For the 6/15/2017 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. The design philosophy shall provide for the highest degree of reliability, by following sound engineering practices and adhering to established economic, operating, safety and environmental guidelines/requirements. The best practices and guidelines outlined in the EPRI Underground Transmission Systems Reference Book shall be followed, along with the latest industry standards and procedures.

5.3 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 to 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 Spare conduits and/or spare pipes shall be installed parallel to underground lines for all major crossings, all submersible water crossings and for long length inaccessible locations.

5.5 The cable system shall be designed in accordance with, but not be limited to, the following industry standards.

5.6. Design shall comply with 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" when specifying pipe type cable.

5.7. Design shall comply with 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" 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 latest edition of the ASTM A523, "Standard for Plain End Seamless and Electric-Resistance-Welded Steel Pipe for High Pressure Pipe Typle Cable Circuits."

5.9 Design shall comply with the latest edition of the ASTM A312/A321M, "Standard Specification for Seamless, Welded and Heavily Cold Worked Austenitic Stainless Steel Pipes."

5.10 Design shall comply with the latest edition of the ASTM A53, "Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-coated, Welded and Seamless High Pressure Pipe Type Cable Circuits."

5.11 Design shall comply with the latest edition of the AEIC CS31, "Specification for Electrically Insulating Pipe Filling Liquids for High-Pressure Pipe-Type Cable."

5.12 Design shall comply with 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" when specifying solid dielectric cable.

5.139. Design shall comply with the latest edition of IEEE 575, "-Guide for the Application of Sheath-Bonding Methods for Single-Conductor Cables and the Calculation of Induced Voltages and Currents in the Cable Sheaths."

5.14 Design and testing shall compky with the latest edition of IEC 62067, "Power Cable with Extruded Insulation and Their Accessories for Rated Voltages Above 150 kV up to 500 kV – Test methods and Requirements"

5.15 Design shall comply with the latest edition of IEE Standard 442, "IEEE Guide for Soil Thermal Resistivity Measurements."

5.16 Design shall comply with the latest edition of the IEEE Std. 40440, "Standard for Extruded & Laminated Dielectric Shielded Cable Joints Rated 2.5 kV – 500 kV when specifying cable systems.

5.10 17 Design and testing- 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 the following:

1. Minimizing route length.
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 existing underground utilities
10. Existing commodities and their depth to be crossed
11. Changes in elevation
12. Sources of thermal energy such as other circuits, steam mains
13. Permitting timelines
14. Soil types
15. Soil thermal resistivity

16. Pulling calculations and maximum reel lengths to determine manhole and splice locations and feasibility of construction**.**

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 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 or granular backfill that is compacted or a fluidized thermal backfill.

6.2.4 The project MVA rating basis shall be confirmed by final ampacity calculations based on the installed line. The preliminary 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 determine~~demonstrate that~~ the ~~expected~~ as-built thermal resistivities~~y~~ ~~is met to validate the calculations inputs~~for use in performing the final ampacity calculations. ~~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 preliminary inputs and used for the final 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

7.1 Pipe Type Cables Systems are comprised of High Pressure Fluid Filled (HPFF) and High Pressure Gas Filled (HPGF) systems. HPFF systems have been installed at 345 kV voltages and lower, HPGF systems up to 138 kV and lower. HPFF systems have been installed since the early 1930s.

7.2 Pipe Type Cables Systems have all three insulated cable phases installed in a common pipe. The pipe itself is designed specifically for the installation of power cables under pressure. The pipe is usually Grade A steel per ASTM 523. There is a Grade B steel. It is more brittle and stronger, but the brittleness may create problems with pipe bending. The most common pipe size used is an 8.625 inch pipe with a wall thickness of 0.250 inch. A 0.375 inch thick wall has been used in long water crossings. There are other pipe sizes available for different voltage levels and cable design.

Coating systems are required for both inside and outside of pipes to protect against corrosion. It is the primary corrosion protection. Coatings maybe a mastic/polyethylene coating or fusion bonded epoxy with an epoxy-concrete. Construction installation methods influence the coating type.

7.3 Pipe coating and a dedicated cathodic protection system are required to protect the integrity of steel pipes and minimize the risk of leaks. The pipe coating is the primary line of defense and the cathodic protection system is the secondary. There are two cathodic protection systems that shall be considered in the design. One is a passive system where anode bags are installed along the pipe route. If a holiday occurs in the pipe coating, the anode bags provide the sacrificial ions instead of the pipe. The other system is an impressed current system where an alternating current source powers a rectifier supplying the ions from an array of anode bags usually located at one of the pipe.

7.4 The conductor in Pipe Type Cables is typically four segmented copper. Aluminum has been used in the past specifically when copper prices were extremely high. Copper is used today to meet high power transfer requirements. Pipe type cable may be insulated with kraft paper or laminated paper polypropylene (LPP) tape. LPP is a thinner tape with a layer polypropylene tape in between two kraft paper tapes. This still provides the necessary electrical insulation required at a reduced thickness which equates to a smaller cable diameter. LPP insulated cables have higher power transfer capability too. There are other tapes on a pipe type cable used for shielding, segmental insulation, moisture barriers, binder tapes and outer shielding tapes. Some of these may altered to meet the need of the project. Two "D" shaped skid wires are spiral wrapped around the final insulated cable. These skid wires drag on the inside of the steel pipe reducing pulling friction while protecting the cable insulation during installation. Skid wire materials also influence the pulling tension.

7.5 Pipe type cables are impregnated with insulating fluid under vacuum and high temperature at the factory. Only HPFF use insulating fluids after cable installation. Various fluid types have been used over time. Viscosities differ among the insulating fluids and temperature. Today's fluids are alkylbenzene product with low viscosity properties. Low viscosity allow for fluid circulation and/or forced cooling if additional power transfer is required of the HPFF cable system. The insulating fluid must kept under a nominal pressure of 200 psi by pressurization/pumping plant.

The insulating fluid for HPGF systems is a high viscosity fluid to slow the fluid from draining out of the cables.

Route elevations need to be taken into consideration for hydraulic calculations in determining pressure settings for the relief valves in the pressurization plant.

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

7.6 Splices connect cable sections together and are commonly called joints. Straight, anchor, stop, semi-stop and trifurcating joints not only connect the cables but provide other features for the cable system if needed. Y joints and H joints are used to cut into existing cable systems to extend or add circuits. It is critical to support all phase cables to prevent thermal mechanical bending (TMB). Insulation over the splices must meet the same performance standard as the cable insulation and control the electrical stress of the splice. All three cable phases are spliced at the same location. The splices are then encased in a carbon steel telescoping pipe of multiple sections. The telescoping pipe is welded together and welded to the pipe installed. It is suggested splices to be installed in manhole for future access.

A cable restraining system shall be used when cable sections are expected to have thermal mechanical movement. Specialized anchor and skid joints shall be used for steep inclines and drastic changes in elevation to minimize and prevent thermal mechanical movement. Restraint locations and design and placement methodology shall follow good engineering practices.

7.7 Terminations are the connection point between the underground cable and the substation bus or overhead transmission line. It also provides the insulation between the cable conductor and grounded structure supporting the termination. For HPFF and HPGF pipe systems, it must seal the insulating fluid or insulating gas from the environment.

Terminations may use air insulation when space is available in the substation or for substations using GIS due to less substation space a gas insulated termination is available. Design shall ensure that the termination is sized to the cable and meets the operating pressures of the cable system for various conditions. Air insulated terminations may have standard insulation creepage distances and high creepage distance for contaminated areas.

It is recommended that the termination mounting plate is dry fitted to the pipe system. This ties all the variables from constructing the termination structure, its foundation and riser pipe length. Proper fitment is critical for the final weld of the mounting plate's tail piece pipe to the riser pipe and ensures the termination will be plumb.

For GIS installations, coordination between GIS manufacture, termination manufacture, cable installation contractor, GIS contractor is mandatory for a successful GIS termination installation.

Check the porcelain stand-off insulators between the termination's mounting plate and support structure for cracking after installation.

Terminations are usually not ampacity limiting but on forced cooled pipe type systems the termination rating needs to meet the cable rating.

7.8 A pressurization/pumping plant is necessary to pressurize the dielectric fluid in HPFF cable systems for all loading conditions. The nominal operating pressure is 200 PSI. The plant is designed and built for the specific circuit parameters such as pipe size, cable size and length of the cable circuits. It is most common for the plant to pressurize two pipe systems. This is achieved by two ladders (piping and valves) supplying the dielectric fluid by pumps driven by two electric motors. The ladders are isolated hydraulically from each other but can be valved together. The plant has a large reservoir tank of dielectric fluid with a blanket pressure of nitrogen over the fluid. The reservoir tank is partitioned to supply fluid to the two cable pipe systems.

The use of a pipe type cable system requires at least one pressurizing plant and possibly two or more depending on reliability criteria and the length of the pipe type system. 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 in the design and siting 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, forced cooling systems, etc.

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.

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]~~Pressurizing plants shall remain powered at all time. Two independent sources of power to the pumping plant are required with an automatic transfer of power to ensure continuous AC feed to the pressurization plant.

Modern plants operate by a programmable logic controller (PLC) that offer information on the circuit(s) and the various systems in the pressurization plant. This data may be alarmed to the control center and sent to a data historian.

A direct current source is also needed for a PLC operated plant. Redundant pressure switches and gauges shall be installed. A separate pressurization pump driven by nitrogen gas shall be considered in the event ALL power is loss to the pressurization plant.

Depending upon the requirements of the underground circuit, a pressurization plant may be designed for circulation of the insulating fluid. Fluid may be circulated down one cable pipe and return to the pressurization in the other pipe. This will smooth hot spots in the cable system. For additional capacity from the HPFF circuit, a separate return pipe (no cables inside) for dielectric fluid should be installed at the time of initial construction. This will allow the dielectric fluid to be circulated through heat exchangers or even refrigeration systems before pumped back into the cable pipe. Some entitities shuttle insulation fluid from end of the cable pipe to the opposite end for additional ampacity. This will require pressurization plants on each end of the cable pipes.

Leak detection systems can be installed in the pressurization plant for HPFF cable systems if an entity deems it is necessary. This may be alarmed for notification to the system control center.

7.9 A crossover cabinet is usually installed on the opposite end of the pipe type cable system from the pressurization plant. Inside this cabinet is an electric valve that opens when necessary (usually when low pressure develops on one pipe) to tie the cable pipes together hydraulically normalizing the pressure on the pipe experiencing low pressure. This valve should be alarmed notifying the control center it has opened for an abnormal reason. Like the pressurization plants, a smart crossover with its own PLC is available where it communicates with the pressurization plant. It can be designed to open and close the valve for various conditions.

7.10 Testing?

7.11 DLR?

7.12 Pipe type cable routes need patrolled on a regular basis. The intent here is to prevent dig in from contractors digging in the vicinity. Cable terminations should be inspected for small weeps of fluid and leaning termination stands. Pressurization plants need inspection and possibly exercising the electric motors connected to the pumps. Some systems are consistently loaded and the pressure never drops low enough for the pumps to activate. For impressed current cathodic protection system, check the voltage on the power supply to the rectifier.

8.0 Solid Dielectric Cable Considerations

8.1 A route thermal survey shall be performed to obtain the native soil thermal resistivity and ambient soil temperatures at expected cable installation depths along the route for use in the rating calculations to select the conductor size.

8.2 Extruded dielectric cable systems can be insulated with ethylene-propylene rubber (EPR) at voltages up to and including 138 kV or with cross-linked polyethylene (XLPE) insulation. Pressurization of the cable system is not required.

8.3 A metallic moisture barrier or sheath is required to prevent moisture from entering the cable. This can be a lead sheath, corrugated copper or aluminum sheath, or copper or aluminum foil laminate.

8.4 Sheath grounding or bonding is the method by which the metallic shield and sheath is connected to the local ground. Cable shield grounding can be multipoint grounding, single point grounding or have crossbonding.

8.5 The cable sheath, bonding cables and ground continuity conductors shall be designed for the expected fault current and clearing time. The cable system shall have grounding link boxes and sheath overvoltage protector link boxes for connecting the cable sheath to the substation ground grid and to facilitate performing jacket integrity tests..

8.6 For single point grounded cable systems, a ground continuity conductor is required for the line for proper fault current to flow. For single point grounded cable systems, a link box with a sheath voltage limiter is required to protect the cable jacket from damage during a fault. For single point grounding, the voltage rise at the open end of the shield shall be limited to 150V.

8.7 For crossbonded grounding, link boxes shall be installed at the transposition points with sheath voltage limiters to protect the cable jacket from damage during a fault

8.8 Sheath voltage limiters shall be adequately sized for nominal and transient voltages that occur during fault conditions.

8.9 Splices shall be of the same insulation class as specified for the cable. The current ratings of the splices shall be as a minimum the current rating of the cable for which the cable splice is designed.

8.10 A jacket integrity test shall be performed on each section of cable prior to and after installation to ensure that the cable jacket has not been damaged during shipping or after cable pulling. The cable jacket shall withstand a dc voltage of 10 kV for 1 minute.

8.11 Cable voltage tests shall be performed on the terminated cables after installation. The cables shall pass these tests when conducted in accordance with the latest applicable IEEE, AEIC, IEC and CIGRE specifications and guidelines.

8.12 An AC soak test at no load and full voltage for a period of 24 hours shall be performed on the installed cable system.

8.13 A one hour AC voltage withstand test at 1.7 x rated line-to-ground voltage shall be performed per IEC 62067. Partial discharge detection measurements shall be performed on all accessories continuously during the voltage test.