For the 7/20/2017 meeting review

~~PJM DESIGNATED ENTITY DESIGN STANDARDS – UNDERGROUND LINES~~

Comment [P1]: PJM Question: Do we know this will become Section 6.0 in the MDS document., or will it be absorbed into Section 3.0, Overhead Lines, with Section 3.0 retitled and the intro to it reworded to accommodate the underground requirements.

X.0) TRANSMISSION LINES MINIMUM REQUIRED 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.

[note that all sections below will be renumbered after establishing what section the UG is in the overall minimum stds document; currently OH is 3.0, SBST 4.0, P&C 5.0]

4.0 UNDERGROUND TRANSMISSION DEFINITIONS

Comment [P2]: Do we refer to all of these terms in the remainder of the document? If not, suggest deleting those not used.

Another thought. In the overhead section we did away with definitions, assuming that the DEs are familiar with the terminology. Do we want to do the same here?

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.

Comment [P3]: Not used in document

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).

Comment [P4]: Not used in document

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).

Comment [P5]: Not used in document

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

Comment [P6]: Not used in document

14. 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).

154. **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).

Comment [P7]: We were advised not to "endorse" particular products; can we be generic?

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 best practices and guidelines, along with applicable latest industry standards and procedures outlined in the EPRI Underground Transmission Systems Reference Book, shall be followed. 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 installedshall be considered 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 Parallel sSpare conduits and/or spare pipes shall be installed parallel to underground linesbe considered for installations at 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 latest edition of the following industry standards, as applicable.

Pipe-Type Cable Systems

5.5.1. ~~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.

5.5.2. ~~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.

5.5.3 ~~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 Type Cable Circuits.”

5.5.4 ~~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.”

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

Solid Dielectric Cable Systems

5.5.6 ~~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.

5.5.7 ~~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.”

5.5.8 ~~Design and testing shall comply 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”

5.5.9 ~~Design shall comply with the latest edition of the~~ IEEE Std. 404, “Standard for Extruded & Laminated Dielectric Shielded Cable Joints Rated 2.5 kV – 500 kV when specifying cable systems.

5.5.10 ANSI/ICEA S-108-720, "Standard for Extruded Insulation Power Cables Rated Above 46 through 345 kV."

5.5.11 IEC 60840, "Power Cables with extruded insulation and their accessories for rated voltages above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV) –Test methods and requirements."

All Cable Systems

5.5.12 ~~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.

5.5.13 IEEE Standard 442, "IEEE Guide for Soil Thermal Resistivity Measurements."

[need to address IEC terminations standards for HPFG]

6.0 ~~GENERAL CONSIDERATIONS~~ DESIGN PARAMETERS

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)
5. ~~and a~~Ability to obtain ownership or easement rights
6. Construction considerations
7. Maintenance access
8. Proximity to obstacles (rivers, major highways, railroads)
9. Traffic control
10. Adjacent existing underground utilities
11. Existing commodities and their depth to be crossed
12. Changes in elevation
13. Sources of thermal energy such as other circuits, steam mains
14. Permitting timelines
15. Soil types
16. Soil thermal resistivity
17. Pulling calculations and maximum reel lengths
18. ~~to determine m~~Manhole and splice locations
19. ~~and f~~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 . Software designed to perform thermal analyses for underground cable systems shall be used.

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 calculations shall be performed for ~~is divided into~~ two conditions, normal (steady-state) and emergency, ~~with all ratings impacted by~~and shall consider 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 A route thermal survey and laboratory testing 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.

6.2.~~3~~ 4~~If not in a duct bank or needed to meet or increase ampacity~~, C~~c~~orrective thermal backfill materials ~~should~~ shall be considered for transmission cable systems if not in a duct bank or needed to meet or increase ampacity. These can be engineered graded sand or granular backfill that is compacted or a fluidized thermal backfill.

6.2.5 The ampacity calculations associated with a pipe type cable encompass many aspects of the cable system including construction and installation. It is imperative for the designated entity to fully understand all of the different parameters which affect the cables normal and emergency ratings. Particular attention must be paid to installing the cable so as to not adversely affect the cables required thermal ratings. A comprehensive review of the cables installation data must be performed in order to determine its actual verses theoretical rating. Installation factors that affect cable ratings include ambient earth temperature, thermal resistivity of existing and placed backfill, spacing between other sources of heat, burial depth, etc.

6.2.4 6 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 the as-built thermal resistivities for use in performing the final ampacity calculations. . 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.

6.2.5 7 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 Thermal Operating Guidelines).

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7.0 Pipe Type Cable Considerations [clean version of this section at end of document]

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. Pipe Type Cables Systems shall have all three insulated cable phases installed in a common steel pipe. The cables transition to three smaller individual stainless steel pipes to permit termination of the cable. Only one insulated cable is installed in the stainless steel pipe.

Comment [P8]: This is essentially the definition presented in the Section 4. Here it is serving as commentary. Suggest striking.

7.2 Pipe Type Cables Systems shall have all three insulated cable phases installed in a common pipe. The steel pipe itself is shall be designed specifically for the installation of power cables under pressure. All pipes shall comply with the latest edition meet the requirements of ASTM A523, "Standard for Plain End Seamless and Electric-Resistance-Welded Steel Pipe for High Pressure Pipe Type Cable Circuits. Grade A or Grade B steel. If Grade B is used, the brittleness shall be considered in the design for construction purposes in order to avoid pipe pending.

7.3 The stainless steel pipe shall comply with the latest edition of ASTM A312/A321M, "Standard Specification for Stainless, Welded and Heavily Cold Worked Austenitic Stainless Steel Pipes."

~~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.~~

~~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~~

7.~~4~~ Coating systems, which is the primary corrosion protection, are required for both inside and outside of ~~the~~ steel pipes to protect against corrosion prior to and after installation. ~~It is the primary corrosion protection.~~ Coatings ~~maybe~~ shall be a mastic or~~/~~ 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.~~

7.~~5~~5 ~~There are two c~~The design shall include a c~~C~~athodic protection system~~s~~, using either ~~that shall be considered~~required ~~in the design. Two systems are available; One is~~ 1) a passive system where galvanic anodes ~~bags~~ are installed along the pipe route.; if ~~If~~ a holiday occurs in the pipe coating, the anode bags provide the sacrificial ions instead of the pipe or 2)~~. The second 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 end of the pipe(s). The cathodic protection system shall be designed to NACE Standard RP0169 latest revision titled "Control of External Corrosion on Underground or Submerged Metallic Piping Systems." Together the coating system and cathodic protection system protect the integrity of steel pipes and minimize leaks.

7.~~4~~ ~~6~~6 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~~ shall be either copper or aluminum. The cable shall comply with AEIC CS-2 latest revision.

Pipe type cables ~~may~~ shall 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 Oo~~ Other tapes on a pipe type cable shall be 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~~ shall be spiral wrapped around the final insulated cable to~~. 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.~~ Skid wire material shall be specified due to the different coefficient of friction (COF) value of the material.

7.~~5~~ ~~7~~7 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.~~Insulation fluids shall meet the AEIC CS31 latest revision and the requirements of the HPFF circuit, such as ~~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.

Route elevation, pipe size, cable size and circuit length shall be taken into consideration for hydraulic calculations in determining the rated fluid pressure on the cable system and pressure settings for the relief valves in the pressurization plant. The typical nominal pressure is 200 psi for a HPFF system.

The fluid in the HPFF system must be at rated pressure prior to energizing the cables. A hydraulic soak period shall be implemented to bring or return the HPFF system to rated pressure. The fluid must be at rated pressure for 24 hours before testing or energizing the cable.

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

The impregnate insulating fluid for HPGF systems ~~is~~ shall be ~~a~~ extra high viscosity fluid to slow the fluid from draining out of the cables during handling and through out the life of the cable.

7.~~6~~ ~~8~~8~~Splices connect cable sections together and are commonly called joints~~. Straight, anchor, stop, semi-stop and trifurcating joints shall be designed to ~~not only~~ connect the cable sections ~~but~~ and provide other features for the cable system ~~if~~ as 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~~ shall be spliced at the same location. The design shall take into account that t~~T~~he splices are ~~then~~ encased in a carbon steel telescoping pipe of multiple sections and that ~~. T~~the telescoping pipe is welded together and welded to the pipe installed. ~~It is suggested~~ Design shall consider that splices~~ to~~ be installed in manholes for future access.

All phase cables shall be supported to prevent thermal mechanical bending (TMB.) ~~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 9~~9~~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~~ terminations 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. The termination's insulation creepage distance~~Air insulated terminations~~ ~~may have~~shall be selected based upon the operating environment.~~with standard insulation creepage distances and or with high creepage distance for contaminated areas.~~

~~It is recommended~~~~Design shall consider~~ It is critical~~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 required~~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 10~~10 A pressurization/pumping plant is ~~necessary~~ required to pressurize the dielectric fluid in HPFF cable systems for all loading conditions. The nominal operating pressure is 200 PSI. The plant ~~is~~ shall be designed and built for the specific circuit parameters such as pipe size, cable size, ~~and~~ length of the cable circuits and any circulation requirements. Additional pressurization/pumping plants may be required for long underground cables, to meet reliability requirements of the owner and if there are multiple hydraulic sections in the cable circuit. Environmental concerns shall be considered in the siting and foundation design for dielectric fluid containment.

A pressurization plant may be designed for circulation. Fluid may be circulated down one cable pipe and return to the pressurization plant 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 owners 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. Fluid circulation, forced cooling, and multiple hydraulic sections will require special valve and pipe schemes.

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~~for independent fluid 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.~~

Pressurization/p~~P~~umping shall have plant alarms and control systems to ensure pressurization of the cable system. Alarm settings shall be based upon criticality and the response time to the alarm. These alarms must be designed and utilized to minimize the loss of dielectric fluids. Improper operation and abnormal conditions shall be reported to the system or local control center ~~remotely~~ for immediate corrective action.
~~corrective action.~~

Leak detection systems can be installed in the pressurization plant for HPFF cable systems if the utility requires it for environmentally sensitive areas. Leak detection compares the predicted fluid entering a cable system versus actual fluid entering the cable system. This can be alarmed before the leak grows larger.

Modern plants operate by a programmable logic controller (PLC) that offer information on the circuit(s) and the various systems inside the pressurization plant. These various systems may be alarmed too. A PLC can provide remote access to the controls in the pressurization plant for a faster response time to an alarm.

The reliability of the cable is no higher than the reliability of the ~~pumping~~ pressurization plant. Pressurizing plants shall remain powered at all time. Two independent sources of power to the ~~pumping~~ pressurization ~~plant~~ are required with an automatic transfer of power to ensure continuous AC feed to the pressurization plant. The second power source can be a backup generator, dedicated off site power line, or an alternate bus source.

~~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~~ ~~11~~11 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 press–ure. 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. If the cable circuit requires an additional pressurization plant, the crossover cabinet may be replaced by the additional pressurization plant.

7.10 Testing

Testing pipe type transmission cables and accessories is vital for qualifying cable and cable components for design, installation verification, qualification/acceptance and operations and maintenance purposes.

Test standards and procedures developed for pipe-type cable by organizations such as the Association of Edison Illuminating Companies (AEIC), the Insulated Conductors Committee (ICC) of the IEEE, the International Electrotechnical Commission (IEC), and the Insulated Cable Engineers Association (ICEA) should be referenced and applied to the Pipe cable system.

The testing of high voltage pipe type cable is highly specialized requiring skilled engineering, technicians and equipment.

The EPRI Green Book dedicates an entire chapter to cable testing which describes the principles of cable and accessory testing, summarizes the applicable standards, guides, and procedures that are commonly accepted by the cable industry. It addresses specific test procedures, laboratories, equipment for ac, impulse, dc, thermomechanical tests, and describes diagnostic procedures employed in the laboratory and in the field.

Any Designated Entity that proposes to install transmission pipe cable shall demonstrate the requisite knowledge needed to ensure proper design, reliability, operation and maintenance of the cable system.

7.11 1313 Dynamic Line Rating is a microprocessor based real time data acquisition and computing system. It repeatedly measures independent variables along the line and within auxiliary equipment (pressurization plant, high speed circulation system or heat exchanger) that define the thermal state of the cable and uses this information to calculate real time cable ratings. If Dynamic Line Rating (DLR) is considered in the design, the design shall consider the operation and maintenance needs to maintain this system.

7.12 1414 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 if it is not alarmed. [look at 5/8/2017 item 4B planning committee document from substation group to assess what they wrote].

Comment [P9]: Nothing in substation text regarding inspections/O&M

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~~ 1 Extruded dielectric cable systems ~~can~~ shall 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~~ 2A metallic moisture barrier or sheath, such as ~~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, ~~.~~ is required to prevent moisture from entering the cable.

8.3 The cable shall have a durable, moisture-resisting thermoplastic compound for use as the jacket to provide mechanical and corrosion protection. The cable shall be designed with an electrically conducting coating on the outside of the jacket that is suitable for jacket integrity tests and that will be electrically continuous after the cable is installed. This coating shall be a graphite varnish coating or a semi-conducting extruded layer.

8.4 ~~Sheath grounding or bonding is the method by which~~ T~~t~~he metallic shield and sheath shall be grounded or bonded to ~~is connected to~~ the local ground, using either ~~. 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 Link boxes shall be constructed of type 304 stainless steel or other non-corroding metal. Link boxes shall have bolted, removable copper or brass links capable to carry the fault current. The link boxes shall be weather-tight.

8.7~~6~~ For single point grounded cable systems, a ground continuity conductor is required for the line for proper fault current to flow. The quantity and size of the ground continuity conductors shall be calculated per IEEE 575. -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 8 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 9 Sheath voltage limiters shall be adequately sized for nominal and transient voltages that occur during fault conditions.

8.9 10 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.

8.11 Terminations shall be sized and rated for the cable system. The terminations and component parts shall be Class 1 terminations as defined in IEEE Standard 48. The proposed terminations shall be supplied with means to maintain the hermetic sealing of the cable system where the metallic cable sheath is connected to the termination. Standoff insulators capable of withstanding 20 kV dc for one minute shall be supplied with each cable termination.

8.12 The cable system shall be designed to prevent damage to the cable during installation based on the manufacturer specified sidewall pressure and cable bending radius limits.

8.13 The cable shall be supported at the termination support structures by clamps and other accessories specifically designed for the cable and its diameter. The cable clamps and bolts shall be designed to not corrode in the specified project environment. For long unsupported vertical inclines, the design shall include a cable support system.

8.14 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.

8.161 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.

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

8.183 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.

PIPE-TYPE SECTION WITHOUT THE TRACKED CHANGES:

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.. Pipe Type Cables Systems shall have all three insulated cable phases installed in a common steel pipe. The cables transition to three smaller individual stainless steel pipes to permit termination of the cable. Only one insulated cable is installed in the stainless steel pipe.

Comment [P10]: This is essentially the definition presented in the Section 4. Here it is serving as commentary. Suggest striking.

7.2 The steel pipe shall comply with the latest edition of ASTM A523, "Standard for Plain End Seamless and Electric-Resistance-Welded Steel Pipe for High Pressure Pipe Type Cable Circuits.

7.3 The stainless steel pipe shall comply with the latest edition of ASTM A312/A321M, "Standard Specification for Stainless, Welded and Heavily Cold Worked Austenitic Stainless Steel Pipes."

7.4 Coating systems, which is the primary corrosion protection, are required for both inside and outside of steel pipes to protect against corrosion prior to and after installation. Coatings shall be a mastic or polyethylene coating or fusion bonded epoxy with an epoxy-concrete. .

7.5 The design shall include a cathodic protection system, using either 1) a passive system where galvanic anodes 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 or 2)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 end of the pipe(s). The cathodic protection system shall be designed to NACE Standard RP0169 latest revision titled "Control of External Corrosion on Underground or Submerged Metallic Piping Systems." Together the coating system and cathodic protection system protect the integrity of steel pipes and minimize leaks.

7.6 The conductor in Pipe Type Cables shall be either copper or aluminum. The cable shall comply with AEIC CS-2 latest revision.

Pipe type cables shall be insulated with kraft paper or laminated paper polypropylene (LPP) tape. Other tapes on a pipe type cable shall be used for shielding, segmental insulation, moisture barriers, binder tapes and outer shielding tapes. Two "D" shaped skid wires shall be spiral wrapped around the final insulated cable to reducing pulling friction while protecting the cable insulation during installation. Skid wire material shall be specified due to the different coefficient of friction (COF) value of the material.

7.7 Pipe type cables are impregnated with insulating fluid under vacuum and high temperature at the factory. Only HPFF use insulating fluids after cable installation. Insulation fluids shall meet the AEIC CS31 latest revision and the requirements of the HPFF circuit, such as fluid circulation and/or forced cooling if additional power transfer is required of the HPFF cable system.

Route elevation, pipe size, cable size and circuit length shall be taken into consideration for hydraulic calculations in determining the rated fluid pressure on the cable system and pressure settings for the relief valves in the pressurization plant. The typical nominal pressure is 200 psi for a HPFF system.

The fluid in the HPFF system must be at rated pressure prior to energizing the cables. A hydraulic soak period shall be implemented to bring or return the HPFF system to rated pressure. The fluid must be at rated pressure for 24 hours before testing or energizing the cable.

The impregnate insulating fluid for HPGF systems shall be extra high viscosity fluid to slow the fluid from draining out of the cables during handling and throughout the life of the cable.

7.8. Straight, anchor, stop, semi-stop and trifurcating joints shall be designed to connect the cable sections and provide other features for the cable system as needed. 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 shall be spliced at the same location. The design shall take into account that the splices are encased in a carbon steel telescoping pipe of multiple sections and that the telescoping pipe is welded together and welded to the pipe installed. Design shall consider that splices be installed in manholes for future access.

All phase cables shall be supported to prevent thermal mechanical bending (TMB.) 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.

7.9. For HPFF and HPGF pipe systems, terminations must seal the insulating fluid or insulating gas from the environment.

Design shall ensure that the termination is sized to the cable and meets the operating pressures of the cable system for various conditions. The termination’s insulation creepage distance shall be selected based upon the operating environment.

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

7.10 A pressurization/pumping plant is required to pressurize the dielectric fluid in HPFF cable systems for all loading conditions. The nominal operating pressure is 200 PSI. The plant shall be designed and built for the specific circuit parameters such as pipe size, cable size, length of the cable circuits and any circulation requirements. Additional pressurization/pumping plants may be required for long underground cables, to meet reliability requirements of the owner and if there are multiple hydraulic sections in the cable circuit. Environmental concerns shall be considered in the siting and foundation design for dielectric fluid containment.

A pressurization plant may be designed for circulation. Fluid may be circulated down one cable pipe and return to the pressurization plant 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 owners 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. Fluid circulation, forced cooling, and multiple hydraulic sections will require special valve and pipe schemes.

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 for independent fluid supply to the two cable pipe systems.

Pressurization/pumping shall have plant alarms and control systems to ensure pressurization of the cable system. Alarm settings shall be based upon criticality and the response time to the alarm. These alarms must be designed and utilized to minimize the loss of dielectric fluids. Improper operation and abnormal conditions shall be reported to the system or local control center for immediate corrective action.

Leak detection systems can be installed in the pressurization plant for HPFF cable systems if the utility requires it for environmentally sensitive areas. Leak detection compares the predicted fluid entering a cable system versus actual fluid entering the cable system. This can be alarmed before the leak grows larger.

Modern plants operate by a programmable logic controller (PLC) that offer information on the circuit(s) and the various systems inside the pressurization plant. These various systems may be alarmed too. A PLC can provide remote access to the controls in the pressurization plant for a faster response time to an alarm.

The reliability of the cable is no higher than the reliability of the pressurization plant. Pressurizing plants shall remain powered at all time. Two independent sources of power to the pressurization are required with an automatic transfer of power to ensure continuous AC feed to the pressurization plant. The second power source can be a backup generator, dedicated off site power line, or an alternate bus source.

7.11 A crossover cabinet 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. If the cable circuit requires an additional pressurization plant, the crossover cabinet may be replaced by the additional pressurization plant.

7.12 Testing

Testing pipe type transmission cables and accessories is vital for qualifying cable and cable components for design, installation verification, qualification/acceptance and operations and maintenance purposes.

Test standards and procedures developed for pipe-type cable by organizations such as the Association of Edison Illuminating Companies (AEIC), the Insulated Conductors Committee (ICC) of the IEEE, the International Electrotechnical Commission (IEC), and the Insulated Cable Engineers Association (ICEA) should be referenced and applied to the Pipe cable system.

The testing of high voltage pipe type cable is highly specialized requiring skilled engineering, technicians and equipment.

The EPRI Green Book dedicates an entire chapter to cable testing which describes the principles of cable and accessory testing, summarizes the applicable standards, guides, and procedures that are commonly accepted by the cable industry. It addresses specific test procedures, laboratories, equipment for ac, impulse, dc, thermomechanical tests, and describes diagnostic procedures employed in the laboratory and in the field.

Any Designated Entity that proposes to install transmission pipe cable shall demonstrate the requisite knowledge needed to ensure proper design, reliability, operation and maintenance of the cable system.

7.13 Dynamic Line Rating is a microprocessor based real time data acquisition and computing system. It repeatedly measures independent variables along the line and within auxiliary equipment (pressurization plant, high speed circulation system or heat exchanger) that define the thermal state of the cable and uses this information to calculate real time cable ratings. If Dynamic Line Rating (DLR) is considered in the design, the design shall consider the operation and maintenance needs to maintain this system.

7.14 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 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 if it is not alarmed. [look at 5/8/2017 item 4B planning committee document from substation group to assess what they wrote].

Comment [P11]: Nothing in substation text regarding inspections/O&M