3.0) TRANSMISSION LINES MINIMUM REQUIRED STANDARDS – LINES

3.2 Underground Lines

[below sections will be renumbered at a later date]

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. Definitions for underground design terminology can be found in the "PJM Underground & Submarine Transmission Cable Rating Methodology Guidelines

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.

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 shall 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 spare conduits and/or spare pipes shall be considered for installations at major crossings, 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 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 (includes HPFF and HPGF cable types).

5.5.2 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 paper-polypropylene-paper (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 ASTM A523, "Standard for Plain End Seamless and Electric-Resistance-Welded Steel Pipe for High Pressure Pipe Type Cable Circuits."

5.5.4 ASTM A312/A312M, "Standard Specification for Seamless, Welded and Heavily Cold Worked Austenitic Stainless Steel Pipes."

5.5.5 AEIC CS31, "Specification for Electrically Insulating Pipe Filling Liquids for High-Pressure Pipe-Type Cable."

5.5.6 NACE Standard SP0169, "Control of External Corrosion on Underground or Submerged Metallic Piping Systems."

Solid Dielectric Cable Systems

5.5.6 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 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 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 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 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."

6.0 DESIGN PARAMETERS

6.1 ROUTING

6.1.1 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. 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 facilities and their depth to be crossed
12. Jack & bore or Horizontal Directional Drilling (HDD) options and potential frac-out releases
13. Changes in elevation
14. Sources of thermal energy such as other circuits, steam mains
15. Permitting timelines
16. Soil types
17. Soil thermal resistivity
18. Pulling calculations and maximum reel lengths
19. Manhole and splice locations
20. 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 Cable ampacity calculations shall be performed for two conditions, normal (steady-state) and emergency, 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.

6.2.4, Corrective thermal backfill materials 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 an underground cable system 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 final thermal ratings. A comprehensive review of the cables installation data must be performed in order to determine its actual verses design 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.

6.2.6 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.

6.2.7 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).

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.

7.2 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. .

7.3 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). Together the coating system and cathodic protection system protect the integrity of steel pipes and minimize leaks.

7.4 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.

7.5 Pipe type cables are impregnated with insulating fluid under vacuum and high temperature at the factory. Only HPFF use insulating fluids after cable installation. Insulation fluids shall meet 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 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.

7.6 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.

7.7 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. Cable terminations shall be selected based on hydraulic calculations for the operating pressure per IEEE Std. 48 for class 1C terminations.

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 or exceed the cable rating.

7.8 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. Insulation fluid can be shuttled 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.

7.9 A crossover cabinet shall be 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.

7.10 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.

8.0 Solid Dielectric Cable Considerations

8.1 Extruded dielectric cable systems 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.

8.2 A metallic moisture barrier or sheath, such as 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 The metallic shield and sheath shall be grounded or bonded to the local ground, using either 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 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.

8.8 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

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

8.10 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.

8.16 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.

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

8.18 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.