Resilient Electric Grids
Superconductor Cable Solutions

April 2023

smarter, cleaner
... better energy

AMSC Corporate Facts

- Headquartered in MA, USA
- Founded in 1987; IPO in 1991
- Sales & Service staff in N. America, Europe, Asia, and Australia
- Wind Energy and T&D Solutions Provider

AMSC Product portfolio

smarter, cleaner
...better energy

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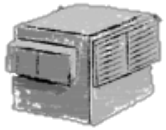

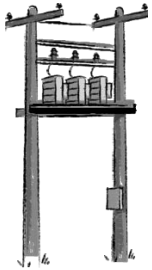

	Electrical Control System for wind turbines (wtECS™)	Transmission Voltage Management (D-VAR®)	Resilient Electric Grid (REG) systems	Distribution Voltage Optimization (D-VAR® VVO)	NEPSI and NEELTRAN	Ship Protection Systems (SPS)
What it is	Components and controls that act as the "brain" and "nerves" of turbines	Voltage regulation solution, driven by power electronics components	System that increases electric grid resiliency, reliability, and load serving capacity	Direct connect 15Kv class power quality system for distribution network	Rectifiers and transformers for industrial equipment. Capacitor banks and harmonic filters for medium-voltage power quality applications.	Advanced HTS-based systems that enhance operational safety
What is does	Maximizes power generation, ROI of wind power installations	Connects renewable energy to grid; provides reactive power compensation	Increases reliability of urban grids and provides cost-effective, simplified solution for urban load growth	Optimally controls voltage, allowing utilities to build distribution networks using distributed generation (DG)	DC power to the load. Line side mitigates common power quality issues in the areas of power-factor correction, harmonic distortion	Degaussing is a magnetic system that interferes with a mine's ability to detect and damage a ship
Target markets	Wind turbine OEMs using AMSC wind turbine designs	Electric utilities, renewable plants, industrial facilities	Urban electric utilities	Electric distribution grids incorporating DG	Industrials including Hydrogen	Navy Surface fleet

ComEd Installation - Chicago

- Successful Integration into the Grid Announced August 31st, 2021
- 12kV, 3000A, 62 MVA
- Classified as a Transmission Asset
- Links together two Distribution terminals otherwise not connected at 12kV
- Creates an additional layer of redundancy in the event of loss of a transmission circuit or transformer

- Substantially increase resiliency with a far smaller footprint

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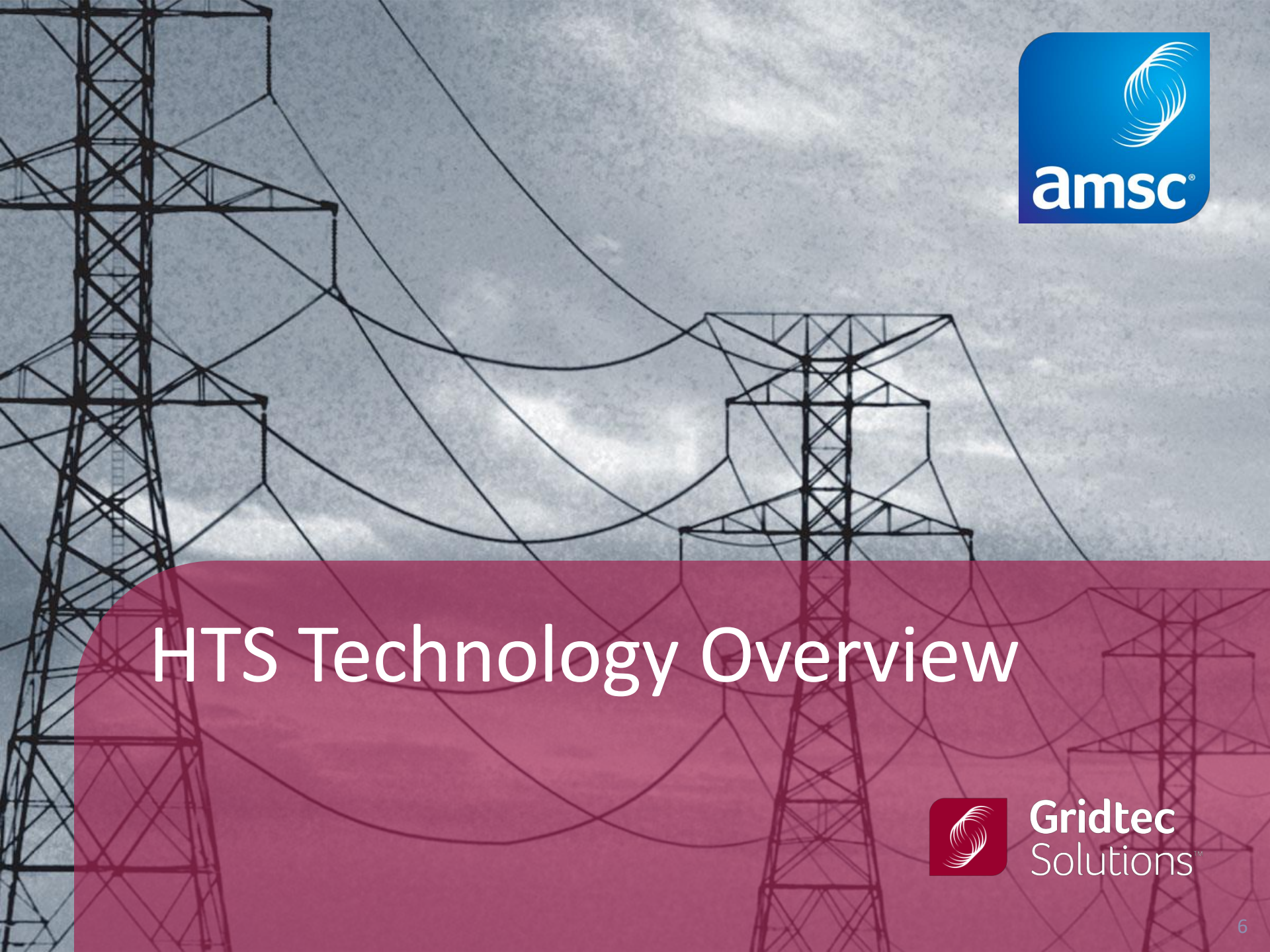
HTS Cable Urban Applications

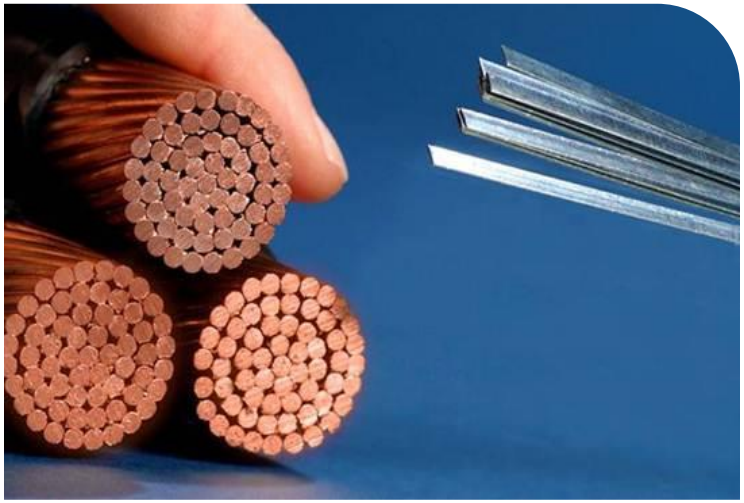


HTS Technology Overview

Gridtec Solutions™

What is a Superconductor?

- **Superconductors are materials that exhibit unique electrical characteristics:**
  - Zero resistance (low losses)
  - High current density (high power)
  - High electro-magnetic shielding (low EMF)
- **These characteristics require:**
  - Cooling below a critical temperature
  - Current levels below a critical current
  - Magnetic field below a certain magnitude



- **Above these critical levels the material "quenches", and current must flow elsewhere**
- **Ceramic high temperature superconductor (HTS) material discovered in 1986**
  - Requires less cooling; cost effective liquid nitrogen may be used
  - 78% of the earth's atmosphere

Development of HTS has enabled utility commercial applications

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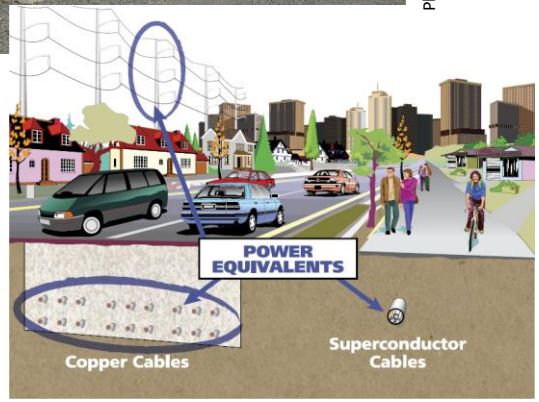
Superconductor AC Power Cables
Unique Electrical Characteristics

- Very high power transfer capability compared to conventional cables solves many siting problems
- Thermal isolation eliminates de-rating, simplifies placement concerns, and minimizes right-of-way
- Optional fault current management capabilities eliminate need to upgrade existing equipment
- Minimal magnetic field

Photo courtesy Long Island Power Authority



Superconductor cables offer unique capabilities

Key HTS Cable PHYSICAL Characteristics

Unique Electrical Characteristics

- Very high current (4000A per phase)
- Near zero resistance (low overall impedance)
- Minimal EMF
- No thermal constraints for placement
- Fault current management

Familiar Physical Characteristics

- Looks like conventional cable
- May be spliced
- May be placed in ducts or direct buried
- Similar bending radius and pulling strengths
- Liquid nitrogen cooling similar to conventional oil cooled cable systems

HTS Cables offer unique capabilities in a familiar package

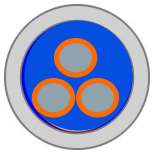
HTS Cable System Designs

Naval / Industrial Applications

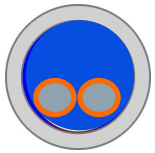
Electric Utility Applications

Low Voltage AC/DC/Degaussing

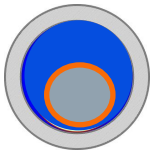
3 phase AC



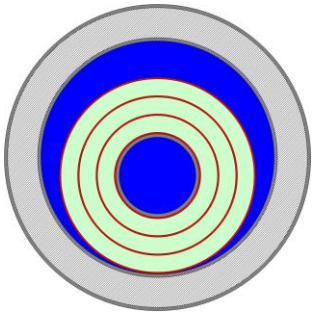
2 pole DC



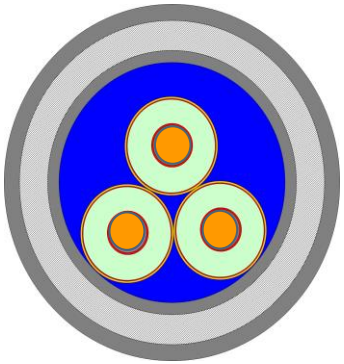
1 pole DC



3 Phase AC, Concentric phases



3 Phase AC, All phases in one cryogenic envelope



HVDC or 3 Phase AC, Separate Phases/Poles

LV → HV

Rated Voltage

HTS Concentric Phase Distribution Cable

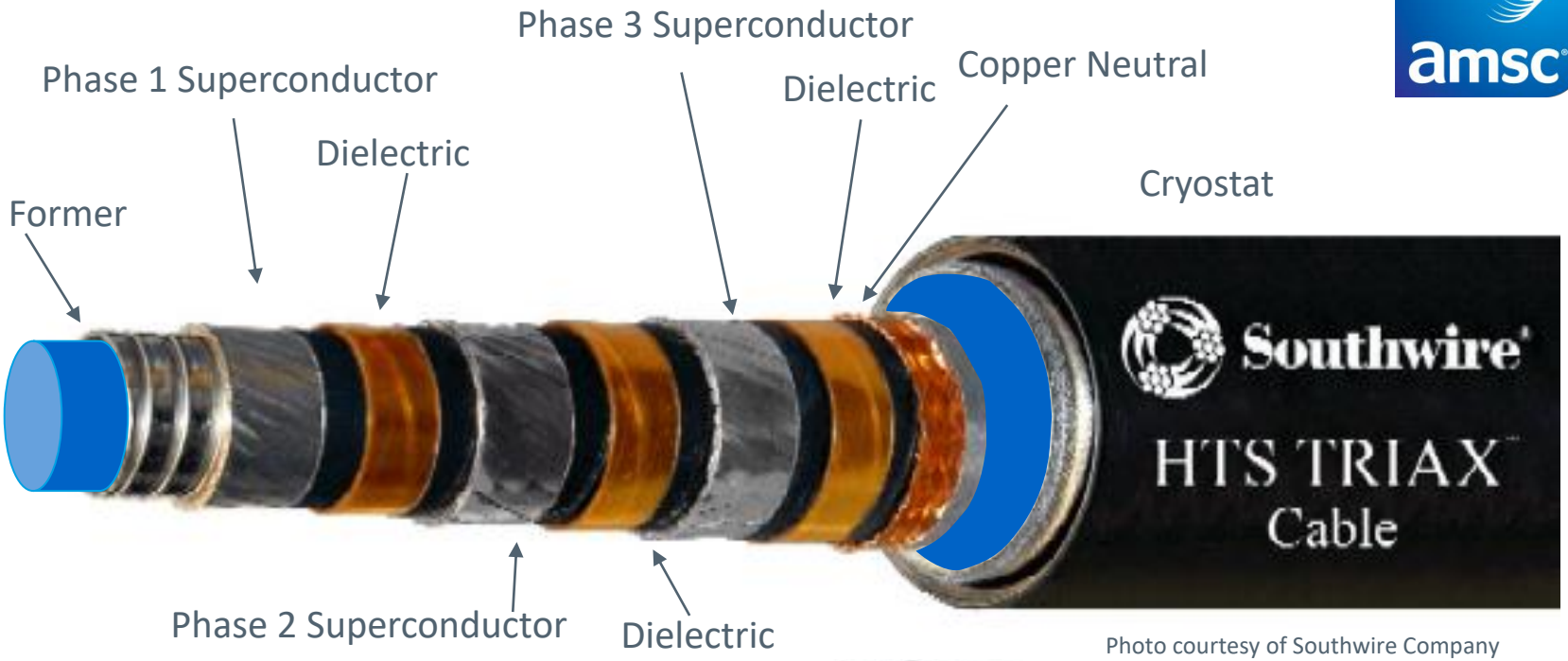


Photo courtesy of Southwire Company

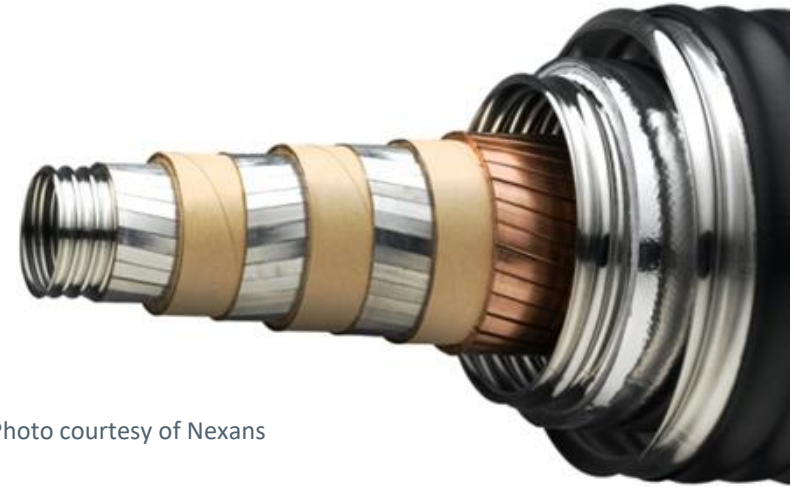
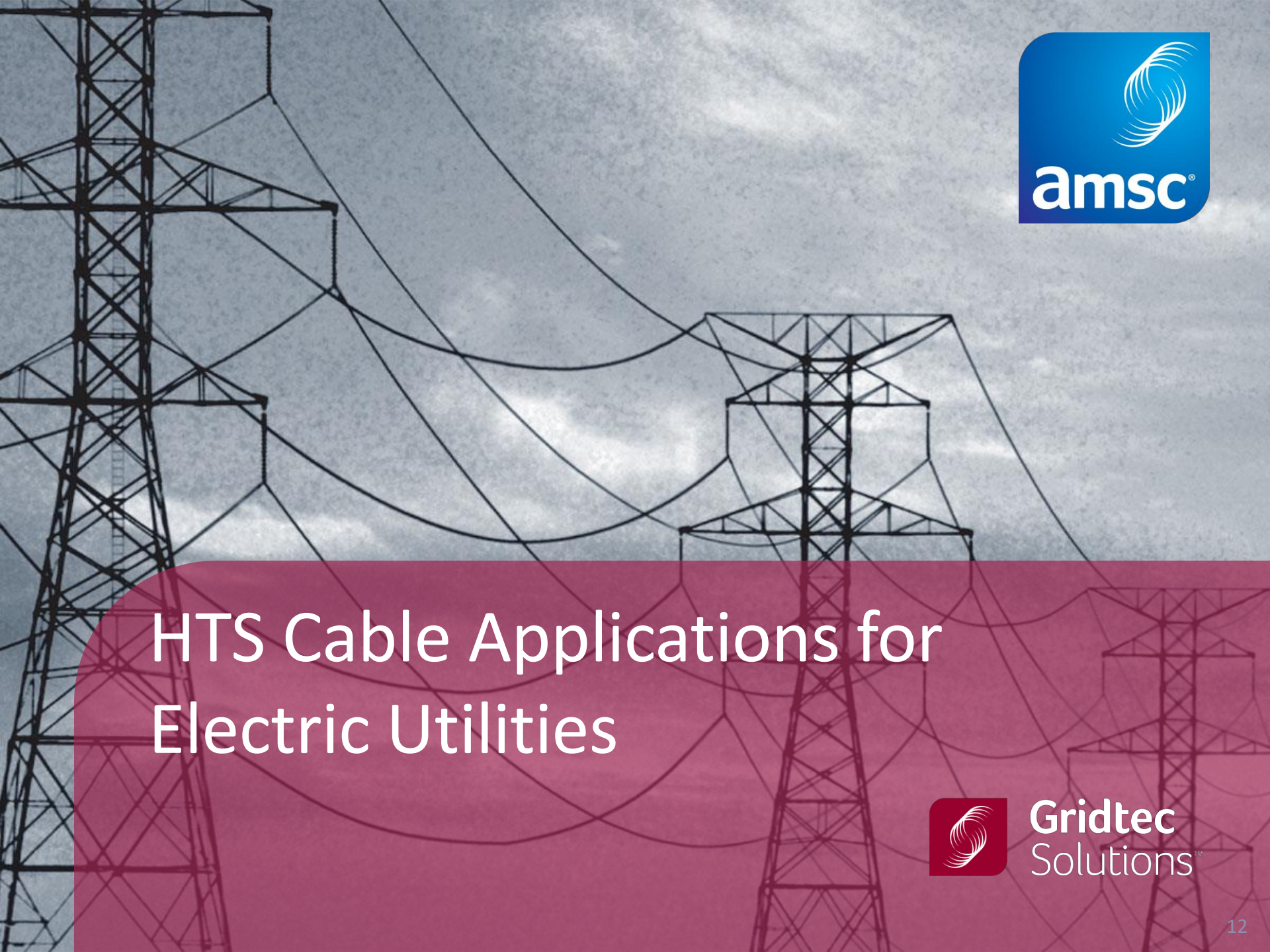


Photo courtesy of Nexans



HTS Cable Applications for Electric Utilities

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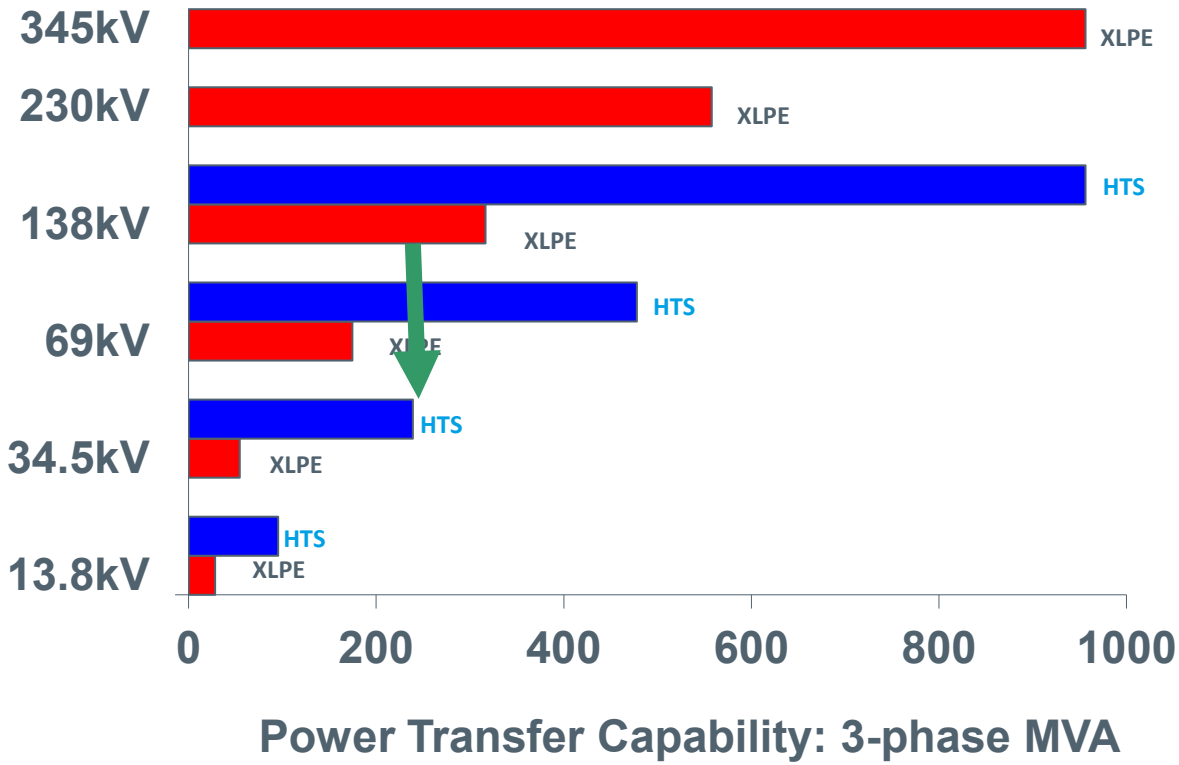
Power Transfer Equivalency of Superconductor Cables



Same Voltage, More Power

Greatly increased power transfer capacity at any voltage level

Same Power, Lower Voltage

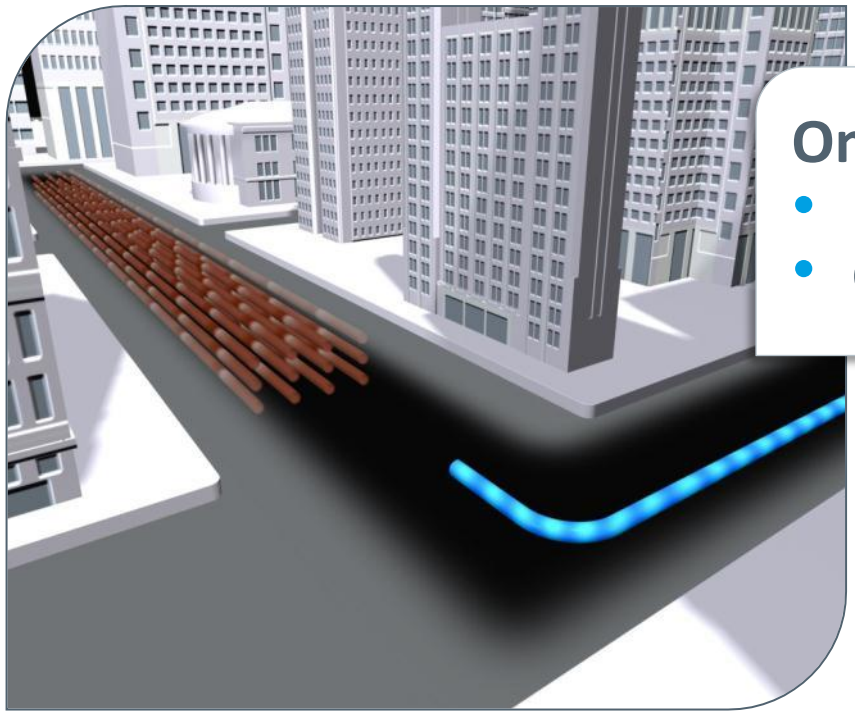
New MV versus HV Siting Opportunity

- "MV Transmission"
- Ideal for NIMBY & ROW sparse environments

* **No XLPE cable de-rating factors applied**.
Superconductor rating based on conventional 4000A breaker rating

HTS Cables provide transmission-level power at distribution voltages

Simplifying Transmission Siting



One MV HTS Cable can replace:

- Many conventional underground circuits
- Overhead transmission line

Photo courtesy Consolidated Edison

HTS Cables Offer New Options to Siting Power Lines

AEP/Bixby Cable System

- Energized in August 2006
- World's first HTS tri-axial voltage cable system in the grid
- Rated 13.8kV, 60MVA, averages 70-80% of rated MVA
- Experienced over 40 through faults with no adverse effects

Photo courtesy Ultera

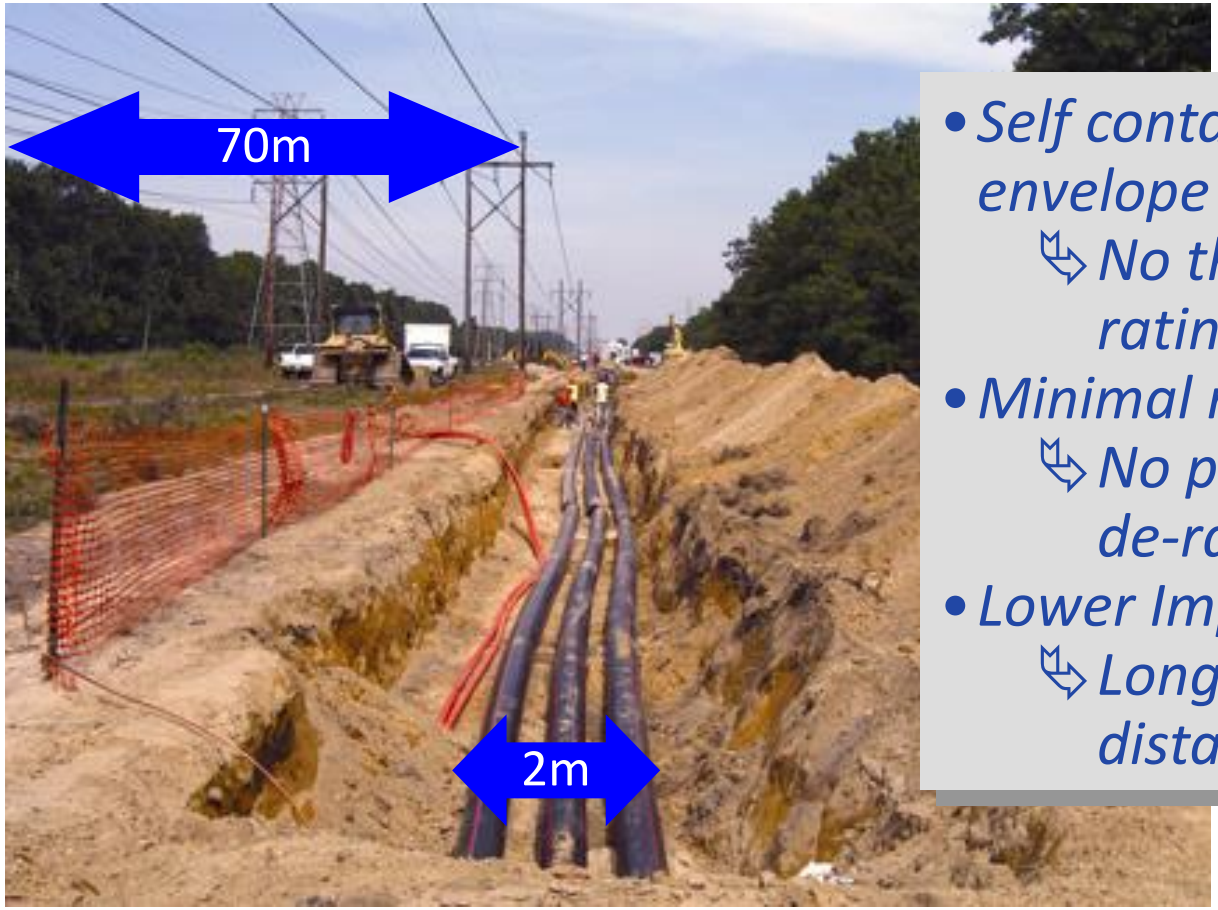
- Long term, uneventful operation proven

Long Island Power Authority Cable

- Energized in April 2008
- World's first HTS transmission voltage cable system in the grid
- Longest, most powerful superconductor cable in the world
- Able to carry 574 MW of power in a four-foot-wide right of way
- Landmark cable installation proving high power, transmission level applications

Over 15 years of superconductor cable experience

Superconductor Example: 138 kV, 575MW Capacity



- *Self contained thermal envelope*
  - *No thermal de-rating*
- *Minimal magnetic field*
  - *No parallel line de-rating*
- *Lower Impedance*
  - *Longer practical distance*

Simplify placement and offer new options to line siting

Ampacity project in Essen, Germany

- Energization announced in May of 2014
- Allows substantial amount of power to be brought into a dense urban environment at 10kV (replaces 110kV line)
- Includes HTS cable and series standalone HTS Fault Current Limiter
- 1km length includes a cable joint

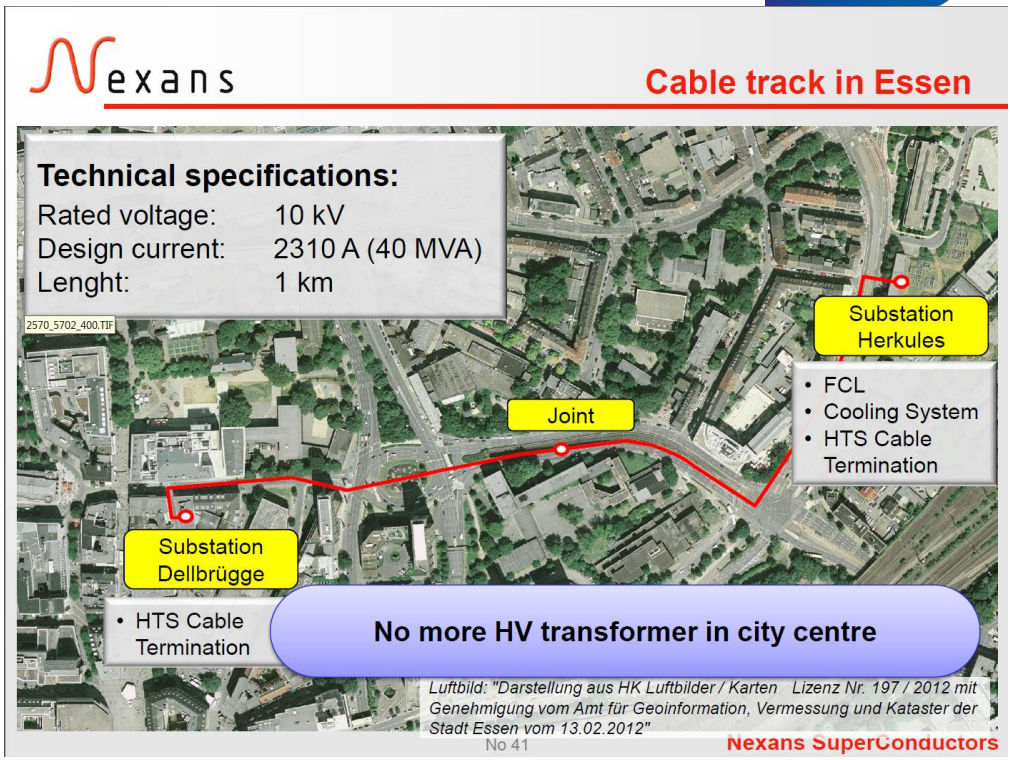


Figure courtesy of Nexans

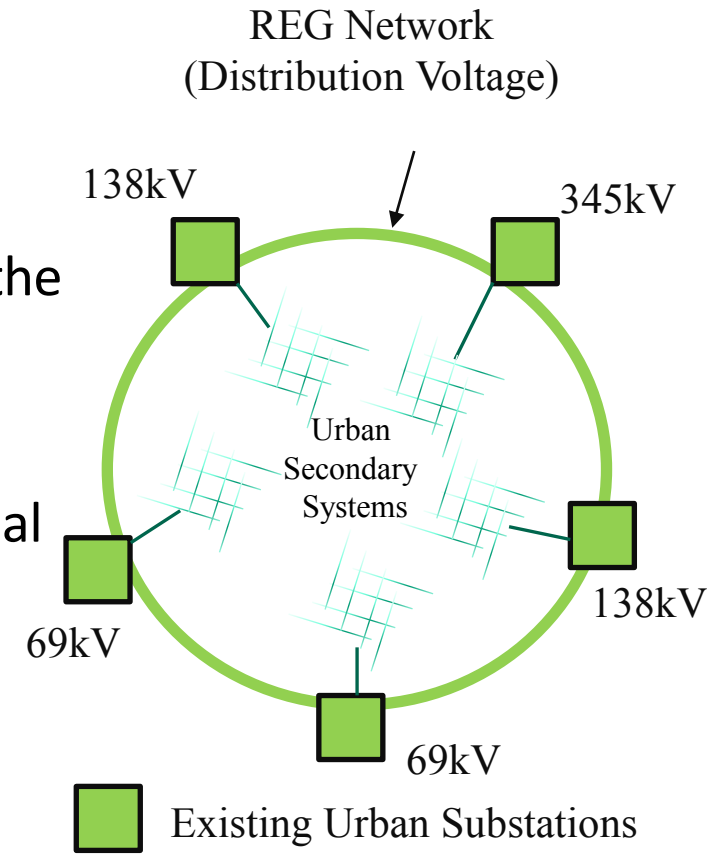
Project minimizes the expansion of an urban substation

ComEd REG Projects

REG Networks Utilize High Temperature Superconductor (HTS) Cables

Creating a higher level network above the existing Urban Secondary System

- ✓REG Networks provide **resiliency** by creating grid **redundancy**
- ✓REG Networks c**onnect** urban substations on the d**istribution side**, effectively **reinforcing** the transmission system
- ✓REG Networks provide **high capacity, distribution voltage connections** with minimal footprint, civil work and permitting
- ✓Approach is independent of **transmission voltage levels,** but compliments the existing transmission system



Possible Second REG Project in Chicago's Central Business District

Chicago's Central Business District (CBD)

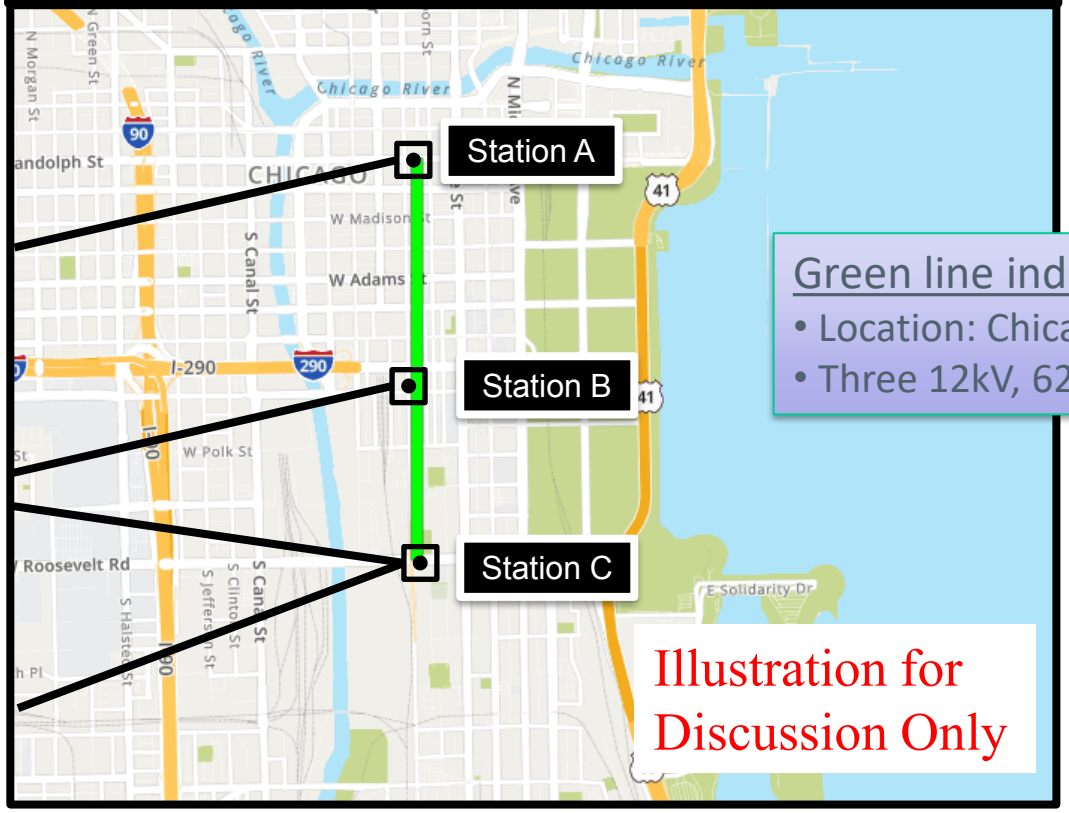


Illustration for Discussion Only

Green line indicates superconducting cables:

- Location: Chicago's Central Business District (CBD)
- Three 12kV, 62MVA superconductor cables

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Initial Project - Northwest

Smaller scale initial phase with similar benefits

- ✓ As a prelude to the possible CBD project, ComEd will implement a REG Network at different Chicago substation to increase the reliability level from N-1 to N-2
- ✓ Project will serve to increase the reliability within the substation by providing a high-capacity link between two terminals in the substation
- ✓ Effort will provide experience and lessons learned to be incorporated into the possible CBD project

Superconductor Cable – Initial Project

Legend

- Superconductor Cable
- Refrigeration Building
- Underground Cable
- Terminations

← North

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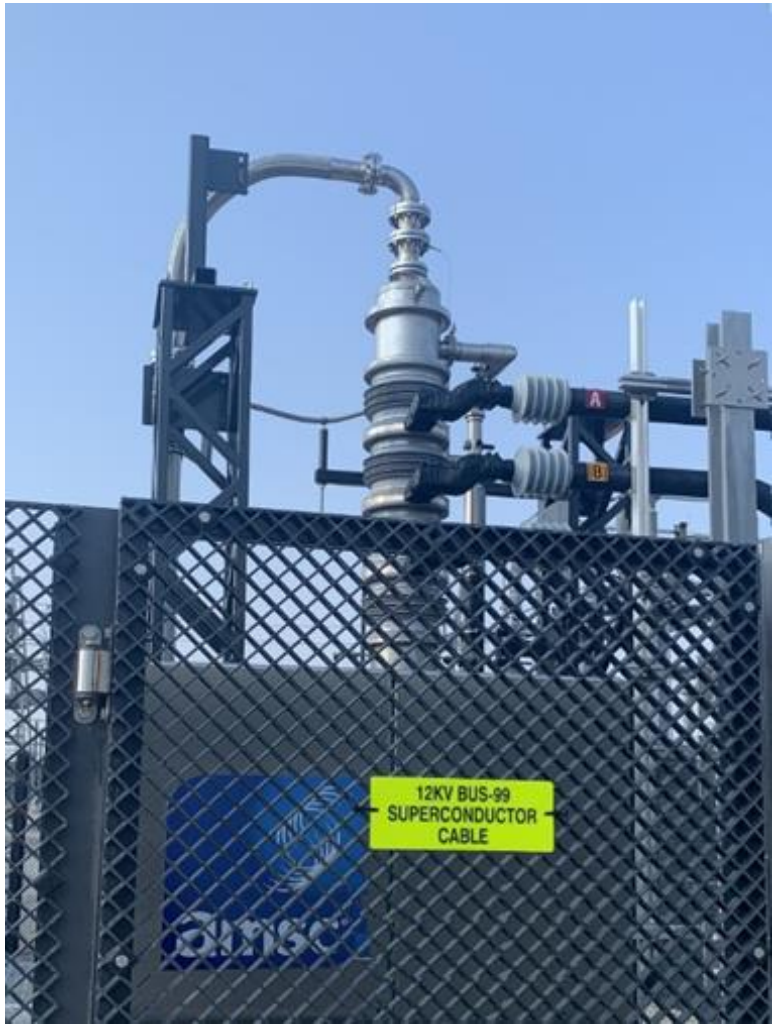
Northwest Installation – Cable Installation

Northwest Installation - Termination

Northwest Installation – Termination 2



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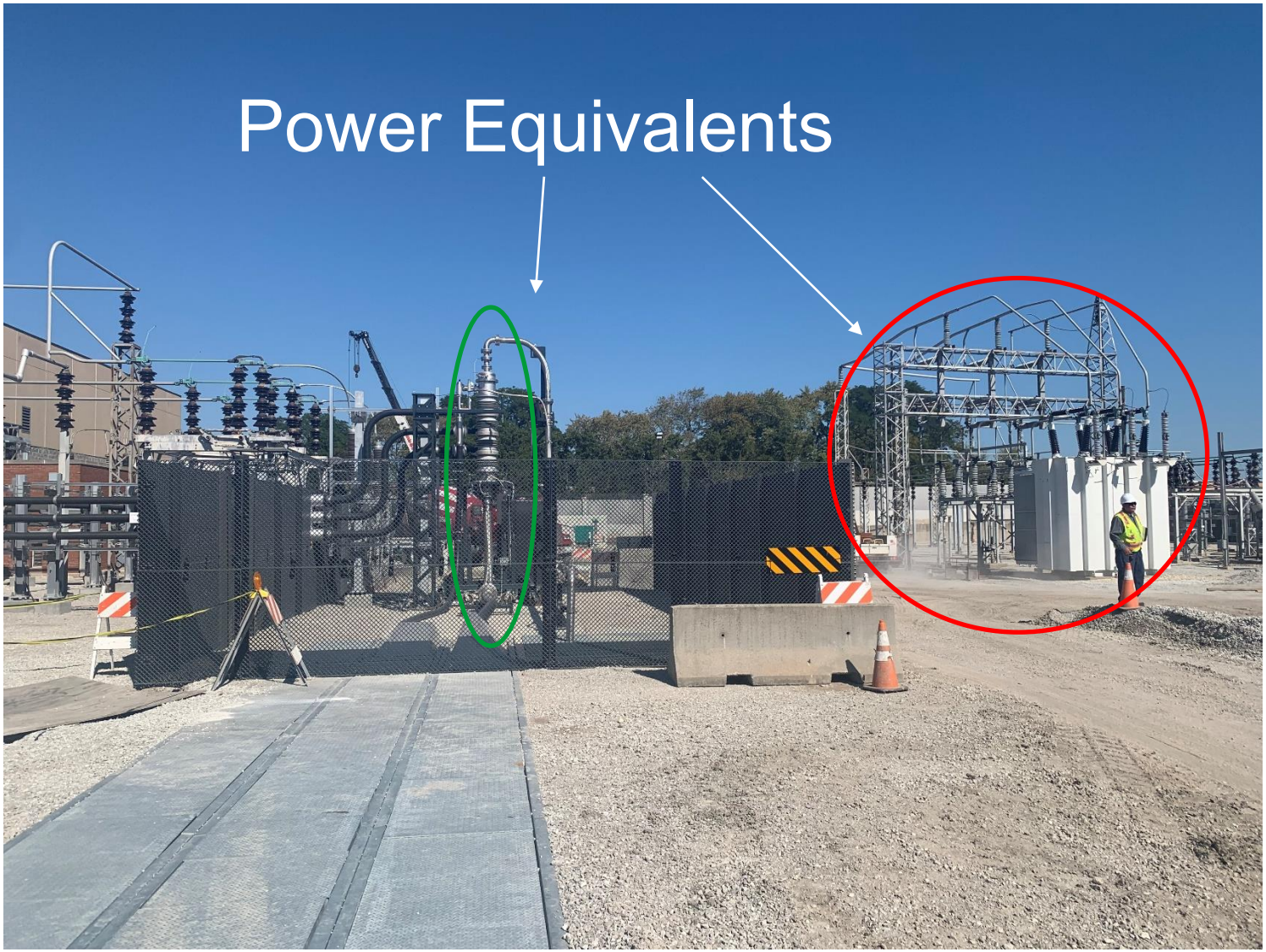
Northwest Installation – Footprint Comparison



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Conclusions

- ✓ **Resilient Electric Grids have benefits over conventional cables.**
  - *Particularly in dense, urban areas*
- ✓ **Resilient Electric Grids can provide an "Alternative to Transmission"**
  - *Transmission Power at Distribution Voltages*
- ✓ **Applications of Resilient Electric Grids include:**
  - *Capacity Increases*
  - *Reliability Increases*
  - *Pipe-type cable replacement*
- ✓ **Resilient Electric Grids projects can be lower cost that projects using conventional Transmission**
- ✓ **Even though Resilient Electric Grid projects are at Distribution Voltage, FERC has ruled them "*Transmission Assets*" at the ComEd project**