allowances to vary the temperature limits when select design parameters are not well known (EPRI, 2006).

8. **Ambient Earth Temperature** is the temperature of the native soil that may change seasonally.

9. **Adjacent Heat Sources** are any localized heat sources including steam pipes, distribution circuits, and transmission circuits that impact ratings due to mutual heating.

10. **Grounding** of transmission cables maintains a continuous ground path to permit fault-current return and lightning and switching surge protection (EPRI, 2006).

11. **Route Thermal Analysis** is based on a field survey used to gain an understanding of the environment surrounding the selected path of the cable at the expected system depth.

12. A **fault** is a physical condition that results in the failure of a component or facility of the transmission system to transmit electrical power in a manner for which it was designed (PJM Manual 35, 2015).

13. **Fault Current Capability** is the maximum allowable current that a cable can withstand during a fault.

14. **Ampacity Software**
a. **CYMCAP©** is Windows-based software designed to perform thermal analyses. It addresses both steady state and transient thermal cable ratings. These thermal analyses pertain to temperature rise and/or ampacity calculations using the analytical techniques described by Neher-McGrath's paper for cable ratings and IEC 853 International standard (Section 10.1).
b. **Underground Transmission Workstation©** is an EPRI software product based on standards and techniques including IEC 60287 and Neher-McGrath's paper for cable ratings (Section 10.1).

5.0 GENERAL REQUIREMENTS

5.1 Underground transmission lines 69 kV and above can be solid dielectric, self-contained fluid filled, or pipe type cables.

5.2. Shunt reactive compensation must be considered and provided, when system conditions dictate. The need for shunt reactive compensation will depend on the overall cable capacitance and the system source impedance under all cable system operating conditions.

5.3 Surge arresters are recommended be installed at all termination locations to protect the underground cable system from transients caused by lightning or switching. However, a switching surge analysis should be performed for cable insulation coordination and protection.

5.4

5.5

5.6. Design shall comply with tThe latest edition of the Association of Edison Illuminating Companies AEIC CS2, "Specifications for
Impregnated Paper and Laminated Paper Polypropylene Insulated High Pressure Pipe Type Cable" should be referenced wwhen specifying pipe type cable.

5.7. Design shall comply with the The latest edition of the Association of Edison Illuminating Companies AEIC CS4, "Specifications for
Impregnated Paper Insulated Low and Medium Pressure Self Contained Liquid Filled Cable" should be referenced when specifying SCFF cable. Note that although PPP insulation can be used on SCFF cables, the AEIC Specification does not include PPP insulation in this specification. This is because pipe type systems make up the majority of transmission applications in the US and SCFF designs using PPP have not been installed to date.

5.8 Design shall comply with the The latest edition of the Association of Edison Illuminating Companies AEIC CS9, "Specification for
Extruded Insulation Power Cables and their Accessories Rated Above 46 kV through 345 kV AC" should be referenced when specifying solid dielectric cable.

5.9. Design shall comply with the latest edition of the IEEE Std. 400, "Standard for Extruded & Laminated Dielectric Shielded Cable Joints Rated 2.5 kV – 500 kV when specifying cable systems.

5.10 Design shall comply with the latest edition of the IEEE Std. 48, "Standard Test Procedures and Requirements for Alternating-Current Cable Terminations 2.5 kV – 765 kV when specifying cable systems.

6.0 GENERAL CONSIDERATIONS

6.1 ROUTING

6.1.1 Alternative routes should be investigated for an underground cable. Route considerations shall include:

1. Minimizing r~~R~~oute length~~should be minimized~~.
2. ~~-~~Routing should avoid or limit activities in environmentally sensitive areas
3. Avoid archeological or historical areas
4. Consider the type of existing land use (easements, urban, suburban, rural) and ability to obtain ownership or easement rights
5. Construction considerations
6. Maintenance access
7. Proximity to obstacles (rivers, major highways, railroads)
8. Traffic control
9. Adjacent ~~Factors such as e~~existing underground utilities
10. Existing commodities and their depth to be crossed

~~, C~~changes in

11. elevation
12. S~~, and s~~ources of thermal energy such as other circuits, steam mains
13. Permitting timelines
14. Soil types
15. Soil thermal resistivity~~, rock~~

~~, and the ability to obtain ownership~~

~~or easement rights should be considered in the selection of an underground route.~~

16. Pulling calculations and maximum reel lengths ~~must be evaluated t~~to determine splice locations and feasibility of construction.

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6.2 Ampacity Overview

6.2.1 The Designated Entity shall determine normal and emergency ratings for both summer and winter seasons using an appropriate facility rating methodology.

6.2.2 Ampacity, or current rating of the cable, is the magnitude of the current at a specified voltage that can be transmitted on the cable system without exceeding insulation temperature limits (EPRI, 2006). Cable ampacity is divided into ~~three~~ two conditions, normal (steady-state) and emergency, with all ratings impacted by the following factors:

1. Cable Insulation
2. Load factor
3. Conductor size, materials, and construction
4. Dielectric losses
5. Mutual heating effect of other heat sources like existing cables, ducts, steam mains or other underground facilities that have an effect on the rating of the cable
6. Ambient earth temperature
7. Depth of burial

8. Type of surrounding environment (soil, duct bank, concrete, grout) and their thermal characteristics

9. Pipe size or conduit size

6.2.3 If not in a duct bank or needed to meet or increase ampacity, corrective thermal backfill materials should be considered for transmission cable systems. These can be engineered graded sand that is compacted or fluidized thermal backfill. ~~The engineered backfill shall be tested to demonstrate expected thermal resistivity.~~

6.2.4 The inputs for the cable ampacity calculations shall be validated by field testing and as-builts of the installation. In-situ soils, placed concrete and engineered backfill shall be tested to demonstrate that the expected thermal resistivity is met to validate the calculations inputs. Ampacity shall be recalculated if the testing values deviate from the inputs. The as-built profile and depths of burial along the installation shall be validated against the inputs used for the ampacity calculations. Ampacity shall be recalculated if the actual installation deviates from the inputs.

6.2.5 For more information concerning how cable rating calculations are implemented in the operation of transmission lines, please see PJM Manual 3: Transmission Operations (Section 2).

7.0 Pipe Type Cable Considerations [this section will be updated for the 6~~5~~/~~18/~~2017 meeting]

7.1 Pressurizing/pumping plants are required and the design and siting of these systems must factor in the risk of leaks into the environment. The use of a pipe type cable system requires at least one pumping plant and possibly two or more depending on reliability criteria and the length of the pipe type system.

7.2 Pumping plant alarms and control systems must be designed and utilized to minimize the loss of dielectric fluids. Improper operation and abnormal conditions shall be reported remotely for immediate corrective action. [pumping plant alarms to system operator; eNotification system.
"remote monitoring part of design—leave in as placeholder]

7.3 The reliability of the cable is no higher than the reliability of the pumping plant. Therefore, two independent sources of power to the pumping plant are recommended.[Dominion comment--uses 2 different busses in same substation. Backup generators 3rd sources; does it count as source?] nitrogen gas driven pump inside bldg. should be considered inside a pressuring plant 2AC feeds or nitrogen crossovers]

7.4 Long underground cables may need pumping plants along the cable route because the plants must be able to maintain cable pressure as the dielectric fluid expands and contracts with load i.e. operating temperature. Additional issues that must be addressed are environmental risk and hotspot mitigation. Management of these issues may require intermediate pumping plants, multiple hydraulic sections, special valve and pipe schemes, circulating dielectric fluid~~oil~~, forced cooling systems, etc.

7.5 The fluid must be at rated pressure prior to energizing the cable.

7.6 Pipe coating and the cathodic protection systems are required to protect the integrity of steel pipes and minimize the risk of leaks. Resistor rectifier circuits shall be discouraged for new installations. [what if in waterway? Need resistor rectifier circuits] coating on pipe primary protection; 2nd protection cathodic protection

Address: anchor joints for elevation changes; drastic change in elevation; thermomechanical movement and bending; sections/lengths between splices relative to maximum pulling values; 2 covers for manholes/locking them; DLR rating writeup

8.0 Solid Dielectric Cable Considerations [this section will be added for the 6~~5~~/20~~18/1~~17 meeting]

Address: grounding/bonding scheme; testing (partial discharge, DC jacket test, 24 hour AC soak, etc.)

~~ADD these sections:~~

~~Cable accessories~~

~~Grounding (Bob)~~

~~Commissioning & Testing Requirements (Jared)~~

~~Submarine Cables~~

~~Seismic issues (Jay/Tom)~~

~~Check terms in the documents---pressuring plants vs. pumping plants (Tom)~~

~~Address link boxes at every splice~~

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