Markups from 3/16/2017 DEDSTF Line Subgroup meeting
Added post 3/16/2017 Meeting

PJM DESIGNATED ENTITY DESIGN STANDARDS – UNDERGROUND LINES

~~***V.B PJM DESIGN AND APPLICATION OF UNDERGROUND TRANSMISSION CABLES***~~

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 **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

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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).

~~1~~5.0 GENERAL REQUIREMENTS

~~1. All new underground transmission lines (500 kV, 345 kV, 230 kV, 138kV, 115kV and 69kV) shall, as a minimum, meet the technical requirements of this document and Section II (Transmission System Design Criteria).~~ Underground transmission lines 100 kV and above can be solid dielectric, self-contained fluid filled, or pipe type cables.

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. **[move to different section]**

3. The 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 when specifying pipe type cable.

4. 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. 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.

6. **[add standards for cable accessories]**

7. If the cable system is to be turned over to the TO for ownership, cable type and cross section should be chosen from those used by the TO. This provides the ability to quickly repair a section of cable with utility stock material should an emergency arise. Contact PJM to determine the types of cable used in a specific Transmission Owner area.

~~2.0 CONDUCTORS~~

~~2.1 Underground transmission lines 100 kV and above can be solid dielectric, self-contained fluid filled, or pipe type cables.~~

~~2.2 Solid dielectric cable may be preferred over pipe type for short length circuits without splices.~~

[add the IEEE or other definitions]

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6.0 GENERAL CONSIDERATIONS

~~3.0~~6.1 ROUTING

3.1 Route length should be minimized. Factors such as existing underground utilities, changes in elevation, and sources of thermal energy such as steam mains, rock, and the ability to obtain ownership or easement rights should be considered in the selection of an underground route.

3.2 Construction in public rights of way such as streets is not preferred for circuits 100 kV and above. Permits for occupation in these corridors usually require the owner of the cable system to pay for the entire cost of relocation of the line, should work on the highway require relocation of the facility. This can be costly and also interrupt service for extended periods of time during the relocation.

[pay attention to UG distribution circuits & try to avoid heat sources; find alternate paths. Consider adjacent thermal sources and existing facilities depth for impact to ampacity]

~~**4.0 GENERAL CONSIDERATIONS**~~

6.2 Ampacity Overview

The Designated Entity shall determine normal and emergency ratings for both summer and winter seasons using an appropriate facility rating methodology. The Designated Entity shall provide documentation of the calculation method, including all assumptions for the input parameters. The **cable** selected shall be compatible with all ampacity ratings.

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 conditions, normal (steady-state), emergency and load dump, with all ratings impacted by the following factors:

1. Cable Insulation
2. Peak current and load–cycle shape
3. Conductor size, materials, and construction
4. Dielectric losses
5. Mutual heating effect of other heat sources like exisiting 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, grout) and their thermal characteristics
9. Pipe size or conduit size

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For more information concerning how cable rating calculations are implemented in the operation of transmission lines, please see PJM Manual 3: Transmission Operations (Section 10.1).

~~4.1 The rating or ampacity of the cable system is the fundamental design requirement that determines the conductor size and the overall cable design. The thermal resistance of the soil along the cable route will also impact the rating of the cable system. Load factor, depth of burial and other sources of heat such as existing ducts, steam mains and other underground facilities have an effect on the rating of the cable~~. A thermal evaluation to determine the soil resistance, known as the thermal rho of the soil must be performed in areas where this data is unknown.

If not in a duct bank, corrective thermal backfill materials should be considered for transmission cable systems. These can be engineered graded sand that is compacted or fluidized thermal backfill. In all cases, the engineered backfill shall be tested to demonstrate expected thermal resistivity.

~~4.2 The load factor of the cable is critical, especially for generator leads which often have a 100 percent load factor.~~

~~4.3 The pipe size or conduit diameter is usually determined as part of the rating calculation~~. Pulling calculations and maximum reel lengths must be evaluated to determine splice locations and feasibility of construction. **[move this to another section]**

4.4 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.

[section 4.4 is too random and discusses different things; suggest move to separate grounding/bonding and cathodic protection sections. Line side arresters next to all terminations needed

[add direct buried vs ductbank

5.0 Pipe Type Cable Considerations

5.1 Pumping plants are required and the design and siting of these systems must factor in the risk of leaks into the environment.

5.2 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]

5.3 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.

5.4 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

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gas driven pump inside bldg. should be considered inside a pressuring plant   2AC feeds or nitrogen crossovers]

5.5 ~~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.

5.6 The fluid must be at rated pressure prior to energizing the cable. ~~Therefore, energy storage or on site generation is required for pumping plants to allow for black start of the cable system.~~

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5.7 Pipe coating and the c~~C~~athodic 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

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~~5.8 There is a great deal of experience in the design of pipe type cable systems. Consequently, splices and terminals can be purchased separately from the pipe cable, i.e. from other specialty vendors who produce these accessories. In all cases, the cable manufacturer should be consulted and dimensional data, as well as design details such as the lay of the outer paper tapes, should be provided to the accessory suppliers by the cable supplier in order to ensure that the accessories fit the pipe type cable.~~

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6.0 MAINTENANCE

For maintenance see section V.L.2.B

ADD these sections:

Definitions (Arleen)

Cable accessories

Grounding (Bob)

Commissioning & Testing Requirements (Jared)

Solid Dielectric cable section similar to 5.0

Submarine Cables

Seismic issues (Jay/Tom)

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

Check PJM's U/G & submarine transmission cable rating methodologies guideline for any use

Address link boxes at every splice

Add need for route thermal analysis

Exclude cable testing since in AEIC documents but can refer to it