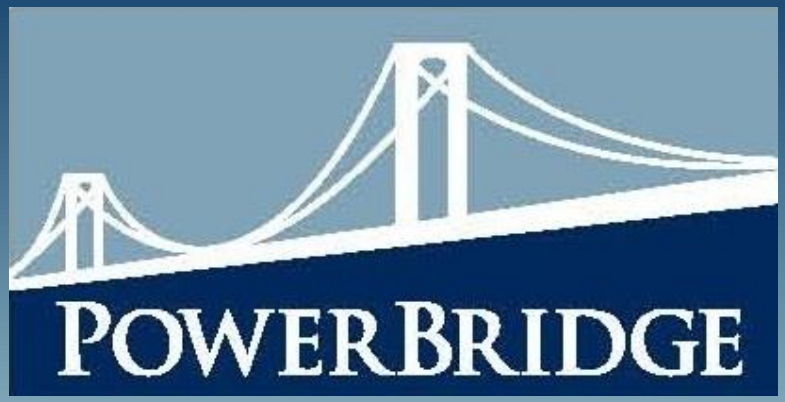
HVDC Development Process

Designated Entity Design Standards Task Force

September 7, 2017
Audubon, PA



- Since 2005:
  - 1320 MW of power transmission infrastructure development, financing, construction and operation
  - $1.5 billion in private investment
- Flagship Projects, both On Budget and Ahead of Schedule:
  - Neptune RTS: 2007; 660 MW; $650 million
  - Hudson: 2013; 660 MW; $850 million
- Actively pursuing additional, complementary projects

NEPTUNE Regional Transmission System

- 65- Mile-Long, 660-MW HVDC Cable Linking PJM Electricity Market with Long Island Power Authority (“LIPA”)
- 51 Miles of Cable are Buried Undersea
- 14 Miles Underground
- Selected by LIPA in June 2004 Via Competitive RFP Process
- Financial Close July 2005 with Investment-Grade Rating
- Completed June 2007 – On Budget and Ahead of Schedule

Neptune RTS Project Team

NEPTUNE Regional Transmission System

Project management, permitting, financing, operations

LIPA Long Island Power Authority

SIEMENS

PRYSMIAN CABLES & SYSTEMS

Principal Contractors:
Top global companies in HVDC and cable technology

NEPTUNE
Regional Transmission System

Two Terminal Monopolar System Metallic Return

- **Advantages of HVDC Transmission**
  - Controlled Power Exchange
  - Limitation of Short Circuit Currents
  - Transmission at variable voltages
  - No fault cascading

NEPTUNE
Regional Transmission System

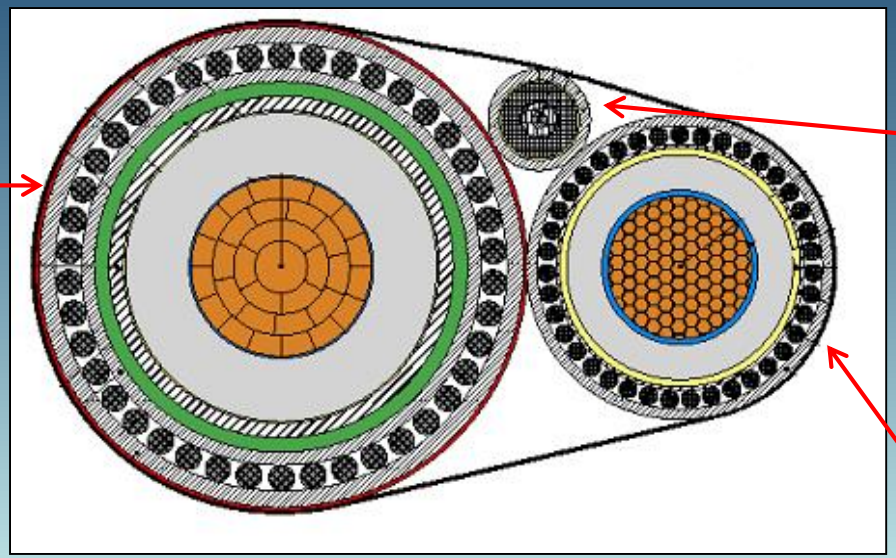
Cables Installed in Multiple Campaigns

NEPTUNE
Regional Transmission System

Sayreville Converter Station

NEPTUNE
Regional Transmission System

Neptune DC Cable



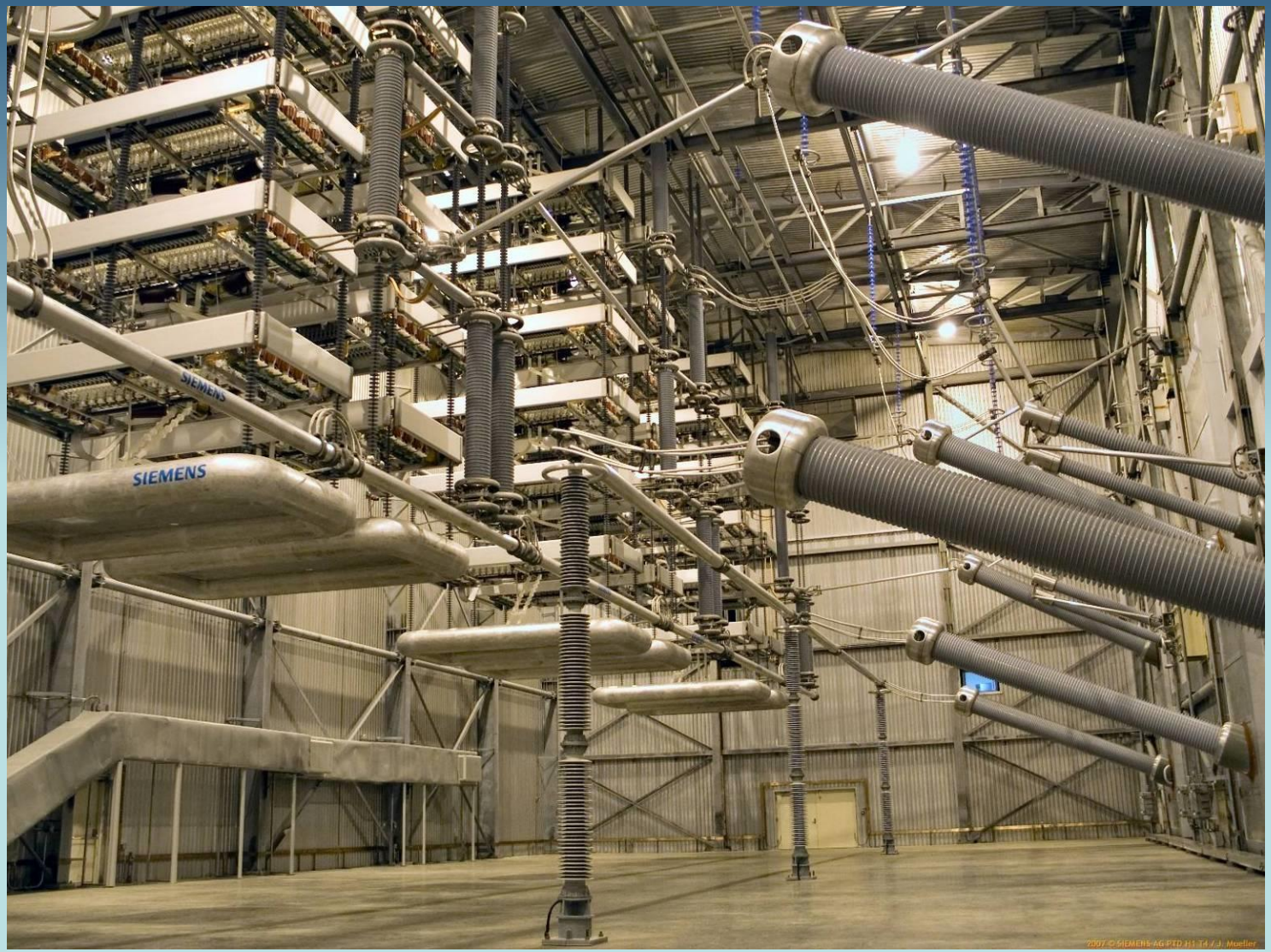
High Voltage Main Cable (Copper Core)

Fiber Optic Cable

Medium Voltage Return Cable

NEPTUNE
Regional Transmission System

Valve Hall

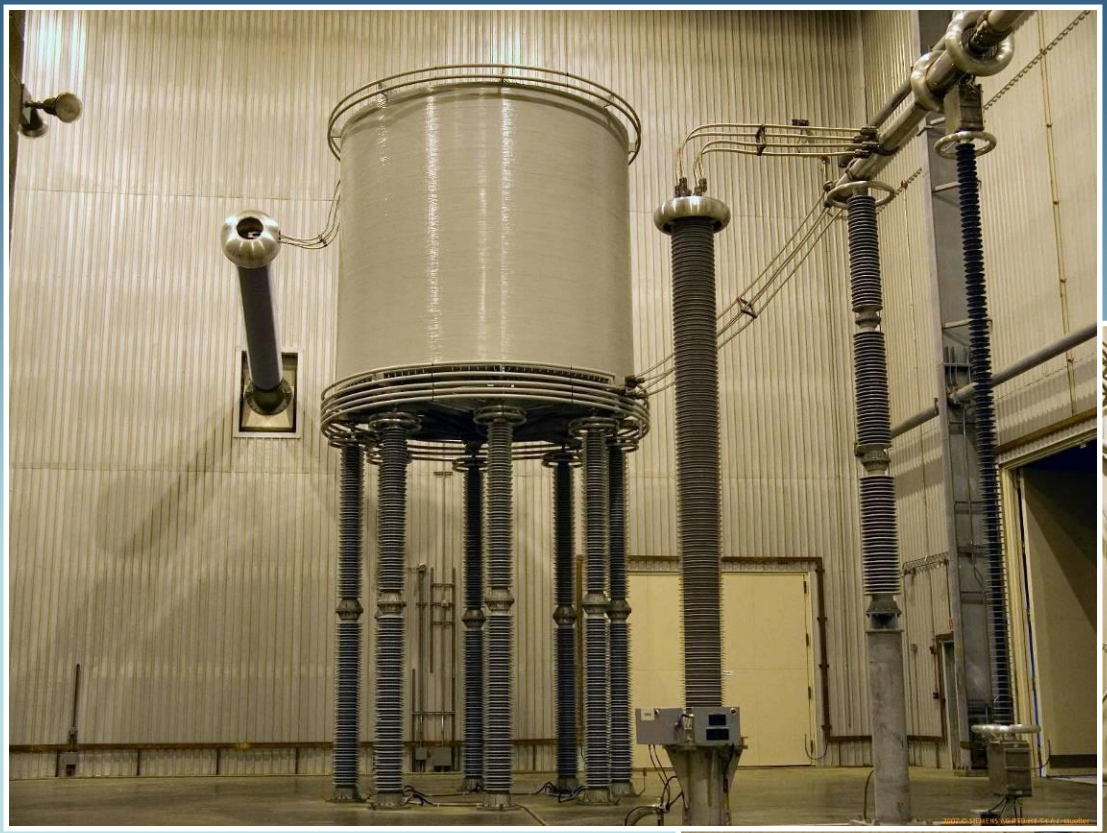


NEPTUNE
Regional Transmission System

Converter Transformer (Single Phase)

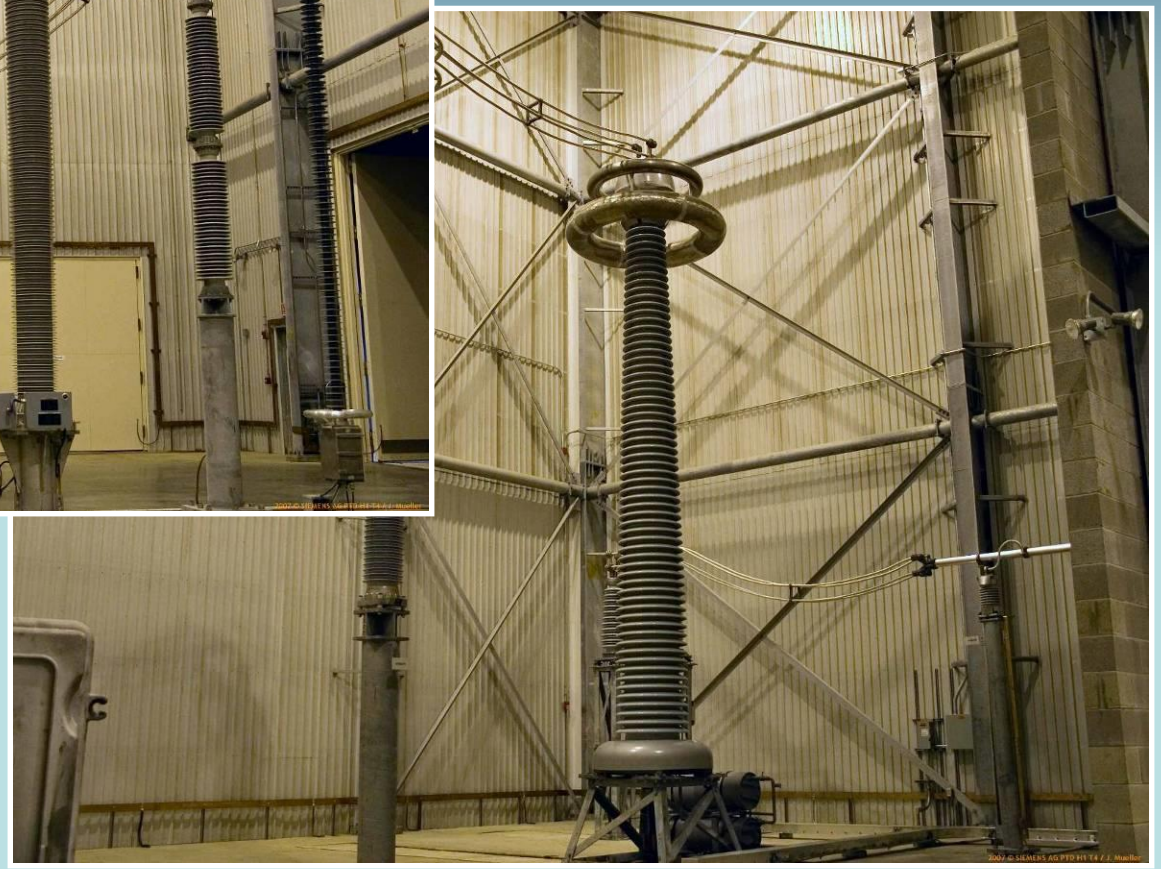
NEPTUNE
Regional Transmission System

DC Hall

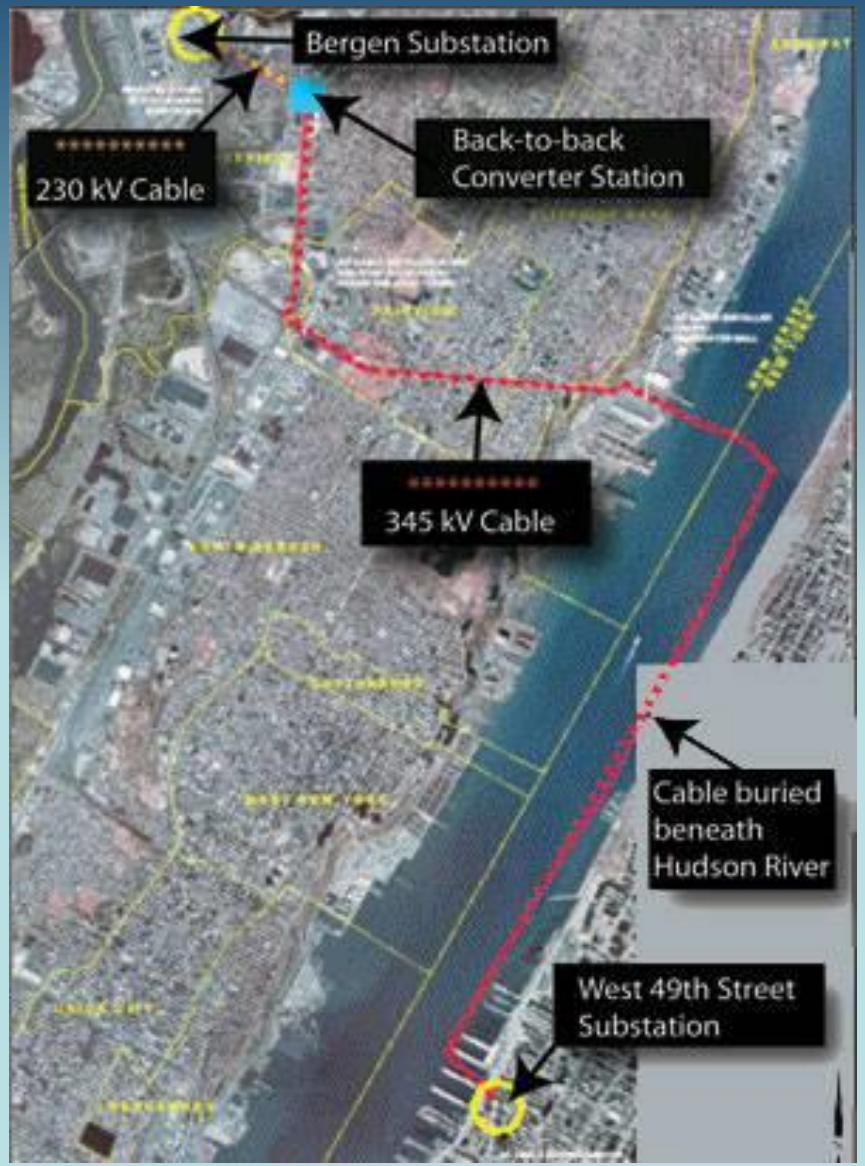


DC Smoothing Reactor

500 kV Cable Termination



Hudson Transmission Project



- 8-mile underground and underwater power cable linking PJM and NY power grids between Ridgefield, New Jersey and West 49th St. Substation in NYC
- Single back-to-back converter station (AC-DC-AC) located in Ridgefield, NJ
- Project commencement in May 2011
- Completed ahead of schedule and under budget May 2013

Hudson Transmission Project Team

HUDSON

Comprising the Neptune Project Team – project management, permitting, financing success

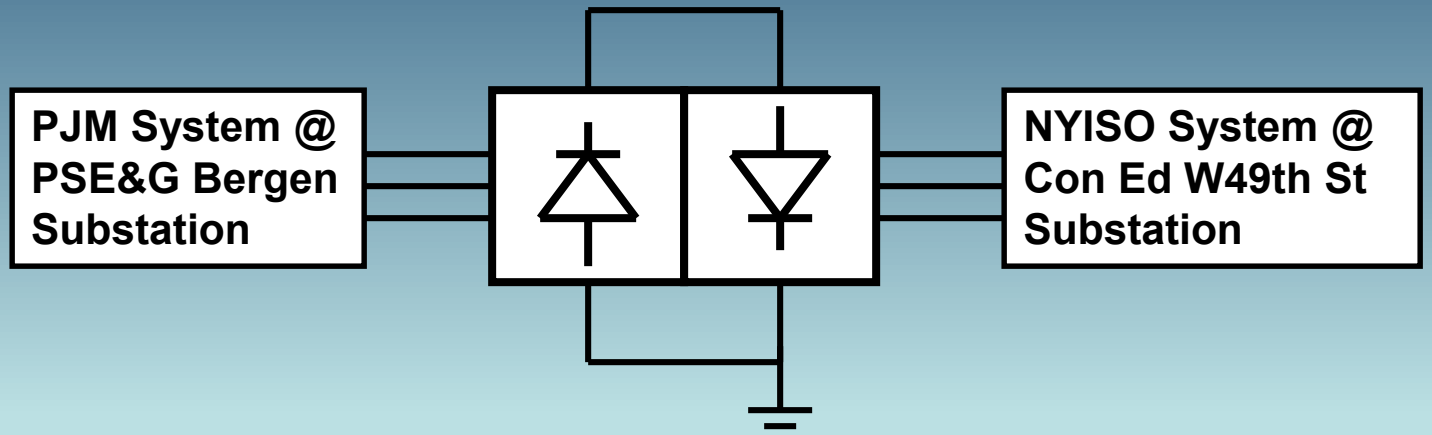
New York Power Authority

SIEMENS

PRYSMIAN CABLES & SYSTEMS

Principal Contractors for Neptune – top global companies in HVDC and cable technology

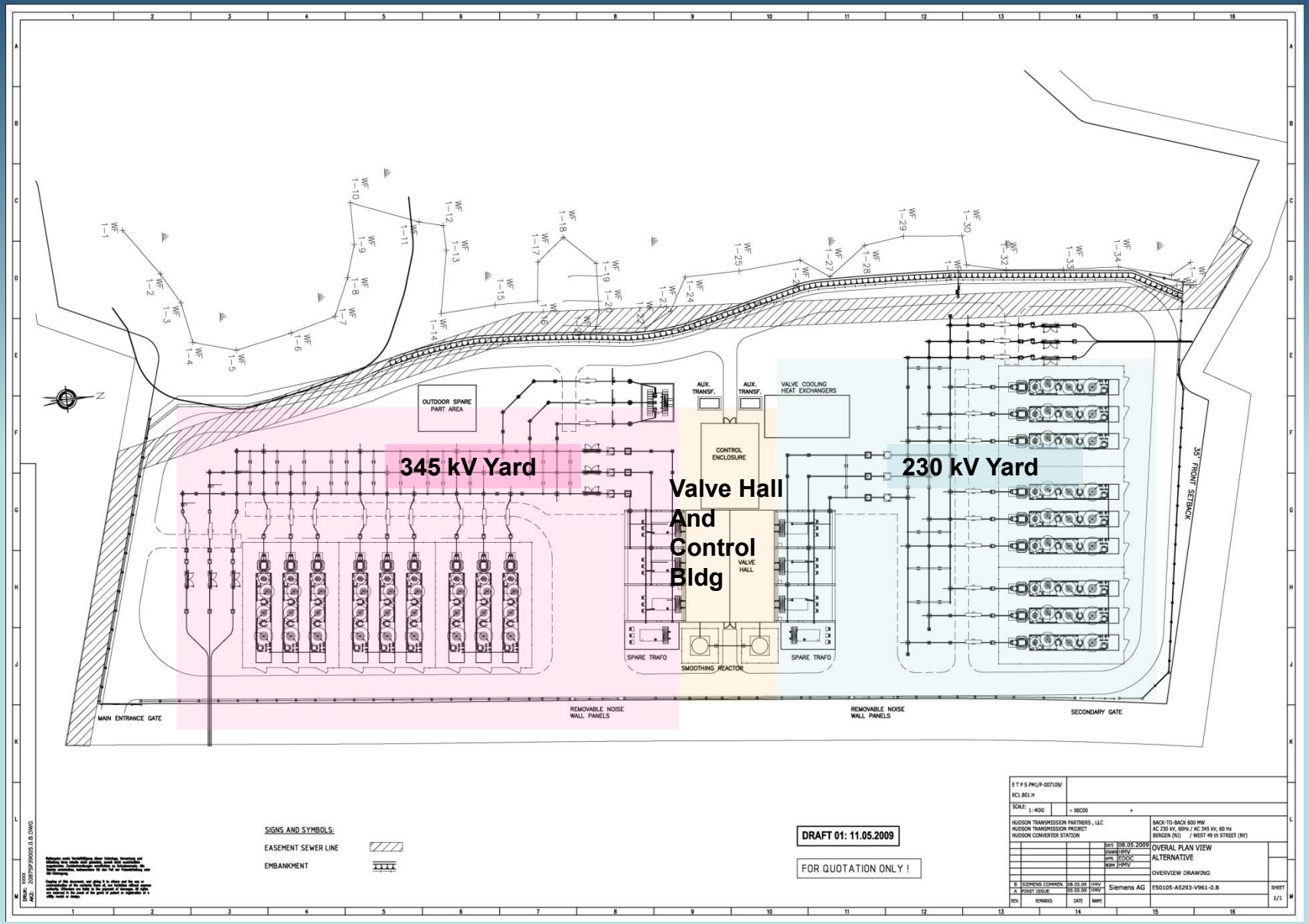
Back-to-Back Monopolar System



Advantages of HVDC Transmission

- Controlled Power Exchange
- Limitation of Short Circuit Currents
- Transmission at variable voltages
- No fault cascading

Back-to-Back Converter Station



HVDC Development Stages

*** = inc. cooperation with Interconnecting Utilities and ISOs**

- Pre-Engineering Studies
- Interconnection Studies*
- Interconnection Agreement (IA) Technical Specification Development*
- Post IA Detailed Design*
- Component Manufacture
- Installation
- Commission Testing*

Pre-Engineering Studies

- Terminal Location(s)
  - Network area(s) that could benefit from new transmission and HVDC
  - Close to robust interconnection points (minimize AC pathway)
  - Sufficient Converter Space (8+Acres for LCC; 5+/-Acres for VSC)
  - Attainable Interconnection Pathway (Existing ROWs; R/R; Water; or Public Roads)
- Project Development to support IR(s) and Permitting
  - Terminal Layouts and One-Line Diagram(s)
  - ROW acquisition
  - Installation Methods
  - Environmental Impacts

Interconnection Studies

- Preliminary Electrical Characteristics
  - Voltage performance: Reactive allowances and limitations
  - Power Quality at interconnecting points
  - Harmonic Impedances (long-term measurements)
- Interconnection Optimization
  - Substation Access
  - Breaker position(s)
- PSS/E Modeling (Best Estimate definitions)
- Feasibility/SRIS Studies
- Technical Specification Development

IA Technical Specification Development

PJM Interconnection, LLC
and
Public Service Electric and Gas Company

TECHNICAL PERFORMANCE SPECIFICATION

For the

Bergen (Hudson Transmission Project) 230 kV
HVDC PROJECT
Ridgefield, NJ

May 9, 2009

Table of Contents

POWERBRIDGE

Post IA Detailed Design

Design Reports

1. **Project Main Circuit Design:** Verify technical parameters of IAs and EPC contract
2. **Reactive Power Flow Exchange:** Verify allowable levels versus filter design
3. **AC Protection and Metering:** Coordinate interconnecting design with utilities
4. **Dynamic Performance:** Verify HVDC system behavior vs. system transients
5. **PLC Filter Design:** Ensure HTP avoids interference with local PLC communication systems
6. **Circuit Breaker Coordination:** Determine station breaker ratings and coordinate with interconnecting utilities.
7. **SSTI Studies:** Evaluate interaction of HVDC Station with local generators and other FACTS
8. **AC System Harmonic Performance**: Verify harmonics do not exceed technical requirements
9. **Insulation Coordination Studies:** Establish insulation and arrester levels of the main equipment for converter station and interconnecting stations
10. **Control Implementation:** Define SCADA system parameters and interconnecting utility data points
11. **Load Flow and Stability Models (PSS/E):** Final models to ISOs & Interconnecting Utilities

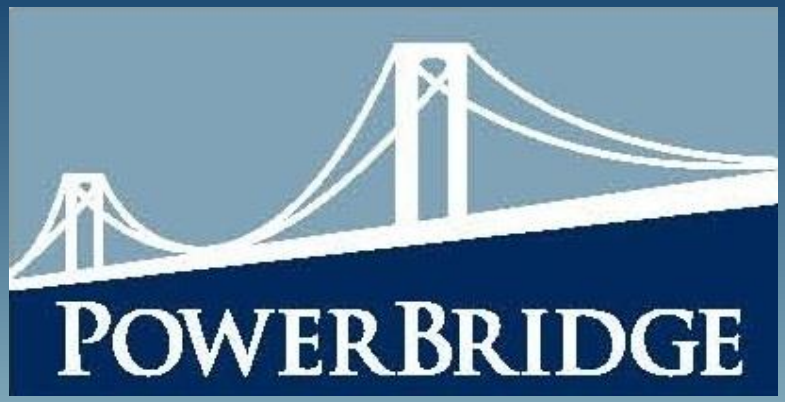
Component Manufacture

- DC Valves
- Converter Transformers
- AC Switchyard Devices
  - Reactive Banks (for LCC; VSC may be NR)
- Protection and Control
  - Individual Panels, inc. FST
  - All-inclusive system, inc. DST (* for witnessing)

Component Manufacture

- Installation
- Commission Testing*
  - Voltage and reactive power control tests
  - AC Harmonic Filter performance tests
  - Power-Line Carrier Filter performance tests
  - Radio Interference performance tests
  - Television Interference performance tests
  - Nameplate Power Transfer
  - Load Losses

NEPTUNE
Regional Transmission System



THANK YOU!

For more information please visit **www.powerbridge.us**