DISCUSSION OF CROSS-LINKED POLYETHYLENE INSULATED CABLES FOR UNDERGROUND PORTIONS OF THE MIDDLETOWN-NORWALK 345 kV PROJECTS

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1. EXECUTIVE SUMMARY

CL&P and UI (the companies) are evaluating the use of cross-linked polyethylene insulated cables (XLPE cables) on the underground portions of the Middletown-Norwalk 345 kV project. As part of their evaluation, the companies performed an in-depth review of 11 of the world's premier 345 kV XLPE cable manufacturers. The companies have determined that XLPE cable systems may provide advantages over high pressure fluid-filed cable systems (HPFF-cables). These advantages include:

- Lower capacitance resulting in lower steady-state charging current and a correspondingly lower risk of high transient and temporary overvoltages.
- Higher load carrying capability.
- Ability to splice cables in discontinuous shifts which would permit cable splicing to occur during periods of low traffic.
- Absence of insulating fluids which eliminates the potential for a release.
- Lower losses.
- Lower maintenance costs.

In certain instances, the companies believe that these benefits outweigh the disadvantages of XLPE cable systems:

- Higher levels of EMF
- Higher costs
- Appreciably fewer years operating experience of extra high voltage (300 kV and above)

2. INTRODUCTION

CL&P and UI (the Companies) are evaluating the installation of XLPE-insulated cables for the approximately 24 miles of double-line 345-kV underground transmission lines on the Middletown-Norwalk (M-N) project. This is a change from the cable system originally proposed for the underground sections of the project. Since the conceptual design of the M-N Project, the Companies performed an extensive review of potential 345-kV XLPE cable suppliers as part of the prequalification of bidders for the 2.1 mile length of 345-kV XLPE cable system for the Bethel to Norwalk project. This review included the companies submitting detailed technical and commercial questionnaires to 11 vendors and then meeting with each vendor to thoroughly discuss each vendor's submittal. The results of this in-depth analysis gave the companies a much better understanding of the maturity of the XLPE cable industry worldwide and provided a great deal of new information on manufacturing quality control processes, raw material and finished product testing and commercial experience.

This document describes in detail the relevant technical and economic considerations that were evaluated.

3. SUMMARY

A summary of the major attributes of the HPFF and XLPF cable system types is provided in Table 1. The remaining sections of this document describe these items in more detail.

Table 1 – Summary Comparison, HPFF vs XLPE Cable System
15.5-mile Singer-Norwalk Line Used for Comparison*

Item	HPFF	XLPE
SYSTEM CONSIDERATIONS		
Capacitance, microfarads/mile/phase	0.461 uf/mi/ph	0.269 uf/mi/ph
Charging current, amperes/mile	34.6 A/mi	20.8 A/mi
Reactive power, MVAR/mile	20.7 MVAR/mi	12.4 MVAR/mi
MVA transfer, each line, typical conditions	633 MVA	825 MVA
MW transfer 15.5 mile line, all charging current flow from one end	546 MW	802 MW
12-hr emergency rating, MVA each line, assuming preload current 70% of rating	1000 MVA	1140 MVA
12-hr emergency rating, MVA each line, assuming preload 70% of 633 MVA	1000 MVA	1190 MVA
INSTALLATION CONSIDERATIONS		
Trench dimensions, width by Depth, inches (assuming 36 inches to top of envelope)	48"W x 64"D	46"W x 63"D
Typical progression rate for pipe or duct, trench feet per day	200	200
Ease of maneuvering around buried obstacles	Difficult	Difficult
Typical vault spacings	2600 ft	1800 ft
Number of vaults for a 15.5-mi line (XLPE can be reduced if 2 lines are in one vault)	32	96
Typical time to make a 3-phase splice, working around the clock	7 days	7 days
Splicing	Continuous	May be 15 10-hour shifts
Number of manufacturers worldwide, meeting the Companies' prequalification requirements	3	4-6
Substation Terminations	same	same
Pressurization plants required at termination	Yes	No
OPERATION AND MAINTENANCE		
Typical maintenance requirements, mandays/year (Rough estimate)	40	10
Time to locate an electrical fault	16-32 hours	16-32 hours
Expected cable damage in event of electrical fault	Large	Small
Able to work on a failed circuit with companion in service?	Yes	Possibly
Time to locate a fluid leak	2 hrs – 2 + weeks	N/A
OPERATING EXPERIENCE		
Number of years operating history, 300 kV and higher	40 yrs	7 yrs
Approximate total number of circuit miles in service, 300 kV and higher	400 mi est	100 mi est
Expected forced outage rate, two 15.5-mile lines, outages in 40 years.	6	20
Expected outage duration, repair failed cable	30 days	21 days
ENVIRONMENTAL CONSIDERATIONS		
Magnetic field for 15GW case MVA/line, 1m height, max level	3.3 mG	28 MG
Magnetic field for 15 GW case, 1 m height, 25-ft from trench centerline	0.23 mG	7 mG
Dielectric fluid, 15.5-mile line, two cable pipes and two return pipes	440,000 gal	N/A

*The parameters listed in this table are for the same cable sizes as proposed in the M-N application, i.e., 2,500 kcmil copper HPFF cable and 3,000 kcmil copper XLPE cable.

4. SYSTEM CONSIDERATIONS

The capacitance of XLPE cable is less than 60% of the capacitance of HPFF cables. This has several major advantages.

- Lower capacitance reduces the voltage variation that occurs when the cable is switched into or out of service.
- Lower capacitance reduces the need for shunt reactors.
- Lower capacitance reduces the losses caused by charging current flowing in the cable.
- Lower capacitance reduces the impacts that cables have on transient and temporary overvoltages during system disturbances.

Extra high voltage (EHV) XLPE-insulated cables have advantages in power transfer, as summarized in Table 1. Not only is the ampacity higher, but the MW transfer is much higher since XLPE cables have a lower charging current.

The 12-hour emergency rating is also much higher than that for a HPFF cable. Table 1 shows the 12-hr emergency rating for a preload current equal to 70% of the continuous current rating, which is the criterion established by NU. When each cable system is pre-loaded to 70% of its continuous current rating, XLPE cable has a 1140 MVA rating, versus 1000 MVA for a HPFF cable system. However, if we establish the preload to be 70 percent of the HPFF steady-state rating for both cases, the XLPE's 12-hr emergency rating increases to 1190 MVA.

The electrical losses on a 345-kV HPFF cable are much higher than those for XLPE-insulated cables – especially dielectric losses, charging current losses, and losses in the compensation equipment. All of those losses operate at 100 percent load factor. The lifetime cost of losses for a HPFF cable system will therefore be much higher than for a XLPE-insulated cable system.

XLPE-insulated cables may have advantages in system restoration especially if pressure is lost on a HPFF system as would be the case following an extended system-wide outage. A few days may be required to repressurize, bleed evolved gas from the terminations, and let the cable "soak" at full pressure before re-energizing to insure any evolved gas has re-dissolved into the dielectric liquid. If there is a system-wide outage, re-energizing the system is further complicated if power to the pumphouse is lost. An XLPE-insulated cable can be re-energized immediately.

5. INSTALLATION CONSIDERATIONS

Significant portions of the cable system will be located in heavily-traveled state roads in Southwest Connecticut. The Connecticut Department of Transportation objects to closing down lanes during the high traffic times of the day. Also, the density of buildings and available land along the route make it very unlikely that all vaults can be located outside the traveled portion of the road. Splicing three phases of 345 kV HPFF cable takes a week with continuous splicing (24 hours a day). XLPE cable has the significant advantage that it does not have to be spliced in one continuous operation.

Manufacturers have indicated that it is feasible to splice XLPE cables in 8-12 hour shifts, and "button-up" the cables satisfactorily until splicing resumes the next day (assuming the splicers are permitted to complete complex operations and wrap waterproofing tape around the assembly.) It is feasible to interrupt the splicing process because the polymeric materials of XLPE cables do not absorb moisture as do the paper insulation of HPFF cables.

Splicing must take place around-the-clock for 345-kV HPFF cables because any amount of moisture absorbed in the paper will degrade the insulation and possibly lead to electrical failures. This makes it impossible to reliably splice HPFF cables in busy traffic areas if the streets cannot be blocked for 24 hours a day.

The rate at which HPFF cables can be installed in pipes vs. XLPE-insulated cables in ducts is similar. Bending radii of both cable types are similar so the ability to maneuver around obstacles is similar and trench dimensions are similar.

XLPE-insulated cables require larger splicing vaults – thirty feet long versus eighteen feet for HPFF cables. Also, with current practices three times as many vaults are needed for XLPE-insulated cables because of shorter vault-to-vault lengths (three per mile versus two per mile) driven by the amount of cable that may be placed on a cable reel and the safety concerns with having two XLPE circuits in a common vault. This latter restriction could be lifted if NU is successful in demonstrating the feasibility of providing barriers or other protective methods which protect the employee and provide the necessary system reliability if two circuits are installed in a common vault.

HPFF cables are more suitable for installing in long directional drills because of the smaller bore diameter and the lower coefficient of friction. However, the companies learned that J-Power (Sumitomo) has recently installed a 3500-ft length of 5000-kcmil conductor, 230-kV XLPE-insulated cable in a directional drill beneath the Mississippi River.

6. POTENTIAL ENVIRONMENTAL CONSIDERATIONS

Fluid leaks on a properly protected HPFF cable systems are unlikely, but a leak could release a significant quantity of dielectric fluid into the environment. Expensive and maintenance-intensive leak detection systems can be added to pressurizing plants to reduce the amount of fluid lost before a leak is detected – but a major pipe breach such as a dig-in can still result in thousands of gallons of insulating fluid loss. XLPE-insulated cables have virtually no dielectric liquid, except perhaps for a small amount in the terminations.

Both HPFF and XLPE cables produce magnetic fields. HPFF cables produce significantly lower fields because the conductors are closer together and the conductors are contained in a steel pipe.

7. OPERATION AND MAINTENANCE

HPFF cable systems require significantly more maintenance than do XLPE cable systems, principally because of the pressurizing plants that require weekly inspection and annual maintenance, in addition to possible repair of pressurization plant components. Maintaining the corrosion coating and cathodic protection system is critical in providing a leak-free system.

Historically HPFF termination failures have occurred when the pressure surge from a cable failure caused damage to the closest termination. This obviously is not a problem with XLPE cable systems.

8. OPERATING EXPERIENCE

In the United States, HPFF cable has been used at 300 kV or above for forty years. HPFF cable has not been used widely outside the U.S. XLPE cable, rated 300 kV and above, has been installed in varying lengths in Europe, the Middle and Far East. The first extra high voltage XLPE installation occurred approximately seven years ago.

Because HPFF cable was used almost exclusively for 230 and 345-kV underground installations in the United States, extensive failure rate data exists for HPPF cable systems. Based on cable consultant's, Cable Consulting International (CCI) data base, CCI predicts that the Applicants could experience six electrical cable and splice failures for the two 15.5 mile underground 345-kV circuits between Singer and Norwalk substations over a 40 year period. The Applicants could experience four electrical cable and splice failures for the two 8.2 mile underground 345-kV circuits between East Devon and Singer substations over that same 40 year period. .

Because virtually all XLPE cable rated 300 kV and above has been installed outside North America, cable failure data is not easily accessible or as reliable as data on cable performance in North America. CCI provided testimony earlier in Docket 272 which predicted that we would experience up to 30 outages in forty years. CCI's data included failures that could occur during commissioning, potential problems found during commissioning partial discharge testing and non-electrical forced outages (e.g., dig-ups). Also, CCI's data did not include 2004 cable performance data which we believe would reduce the XLPE failure rate further from that provided the Connecticut Siting Council in 2002 and again in 2004.

The Companies were able to gain an additional perspective on the reliability of XLPE cable systems during the process of evaluating eleven potential cable manufacturers for the 345 kV XLPE cable system being installed on the Bethel-Norwalk project. Assisting NU in this evaluation were multiple cable consultants with extensive expertise in both fluid filled and solid dielectric cable systems. This extensive evaluation included detailed meetings with each cable manufacturer to analyze their cable manufacturing and splice technology, testing, quality control processes, and installation methods. It was the consensus of the review team that there have been significant improvements made in both the manufacturing and installation of XLPE cable systems and that world-wide there appear to be manufacturers that have the capability to produce and install 345-kV XLPE cable that may be almost as reliable as 345-kV HPFF cable. The Companies believe that the risk associated with using XLPE cable systems can be further reduced by the employment of rigorous cable specifications, closely monitoring the origin, shipping and handling of the raw materials used to manufacture the cable, monitoring the cable manufacturing processes and factory testing, witnessing rigorous cable installation commissioning tests and where appropriate, outsourcing the cable systems to multiple cable manufacturers.