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To: Stephen G. Whitley, Senior Vice President & Chief Operating Officer

From: Peter T. Brandien

Re: **Discussion of Cable Technologies Under Evaluation for use in the Southwest Connecticut 345 kV Transmission Project**

Date: March 14, 2005

Summary and Conclusion

The Southwest Connecticut 345 kV Project will require the installation of Extra High Voltage cables (EHV). The debate is whether to utilize a proven reliable technology, High Pressure Fluid Filled cables (HPFF), or the developing technology, Cross-Linked Polyethylene cables (XLPE). XLPE cables are an appropriate alternative due to the lower capacitance, higher current carrying capability, easier installation techniques, and the reduced environmental exposure as compared to a fluid filled cable system such as HPFF cable.

Based on our examination of the data entered into the Southwest Connecticut 345 kV siting process, information gathered by ISO-NE in the administration of the Bethel-Norwalk 345 kV Project RFP, review of various white papers on the subject of underground cable, and consultation with cable experts we believe that either technology can be installed and operated reliably.

In order to ensure that reliability can be maintained for XLPE cable installations we would strongly recommend the following:

1. Installation of two cables per phase.
2. Use the same spec and vendor for the cable and the splice.

3. Utilize duct bank installation rather than direct buried in urban areas.
4. At minimum, provide spare conduit in the duct bank for future additions and/or replacement should there be a single cable failure.
5. To minimize induced voltages in parallel cables or the cable sheath utilize "cross bonding" techniques.
6. Acceptance testing should include a test with the cable and splice as a "system."

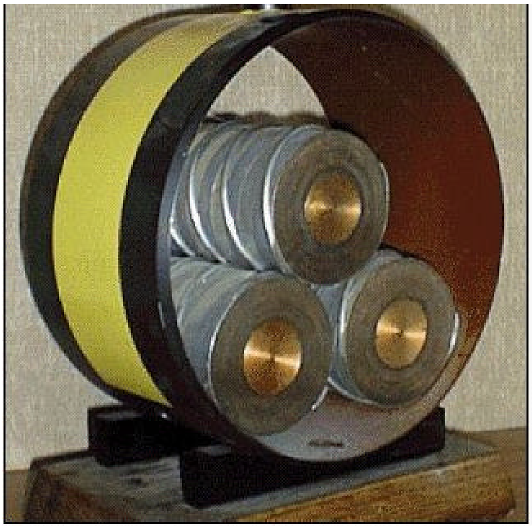
Background

The technology of Extra High Voltage cables, EHV, is at a crossroads. The industry is moving away from High Pressure Fluid Filled cables (HPFF), in favor of solid dielectric cables, i.e. Cross-Linked Polyethylene cables (XLPE). This is especially true for voltages 400 kV and below. Correspondingly, the number of manufacturers of HPFF cables has dropped due to mergers, acquisitions and the shift to alternate cable technologies.

Over the last 10-15 years, XLPE cables have advanced to the point where the cable can be manufactured without voids or impurities, which previously had lead to premature cable failures due to high electrical stresses within the cable. In addition, the splicing and cable terminations have also seen advances. Although there are few XLPE cable systems above 300 kV, cable experts are cautiously optimistic that with proper engineering and installation methods a reliable EHV XLPE cable system can be implemented.

Cable Types Considered for the Bethel-Norwalk Project

Two types of Extra High Voltage Cables (EHV) cables were evaluated for use in the Southwest Connecticut 345 kV Bethel-Norwalk (Phase I) transmission project, High Pressure Fluid Filled (HPFF), Cables and Cross-Linked Polyethylene (XLPE), Cables.



Three-Phase High Pressure Fluid Filled, (HPFF)   Single Phase Cross-Linked Polyethylene, (XLPE)

High Pressure Fluid Filled Cables

Historically, the predominant EHV cable technology installed in North America has been the HPFF cables. The fluid in the cables initially was a blend of mineral oils, and therefore the cables were referred to as oil filled (OF). Today synthetic fluids are used and the cables are more commonly referred to as fluid filled (FF) cables. HPFF cables in the 200 kV to 275 kV range have been around since late 1950's. These cables used a paper tape insulation protected by a spiral skid wire insulated with a hydrocarbon insulating fluid, all three phases housed inside a steel pipe of adequate size. The coated steel pipes are installed at site first, tested and cables pulled inside the pipe system normally with all three phases in trefoil formation. The pipes are protected against corrosion by providing cathodic protection. Higher operating capability (temperature) is achieved by re-circulation or forced cooling of the fluid in the pipe by adding a return fluid pipe in parallel to the conductor pipes with oil circulation system and cooling system. These systems are provided at the terminals or intermittently along the routes.

In the late 1980's alternatives to paper insulation was introduced, polypropylene paper laminate (PPL). PPL is a laminate comprising a thin layer of polypropylene tape sandwiched between two layers of paper tape and can be applied using existing manufacturing methods. The advantage of PPL insulation is that it can operate at higher temperatures than the traditional paper insulated cable, i.e. greater current carrying capability. Since the mid-1980's EHV HPFF cables have been considered highly reliable following 20-30 years of refining the manufacturing and installation methods.

The fluid in the HPFF cable system is an integral part of the cable electrical insulation. The system must be maintained under pressure, approximately 250#, to ensure that the oil impregnates the paper insulation. One of the concerns raised about the use of HPFF cables is the release of the insulating fluid to the environment. Most of the time this is caused by a breach of the pipe from a third party dig-up. Since the cable is under pressure a significant amount of fluid can be released before the leak can be isolated.

Cross-Linked Polyethylene Cable

The cable technology has advance through the years with the development of the XLPE cable. XLPE is an extruded dielectric cable that was first commercially introduced in the early 1960's. Throughout the 1970's and 1980's, Europe and Japan continued to develop and install XLPE technology for use at voltages above 138 kV. By the late 1970's, both Europe and Japan had installed XLPE cable (w/o splices) for 230 kV and 275 kV respectively. By the late 1980's both Europe and Japan had cable systems (w/splices) installed for 245 kV and 275 kV.

There are many XLPE cable installations world wide, but they have relatively limited in-service experience at these voltage levels and for lengths over 1000 meters. However, XLPE cable offers faster and easier installation compared to other cable types as well as less downtime for repair and maintenance.

The materials used and the methods of manufacturing XLPE cables along with the design, manufacturing methods and materials used for the splices and cable terminations differ significantly amongst manufacturers. The reliability of the XLPE systems installed to date has only been achieved as a result of intensive involvement of the utility at all stages of the project; design, manufacturing, testing, installation, commissioning and in-service monitoring.

XLPE cable systems can be directly buried or installed in a duct bank. Direct buried, these cable systems have a 10 – 15% greater ampacity than the same cable system installed in a duct bank, as there is no dead air space to impede heat transfer. HPFF cables are typically rated for continuous operation at a conductor temperature of 85°C. Whereas, XLPE cables are typically rated for continuous operation at a conductor temperature of 90°C.

The method of manufacturing XLPE doesn't allow inspection during the extrusion process. Whereas, HPFF cables are wrapped with PPL tape which can be observed/inspected during the manufacturing process, the XLPE cables extrusion and cross linking processes take place in a fully encased processing plant in which the cable is not visible but continuously monitored for quality control. The black core screen of the emerging cable similarly prevents visual examination. The integrity of the cable dielectric is also checked automatically during the manufacturing process. Specially the cross linking of the PVC sheath which is done by a radiation method which highly improves the cable dielectric qualities.

The splicing of any cable system, particularly XLPE cables, tends to be the most unreliable components of the entire system. Since EHV XLPE cables are relatively new, the splicing designs are only standardized between various manufacturers. Cable experts are cautiously optimistic about the reliability of EHV XLPE cable systems. They believe that XLPE cables can be manufactured reliably and that, particularly with proper engineering in design of the splices, longer lengths of EHV XLPE cable systems can be installed and operated reliably.

Comparison of HPFF vs. XLPE

	High Pressure Fluid Filled, (HPFF)	**Cross-Linked Polyethylene, (XLPE)**
Design/Manufacturing	• Proven Reliable – Over 30 years experience at these voltage levels • Fewer Manufacturers as Industry moves toward XLPE	• Improving design/manufacturing techniques • Direction the Industry Heading • Limited in-service experience at 345 kV
Installation	• Mature installation techniques • Greater Availability of experienced personnel • Continuous Piping	• Duct or Direct Burial • Limited Experience Splicing at Higher Voltages 345 kV • Availability of Skilled

	System Between Terminals	Craftsman • Best Practice – Installation of Partial Discharge Monitors for Each Splice
Operation & Maintenance	• Higher Capacitance - More Reactive Compensation Required • Lower Operating Temperature, Reduces Current Carrying Capability • More Auxiliary Equipment (Cable Fluid/Pressurization System, Piping Cathodic Protection)	• Lower Capacitance • Higher Operating Temperature – May Eliminate 345 kV Series Reactor Required for Line Out Conditions • Cautiously Optimistic About Going Forward Reliability • Operating temperature can he continuously monitored by sensors
Environmental Impact	• Fluid Filled • Usually installed as 3-phases in one pipe, which cancels out the EMF.	• Solid Core • Usually installed as a single-phase in each conduit creating the potential for EMF problems.

Reliability

Consideration of fault rates of both XLPE and HPFF cable is necessary to assess projected reliability. ISO-NE reviewed testimony and white papers provided to the Connecticut Siting Council (CSC), as well as consulted with various cable experts on the reliability of both HPFF and XLPE cable technologies. Evaluation considered the cable manufacturing processes, splice technology, quality control processes and testing, as well as installation methods.

Information in Docket 272 showed fault rates for three-phase 345-kV cable, expressed as number of events per year, per 100 miles of single phase cables as follows:

Cable Type	Actual (per 100 miles of cable per year)
HPFF in steel pipe	0.5
XLPE in Duct - Optimistic	0.64
XLPE in Duct - Realistic	2.02
XLPE in Duct - Pessimistic	9.93

While HPFF may be slightly more reliable than XLPE, both cable types can be operated reliably.

References

Gregory, B., Notman, D., and Lloyd, S., Cable Consulting International Ltd, "A Review of 200 kV and Above XLPE Cable System in Commercial Operation Throughout the World", Engineering Report 117, December 22, 2001

Forrest, D.W., and Mosier, R.I., Northeast Utilities Service Company, "Discussion of Cross-Linked Polyethylene Insulated Cable for Underground Portions of the Middletown-Norwalk 345 kV Projects", December 20, 2004

Connecticut Siting Council, "Docket 272 Updated 345-KV Fault Rate Calculations", January 14, 2005

Public Service Commission, State of Wisconsin, "Underground electric Transmission Lines", August 2004

Wilson, C., Energy Initiatives Group, *draft* "White Paper For High-Voltage Alternating-Current Cable System Projects", January 2004

PTI Seminar in Underground Cable Technologies, March 2004