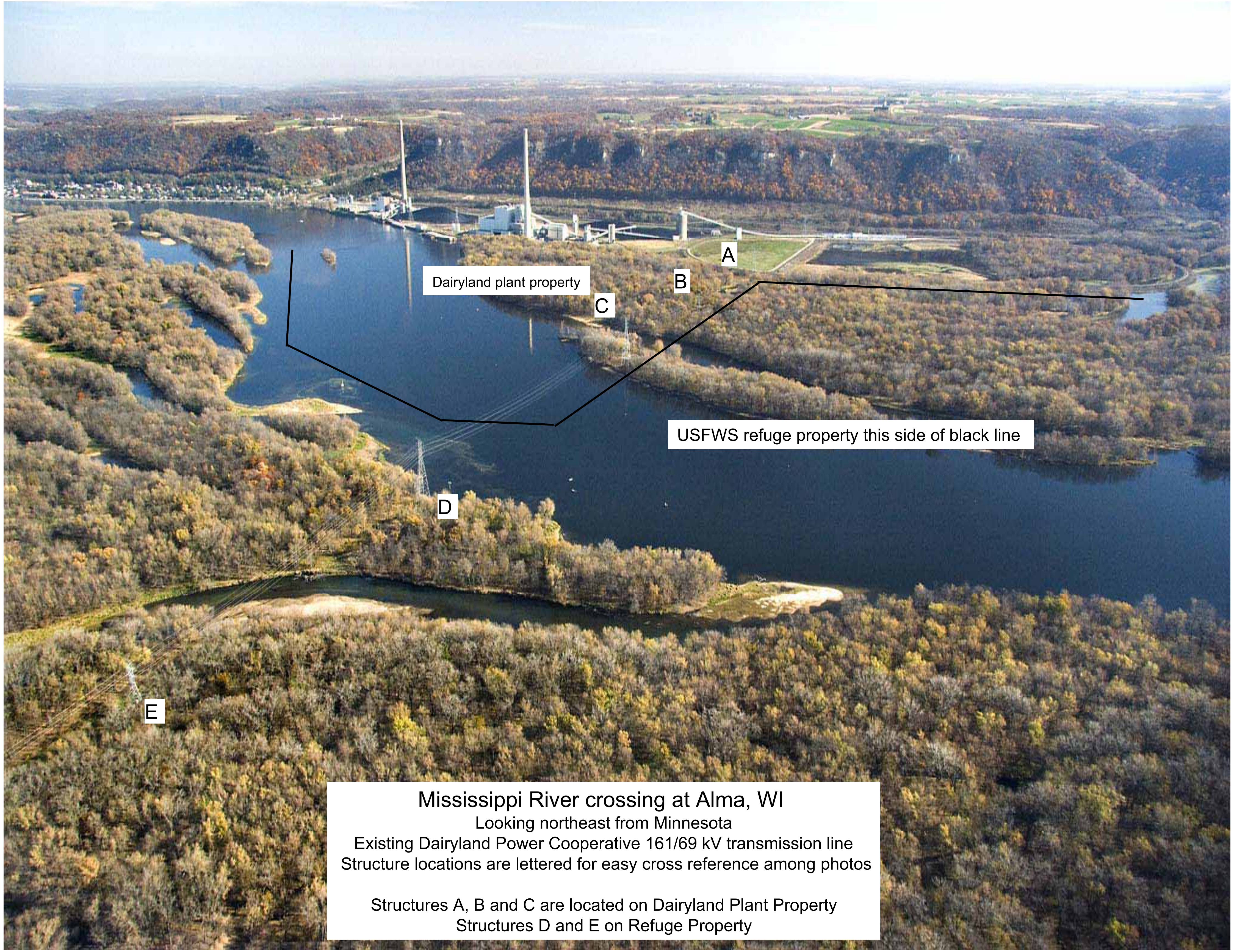
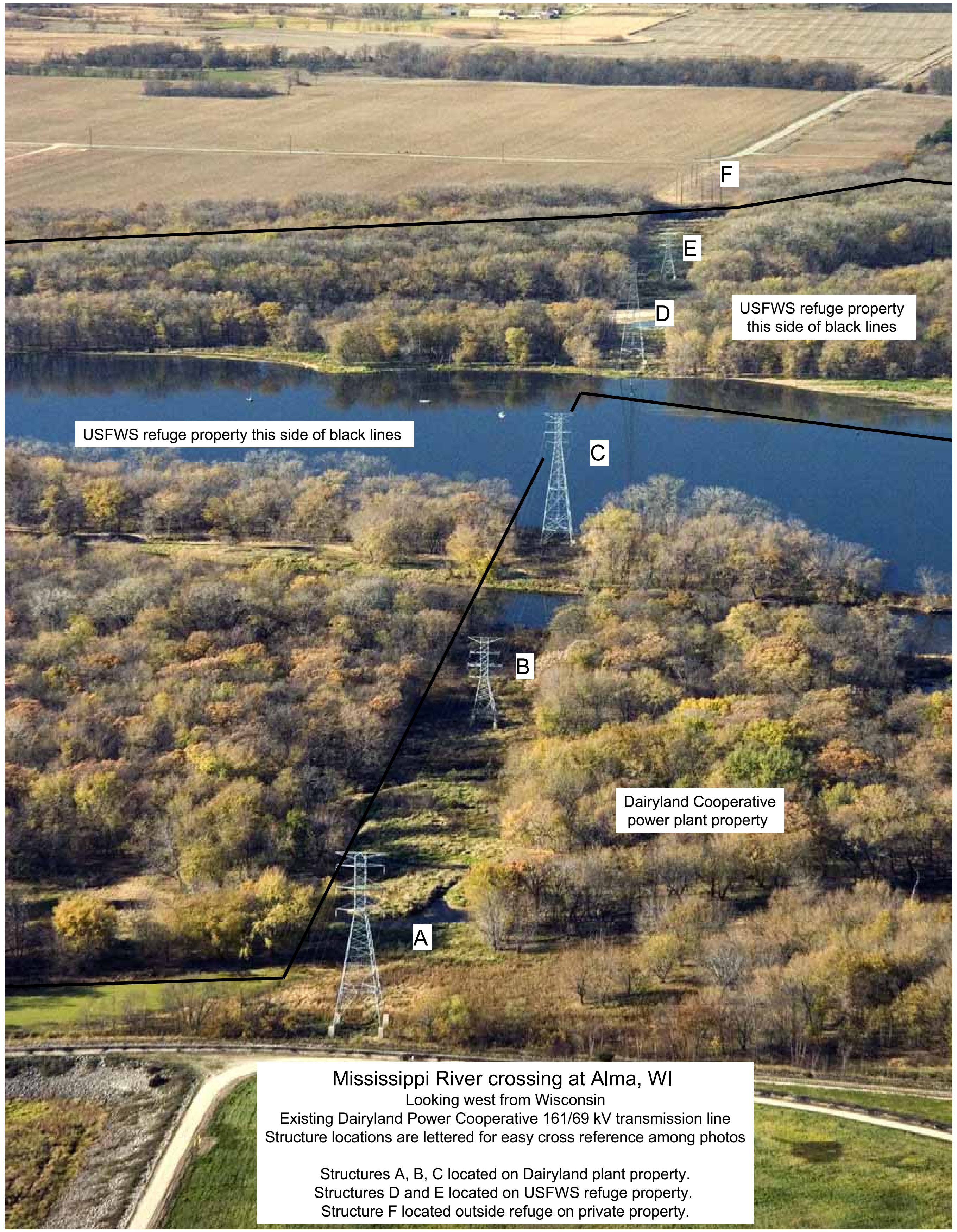
Appendix D is a reprint of Appendices E1, E2, and E3 from the applicant's January 2010 Route Permit Application (RPA). RPA Appendix E1 contains photos of existing transmission line crossings at Alma, Winona and La Crescent. RPA Appendix E2 describes the Mississippi River crossing design options at Alma (referred to in the Draft EIS as the Kellogg crossing). RPA Appendix E3 provides a detailed underground feasibility analysis for the Kellogg crossing.

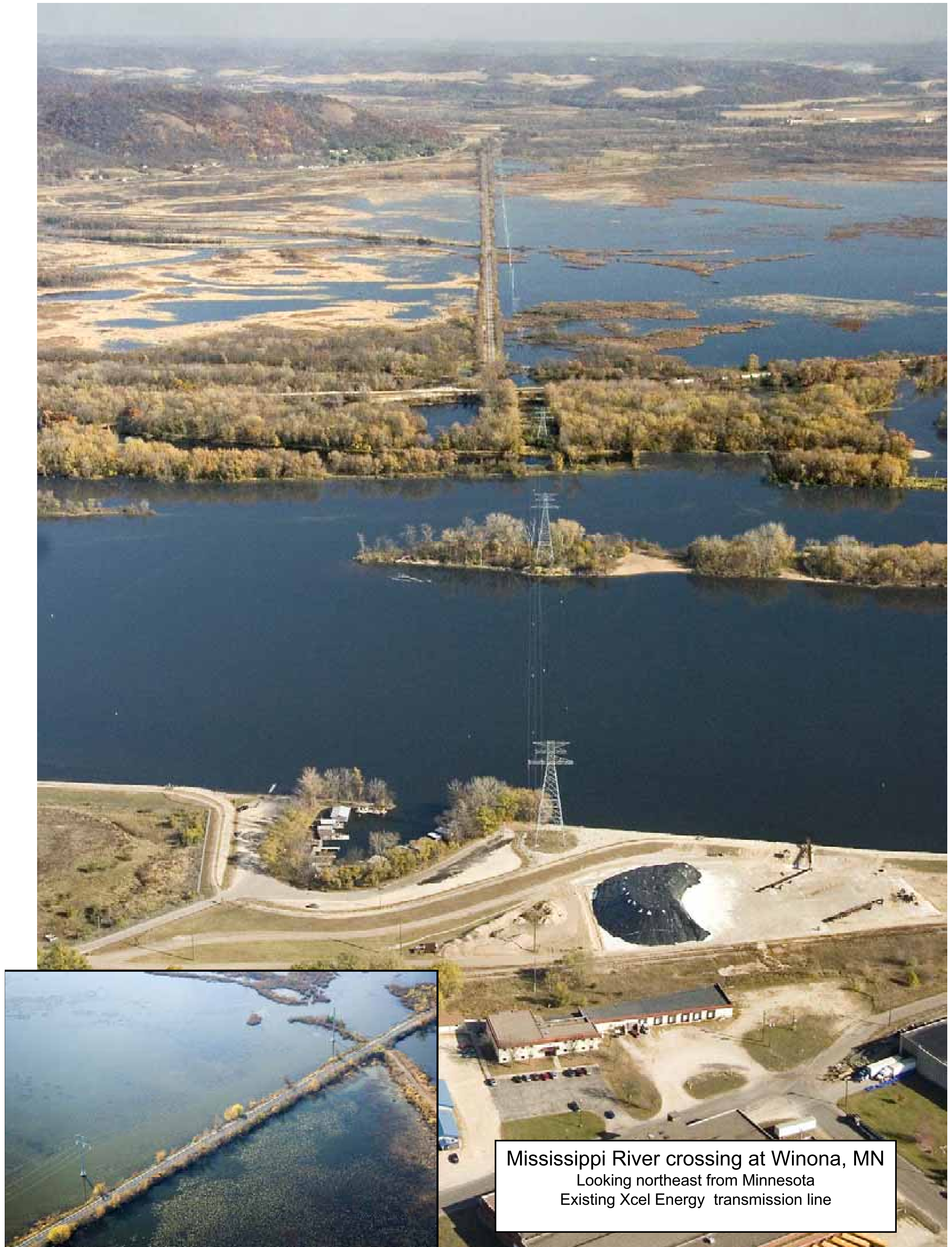

Mississippi River Crossing at Alma, WI
Existing Dairyland 161/69 kV transmission line pole locations are lettered for easy cross reference among photos

Green shading is an approximation of lands owned/managed by the US Fish and Wildlife Service National Wildlife Refuge


Dairyland plant property
A
B
C
D
E
USFWS refuge property this side of black line
Mississippi River crossing at Alma, WI
Looking northeast from Minnesota
Existing Dairyland Power Cooperative 161/69 kV transmission line
Structure locations are lettered for easy cross reference among photos
Structures A, B and C are located on Dairyland Plant Property
Structures D and E on Refuge Property


F
E
D
USFWS refuge property
this side of black lines
USFWS refuge property this side of black lines
C
B
Dairyland Cooperative
power plant property
A
Mississippi River crossing at Alma, WI
Looking west from Wisconsin
Existing Dairyland Power Cooperative 161/69 kV transmission line
Structure locations are lettered for easy cross reference among photos
Structures A, B, C located on Dairyland plant property.
Structures D and E located on USFWS refuge property.
Structure F located outside refuge on private property.

Legend
Existing 100ft River Crossing Right-of-Way
Existing Transmission Network
(HDR, WI PSC)
Substation
Generation Facility
69 kV Transmission Line
161 kV Transmission Line
Jurisdiction
(WIDNR)
U.S. Fish and Wildlife Service
0
2,000
Feet
1:12,000
1 inch equals 1,000 feet when printed at 22x34
Existing Permitted
Right of Way Width
100 ft.
Floodplain Width
3.2 miles
River Channel
Width
2,650 ft.
Trempealeau
National
Wildlife Refuge
Upper Mississippi River
National Wildlife
and Fish Refuge
BUFFALO
WINONA
TREMPEALEAU
MARSHLAND
EAST
WINONA
COMMUNITY
MEMORIAL
HOSPITAL
Great River Rd
Bluff Siding Rd
Thomas Rd
Sommers Rd
State Road 35/54
35
43
Sarnia St
Mark St
Shive Rd
Frontenac Dr
Parks Ave
CapX2020
Hampton • Rochester • La Crosse 345 kV Transmission Project
Xcel Energy • Dairyland Power Cooperative • Rochester Public Utilities • WPPI • Southern Minnesota Municipal Power Agency
Winona
Potential Crossing Area



Mississippi River crossing at Winona, MN
Looking northeast from Minnesota
Existing Xcel Energy transmission line


Legend
Existing 100ft River Crossing Right-of-Way
Existing Transmission Network
(HDR, WI PSC)
Substation
Generation Facility
69 kV Transmission Line
161 kV Transmission Line
Jurisdiction
(WIDNR)
U.S. Fish and Wildlife Service
0 2,000 Feet
River Channel Width 730 ft.
Existing Permitted Right of Way Width 100 ft.
River Channel Width - 1,150 ft.
Floodplain Width 2.5 miles (following existing ROW)
Upper Mississippi River National Wildlife and Fish Refuge
Upper Mississippi River National Wildlife and Fish Refuge
LACRESCENT
La Crescent
FRENCH ISLAND
French Island
LACROSSE
STATEWIDE HABITAT AREAS
ST FRANCIS MEDICAL CENTER
La Crosse
WINONA
HOUSTON
LA CROSSE
HOUSTON
CapX2020
Hampton • Rochester • La Crosse 345 kV Transmission Project
Xcel Energy • Dairyland Power Cooperative • Rochester Public Utilities • WPPI • Southern Minnesota Municipal Power Agency
La Crosse
Potential Crossing Area


US Highway 61
Railroad
Existing transmission line (approximated with black line)
Mississippi River crossing at La Crescent, MN
Looking east from Minnesota
Existing Xcel Energy transmission line

Mississippi River crossing at La Crescent, MN
Main channel looking northeast from Minnesota
Existing Xcel Energy transmission line

## Appendix E2:

## Mississippi River Crossing Design Dra  ings

The Mississippi River presents unique considerations that will require the use of multiple-circuit, specialty structures. A portion of this crossing is on Upper Mississippi River Wildlife Refuge (Refuge) lands managed by the U.S. Fish and Wildlife Service (USFWS). A Special Use Permit will be required to cross the Refuge and the Applicant will work closely with the USFWS to identify the most appropriate structure design.

An existing double-circuit transmission line crosses the Mississippi River and Refuge at the Project's proposed crossing location. The existing line crosses approximately 0.5 mile of Refuge lands and includes two structures on refuge property. The line is constructed on a 180-foot-wide permitted ROW. An area approximately 125 feet wide and 1,900 feet long is maintained cleared of trees. The two main river crossing structures are 180 feet tall.

Several possible designs for the proposed river crossing are described in this appendix. The design options demonstrate tradeoffs between structure height and easement width while maintaining only three structures on refuge lands. Minimum conductor clearance over the Mississippi River main channel in all instances is approximately 90 feet, per by US Army Corps of Engineers requirements.

- Option A: A design that stays within the existing 125-foot wide tree clearing. However, this results in main channel crossing structures of 275 feet in height. The Federal Aviation Administration (FAA) requires lighting of poles exceeding 200 feet above ground level, and may also require poles to be painted alternating red and white.
- Option B: The shortest possible pole design with horizontal circuit configuration. This keeps the main channel crossing structures less than 200 feet tall, avoiding FAA lighting requirements and keeps all the conductors in one plane, which is often preferred by those who are concerned about bird impacts. This design requires a 280-foot cleared ROW.
- Options C and D: A combination of options A and B keeps main channel crossing structures of less than 200 feet while using narrower structures elsewhere to minimize the need for additional ROW and tree clearing on refuge lands.

These overhead options are represented in the attached pages through the use of plan view, or aerial photo, drawings. These drawings incorporate black and white aerial photographs, obtained by the Applicant in November 2008, as a background. Numbered black dots represent transmission structure locations. Also noted on each drawing is the right-of-way width required by each option, and a black line with grey cross hatching that represents US Fish and Wildlife Service Upper Mississippi National Wildlife Refuge lands. The oval train tracks at Dairyland Power Cooperative's Alma generating station is at the bottom right. The distance between the western most structure, 1, and the eastern most structure, 9, is approximately 1.5 miles, or slightly wider than the river flood plane in this area. Sketches of the various structure types proposed for each design are inset in the drawings and are numbered and dimensioned. The following tables summarize structure height and right-of-way width for each option.



CapX2020 Minnesota Route Permit – Appendix E2

Table E1:
Option A  Mississippi River Crossing

| tructure | eight feet | Width of Right of Way at tructure feet | Location Comment |
|---|---|---|---|
| 1 | 105 | 125 | Private property |
| 2 | 130 | 125 | Wildlife refuge |
| 3 | 130 | 125 | Wildlife refuge |
| 4 | 275 | 125 | Wildlife refuge; river crossing structure; height triggers FAA lighting requirements |
| 5 | 275 | 125 | Dairyland Power property; river crossing structure; height triggers FAA lighting requirements |
| 6 | 135 | 125 | Dairyland Power property |
| 7 | 195 | 125 | Dairyland Power property |
| 8 | 195 | 125 | Dairyland Power property |
| 9 | 100 | 125 | Private property |

Table E2:
Option   Mississippi River Crossing

| tructure | eight feet | Width of Right of Way at tructure feet | Location Comment |
|---|---|---|---|
| 1 | 60 | 270 | Private property |
| 2 | 85 | 270 | Wildlife refuge |
| 3 | 80 | 270 | Wildlife refuge |
| 4 | 199 | 280 | Wildlife refuge; river crossing structure |
| 5 | 199 | 280 | Dairyland Power property; river crossing structure |
| 6 | 80 | 280 | Dairyland Power property |
| 7 | 140 | 280 | Dairyland Power property |
| 8 | 140 | 280 | Dairyland Power property |
| 9 | 60 | 270 | Private property |

Table E3:
Option C Mississippi River Crossing

| tructure | eight feet | Width of Right of Way at tructure feet | Location Comment |
|---|---|---|---|
| 1 | 105 | 125 | Private property |
| 2 | 130 | 125 | Wildlife refuge |
| 3 | 130 | 125 | Wildlife refuge |
| 4 | 199 | 280 | Wildlife refuge; river crossing structure |
| 5 | 199 | 280 | Dairyland Power property; river crossing structure |
| 6 | 80 | 280 | Dairyland Power property |
| 7 | 140 | 280 | Dairyland Power property |
| 8 | 140 | 280 | Dairyland Power property |
| 9 | 60 | 270 | Private property |

Table E4:
Option D Mississippi River Crossing

| tructure | eight feet | Width of Right of Way at tructure feet | Location Comment |
|---|---|---|---|
| 1 | 105 | 125 | Private property |
| 2 | 130 | 125 | Wildlife refuge |
| 3 | 130 | 125 | Wildlife refuge |
| 4 | 196 | 180 | Wildlife refuge; river crossing structure |
| 5 | 196 | 180 | Dairyland Power property; river crossing structure |
| 6 | 130 | 125 | Dairyland Power property |
| 7 | 195 | 125 | Dairyland Power property |
| 8 | 195 | 125 | Dairyland Power property |
| 9 | 100 | 125 | Private property |





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Appendix E3:

Mississippi River Underground Crossing Feasibility Analysis

Applicant's Conclusions and Comments

The Applicant engaged an engineering firm to determine the feasibility of underground installation for the double circuit 345 kV line at the Alma River Crossing. That analysis is attached.

The length of the underground alternative studied is 1.3 miles and has an estimated cost of $90 million. This is approximately $70 million per mile for underground double circuit 345 kV compared to approximately $2 million per mile for overhead.

Underground transmission cable, especially at high voltages such as 345 kV, is much different than underground distribution cable. Transmission cables are several inches in diameter and must be contained in 10 to 30 inch pipes. Multiple conductors per phase are required. When open trench methods place the conductors close to the surface, they must be encased in concrete to protect them from potential damage.

Based on the engineer's analysis and the Applicant's own experience, the Applicant concluded that undergrounding is not a prudent alternative because there are not benefits that justify a $90 million additional expenditure. The key considerations were aesthetic impacts, avian impacts, cost and reliability.

Overhead and underground alternatives have different aesthetic and avian impacts. However, these impacts can be successfully mitigated with wire marking techniques and appropriate design alternatives. The Project's overhead options consolidate the existing and proposed transmission lines into single structures.

Aesthetic impacts and the risk of bird impacts can be reduced with underground construction. However, with the underground alternative studied, the existing double circuit overhead line at the Alma Crossing would remain in place. In addition, underground construction would involve more ground disturbance during construction than overhead alternatives due to the need to construct with horizontal directional drill and open trench methods. In this instance, the underground alternative results in a 235 foot wide cleared right-of-way containing eight 10-inch borings under the river spaced 25 feet apart. Temporary construction areas would require additional tree clearing. High pressure fluid-filled pipe technology contains a mineral oil dielectric coolant that, while manageable, is a potential environmental issue that is not present with overhead construction. In addition, the underground design would require is transition stations. Similar to small fenced substations, a transition station is required at each end to transition from underground to overhead cable. Each transition station would be approximately one acre in size.





The underground alternative also has unique reliability concerns. Failures of underground cables take longer to locate and repair than overhead alternatives. Complete replacement of a span of cable, if necessary, would leave the transmission line out of service for several months.

The attached underground feasibility report was prepared using aerial photographs and USGS topographic maps. No further site-specific investigation was conducted during this feasibility stage. Potential environmental issues discussed in the report are general to underground installations and are not necessarily project specific.

December 30, 2009

# XCEL ENERGY

## CapX Hampton – Rochester – La Crosse 345kV Project

*Alma Mississippi River Crossing*
*Underground Report*

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POWER ENGINEERS

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# I. EXECUTIVE SUMMARY

## Scope of Work

Xcel Energy (Xcel) requested that a comparison be made of alternative 345kV underground cable systems for the CapX Hampton – Rochester – La Crosse 345kV Project Alma Mississippi River Underground Crossing.

## Underground Cable Systems

Two basic types of underground cable systems were considered for the CapX Hampton – Rochester – La Crosse 345kV Project Alma Mississippi River Underground Crossing, namely an extruded dielectric, cross-linked polyethylene (XLPE), (extruded) cable system and a high-pressure fluid-filled pipe-type (HPFF) cable system. Details of the construction of the cables and major accessories for each of these cable systems are included in Section II. The major pros and cons of each of these cable systems are as follows:

### *Extruded Dielectric Cable Systems*

Pros:

- Essentially no operation and maintenance requirements.
- High reliability reported for systems of modern design at voltages 230kV and below in the USA, Japan and European countries.
- Higher normal operating and short circuit temperature ratings as compared to HPFF systems.
- Installation environmental condition requirements for splicing and terminating less stringent.
- Lower dielectric loses.
- Shorter time required for repair.
- Concrete encased duct bank systems provide mechanical protection from dig-ins and allow for short lengths of trench to be opened for construction activities.

Cons:

- Susceptible to damage from dig-ins if direct buried, more so than HPFF pipe-type cable systems.
- Potential for induced sheath voltages and losses.
- Trench for installation of each cable length (direct buried) must be left open for the entire length during cable installation.
- Duct bank/conduit installation may reduce thermal performance and increases cost.
- XLPE insulation not as forgiving (fluid-impregnated paper insulation is more tolerant of manufacturing defects, and variances).
- Limited use at 345kV in US.

### *HPFF Pipe Type Cable Systems*

Pros:

- Long experience record dating from 1930's with extensive use in the U.S.
- Very high reliability based on utility records.
- Steel pipe affords mechanical strength and protection from "dig-ins."
- Short length of trench can be opened for construction activities.
- The cable and other materials can be manufactured and installed by firms located in the United States.
- For direction drilling installations the casing installed can also be utilized as the cable conduit.
- Allows for dielectric fluid circulation to help increase ampacity.

Cons:

- Pipe susceptible to corrosion.
- Requires very large specially designed equipment for installation activities.
- Requires specialists for specific installation activities.
- May require long repair time in case of faults in the cable system.
- Requires installation and maintenance of a cathodic protection system.
- Requires maintenance of monitoring and pressurization system.

## Cable Case Summary

The options for installation of the 345kV circuits circuit are summarized below. For each case, the cable system type, number of cables per phase, installation depth and ampacity are provided.

Table 1: Ampacity Results

| Case # | 345kV Circuit | Cables per Phase | Cable Type | Burial Depth | Number of Bores - Spacing | Total Ampacity |
|---|---|---|---|---|---|---|
| 1 | 5000 kcmil | 6* | XLPE | 30-ft | 6 - 40-ft | 3700A |
| 2 | 2500 kcmil | 4 | HPFF | 20-ft | 4 - 25-ft | 3700A |

* Due to software limitation, the 345kV XLPE case attached in the appendix shows only 4 cables per phase. The total of 6 required cables per phase was extrapolated from the cable rating in the aforementioned case.



## Cost Estimates

The estimated installed costs for the XLPE and HPFF pipe-type insulated cable systems for the CapX Hampton – Rochester – La Crosse 345kV Project Alma Mississippi River Underground Crossing are:

Table 2: Cost Summary Table *

| Description | Material (One Circuit) | Labor (One Circuit) | Total (One Circuit) | Total (Two Circuits) |
|---|---|---|---|---|
| 345kV XLPE 5000 kcmil Copper Conductor | $64,631,645 | $33,099,965 | $97,731,610 | $195,463,220 |
| 345kV HPFF 2500 kcmil Copper Conductor | $25,426,148 | $19,675,275 | $45,101,423 | $90,202,846 |

* A 15 % contingency is included in the estimates.

The addition of a multiple circuits will require additional materials, horizontal directional drills, open trenching, manholes, and transition stations. There will be little to no overlap between additional circuits. The costs included in the table above for multiple circuits can be accounted for by simply summing the relevant individual circuit costs.

## II. PROJECT DESCRIPTION

POWER prepared this report for Xcel's CapX Hampton – Rochester – La Crosse 345kV Project Alma Mississippi River Underground Crossing.

Cross-linked polyethylene (XLPE) and high-pressure fluid-filled (HPFF) systems were analyzed for the underground portion of the line. The following describes the design criteria and assumptions used in the analysis.

For both types of cable systems a number of variables remain constant. These include but are not limited to: bore length, earth ambient temperature, thermal resistivites, load factors, and burial depths as described in the Cable System Evaluation Report as well as the Ampacity Design Criteria.

The Horizontal Directional Drill (HDD) depth is controlled largely by the casing bending limitations. For example, the HDD reaches a depth of 20-ft for the HPFF system using a 10-inch casing. The heat dissipation characteristics decrease as depth increases, which ultimately increases the spacing and size of cables needed to achieve the target ampacity. For this reason a 345kV XLPE requires six (6) bores using smaller casings to decrease the overall required depth to 30-ft. However, even at this depth a 40-ft spacing is required between each bore. The drawings included in the appendices show the profile view of the HDD and typical cross sections for each configuration.



### Cable System Evaluation Report

Cable System HPFF ☑ LPFF ☐ Solid Dielectric ☑
Codes AEIC ☑ IEC ☐ ICEA ☐ IEEE ☑
Conductor Size (kcmil/AWG) 1750-5000
Conductor Type Copper
Insulation Thickness (mils) XLPE: 1023, PPP: 600
Insulation Material PPP/XLPE
Installation Method HDD
Shield Type
Jacket Yes ☑ No ☐ TYPE: polyethylene
Fiber Optic Strand (PMT) Yes ☐ No ☑
Describe

a) Voltage Class: 345kV
b) Conductor: Copper X Aluminum ____
Construction Segmented
c) Insulation: *XLPE ☑ EPR ☐ Kraft Paper ☐ Poly Paper ☑

*XLPE maximum stress design AEIC CS9-06 Yes ☐ No ☑

As an option
High-Pressure-Fluid-Filed (HPFF) X
High-Pressure-Gas-Filled (HPGF)
Self-Contained-Fluid-Filled (SCFF)

d) Shield:
e) Jacket: XLPE: Polyethylene
f) Skid Wire Type Stainless Steel

A. Cable Operating Parameters

1. Ampacity Requirements

a.) Maximum Steady State 3700 A @ 345kV
b.) Emergency/Load
c.) Load Factor 75%
d.) Ultimate Short Circuit Amps ____ Cycles ____
e.) Shield Operation Cross-bonded ☐ Multi-Point ☐ Single-point ☑
f.) Shield Open Circuit Voltage Limit 150V

B. Operating Design Criteria

1. Earth Rho (Cº-cm/Watt) - Per Geotherm 90 Cº-cm/Watt
2. Earth Ambient (Cº) (as provided) 15° C
3. Air Ambient (Cº) N/A
4. Maximum Conductor Operating Temperature (Cº) EPR ___ XLPE 90 Paper 85
5. Emergency Conductor Operating Temperature (Cº) EPR ___ XLPE 105 Paper 105
6. Soil Thermal Resistivity (Rho) (Cº-cm/Watt) 90°C-cm/W
Grout Resistivity (Cº-cm/Watt) 70°C·cm/W

C. Installation Parameters

1. Substation Terminator Constraints ___
2. Cable System Burial Depth 60-ft Maximum 20-ft Minimum
3. Manholes
   a.) Burial Depth TBD
   b.) Single Circuit ☑ Double Circuit ☐
   c.) Comments

4. Route Criteria ___

5. Cathodic Protection Thermocouples included at CP test stations. ISP/ Rectifier/ Anode Bed

6. Permits Obtained by Xcel Energy

7. Duct Bank/Pipe Encasement (Configuration) ___

8. Communication Ducts: N/A

9. Accessories
a.) Splices Per cable manufacturer’s recommendation

b.) Arresters MCOV Per cable manufacturer’s recommendation
Leakage Distance ___
Duty Cycle Rating ___

c.) Terminations Per cable manufacturer’s recommendation

d.) Cable Clamps Per cable manufacturer’s recommendation

e.) Link Boxes (Sheath Grounding) Per cable manufacturer’s recommendation

## Ampacity Studies

POWER Engineers, Inc. (POWER) performed an XLPE and HPFF cable sizing/ampacity study for the CapX Hampton – Rochester – La Crosse 345kV Project Alma Mississippi River Underground Crossing. The primary purpose of the study was to determine a minimum conductor size based on the design requirements provided by XCEL.

POWER used CYME International's Cable Ampacity Program (CAP) to model the cable system. The cable systems analyzed were Cross-Linked Polyethylene (XLPE) and High-Pressure Fluid-Filled (HPFF). These cable systems were analyzed using the following design criteria.

- Ampacity
  - Normal ....................................... 3,700 Amps at 345kV
- Load Factor ....................................... 75%
- Conductor Material....................................... Copper
- Thermal Resistivity (ρ, rho)
  - Native Soil ....................................... 90°C-cm/W
  - Grout ....................................... 70°C-cm/W
- Ambient Temperature
  - Earth....................................... 15°C
- Maximum Conductor Operating Temperature
  - Steady State
  - XLPE ....................................... 90°C
  - HPFF....................................... 85°C
  - Emergency
  - XLPE ....................................... 105°C
  - HPFF....................................... 105°C
- Burial Depth (Top of System)
  - Minimum ....................................... 20 feet
  - Maximum....................................... 60 feet
- Bore Length....................................... 3000 feet

Four cases were successfully run using depths determined by the drill path for the appropriate casing size. Multiple cables per phase were used since it is impractical to achieve the required ampacities at the given depths with a single cable. Note that the native thermal resistivity is assumed to be 90°C·cm/W. This value is a typical value and may actually be higher or lower depending on the particular soil conditions found at the project site. Table 3 includes a summary of the cases including number of bores, spacing, casing size, depth, and ampacity with operating temperature.



Table 3: Ampacity Results

| Cable System Type and Conductor Size | Cables Per Phase | Number of Bores (Spacing) | Bore Casing Size | Depth | Ampacity per Cable (Temperature) |
|---|---|---|---|---|---|
| 345kV XLPE 5,000 kcmil CU | 6* | 6 (40-ft) | 30-inch | 30-ft | 625A (88°C) |
| 345kV HPFF 2,500 kcmil CU | 4 | 4 (25-ft) | 10-inch | 20-ft | 925A (82°C) |

* Due to software limitation, the 345kV XLPE case attached in the appendix shows only 4 cables per phase. The total of 6 required cables per phase was extrapolated from the cable rating in the aforementioned case.

Detailed ampacity calculations are located at the end of this report.

## 345kV XLPE Installation Concerns

Due to the high ampacity requirements, a 345kV XLPE system is not feasible when compared to a 345kV HPFF system. This system would require a large conductor size and the use of multiple cables per phase. The cable itself would be available only from a limited number of manufacturers and would have a high cost. In addition, the cable would weigh approximately 40 pounds per foot and would have a required reel length of 3,000-ft. A reel of this length would weigh 12,000 pounds and would pose a problem for transportation to the work site. The total amount of cable required for the line would likely require the use of a barge for transportation. Once at the site, the cable could either be offloaded and installed or installed directly from the barge. Both options have their own difficulties and high cost. In addition to these problems, the 345kV XLPE installation requires additional bores with much larger spacing. This greatly increases the impact of the line since the actual work site as well as the final installation itself will take up a much larger area. A higher number of cables means a larger transition station will be required on each end as well. The end result is that the footprint of the 345kV XLPE installation will likely be about twice as large as that of the 345kV HPFF installation, and it would cost about twice as much per circuit. Due to the concerns about materials, procurement, transportation, installation, cost, and overall impact, a 345kV XLPE system is not as feasible for this project as a 345kV HPFF system.

## III. UNDERGROUND CABLE SYSTEMS

### Introduction

Two basic types of underground cable systems are being considered. These systems are an extruded cross-linked polyethylene cross-linked polyethylene (XLPE) insulated cable system and a high-pressure-fluid-filled pipe-type (HPFF) cable system. A brief summary of the construction of the cables and accessories for each of these cable systems follows. The pros and cons of these two cable systems are included.

### Reliability

While underground transmission lines are highly reliable, their down times are significantly longer than their overhead counterparts when trouble is encountered. As a result, particular design practices are used to alleviate the problem with alternative T-lines or 100% redundancy. By implementing a design to ensure continuous operation, the reliability of underground transmission lines significantly increases.

### Extruded Dielectric Cable Systems

***Cable***

The components of a typical dielectric cable are shown in Figure 1. The typical cable consists of a stranded copper or aluminum conductor, semi-conducting extruded conductor shield, extruded dielectric insulation, extruded semiconducting insulation shield, a lead, aluminum, copper or stainless steel sheath moisture barrier, and a protective jacket. The inclusion of a moisture barrier is typical of French and other non-U.S. cables, but has not been a standard feature of U.S. extruded dielectric cables until recently (last ten years).

A metallic shield, tape or drainwire, is required to carry fault current when a sheath is not used.

Insulation materials used for extruded dielectric cables include:

- <u>Thermoplastic Polyethylene Compounds</u>

  Typical thermoplastic polyethylene insulation materials are low-density polyethylene (LDPE), high molecular weight polyethylene (HMWPE) and high-density polyethylene (HDPE).



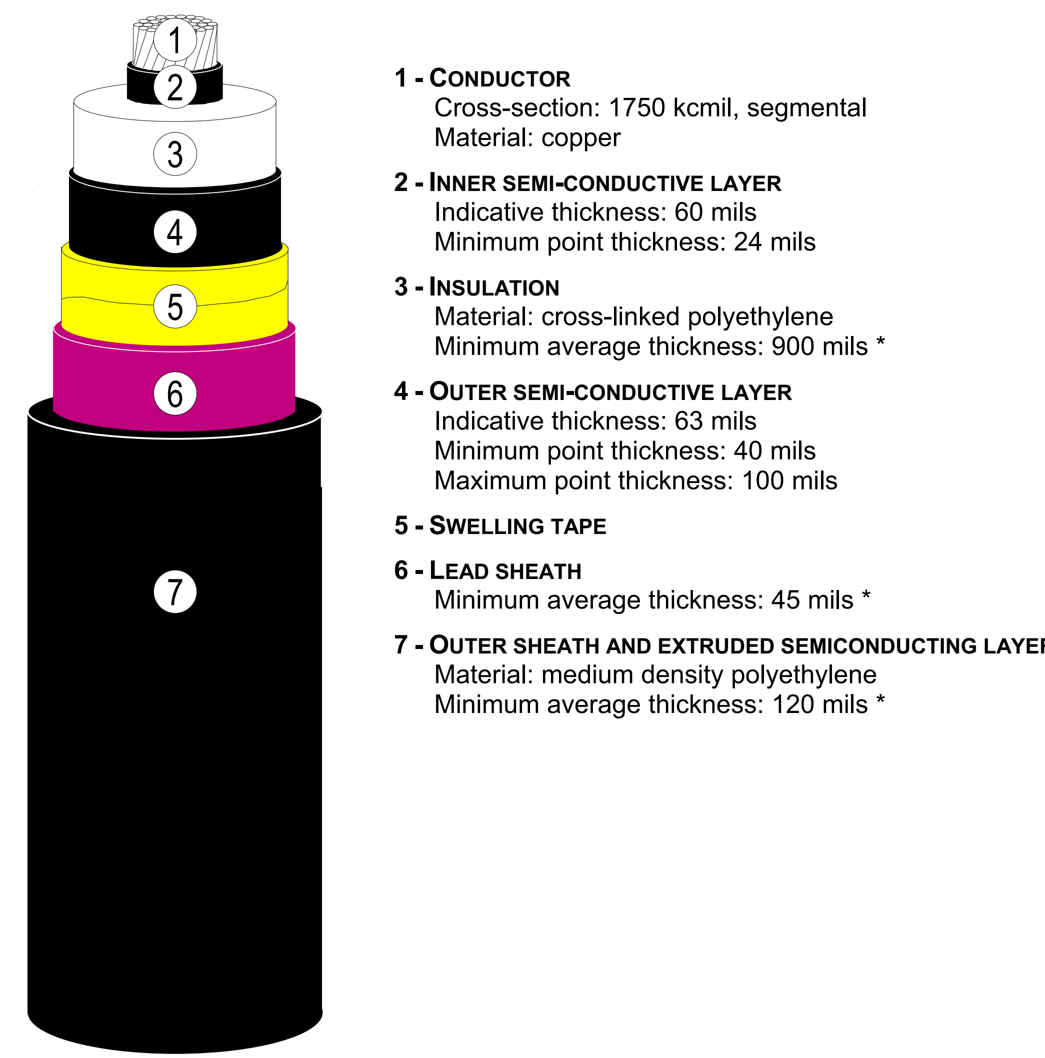



**Figure 1: Typical XLPE Cable**

- Thermosetting Compounds

  Ethylene propylene rubber (EPR) and cross-linked polyethylene (XLPE) are typical thermosetting insulation compounds.

It is interesting to note that each of these insulation materials enjoys preferential use in different parts of the world. For instance, the preferred extruded dielectric insulation in France is LDPE, in Italy EPR, and in most of Europe, Japan and the U.S. XLPE. The reason for this difference is likely that no one extruded dielectric insulation material has emerged as conclusively superior to the others in all aspects for every application, including manufacturing, cost and reliability.

Materials used for semi-conducting extruded conductor and insulation shields are semi-conducting PE, XLPE and EPR compounds. PE compounds are used with PE and XLPE insulation, XLPE compounds with XLPE insulation, and EPR compounds with EPR insulation.

Cable Jackets are typically extruded PE and on rare occasions polyvinyl chloride (PVC).

Extruded dielectric cables are manufactured using one of the following extrusion techniques:

- The conductor shield and insulation are extruded in tandem over the conductor. Extrusion of the insulation shield is a separate operation.

- The insulation shield, insulation and conductor shield is extruded in tandem over the conductor. This method is known as triple tandem extrusion. Triple extrusion is the preferred and recommended technique.

The metallic shield, tape, concentric neutrals, etc., and jacket, as applicable, are applied later in separate operations.

Vulcanization of thermosetting insulation compounds, EPR and XLPE, occurs via a dry cure or steam cure process in a tube called a curing tube. After vulcanization, the insulation is cooled with water or gas in a cooling tube.

Three major types of extruder lines are used to produce extruded dielectric cable; they are catenary, MDCV (long land die) and vertical extruder lines. Vertical extruder lines are often used when heavy insulation walls are required, for cables rated in excess of 35kV and for guaranteeing concentricity.

The manufacturing process for extruded cables is of critical importance in ensuring a reliable end product, since extruded dielectric insulations are not self-healing. Fluid-impregnated paper insulation is much more tolerant of manufacturing defects. As such, quality control during manufacture of extruded dielectric cables is critical to minimize moisture contamination, voids, contaminants and protrusions. Insulation contamination can be minimized by manufacture of and use of super clean insulation compounds; transportation and storage of the compounds in sealed facilities; and screening out of contaminants at the extruder head.

Voids and moisture contamination are inevitable results of steam vulcanizing, water-cooling and cross-linking agent decomposition. Dry (gas) curing produces smaller and fewer voids and less moisture contamination.



Lead sheaths are typically extruded (see end of this section for typical cable cross-section drawings and data); however, other types of water impervious material are available. The following table compares the various types of sheath materials.

Table 4: Cable Sheath Comparison

| | Extruded Lead | Extruded Aluminum | Metallic Foil Laminate | Copper | Stainless Steel |
|---|---|---|---|---|---|
| Dimensional Stability | Poor | Good | Poor | Very Good | Very Good |
| Fluid-Imperviousness | Very Good | Very Good | Good | Very Good | Very Good |
| Flexibility | Good | Poor | Very Good | Very Good | Very Good |
| Mechanical Strength | Good | Very Good | Poor | Very Good | Very Good |
| Cable Diameter (per unit) | 1.0 | 1.0 | 1.0 | 1.05 | 1.14 |
| Cable Weight (per unit) | 1.59 | 1.0 | 1.09 | 1.27 | 1.34 |
| Minimum Bending Radius | 15Ds | 15Ds | 15Ds | 12Ds | 12Ds |
| Corrosion Resistance | Very Good | Poor | Poor | Very Good | Very Good |

Ds = Diameter of metallic sheath

### *Cable Accessories*

The three basic cable accessories for extruded dielectric cables are splices, terminations and sheath bonding materials.

Premolded splices are recommended to joint 345kV extruded dielectric cables. Cable preparation for splicing is as follows:

Insulation and shields are removed from the conductor; and the insulation is penciled. The conductor ends are then joined by a compression splice or MIG welding (aluminum conductor only).

The perceived disadvantages of traditional jointing methods compared to premolded are, as assembly is complex, specially trained craftsmen required and no factory testing is possible. The premolded joint offers simpler construction. Also all parts produced can be factory tested prior to field installation (see end of this section for premolded splice cross-section for extruded dielectric cable)

Terminations are available for extruded dielectric cable to allow transitions to overhead lines or above ground equipment. A manufacturer's catalog page showing a cross-section of a typical termination follows. A synthetic rubber stress cone is placed over the insulation to control stress and the interior of the termination body is filled with a synthetic or silicone fluid. Termination bodies are typically made of porcelain and include skirts to minimize the probability of external flashovers due to contamination.

Sheath cross bonding may be required for long extruded dielectric cable systems to minimize or eliminate sheath currents, sheath losses and sheath voltage.

### Cable Maintenance and Repair

XLPE cable requires little maintenance since it is usually installed in a duct bank. Duct inspections are performed in conjunction with routine manhole inspections. Furthermore, ducts are seldom cleaned unless a new circuit, cathodic protection, or grounding is being installed. Unless environmental conditions dictate more frequent inspections, a yearly manhole inspection is generally sufficient to examine cable sheaths, protective jackets, joint casings, cable neutrals, and general physical condition of the manhole. Terminations should also be visually checked on a yearly basis to ensure a properly operating system. In the unlikely event of an electrical fault, the cable failure must be located which requires specialized equipment as well as a knowledgeable crew to pinpoint the failure. The time it takes to locate the fault location depends largely on the environmental surroundings and access to the cable for testing. Once pinpointed, an entire section of cable can be removed and replaced between manhole sections, or the duct bank can be opened up and an experienced splicing crew can rejoin the cable ends. The amount of time the system is depends entirely on the fault location and the repair method that provides the most advantageous solution. Typical repair time can range from two to four weeks.

### Pros and Cons

The pros and cons of extruded dielectric cable systems for use in high voltage applications are as follows:

Pros:

- Essentially no operation and maintenance requirements.
- High reliability reported for systems of modern design at voltages of 230kV and below in Japan, the US and European countries. Extensive use and success at 400kV in France and Japan.
- Higher normal operating and short circuit temperature ratings as compared to HPFF systems.
- Installation environmental condition requirements for splicing and terminating less stringent.
- Shorter time required for repair.
- Dielectric losses for extruded cable systems considerably less than paper insulated cable systems.
- Less specialized installation equipment required.

Cons:

- Susceptible to damage from dig-ins if direct buried more so than HPFF cable systems.
- Potential for induced sheath voltages and losses.
- Trench for installation of each cable length (direct buried) must be left open during cable installation.
- Duct bank/conduit installation reduces thermal performance and increases cost.
- XLPE insulation not forgiving (fluid-impregnated paper insulation is more tolerant of manufacturing defects, and variances).
- Limited splicing/terminating workforce in USA.



## High-Pressure Pipe-Type Cable Systems

### Cable

The construction of a typical high-pressure pipe-type (HPPT) cable (high-pressure-gas-filled pipe-type and high-pressure-fluid-filled pipe-type cables) is shown on the following manufacturer's drawing. The cables are typically composed of a conductor, conductor shield (carbon black or metalized paper tapes), insulation (Kraft paper or paper/polypropylene laminate impregnated with polybutene or alkylbenzene fluids), insulation shield (carbon black or metalized paper tapes), a moisture barrier (non-magnetic tapes and metalized mylar tapes), and skid wires (zinc, stainless, brass). The moisture barrier prevents moisture and other contamination and loss of impregnating fluid prior to installation. The skid wires prevent damage to the cable during pulling.

Three HPPT cables are pulled into a low-carbon steel pipe to constitute a cable system. The pipe is coated on the inside with an epoxy coating to prevent oxidation prior to fluid-filling and to reduce pulling friction and tension. The pipe exterior is coated with HDPE or Polypropylene to protect the pipe from environmental corrosion and to isolate the pipe from "ground" to allow use of a cathodic protection system.

A triangular cable configuration is preferred in contrast to a cradle configuration, as it reduces pipe losses and, as a direct result, increases load capacity. Increases in pipe losses for cradled versus triangular cable configuration ranges from 20% to 45%.

HPFF cable systems are filled with pressurized low viscosity polybutene or alkylbenzene fluids.

Cathodic protection is applied to pipes used in HPFF cable systems. This protection inhibits pipe corrosion, thereby minimizing pipe leaks due to corrosion. Most forms of cathodic protection utilize one of two methods: the galvanic-anode system or the impressed-current system. With both systems, anodes are placed in the ground to draw a DC current along the cable pipe into the anodes where metallic deterioration and corrosion are allowed to occur. In most systems an isolator/surge protector is used to block the DC current from entering the station grounding grid but allowing for large AC surges to be safely discharged in the station grid. Through the use of cathodic protection, the reliability of the pipe type system can maintain a high level of performance.

The manufacturing process for HPFF cables is similar to the process used for paper insulated lead-covered cables. A conductor core is covered by helically wound layers of metalized or carbon black paper tape for conductor and insulation shield and high quality Kraft paper or paper/polypropylene laminated for insulation. The insulated cable is dried and then impregnated with fluid in large pressurized tanks.

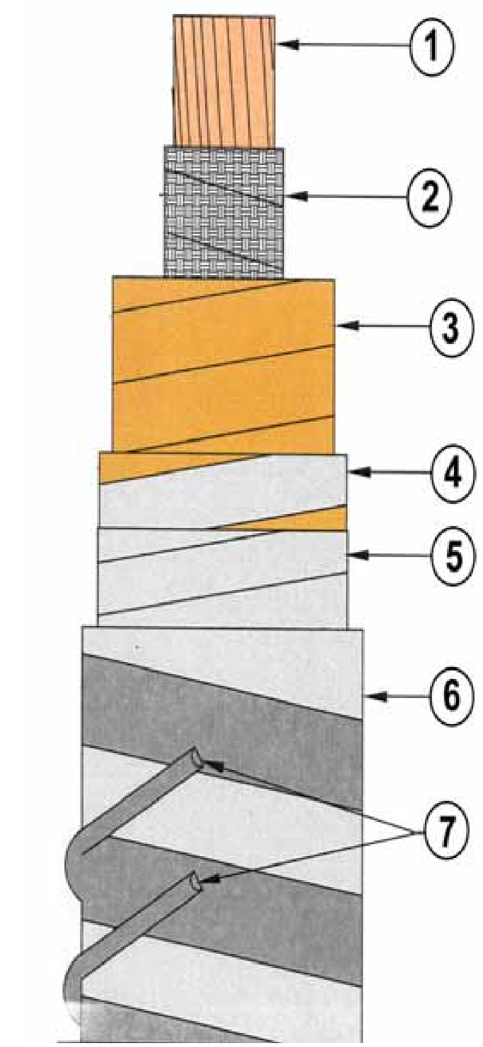
### Cable Accessories

Splicing of HPFF cables begins with removal of the insulation and shields from the conductor, the insulation is step-penciled. The conductor ends are then joined by a ram press, compression connector or MIG welding (aluminum conductor only). Insulation paper tape is wound around the spliced conductor, filling the step-penciled area of the insulation. Metalized tapes or carbon black tapes are used to re-establish the conductor and insulation shields. Small rolls of paper tape are used, as the three cables are very close together.

***Maintenance and Repair***

To ensure reliable, uninterrupted service, routine maintenance must be completed on cable systems as well as the associated components. Because of the more intricate systems involved with the high pressure fluid filled system, maintenance and occasional repair can be expected to be higher than that of the solid dielectric system. The hardest and often times most over looked component of the pipe type system is the pipe coating, which left un-inspected can cause catastrophic failure to the entire system. Because the cable itself is contained inside of a steel pipe, the pipe coating must be maintained in order to ensure proper operating pressures, and should be tested at least every other year. Repair of the cable pipe is an extensive process but will generally only leave the system off line for a number of days. Routine inspections and testing of the pumping plant must be preformed in order to sustain the proper operating pressures. Although the plant has a number of different sensors and alarms, a thorough yearly inspection is recommended. Other components of the cathodic protection system should be routinely tested such as the rectifier and the isolator/surge protector (ISP). Current levels, as well as voltage levels, should be tested monthly and any significant changes noted as a possible system breakdown. Anodes output levels should also be tested and replaced when necessary. As with extruded cables, electrical failures require locating the fault followed by the on site determination of repair needs. However, because the high pressure fluid filled system utilizes a pressure filled pipe, the dielectric fluid must be capped off while repairs are made. To do this a pipe freeze is initiated using liquid nitrogen to inhibit the fluid flow. Once cable splicing is finished and a repair sleeve installed, the freeze can be removed and any contaminates can be evacuated from the system. In the event of termination failure, the cable generally must be replaced all the way back to the splicing trifurcator. Typical repair time can range from two to six weeks.






**1 - Conductor**
Cross-section: 2500 kcmil segmental
Material: copper

**2 – Conductor Shield**
Carbon Black Paper Tapes

**3 - Insulation**
Material: Impregnated Paper (LPP)

**4 – Insulation Shield**
Metalized Paper Tape

**5 - Insulation Shield**
Metalized Polyester Tape

**6 – Zinc Alloy Tape**

**7 – D-Shaped Skid Wires**
Material: Zinc or Stainless Steel

**Figure 2: Typical HPFF Cable**

Terminations are made by first separating the three cables using a trifurcator. Single-phase terminations are then made in fluid-filled terminators.

***Pros and Cons***

The advantage and disadvantages of HPFF cable systems for use in high voltage applications are as follows:

Pros:
- Long experience record dating from 1930's with extensive use in the U.S.
- Very high reliability based on utility records.
- Steel pipe affords mechanical strength and protection from "dig-ins."
- Short lengths of trench can be opened for construction activities.
- The cable and other materials are manufactured and installed by firms located in the U.S.
- For directional drilling installations, the casing installed can also be utilized as the cable conduit.

Cons:
- Pipe susceptible to corrosion, cathodic protection required.
- Requires very large specially designed equipment for installation activities.
- Requires specialists for specific installation activities.
- Requires very long repair time in case of faults in the cable system.
- Requires installation and maintenance of a cathodic protection system.
- Requires maintenance of pressurization system.



## IV. TERMINATION STRUCTURE / STATION

The difference in the two cable systems comes from the manufacturing process and operation characteristics of each type of cable. For the XLPE system, typically larger insulation thicknesses are seen, but a pumping plant and cathodic protection is not required like that of an HPFF system. Further considerations arise at the termination locations. For the HPFF system a transition station must be erected to facilitate the pumping plant, oil filled terminations, and the cathodic protection system. Typical termination stations have a footprint in the range of 250-ft by 250-ft. However, this may be a benefit as a number of switching arrangements can be attained, as well as the addition of circuit protection, monitoring, and voltage regulation. The XLPE system can be converted to an overhead line in a much simpler fashion with the use of a transition structure, because the underground cables, as well as all of the required terminations, can be attached directly to the structure.

The Pros and Cons of each configuration are provided below:

### Termination Structure

Pros:
- Essentially no operation and maintenance requirements.
- High reliability
- Small structural footprint
- Terminations can be located on structure
- Lower installation cost

Cons:
- Can only be used for XLPE cable
- Failure of structure may result in prolonged outage

### Termination Station

Pros:
- Works with both cable systems
- More switching capabilities
- Increased protection capabilities/schemes
- SCADA can be installed in the station
- Voltage regulation, if required can be incorporated

Cons:
- Larger footprint
- Higher cost
- Higher maintenance costs

# V. COST ESTIMATE

## Introduction

The cost estimate for the cable system was compiled using quotations from high voltage cable manufacturers and contractors familiar with the installation of high voltage underground cable systems.

## Cost Estimate Assumptions

1) Single point bonding of XLPE cable sheaths was assumed.
2) Materials used in the cost estimates meet all applicable industry standards.
3) It was assumed construction will be performed by craftsmen experienced in installing high voltage underground transmission systems.
4) XCEL to obtain all environmental, local, state, and federal permits as required.
5) No contingency for internal XCEL costs.
6) No contingency for dewatering costs.
7) A 15% contingency was added.
8) No contingency for rock excavation costs.

## Summary of Cost Estimates

A summary of the costs for the cable investigated has been included in Table 5 below.

Table 5: Cost Summary Table *

| Description | Material (One Circuit) | Labor (One Circuit) | Total (One Circuit) | Total (Two Circuits) |
|---|---|---|---|---|
| 345kV XLPE 5000 kcmil Copper Conductor | $64,631,645 | $33,099,965 | $97,731,610 | $195,463,220 |
| 345kV HPFF 2500 kcmil Copper Conductor | $25,426,148 | $19,675,275 | $45,101,423 | $90,202,846 |

* A 15 % contingency is included in the estimates.

The costs included in the table above for multiple circuits can be accounted for by simply summing the relevant individual circuit costs.



# VI. Installation Methods

## Overview of Horizontal Directional Drilling (HDD)

### *Development and Uses*

Originally used in the 1970s, directional crossings are a marriage of conventional road boring and directional drilling of oil wells. Pipelines have been installed for carrying oil, natural gas, water and other products using HDD. Ducts have been installed to carry electric and fiber optic cables. Besides crossing under rivers and waterways, HDD installations have been made crossing under highways, railroads, airport runways, shore approaches, islands, areas congested with buildings, pipeline corridors and future water channels.

### *Technology Limits*

The longest installation, since the inception of HDD, has been about 6,000 feet with pipe diameters up to 60 inches. Although directional drilling was originally used primarily on the U.S. Gulf Coast through alluvial soils, more and more crossings are being undertaken through gravel, cobble, glacial till and hard rock. Adequate space must be available to allow rigs to set up for the duration of the installation.

### *Advantages*

HDD installations have the least environmental impact of any alternate method. The technology also offers maximum depth of cover under the obstacle, thereby affording maximum protection and minimizing maintenance costs. HDD crossings have a reasonably predictable and short construction schedule. Directional drilling may minimize social impacts such as extensive highway closures and traffic congestion under the right conditions. Perhaps most significant advantage is that HDD crossings are in select cases, less expensive than other methods.

### *Machine Types*

There are several types of machines available for HDD. They are primarily separated into small or mini, medium and large sizes, according to thrust and pull back force capabilities.

Small or mini size rigs have thrust and pull back forces of less than 30,000 pounds. Typically these rigs have ranges limited to 2 to 300 feet and can install 2 to 6 inch product casings.

Medium size rigs have thrust and pull back forces in the range of 30 to 100,000 pounds. Ranges are longer with the upper limit approaching 1,500 to 2,000 feet. These rigs can install 6 to 20 inch product casings, depending on length and specific forces.

Large size rigs have thrust and pull back forces in the range of 125 to 750,000 pounds. Ranges of installation can exceed 5,000 feet and product casings can be 6 to 60 inches.

### Technique

A pilot hole is drilled beginning at a prescribed angle from horizontal and continues under and across the obstacle along a design profile made up of straight tangents and long radius arcs. Concurrent to drilling the pilot hole, the contractor may elect to run a larger diameter “wash pipe” that will encase the pilot drill string. The wash pipe acts as a conductor casing providing rigidity to the smaller diameter pilot drill string and will also save the drilled hole, should it be necessary to retract the pilot string for bit changes. The directional control is brought about by a small bend in the drill string just behind the cutting head. The pilot drill string is not rotated except to orient the bend. If the bend is oriented to the right, the drill path then proceeds in a smooth radius bend to the right. The drill path is monitored by an electronic package housed in the pilot drill string near the cutting head. The electronic package detects the relationship of the drill string to the earth’s magnetic field, gravitational field and its inclination. This data is transmitted back to the surface where calculations are made as to the location of the cutting head. Surface location of the drill head also can be used where there is reasonable access.

Once the pilot hole is complete, the hole must be enlarged to a suitable diameter for the product pipeline. For instance, if the pipeline to be installed is 36 inch in diameter, the hole may be enlarged to 48 inch diameter or larger. This is accomplished by “pre-reaming” the hole to successively larger diameters. Generally, the reamer is attached to the drill string on the bank opposite the drilling rig and pulled back into the pilot hole. Joints of drill pipe are added as the reamer makes its way back to the drilling rig. Large quantities of slurry are pumped into the hole to maintain the integrity of the hole and to flush out cuttings.

Once the drilled hole is enlarged, the product pipeline can be pulled through it. The pipeline is pre-fabricated at the end of the bore opposite the drilling rig. A reamer is attached to the drill string and then connected to the pipeline pullhead via a swivel. The swivel prevents any translation of the reamer’s rotation into the pipeline string allowing for a smooth pull into the drilled hole. The drilling rig then begins the pullback operation, rotating and pulling on the drill string and once again circulating high volumes of drilling slurry. The pullback continues until the reamer and pipeline break ground at the drilling rig.

After the pipe has been pulled through the drilled hole, bore spacers and conduit are installed in the pipe. The bore spacers are typically spaced five feet apart to allow support of the conduit. Once the conduit is installed, one end of the pipe is temporarily sealed and grout is pumped into the opposite end until the pipe system is full.

Prior to construction there are several activities that must be accomplished. These activities include: soil borings, thermal resistivity testing of the soil and surveying the route. The daily activities for a typical HDD operation are presented below. This timetable is based on drilling 1200 feet.

Mobilize: The mobilization of the HDD equipment will require a minimum of 30 days with an additional minimum 30 days notice.

Day 1: The drilling equipment is setup. (This assumes setup location has been identified and approved by Xcel and Permitting Agencies)

Day 1-5: Product casing is laid out and prepared on exit side of the drilling operation.

Day 2: Excavation and setup of entry position and the anticipated exit position is located.



Day 2-4: The pilot hole is drilled beginning at the prescribed angle and under and across the obstacle along the designed profile. Expected minimum drilling rate of 40 feet/hour for the pilot hole (30 drilling hours based on 12 hour shifts).

Day 5: The drilling equipment is reset for back ream and pullback of product pipe.

Day 6-8: The drilled hole is enlarged and the product pipe (casing) is pulled into the enlarged borehole. Expected drilling rate of 35 feet/hour for the back ream and casing installation. (30 drilling hours based on 12 hour shifts).

Day 8: The area around the exit hole is excavated and the casing lowered to design depth and configuration.

Day 9: The drilling equipment is disassembled and demobilized.

Day 10: The area around the entry hole is excavated and the casing lowered to the design depth and configuration. The equipment for the conduit installation is setup.

Day 11-12: The installation of the bore spacers and conduit are installed in the pipe. Once the conduit is installed, grout is pumped into the pipe system.

Day 13: Installation of the land-side duct bank begins.

### Layout and Design

Heavy equipment is required at both ends of the installation. This equipment must remain in position while the installation progresses to completion.

### Work Space

The rig spread requires a minimum 100-foot wide by 150-feet long area as shown in Figure 3. This area should extend from the entry point away from the installation, although the entry point should be at least 10 feet inside the prescribed area. Since many components of the rig spread have no predetermined position, the rig site can be made up of smaller irregular areas. Operations are facilitated if the area is level, hard standing and clear of overhead obstructions. The drilling operation requires large volumes of water for the mixing of the drilling slurry. A nearby source of water is necessary.

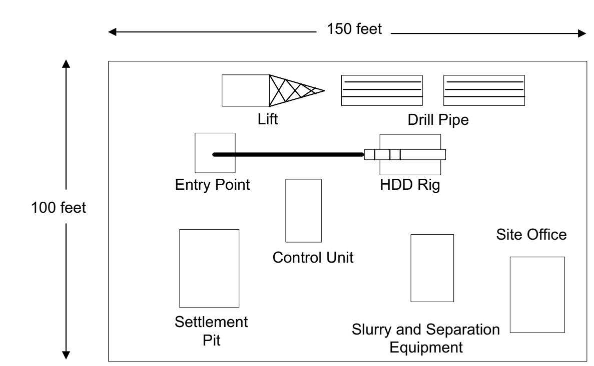



Figure 3: Typical HDD Setup Area

Strong consideration should be given to provide a sufficient length of workspace to fabricate the product pipeline into one string. The width will be as necessary for normal pipeline construction although a workspace of 100-feet wide by 150-feet long should be provided at the exit point. The length will assure that during the pullback the pipe can be installed in one uninterrupted operation. Tie-ins of successive strings during the pullback operation increase the risk considerably because of the tension changes going from dynamic friction to static friction with respect to the product being used. If manholes are located 600 feet apart, then a space of 600 feet should be available beyond the exit pit for product pipe laydown prior to pulling it into the drilled path.

Once the work locations have been chosen, the area should be surveyed and detailed drawings prepared. The eventual accuracy of the drill profile and alignment is dependent on the accuracy of the survey information.

### *Profile Design Parameters*

Once the installation profile has been taken and the geotechnical investigation completed, a determination of the depth of cover under the existing groundline is made. Factors considered may be the presence of existing pipeline or cable crossings at the locations along the desired route. Minimum depth recommended is 10 feet to prevent loss of drilling fluids.

An entry angle between 8° and 20° can be used for most installations. It is preferable that straight tangent sections are drilled before the introduction of a long radius curve. The radius of the curve is determined by the bending characteristic of the product pipeline, increasing with the diameter. A general “rule of thumb” for the radius of curvature is 100 feet/inch diameter for steel line pipe. The curve usually brings the profile to the elevation providing the design cover of the pipeline under groundline and obstructions. Long horizontal runs can be made at this elevation before curving up towards the exit point. Exit angle should be kept between 5° and 12° to facilitate handling of the product pipeline during pullback. Most downhole survey tools are electronic devices that give a magnetic azimuth (for “right/left” control) and inclination (for “up/down” control). Surface locators can also be used in conjunction with the downhole electronic package.

The accuracy of the drill profile is largely dependent on variations in the earth’s magnetic field. For instance, large steel structures (bridges, pilings, other pipelines, etc.) and electric power transmission lines affect magnetic field readings. However, a reasonable drill target at the pilot hole exit location is 10 feet left or right, and -10 feet to + 30 feet in length, although greater accuracy has been achieved.

Normally, survey calculations are conducted every 30 feet during pilot hole operations. The contractor should provide as-built drawings that are based on these calculations. Alternate methods such as gyroscoping, ground penetrating radar or sound transmitting devices may also be used to determine the as-built position.



### *Special Considerations for Water Crossings*

When crossing any body of water a number of concerns arise, and generally these concerns are area specific. The main issues involve the type of the body of water to be crossed, whether or not the area is environmentally sensitive, the location of any access points, environmental control, and permitting. When performing any work around bodies of water special permitting is usually required, as is an environmental impact study. In addition, extensive measures must be taken in preserving the natural water flow. This can range anywhere from erosion control to complete removal of all excavated soils. Because horizontal directional drilling uses bentonite, a clay type drilling fluid to stabilize the bore and reduce mechanical wear, concerns of frac-out into the water body arise. However, because bentonite is of a natural origin, fracing-out into the body of water generally is not a large concern

## VII. Operation and Reliability

### Overhead Transmission

Overhead line is relatively easy to operate, maintain, troubleshoot and repair. Overhead lines are susceptible to outages resulting from lightning, high wind, wind blown debris, equipment failure and vandalism. At the 345kV level, phase spacing is sufficient to eliminate most problems from flying debris such as tree limbs and proper design eliminates problems with conductor slap. This leaves lightning, high winds, equipment failure and vandalism as the predominant causes of outages. In the case of a short circuit the protective relays normally detect the fault and trip the circuit opens within three to five cycles. Since the line is above ground, faulted sections are usually quickly identified by line patrols with direction from fault locating relays and digital fault recorders. Repair time for most components can be completed within a few hours.

Overhead line currents are limited by annealing of the conductor material which reduces the mechanical strength. High currents also increase the sag due to thermal expansion which reduces ground clearance. Transmission lines with ACSR conductors are designed for normal operation at about 75$^{o}$ C but they can be operated up to 100$^{o}$ C for a number of hours during emergency conditions and may be operated up to 125$^{o}$ C for a short duration.

### Underground Transmission

Underground line is relatively easy to operate and maintain although it is more difficult to troubleshoot and repair. Maintenance procedures for XLPE systems include various items such as visual and/or operational inspections of the cable terminations, manholes, and temperature monitoring system inspection and testing. With proper maintenance, the design life of an underground line is approximately 40 years. Underground lines are susceptible to outages resulting from dig in's and cable, splice or equipment failure.

Generally, the conductor of an underground transmission line will be twice the size of an equivalent overhead transmission line. This is a result of the limited heat dissipation due to cable insulation and below grade encasement. This extra mass of copper or aluminum combined with the slow thermal transients of the encasement provides a significant advantage when it comes to short-term overloads. A typical underground transmission line may operate at 20-30 percent above nominal rating for up to 3 days without any degradation to the cable.

Operating losses in cable systems include conductor losses, dielectric losses, proximity effect losses, and sheath losses. Generally, underground cable losses are higher than that for an equivalent overhead circuit.

Underground transmission lines may be designed for future upgrade with a relatively small capital cost. Even lines that were not originally planned for upgrade may be converted by any of the following options:

- Reconductoring
- Accepting a higher voltage stress on the cable.
- Changing cable insulation for higher voltage operation by using a reduced wall thickness or changing from laminated paper insulation to LPP insulation.
- Dynamic ampacity ratings associated with continuous monitoring.



## VIII. Comparison of Environmental Impacts of Overhead and Underground Transmission Line Construction

The environmental impacts of overhead transmission line construction differs substantially from underground construction. These differences are discussed below:

### Right of Way Widths

Underground right of way widths can be limited to the area containing the line and an area on each side of the line set aside to protect the line from unintentional excavation damage and for access. The underground line can be placed adjacent to the existing 161kV overhead line river crossing. Assuming a separation of 25-ft to the north of the overhead lines, a right of way of 235-ft would be sufficient for the 345kV HPFF cable system installation. For the 345kV XLPE installation, approximately 360-ft would be required.

### Ground Disturbance

Ground disturbance for overhead construction is limited to structure locations. Underground construction involves extensive ground disturbance including trenching along the entire line length, bore pit excavation at each end of a directional boring, and installation of splicing and pull-through vaults as necessary.

Long underground cable systems may also require intermediate stations to install reactors. Each of these stations will require installation of equipment inside a fenced area with a footprint of about 40,000 square feet.

Sensitive features such as streams and rivers, etc. exist in the line route. While overhead construction has the flexibility to span features such as rivers, streams and wetlands, underground construction does not have as much flexibility and requires construction through these sensitive features if they are crossed by the line route. Directional drilling or boring may be required for underground construction in order to avoid impacts to streams, rivers and wetlands. However, where directional drilling is not feasible, trenching through sensitive areas would be required for underground construction.

Underground construction requires extensive coordination with other underground utilities to avoid damage during construction. This level of coordination usually exceeds that required for overhead construction. The potential to disrupt or damage underground utilities is usually greater with underground construction.

Replacement or repair activities may have additional ground disturbance for underground lines. Overhead repair work usually involves light impact at the structure locations. Secondary off-site ground disturbing impacts may be required for underground lines if selective fill is required for heat dissipation. Materials source sites must be excavated to obtain this select fill material.

### Land Use and Aesthetics

Overhead construction can be visually intrusive in sensitive visual environments. Urban underground construction, if properly rehabilitated, typically has lower visual impacts than overhead construction. In rural areas, underground rights of way may be highly visual due to the clearing required for the right of way.

Overhead construction may not be suitable for congested urban areas and may impact urban land uses more than underground construction. In rural settings, underground construction may be much more disruptive to agricultural or rural land uses than overhead construction. Farming can usually be conducted under overhead lines (with the exception of structure locations) while it would be prohibited over underground lines to avoid damaging the line.

### Electric fields, magnetic fields and Noise

Underground construction in pipes or shielded cable eliminates electrical fields at the right of way boundary. Magnetic fields are generally higher directly over an underground installation compared to an overhead installation. Magnetic fields tend to decrease more rapidly with distance for underground installations compared to overhead.

Overhead lines emit a hiss or low hum (corona) during rainstorms or humid periods. Underground lines are silent for the most part with the exception of the immediate area near termination points.

### Right of Way Clearing and Vegetation Control

In undeveloped areas, underground construction requires the right of way to be totally cleared to allow for construction and establishment of the right of way. This includes trees, brush, and ground cover. While low growing vegetation can be reestablished over an underground installation, trees or plants with woody roots cannot be allowed to grow over the line.

Overhead construction requires complete clearing only in the area of the structures and removal of trees along the line route to provide for electrical clearance and maintenance. Lower vegetation such as brush, shrubs, and ground covers can usually be left as long as it will not interfere with maintenance and access to the line. Both underground and overhead construction techniques may require long term vegetation control in the right of way.



### Erosion Control in Unstable Areas

Extensive erosion control measures are required for underground lines because a trench is dug the entire line length and the right of way is totally cleared. In areas with hilly terrain and erosive soils, significant erosion and sedimentation impacts can arise from underground construction. Due to less ground disturbing activity, overhead lines usually result in lesser erosion impacts.

Careful placement of structure locations or engineered foundation arrangements can avoid or mitigate unstable geology or soils in overhead construction. Underground construction does not have the flexibility to avoid unstable areas encountered by the line route; thus the potential for impacts to unstable areas may be greater with underground construction.

# Summary Results

**Study:** Xcel Energy 345kV HPFF River Crossing

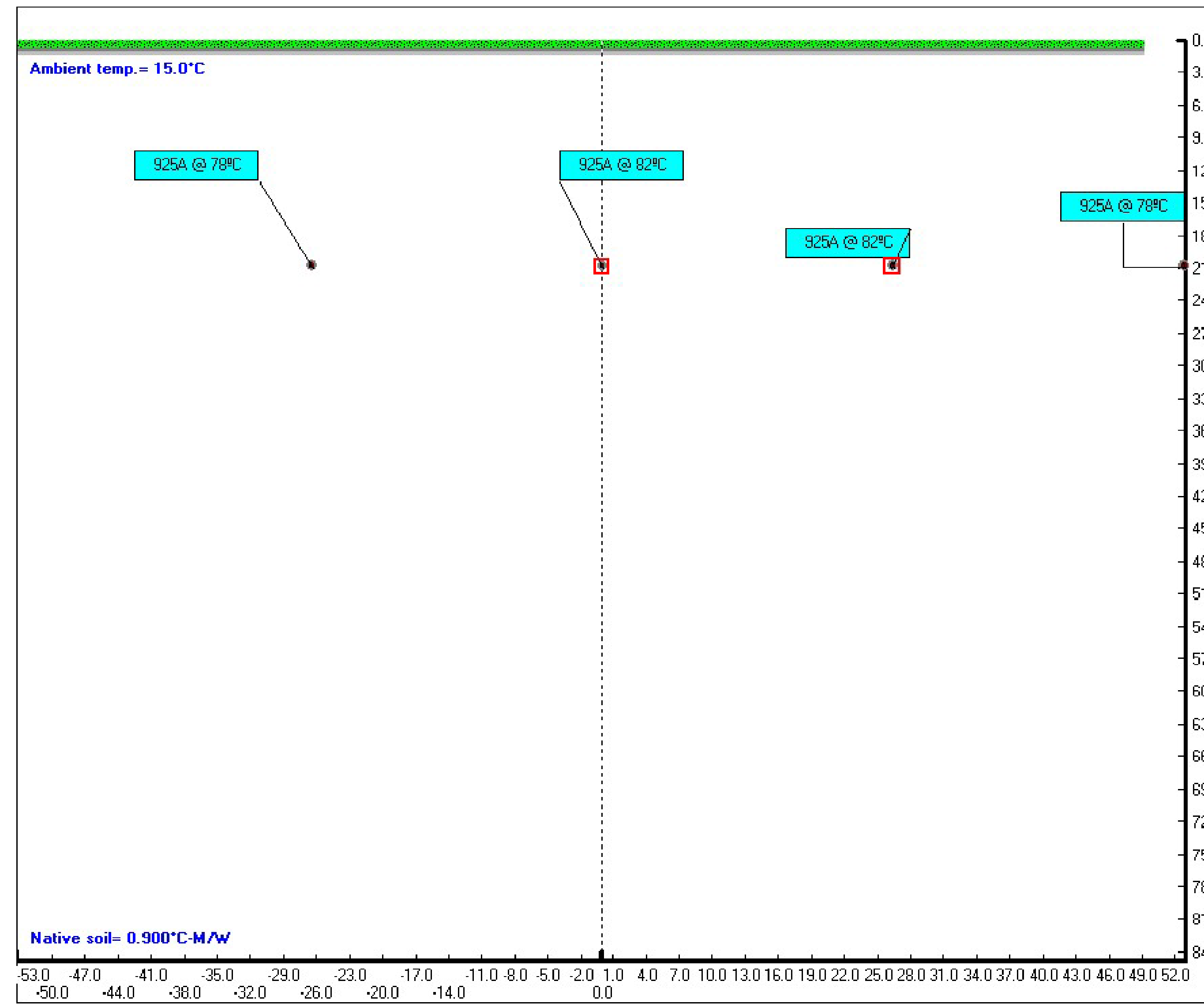
**Execution:** 02 345kV 2500kcmil Cu 600milPPP rho=90 15°C, d=25',925A@82°C

**Date:** 4/23/2008

**Frequency:** 60 Hz

**Conductor Resistances:** IEC-228

| Installation Type: Buried Pipes | | |
|---|---|---|
| **Parameter** | **Unit** | **Value** |
| Ambient Soil Temperature at Installation Depth | °C | 15 |
| Thermal Resistivity of Native Soil | °C.m/W | 0.9 |
| Non-Isothermal Earth surface modeling | Enabled/Disabled | Disabled |




## Ampacity Studies

| Summary Results | | | | | | | |
|---|---|---|---|---|---|---|---|
| Solution converged | | | | | | | |
| Cable\Cable type no | Circuit | Phase | Location | | Load Factor | Temperature | Ampacity |
| | | | X[ft] | Y[ft] | [p.u.] | [°C] | [A] |
| 1 \ 1 | 1 | ABC | 0 | 20.833 | 0.75 | 82.4 | 925 |
| 2 \ 1 | 2 | ABC | 26.416 | 20.833 | 0.75 | 82.4 | 925 |
| 3 \ 1 | 3 | ABC | -26.416 | 20.833 | 0.75 | 78 | 925 |
| 4 \ 1 | 4 | ABC | 52.833 | 20.833 | 0.75 | 78 | 925 |

## Cables input data

**Study:** Xcel Energy 345kV HPFF River Crossing
**Execution:** 02 345kV 2500kcmil Cu 600milPPP rho=90 15°C, d=25',925A@82°C
**Date:** 4/23/2008

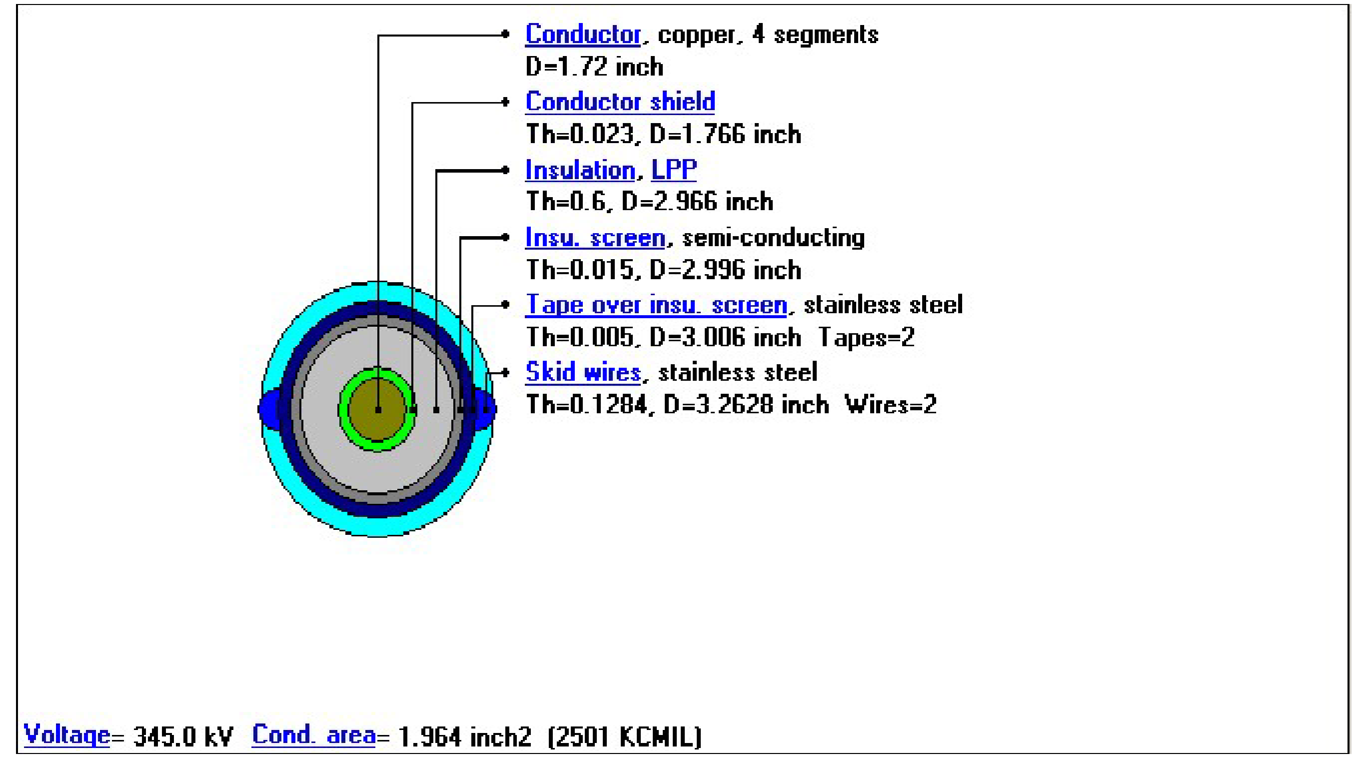
| No | Description | Unit | 1 |
|---|---|---|---|
| **General cable information** | | | |
| 1 | Cable type no | | 1 |
| 2 | Number of cores | | 3 |
| 3 | Voltage | kV | 345 |
| 4 | Conductor area | $inch^2$ | 1.964 |
| 5 | Maximum Steady-State Conductor Temperature | °C | 85 |
| 6 | Maximum Emergency Conductor Temperature | °C | 105 |
| **Construction** | | | |
| ***Conductor*** | | | |
| 7 | Material | | copper |
| 8 | Resistivity @20°C | uΩ.cm | 1.7241 |
| 9 | Temperature coefficient | 1/K | 0.00393 |
| 10 | Construction | | 4 segments |
| 11 | Is cable dried? | | No |
| 12 | ks (Skin effect coefficient) | | 0.44 |
| 13 | kp (Proximity effect coefficient) | | 0.37 |
| 14 | Diameter | inch | 1.72 |
| ***Conductor shield*** | | | |
| 15 | Is layer present? | | Yes |
| 16 | Thickness | inch | 0.023 |
| 17 | Diameter | inch | 1.766 |
| ***Insulation*** | | | |
| 18 | Is layer present? | | Yes |
| 19 | Material | | LPP |
| 20 | Thermal resistivity | K.m/w | 6.5 |
| 21 | Dielectric loss factor - ( tan δ ) | | 0.001 |
| 22 | Relative permeability ( ε ) | | 3.5 |
| 23 | Thickness | inch | 0.6 |
| 24 | Diameter | inch | 2.966 |
| ***Insulation screen*** | | | |
| 25 | Is layer present? | | Yes |
| 26 | Material | | semi-conducting |
| 27 | Thickness | inch | 0.015 |
| 28 | Diameter | inch | 2.996 |
| ***Sheath reinforcing tape/Tape over insulation screen*** | | | |
| 29 | Is layer present? | | Yes |
| 30 | Material | | stainless steel |
| 31 | Resistivity @20°C | uΩ.cm | 70 |
| 32 | Temperature coefficient | 1/K | |

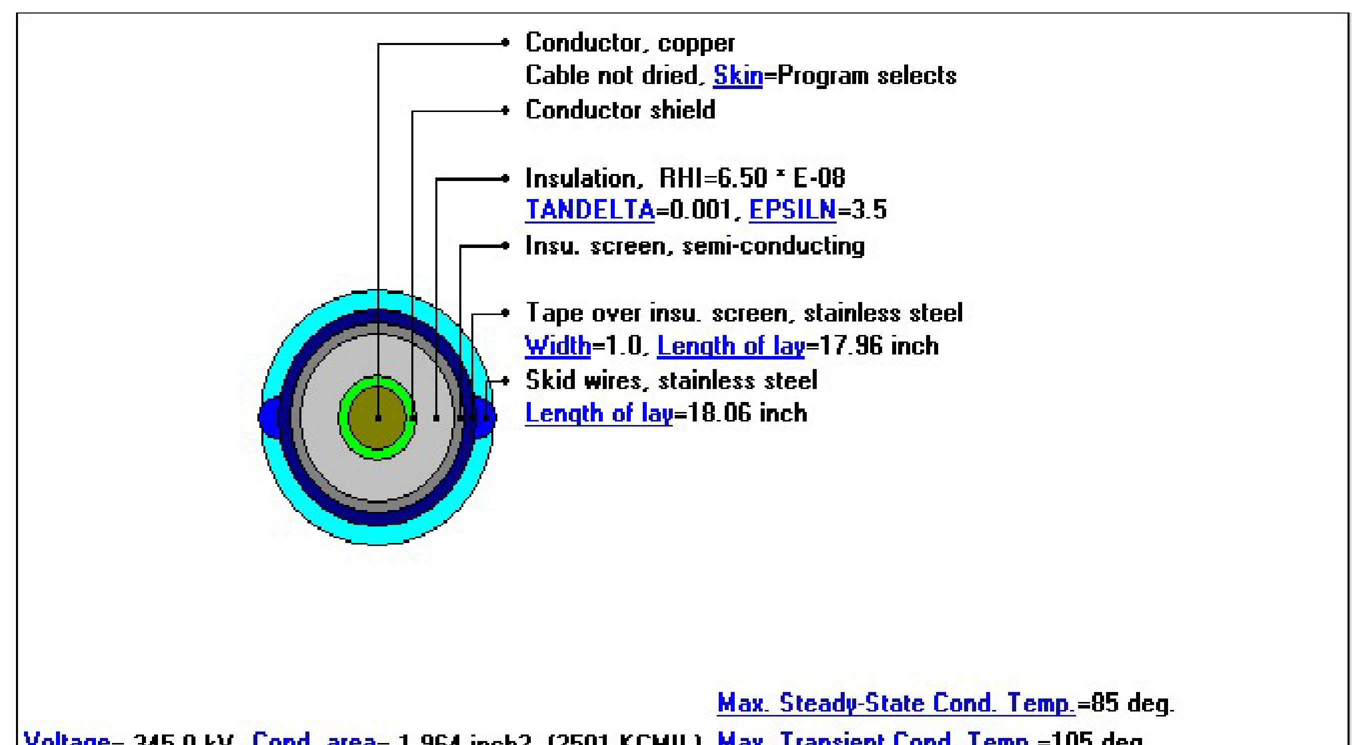
| | | | |
|---|---|---|---|
| 33 | Tape width | inch | 1 |
| 34 | Length of lay | inch | 17.96 |
| 35 | Number of tapes | | 2 |
| 36 | Thickness | inch | 0.005 |
| 37 | Diameter | inch | 3.006 |
| ***Concentric neutral/Skid wires*** | | | |
| 38 | Is layer present? | | Yes |
| 39 | Is around each core? (Only for Three core cable) | | No |
| 40 | Material | | stainless steel |
| 41 | Resistivity @20°C | uΩ.cm | 70 |
| 42 | Temperature coefficient | 1/K | |
| 43 | Length of lay | inch | 18.06 |
| 44 | Number of wires | | 2 |
| 45 | Wire gauge | | Unknown |
| 46 | Thickness | inch | 0.1284 |
| 47 | Diameter | inch | 3.2628 |

| No | Description/Value | Unit | 1 |
|---|---|---|---|
| **SPECIFIC INSTALLATION DATA** | | | |
| ***Loss factor constant*** | | | |
| 1 | Loss factor constant | | 0.3 |
| ***Duct construction*** | | | |
| 2 | High pressure oil filled pipe type | | Yes |
| 3 | Resistivity (RH) | | 0 |
| ***Cables touching*** | | | |
| 4 | Single conductor cables touching | | Yes |
| ***Pipe coating*** | | | |
| 5 | Polyethylene | | Yes |
| 6 | Resistivity (RH) | | 6 |
| ***Pipe material*** | | | |
| 7 | Steel pipe | | Yes |
| 8 | Pipe material factor | | 1.7 |
| ***Duct/Pipe dimensions*** | | | |
| 9 | Inside diameter of Duct/Pipe | inch | 10.0200003 |
| 10 | Outside diameter of Duct/Pipe | inch | 10.7500003 |
| 11 | Pipe coating diameter | inch | 10.8500003 |

| No | Symbol | Description | Unit | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|
| **Temperature calculations** | | | | | | | |
| 1 | | Cable type no | | 1 | 1 | 1 | 1 |
| 2 | | Circuit no | | 1 | 2 | 3 | 4 |
| 3 | | Phase | | ABC | ABC | ABC | ABC |
| 4 | $\theta_c$ | Conductor temperature | °C | 82.4 | 82.4 | 78 | 78 |
| 5 | $\theta_i$ | Sheath/Shield temperature | °C | 70.4 | 70.4 | 66.2 | 66.2 |
| 6 | $\theta_j$ | Armour/Pipe or Jacket temperature | °C | 65.7 | 65.7 | 61.2 | 61.2 |
| 7 | $\theta_s$ | Exterior duct temperature | °C | 65.3 | 65.3 | 60.8 | 60.8 |
| 8 | $\theta_a$ | Ambient temperature | °C | 15 | 15 | 15 | 15 |

**Cable type no:** 1
**Cable type:** PIPE TYPE (TRIANGULAR)
**Cable ID:** 345CU2.50H
**Cable title:** 345kV 2500kcmil Cu 600 mils LPP HPFF

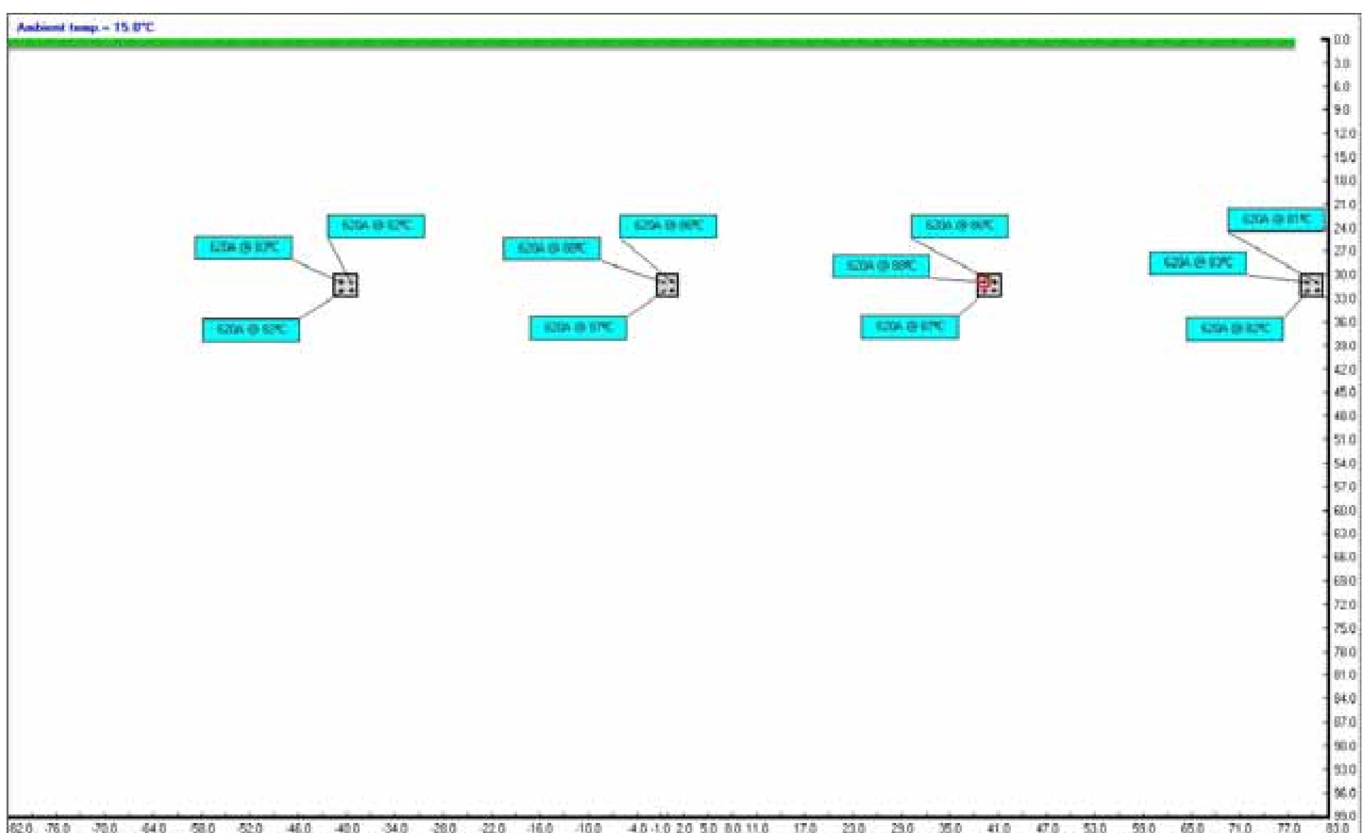


# Summary Results

**Study:** Xcel Energy 345kV River Crossing
**Execution:** 05 345kV 5000kcmil CU 1023mil XLPE, d=30', 620A, 87°C
**Date:** 5/9/2008
**Frequency:** 60 Hz
**Conductor Resistances:** IEC-228

| Installation Type: Multiple Duct Banks Backfills | | | | | | | |
|---|---|---|---|---|---|---|---|
| Parameter | | | | | | Unit | Value |
| Ambient Soil Temperature at Installation Depth | | | | | | °C | 15 |
| Thermal Resistivity of Native Soil | | | | | | °C.m/W | 0.9 |
| Layers | | Dimensions [ft] | | | | Type | Thermal Resistivity [°C.m/W] |
| No. | Name | X Center | Y Center | Width | Height | | |
| 1 | DB 2X2 | -40 | 31.469 | 2.938 | 2.938 | Standard ductbank | 0.6 |
| 2 | DB 2X2 | 0 | 31.469 | 2.938 | 2.938 | Standard ductbank | 0.6 |
| 3 | DB 2X2 | 40 | 31.469 | 2.938 | 2.938 | Standard ductbank | 0.6 |
| 4 | DB 2X2 | 80 | 31.469 | 2.938 | 2.938 | Standard ductbank | 0.6 |




| Summary Results | | | | | | | |
|---|---|---|---|---|---|---|---|
| Solution converged | | | | | | | |
| Cable\Cable type no | Circuit | Phase | Location | | Load Factor | Temperature | Ampacity |
| | | | X[ft] | Y[ft] | [p.u.] | [°C] | [A] |
| 1 \ 1 | 1 | A | -40.609 | 30.977 | 0.75 | 82.8 | 620 |
| 2 \ 1 | 1 | B | -39.391 | 30.977 | 0.75 | 81.6 | 620 |
| 3 \ 1 | 1 | C | -40.609 | 32.195 | 0.75 | 82.2 | 620 |
| 4 \ 1 | 2 | A | -0.609 | 30.977 | 0.75 | 87.5 | 620 |
| 5 \ 1 | 2 | B | 0.609 | 30.977 | 0.75 | 86 | 620 |
| 6 \ 1 | 2 | C | -0.609 | 32.195 | 0.75 | 87.1 | 620 |
| 7 \ 1 | 3 | A | 39.391 | 30.977 | 0.75 | 87.6 | 620 |
| 8 \ 1 | 3 | B | 40.609 | 30.977 | 0.75 | 86 | 620 |
| 9 \ 1 | 3 | C | 39.391 | 32.195 | 0.75 | 87.1 | 620 |
| 10 \ 1 | 4 | A | 79.391 | 30.977 | 0.75 | 82.9 | 620 |
| 11 \ 1 | 4 | B | 80.609 | 30.977 | 0.75 | 81.2 | 620 |
| 12 \ 1 | 4 | C | 79.391 | 32.195 | 0.75 | 82.3 | 620 |

# Cables input data

**Study:** Xcel Energy 345kV River Crossing
**Execution:** 05 345kV 5000kcmil CU 1023mil XLPE, d=30', 620A, 87°C
**Date:** 5/9/2008

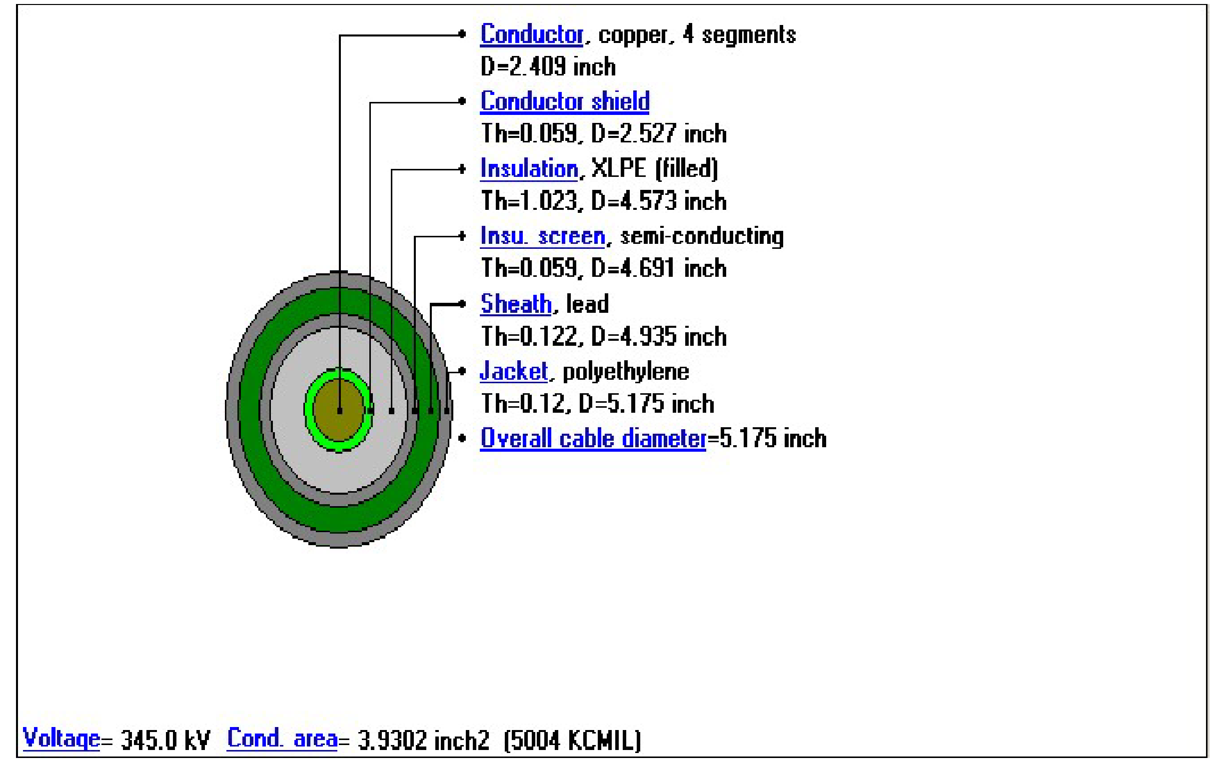
| No | Description | Unit | 1 |
|---|---|---|---|
| **General cable information** | | | |
| 1 | Cable type no | | 1 |
| 2 | Number of cores | | 1 |
| 3 | Voltage | kV | 345 |
| 4 | Conductor area | $inch^2$ | 3.9302 |
| 5 | Maximum Steady-State Conductor Temperature | °C | 90 |
| 6 | Maximum Emergency Conductor Temperature | °C | 105 |
| **Construction** | | | |
| ***Conductor*** | | | |
| 7 | Material | | copper |
| 8 | Resistivity @20°C | uΩ.cm | 1.7241 |
| 9 | Temperature coefficient | 1/K | 0.00393 |
| 10 | Construction | | 4 segments |
| 11 | Is cable dried? | | No |
| 12 | ks (Skin effect coefficient) | | 0.44 |
| 13 | kp (Proximity effect coefficient) | | 0.37 |
| 14 | Diameter | inch | 2.409 |
| ***Conductor shield*** | | | |
| 15 | Is layer present? | | Yes |
| 16 | Thickness | inch | 0.059 |
| 17 | Diameter | inch | 2.527 |
| ***Insulation*** | | | |
| 18 | Is layer present? | | Yes |
| 19 | Material | | XLPE (filled) |
| 20 | Thermal resistivity | K.m/w | 3.5 |
| 21 | Dielectric loss factor - ( tan δ ) | | 0.005 |
| 22 | Relative permeability ( ε ) | | 3 |
| 23 | Thickness | inch | 1.023 |
| 24 | Diameter | inch | 4.573 |
| ***Insulation screen*** | | | |
| 25 | Is layer present? | | Yes |
| 26 | Material | | semi-conducting |
| 27 | Thickness | inch | 0.059 |
| 28 | Diameter | inch | 4.691 |
| ***Sheath*** | | | |
| 29 | Is layer present? | | Yes |
| 30 | Is around each core? (Only for Three core cable) | | No |
| 31 | Material | | lead |
| 32 | Resistivity @20°C | uΩ.cm | 21.4 |
| 33 | Temperature coefficient | 1/K | 0.004 |
| 34 | Corrugated construction | | Non-corrugated |
| 35 | Thickness | inch | 0.122 |
| 36 | Diameter | inch | 4.935 |
| ***Jacket*** | | | |
| 37 | Is layer present? | | Yes |
| 38 | Material | | polyethylene |
| 39 | Thermal resistivity | K.m/w | 3.5 |
| 40 | Thickness | inch | 0.12 |
| 41 | Diameter | inch | 5.175 |
| ***Overall cable diameter*** | | | |
| 42 | Diameter | inch | 5.175 |

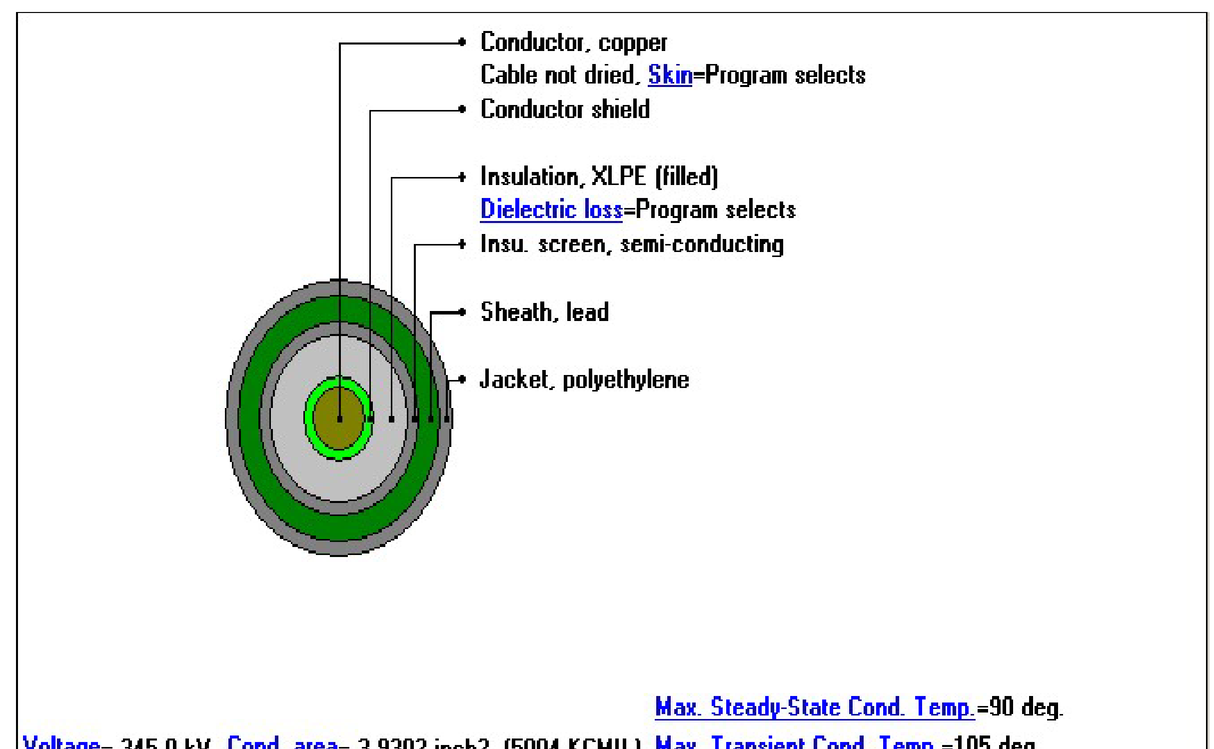
| No | Description/Value | Unit | 1 |
|---|---|---|---|
| **SPECIFIC INSTALLATION DATA** | | | |
| ***Bonding*** | | | |
| 1 | 1-CON, sheaths single point bonded, triang. configuration | | Yes |
| ***Loss factor constant*** | | | |
| 2 | Loss factor constant | | 0.3 |
| ***Duct construction*** | | | |
| 3 | PVC duct in concrete or buried | | Yes |
| 4 | Resistivity (RH) | | 6 |
| ***Cables touching*** | | | |
| 5 | Single conductor cables NOT touching | | Yes |

| No | Symbol | Description | Unit | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|
| **Temperature calculations** | | | | | | | | |
| 1 | | Cable type no | | 1 | 1 | 1 | 1 | 1 |
| 2 | | Circuit no | | 1 | 1 | 1 | 2 | 2 |
| 3 | | Phase | | A | B | C | A | B |
| 4 | $\theta_c$ | Conductor temperature | °C | 82.8 | 81.6 | 82.2 | 87.5 | 86 |
| 5 | $\theta_i$ | Sheath/Shield temperature | °C | 77.3 | 76.1 | 76.7 | 82.1 | 80.6 |
| 6 | $\theta_j$ | Armour/Pipe or Jacket temperature | °C | 76.6 | 75.5 | 76 | 81.4 | 79.9 |
| 7 | $\theta_s$ | Exterior duct temperature | °C | 69.7 | 68.5 | 69.1 | 74.6 | 73.1 |
| 8 | $\theta_a$ | Ambient temperature | °C | 15 | 15 | 15 | 15 | 15 |

| 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|
| | | | | | | |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 3 | 3 | 3 | 4 | 4 | 4 |
| C | A | B | C | A | B | C |
| 87.1 | 87.6 | 86 | 87.1 | 82.9 | 81.2 | 82.3 |
| 81.6 | 82.1 | 80.5 | 81.6 | 77.4 | 75.7 | 76.9 |
| 80.9 | 81.5 | 79.8 | 81 | 76.8 | 75.1 | 76.2 |
| 74.1 | 74.7 | 73 | 74.2 | 69.9 | 68.1 | 69.3 |
| 15 | 15 | 15 | 15 | 15 | 15 | 15 |

**Cable type no:** 1
**Cable type:** EXTRUDED
**Cable ID:** 345CU5.00X
**Cable title:** 345kV 5000 kcmil Cu 1023 mils XLPE 122 mils Pb Sheath



POWER ENGINEERS

Preliminary

**Xcel Energy, CapX Hampton – Rochester – La Crosse 345kV Project Alma Mississippi River Underground Crossing**
**345kV HPFF Transmission Line**

Prepared by: JWH
Checked by:

**2500** kcmil Cu
**4** Cables/phase
**3700** Amps
**6900** feet - Total Length
**1** Number of Operational Circuits
**0** Number of Spare Pipes (Pipe only, no Cable)
**0** Number of communication ducts

| Description | Quantity | Material Price | Total Material Price | Labor Price | Total Labor Price | Total Price |
|---|---|---|---|---|---|---|
| **Pipe and Accessories Section:** | | | | | | |
| Cable pipe, 10" nominal, Pritec, per foot | 14500 | $40.00 | $580,000 | $65.00 | $942,500 | $1,522,500 |
| Cable pipe, 10" nominal, Fusion Bonded, per foo | 13200 | $45.00 | $594,000 | $65.00 | $858,000 | $1,452,000 |
| Cable pipe field flares, each | 11 | $85.00 | $935 | $226.00 | $2,486 | $3,421 |
| Cable pipe chill rings, each | 382 | $34.50 | $13,179 | $224.00 | $85,568 | $98,747 |
| Cable pipe joint and pipe-coating repair sleeves, | 400 | $22.00 | $8,800 | $125.00 | $50,000 | $58,800 |
| Trifurcator, each | 8 | $9,500.00 | $76,000 | $5,000.00 | $40,000 | $116,000 |
| Riser pipe stainless steel 5-inch, per foot | 960 | $50.00 | $48,000 | $29.00 | $27,840 | $75,840 |
| Cathodic Protection: | | | | | | |
| Anodes/grounding, each | 5 | $200.00 | $1,000 | $100.00 | $500 | $1,500 |
| Rectifiers, each | 1 | $4,000.00 | $4,000 | $4,800.00 | $4,800 | $8,800 |
| Isolator Protectors, each | 4 | $8,200.00 | $32,800 | $4,800.00 | $19,200 | $52,000 |
| Cathodic Protection Test Stations, each | 8 | $1,500.00 | $12,000 | $1,100.00 | $8,800 | $20,800 |
| Anode Junction boxes, each | 1 | $1,500.00 | $1,500 | $1,100.00 | $1,100 | $2,600 |
| Pressurization Plant, each | 1 | $500,000.00 | $500,000 | $50,000.00 | $50,000 | $550,000 |
| Polybutene dielectric fluid (HPFF) (gal.) | 89200 | $11.00 | $981,200 | $6.00 | $535,200 | $1,516,400 |
| Other (provide a description) | | | | | | |
| | | | | | | |
| **Cable and Accessories Section:** | | | | | | |
| Cable, feet | 86800 | $113.00 | $9,808,400 | $15.00 | $1,302,000 | $11,110,400 |
| Terminators, each | 24 | $81,000.00 | $1,944,000 | $15,000.00 | $360,000 | $2,304,000 |
| Arresters, each | 24 | $10,000.00 | $240,000 | $2,500.00 | $60,000 | $300,000 |
| Splices, each | 24 | $28,500.00 | $684,000 | $66,000.00 | $1,584,000 | $2,268,000 |
| Spare Terminations | 2 | $81,000.00 | $162,000 | $0.00 | $0 | $162,000 |
| | | | | | | |
| | | | | | | |
| **Earthwork:** | | | | | | |
| Excavation, no rock, per cubic yard, including ha | 22100 | $15.00 | $331,500 | $30.00 | $663,000 | $994,500 |
| Soil Backfill, including hauling, per cubic yard | 20484 | $25.00 | $512,100 | $25.00 | $512,100 | $1,024,200 |
| Concrete Encasement, per cubic yard | 1616 | $130.00 | $210,080 | $20.00 | $32,320 | $242,400 |
| Vault, each | 8 | $40,000.00 | $320,000 | $25,000.00 | $200,000 | $520,000 |
| Horizontal direction drill, per foot | 13200 | $300.00 | $3,960,000 | $500.00 | $6,600,000 | $10,560,000 |
| Dewatering, per trench foot | 14400 | $8.00 | $115,200 | $15.00 | $216,000 | $331,200 |
| Sheeting and shoring, per trench foot | 1500 | $20.00 | $30,000 | $25.00 | $37,500 | $67,500 |
| Landscape restoration, lot | 144000 | $2.50 | $360,000 | $2.50 | $360,000 | $720,000 |
| Loam and seed, per square foot | 360000 | $0.25 | $90,000 | $0.25 | $90,000 | $180,000 |
| | | | | | | |
| | | | | | | |
| **Termination Work** | | | | | | |
| Substation Termination Structures | 8 | $20,000.00 | $160,000 | $16,000.00 | $128,000 | $288,000 |
| Substation Foundations | 8 | $8,000.00 | $64,000 | $12,000.00 | $96,000 | $160,000 |
| Transition Structures, includes relay equipment | 0 | $40,000.00 | $0 | $15,000.00 | $0 | $0 |
| Transition Structure Foundations | 0 | $20,000.00 | $0 | $10,000.00 | $0 | $0 |
| Other (provide a description) | | | | | | |
| Substation | 1 | $265,000.00 | $265,000 | $650,000.00 | $650,000 | $915,000 |
| | | | | | | |
| | | | $0 | | $0 | $0 |
| | | | | | | |
| Subtotal | | | $22,109,694 | | $15,516,914 | $37,626,608 |
| Contingency | **15%** | | $3,316,454 | | $2,327,537 | $5,643,991 |
| Subtotal | | | $25,426,148 | | $17,844,451 | $43,270,599 |
| **Unallocated Costs:** | | | | | | |
| **2%** Engineering, lot | 1 | $0.00 | $0 | $865,411.98 | $865,412 | $865,412 |
| **2%** Construction Management, lot | 1 | $0.00 | $0 | $865,411.98 | $865,412 | $865,412 |
| Mobilization, each | 1 | $0.00 | $0 | $50,000.00 | $50,000 | $50,000 |
| Demobilization, each | 1 | $0.00 | $0 | $50,000.00 | $50,000 | $50,000 |
| **0%** Real Estate/Permitting | 0 | $0.00 | $0 | $0.00 | $0 | $0 |
| | | | | | | |
| | | | | | | |
| **Total Price (should add up to Lump Sum** | | | $25,426,148 | | $19,675,275 | $45,101,423 |



# Cost Estimates

POWER ENGINEERS

Preliminary

| Summary of Costs | Quantity | Material Price | Labor Price | Unit Cost | Total Price |
|---|---|---|---|---|---|
| Earthwork, ft | 14400 | $1,648,880 | $1,910,920 | $248 | $3,559,800 |
| Trenchless Installations, ft | 13200 | $3,960,000 | $6,600,000 | $800 | $10,560,000 |
| Manholes,ea | 8 | $320,000 | $200,000 | $65,000 | $520,000 |
| Cable,ft | 86800 | $9,808,400 | $1,302,000 | $128 | $11,110,400 |
| Splices, ea | 24 | $684,000 | $1,584,000 | $94,500 | $2,268,000 |
| Terminations, ea | 26 | $2,106,000 | $360,000 | $94,847 | $2,466,000 |
| Arresters, ea | 24 | $240,000 | $60,000 | $12,500 | $300,000 |
| Pipe, ft | 27700 | $1,174,000 | $1,800,500 | $108 | $2,974,500 |
| Pipe Accessories, ft | 801 | $1,628,114 | $791,094 | $3,021 | $2,419,208 |
| Cathodic Protection System, ea | 1 | $51,300 | $34,400 | $85,700 | $85,700 |
| Termination Structures, ea | 8 | $489,000 | $874,000 | $170,375 | $1,363,000 |
| **Subtotal** | 0 | $22,109,694 | $15,516,914 | | $37,626,608 |
| 15% Contingency | | $3,316,454 | $2,327,537 | | $5,643,991 |
| MOB & DEMOB | 1 | $0 | $100,000 | | $100,000 |
| 4% Engineering & Construction Man. | 1 | $0 | $1,730,824 | | $1,730,824 |
| 0% Real Estate/Permitting | 1 | $0 | $0 | | $0 |
| **Total** | | $25,426,148 | $19,675,275 | | $45,101,423 |
| 0% Escalation Factor | | $0 | $0 | | $0 |
| **Grand Total** | | $25,426,148 | $19,675,275 | | $45,101,423 |



POWER ENGINEERS

Preliminary

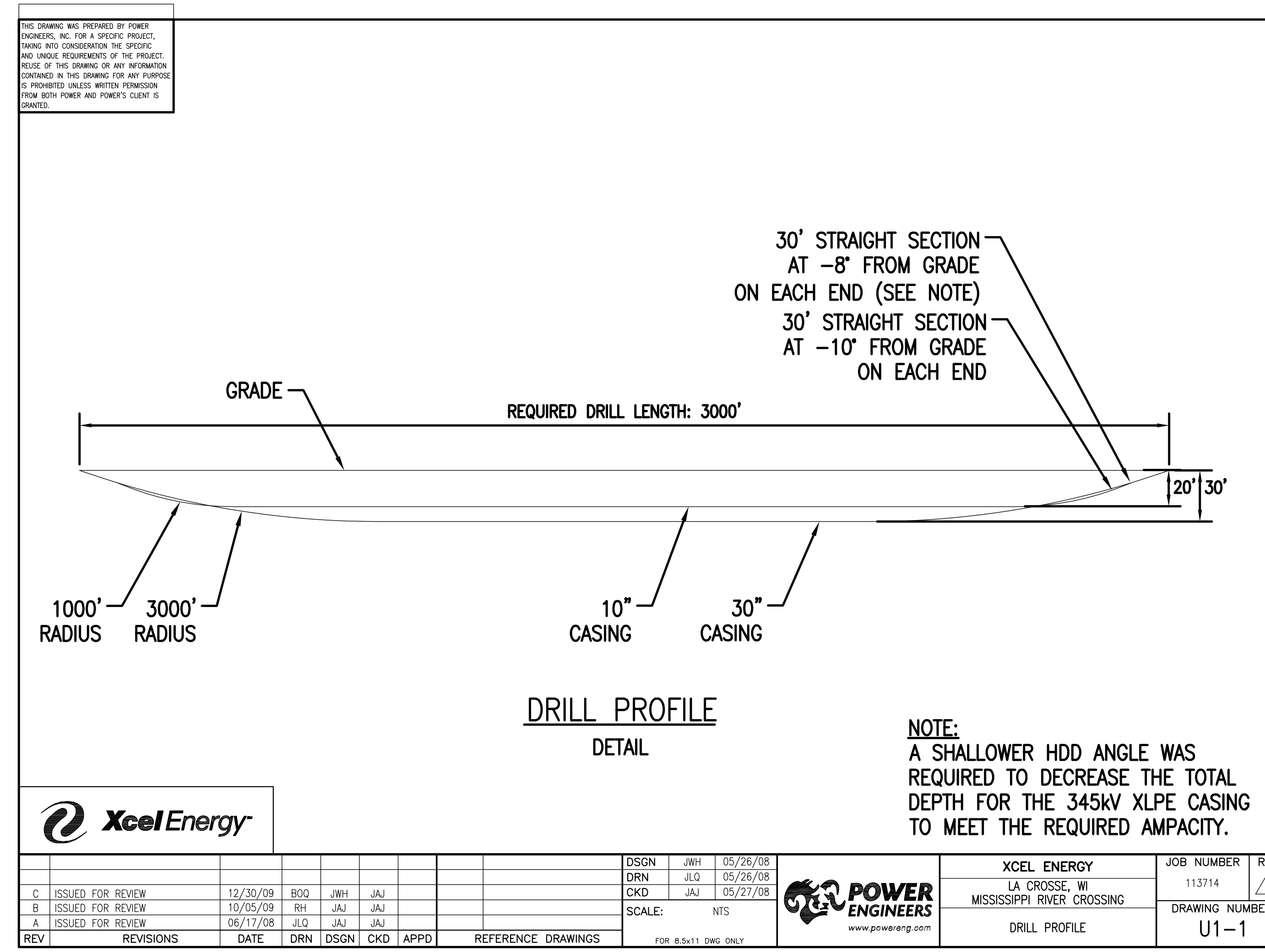
**Xcel Energy, CapX Hampton – Rochester – La Crosse 345kV Project Alma Mississippi River Underground Crossing**
**345 kV XLPE Transmission Line**

**Prepared by: JWH**
**Checked by:**

**5000 kcmil CU**
**18 Cables**
**1600 Amps**
**6900 feet**
**1 Number of Duct Banks**
**24 Number of Cable Ducts**
**0 Number of Comm Ducts**

| Description | Quantity | Material Price | Total Material Price | Labor Price | Total Labor Price | Total Price |
|---|---|---|---|---|---|---|
| **Cable and Accessories Section:** | | | | | | |
| XLPE cable, per foot | 132100 | $225.00 | $29,722,500 | $15.00 | $1,981,500 | $31,704,000 |
| Terminators, each | 36 | $81,000.00 | $2,916,000 | $15,000.00 | $540,000 | $3,456,000 |
| Arresters, each | 36 | $10,000.00 | $360,000 | $2,500.00 | $90,000 | $450,000 |
| Splices, each | 36 | $30,000.00 | $1,080,000 | $70,000.00 | $2,520,000 | $3,600,000 |
| Grounding system for vaults, each | 24 | $2,500.00 | $60,000 | $3,500.00 | $84,000 | $144,000 |
| Link boxes, single phases | 24 | $5,000.00 | $120,000 | $500.00 | $12,000 | $132,000 |
| Cable clamps, each | 600 | $200.00 | $120,000 | $100.00 | $60,000 | $180,000 |
| Continuity conductor, per foot | 15000 | $4.00 | $60,000 | $2.00 | $30,000 | $90,000 |
| Continuity conduit | 41900 | $1.50 | $62,850 | $8.00 | $335,200 | $398,050 |
| Jacket Integrity Test, cable segment | 18 | $0.00 | $0 | $2,500.00 | $45,000 | $45,000 |
| Other (provide a description) | | | | | | |
| | | | | | | |
| | | | | | | |
| **Duct Bank and Earthwork:** | | | | | | |
| Conduit, per foot | 167300 | $7.00 | $1,171,100 | $15.00 | $2,509,500 | $3,680,600 |
| Spacers, each | 34560 | $8.00 | $276,480 | $15.00 | $518,400 | $794,880 |
| Bore Spacers, each | 3960 | $175.00 | $693,000 | $15.00 | $59,400 | $752,400 |
| Excavation, no rock, per cubic yard, including | 9200 | $15.00 | $138,000 | $30.00 | $276,000 | $414,000 |
| Soil Backfill, including hauling, per cubic yard | 6000 | $25.00 | $150,000 | $25.00 | $150,000 | $300,000 |
| Duct encasement concrete, per cubic yard | 3200 | $130.00 | $416,000 | $20.00 | $64,000 | $480,000 |
| Vault, each | 24 | $40,000.00 | $960,000 | $25,000.00 | $600,000 | $1,560,000 |
| Horizontal direction drill, per foot | 19800 | $300.00 | $5,940,000 | $500.00 | $9,900,000 | $15,840,000 |
| 30" Bore Casing, per foot | 19800 | $500.00 | $9,900,000 | $200.00 | $3,960,000 | $13,860,000 |
| Casing Fill, cubic yards | 2898 | $150.00 | $434,700 | $75.00 | $217,350 | $652,050 |
| Dewatering, per trench foot | 21600 | $8.00 | $172,800 | $15.00 | $324,000 | $496,800 |
| Sheeting and shoring, per trench foot | 2200 | $20.00 | $44,000 | $25.00 | $55,000 | $99,000 |
| Landscape restoration, lot | 216000 | $2.50 | $540,000 | $2.50 | $540,000 | $1,080,000 |
| Loam and seed, per square foot | 540000 | $0.25 | $135,000 | $0.25 | $135,000 | $270,000 |
| Other (provide a description) | | | | | | |
| | | | | | | |
| | | | | | | |
| **Termination Work** | | | | | | |
| Substation Termination Structures | 12 | $20,000.00 | $240,000 | $10,000.00 | $120,000 | $360,000 |
| Substation Foundations | 12 | $3,000.00 | $36,000 | $2,000.00 | $24,000 | $60,000 |
| Other (provide a description) | | | | | | |
| Substation | 1 | $398,000.00 | $398,000 | $225,000.00 | $225,000 | $623,000 |
| | | | | | | |
| Subtotal | | | $56,201,430 | | $25,430,350 | $81,631,780 |
| 15% Contingency | | | $8,430,215 | | $3,814,553 | $12,244,768 |
| Subtotal | | | $64,631,645 | | $29,244,903 | $93,876,548 |
| **Unallocated Costs:** | | | | | | |
| Engineering, lot (2%) | 1 | $0.00 | $0 | $1,877,530.96 | $1,877,531 | $1,877,531 |
| Construction Management, lot (2%) | 1 | $0.00 | $0 | $1,877,530.96 | $1,877,531 | $1,877,531 |
| Mobilization, lot | 1 | $0.00 | $0 | $50,000.00 | $50,000 | $50,000 |
| Demobilization, lot | 1 | $0.00 | $0 | $50,000.00 | $50,000 | $50,000 |
| Real Estate/Permitting | 0 | $0.00 | $0 | $0.00 | $0 | $0 |
| Other (provide a description) | | | | | | |
| | | | | | | |
| | | | | | | |
| **Total Price (should add up to Lump Sum** | | $ | $64,631,645 | $ | $33,099,965 | $97,731,610 |
| | | | | | | |

| Summary of Costs | Quantity | Material Price | Labor Price | Unit Cost | Total Price |
|---|---|---|---|---|---|
| Duct Bank, ft | 20700 | $14,126,080 | $8,863,650 | $1,111 | $22,989,730 |
| Trenchless Installations, ft | 19800 | $5,940,000 | $9,900,000 | $800 | $15,840,000 |
| Manholes,ea | 24 | $960,000 | $600,000 | $65,000 | $1,560,000 |
| Cable,ft | 132100 | $29,722,500 | $1,981,500 | $240 | $31,704,000 |
| Splices, ea | 36 | $1,080,000 | $2,520,000 | $100,000 | $3,600,000 |
| Terminations, ea | 36 | $2,916,000 | $540,000 | $96,000 | $3,456,000 |
| Arresters, ea | 36 | $360,000 | $90,000 | $12,500 | $450,000 |
| Additional Cable Accessories, ft | 20700 | $422,850 | $566,200 | $48 | $989,050 |
| Termination Structures, ea | 12 | $674,000 | $369,000 | $86,917 | $1,043,000 |
| 15% Contingency | | $8,430,215 | $3,814,553 | | $12,244,768 |
| MOB & DEMOB | 1 | $0 | $100,000 | | $100,000 |
| Engineering Construction Management Services | 1 | $0 | $3,755,062 | | $3,755,062 |
| **Total** | | $64,631,645 | $33,099,965 | | $97,731,610 |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30' STRAIGHT SECTION AT –8' FROM GRADE ON EACH END (SEE NOTE)
30' STRAIGHT SECTION AT –10' FROM GRADE ON EACH END
GRADE
REQUIRED DRILL LENGTH: 3000'
20'
30'
1000' RADIUS
3000' RADIUS
10" CASING
30" CASING
DRILL PROFILE
DETAIL
NOTE:
A SHALLOWER HDD ANGLE WAS REQUIRED TO DECREASE THE TOTAL DEPTH FOR THE 345kV XLPE CASING TO MEET THE REQUIRED AMPACITY.
XcelEnergy
C ISSUED FOR REVIEW 12/30/09 BOQ JWH JAJ
B ISSUED FOR REVIEW 10/05/09 RH JAJ JAJ
A ISSUED FOR REVIEW 06/17/08 JLQ JAJ JAJ
REV REVISIONS DATE DRN DSGN CKD APPD
REFERENCE DRAWINGS
DSGN JWH 05/26/08
DRN JLQ 05/26/08
CKD JAJ 05/27/08
SCALE: NTS
FOR 8.5x11 DWG ONLY
POWER ENGINEERS
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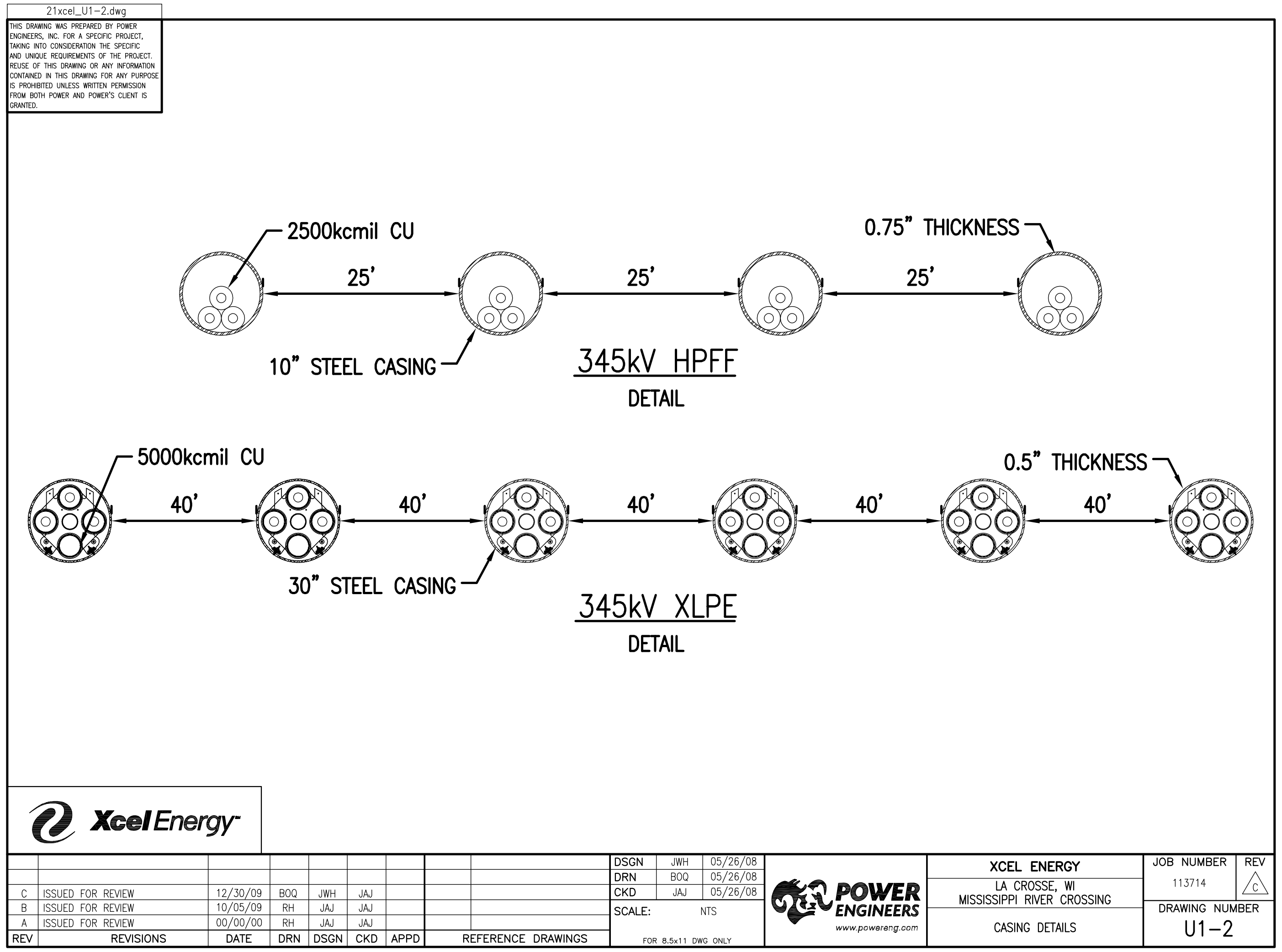
XCEL ENERGY
LA CROSSE, WI
MISSISSIPPI RIVER CROSSING
DRILL PROFILE
JOB NUMBER 113714
REV C
DRAWING NUMBER
U1–1

**HDD Details**




## Termination Details

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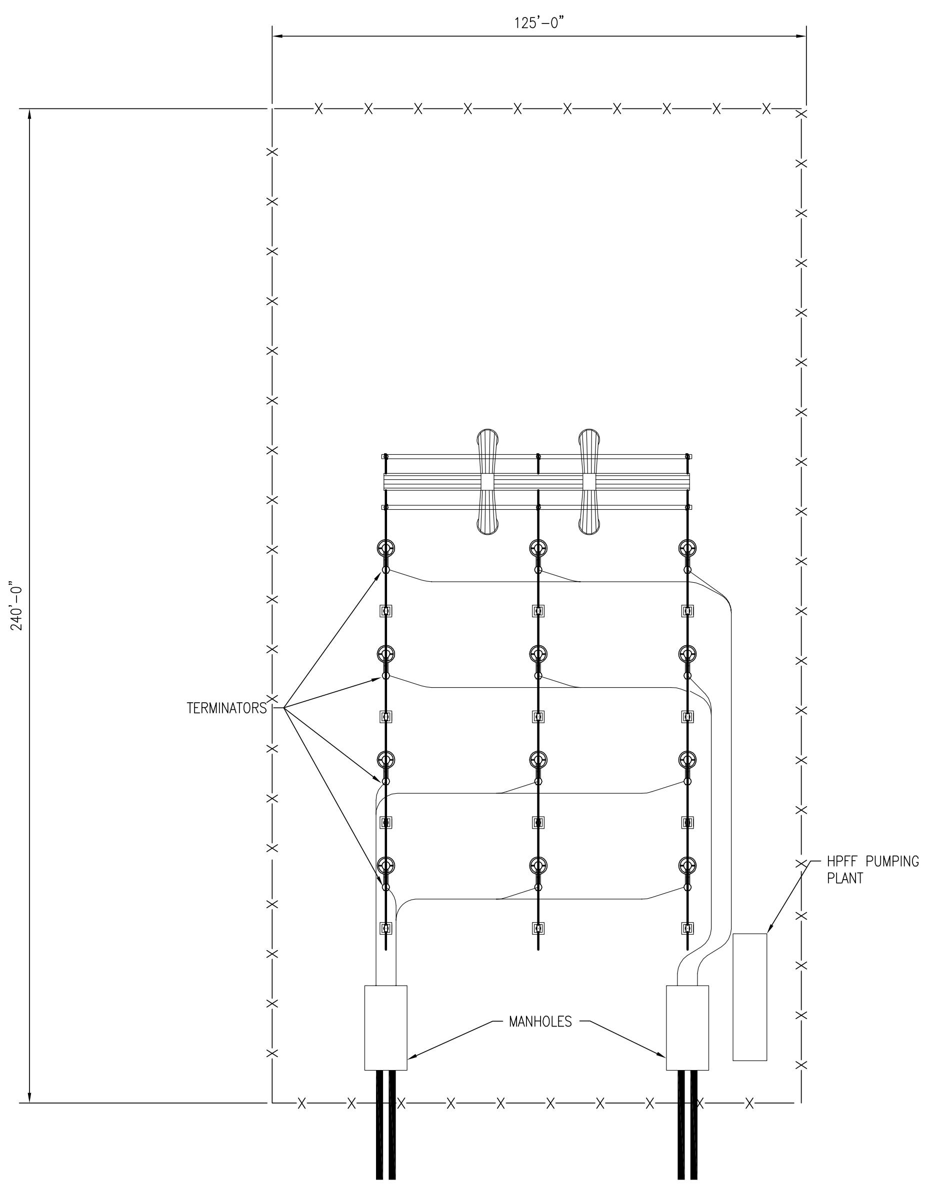
| REV | REVISIONS | DATE | DRN | DSGN | CKD | APPD |
|---|---|---|---|---|---|---|
| C | ISSUED FOR REVIEW | 12/30/09 | BOQ | JAJ | JAJ | |
| B | ISSUED FOR REVIEW | 10/05/09 | RH | JAJ | JAJ | |
| A | ISSUED FOR REVIEW | 06/17/08 | JLQ | JAJ | JAJ | |




Xcel Energy

| | |
|---|---|
| DSGN | JAJ 06/16/08 |
| DRN | JLQ 06/16/08 |
| CKD | JAJ 06/16/08 |
| SCALE: | NTS |

FILE

REFERENCE DRAWINGS

FOR 8.5x11 DWG ONLY

POWER ENGINEERS www.powereng.com

XCEL ENERGY
LA CROSSE, WI
MISSISSIPPI RIVER CROSSING
HPFF TERMINATION STATION DETAILS

JOB NUMBER 113714 REV C

DRAWING NUMBER S1-1

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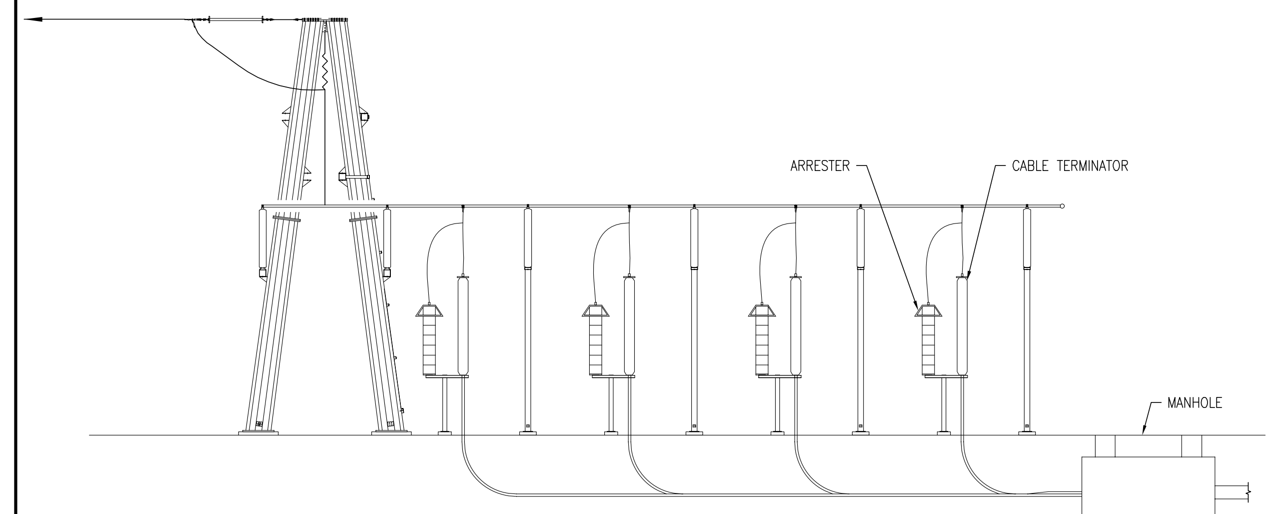
| REV | REVISIONS | DATE | DRN | DSGN | CKD | APPD |
|---|---|---|---|---|---|---|
| C | ISSUED FOR REVIEW | 12/30/09 | BOQ | JAJ | JAJ | |
| B | ISSUED FOR REVIEW | 10/05/09 | RH | JAJ | JAJ | |
| A | ISSUED FOR REVIEW | 06/17/08 | JLQ | JAJ | JAJ | |




Xcel Energy

| | |
|---|---|
| DSGN | JAJ 06/16/08 |
| DRN | JLQ 06/16/08 |
| CKD | JAJ 06/16/08 |
| SCALE: | NTS |

21XCEL_S1-2.DWG

REFERENCE DRAWINGS

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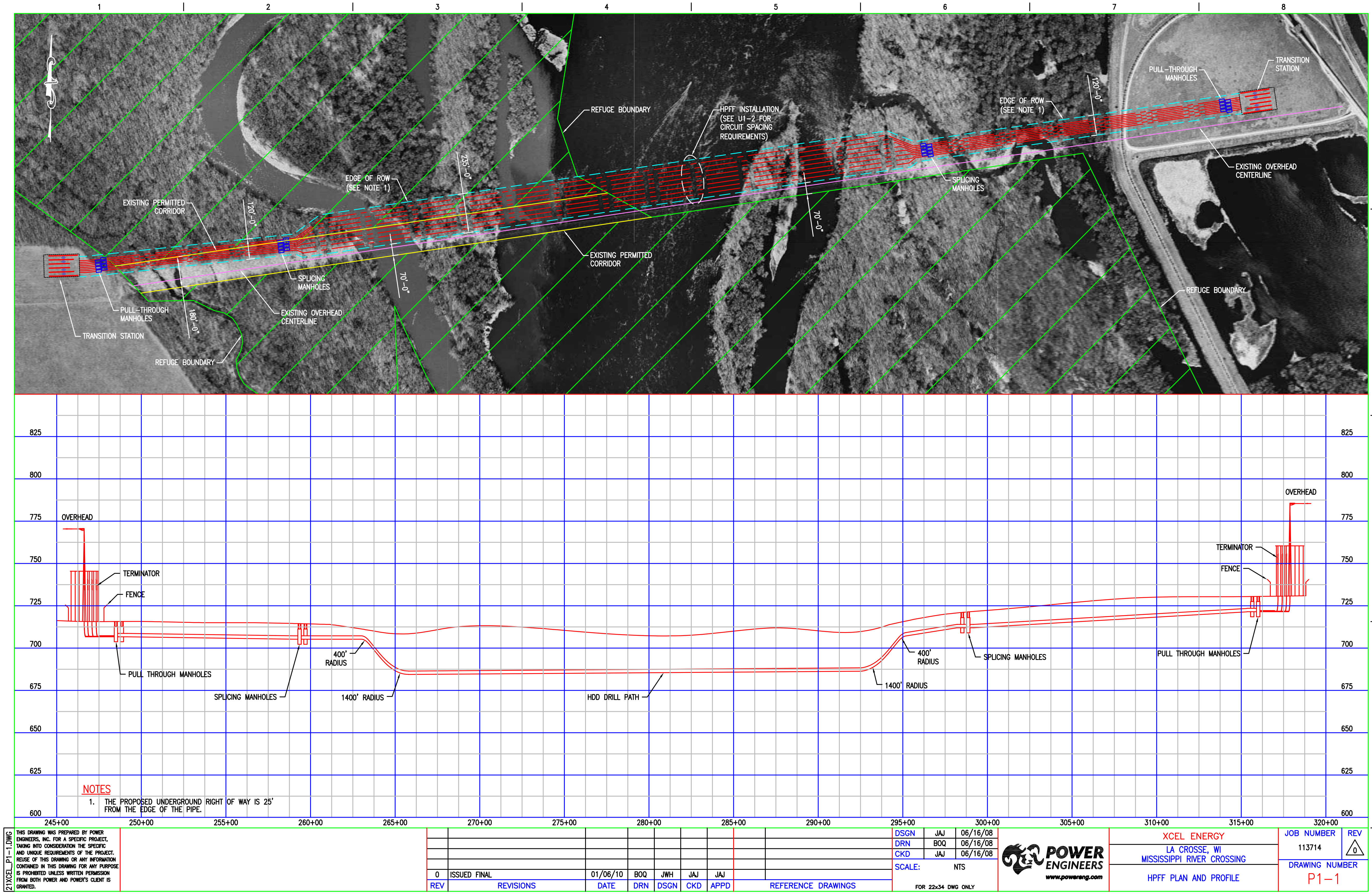
POWER ENGINEERS www.powereng.com

XCEL ENERGY
LA CROSSE, WI
MISSISSIPPI RIVER CROSSING
HPFF TERMINATION STATION DETAILS

JOB NUMBER 113714 REV C

DRAWING NUMBER S1-2

# Plan and Profile


PULL-THROUGH MANHOLES
TRANSITION STATION
EDGE OF ROW (SEE NOTE 1)
120'-0"
REFUGE BOUNDARY
HPFF INSTALLATION (SEE U1-2 FOR CIRCUIT SPACING REQUIREMENTS)
EDGE OF ROW (SEE NOTE 1)
235'-0"
EXISTING PERMITTED CORRIDOR
SPLICING MANHOLES
EXISTING OVERHEAD CENTERLINE
70'-0"
180'-0"
REFUGE BOUNDARY
OVERHEAD
TERMINATOR
FENCE
PULL THROUGH MANHOLES
SPLICING MANHOLES
400' RADIUS
1400' RADIUS
HDD DRILL PATH
NOTES
1. THE PROPOSED UNDERGROUND RIGHT OF WAY IS 25' FROM THE EDGE OF THE PIPE.
21XCEL_P1-1.DWG
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0 ISSUED FINAL 01/06/10 BOQ JWH JAJ JAJ
REV REVISIONS DATE DRN DSGN CKD APPD
REFERENCE DRAWINGS
DSGN JAJ 06/16/08
DRN BOQ 06/16/08
CKD JAJ 06/16/08
SCALE: NTS
FOR 22x34 DWG ONLY
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LA CROSSE, WI
MISSISSIPPI RIVER CROSSING
HPFF PLAN AND PROFILE
JOB NUMBER 113714
REV 0
DRAWING NUMBER P1-1

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