University of Pittsburgh

Evaluating Medium Voltage, Multilevel Topologies in Electric Grid Applications:

Realization and High Voltage Academic Facilities for Testing

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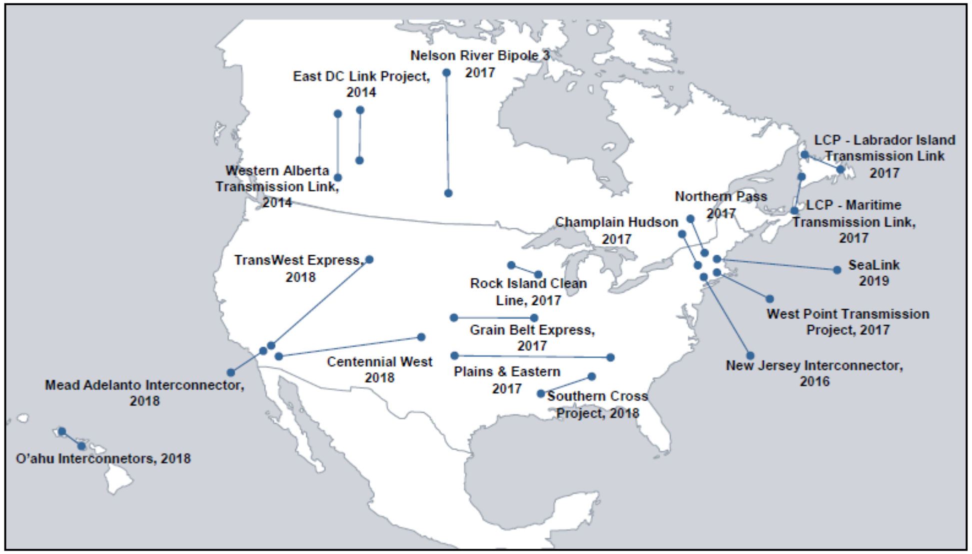
Outline of Discussion

- **Section 1: Medium Voltage Power Electronics and Success Stories in Practice – Utility Case**
- **Section 2: Medium Voltage Power Electronics and Success Stories in Practice – Motor Drive Case**
- **Segment 3: Control and Architectures of Multiport Dual-Active Bridge Based Converters**
- **Segment 4: Where are the medium voltage lab facilities?**

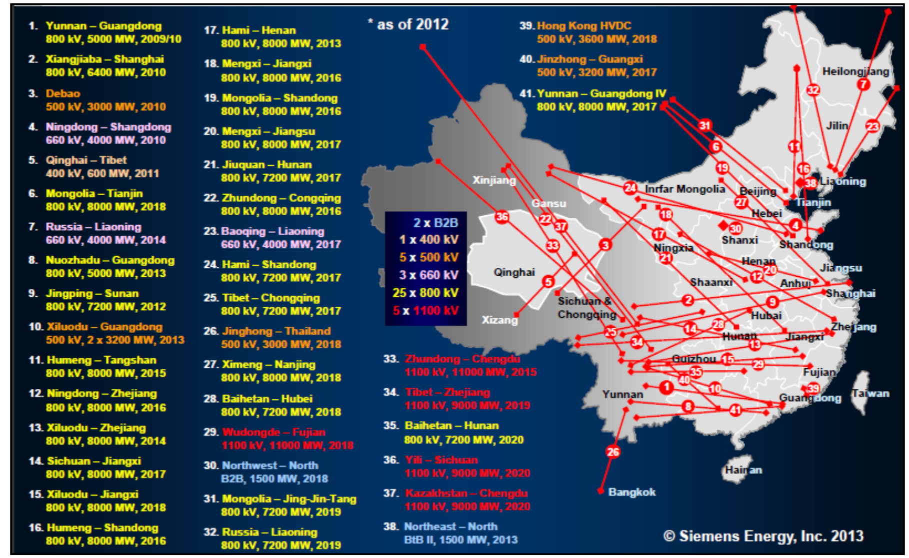
Section 1:
Medium Voltage Power Electronics and Success Stories in Practice

Utility Case

Planned HVDC Installations Around the World



North America

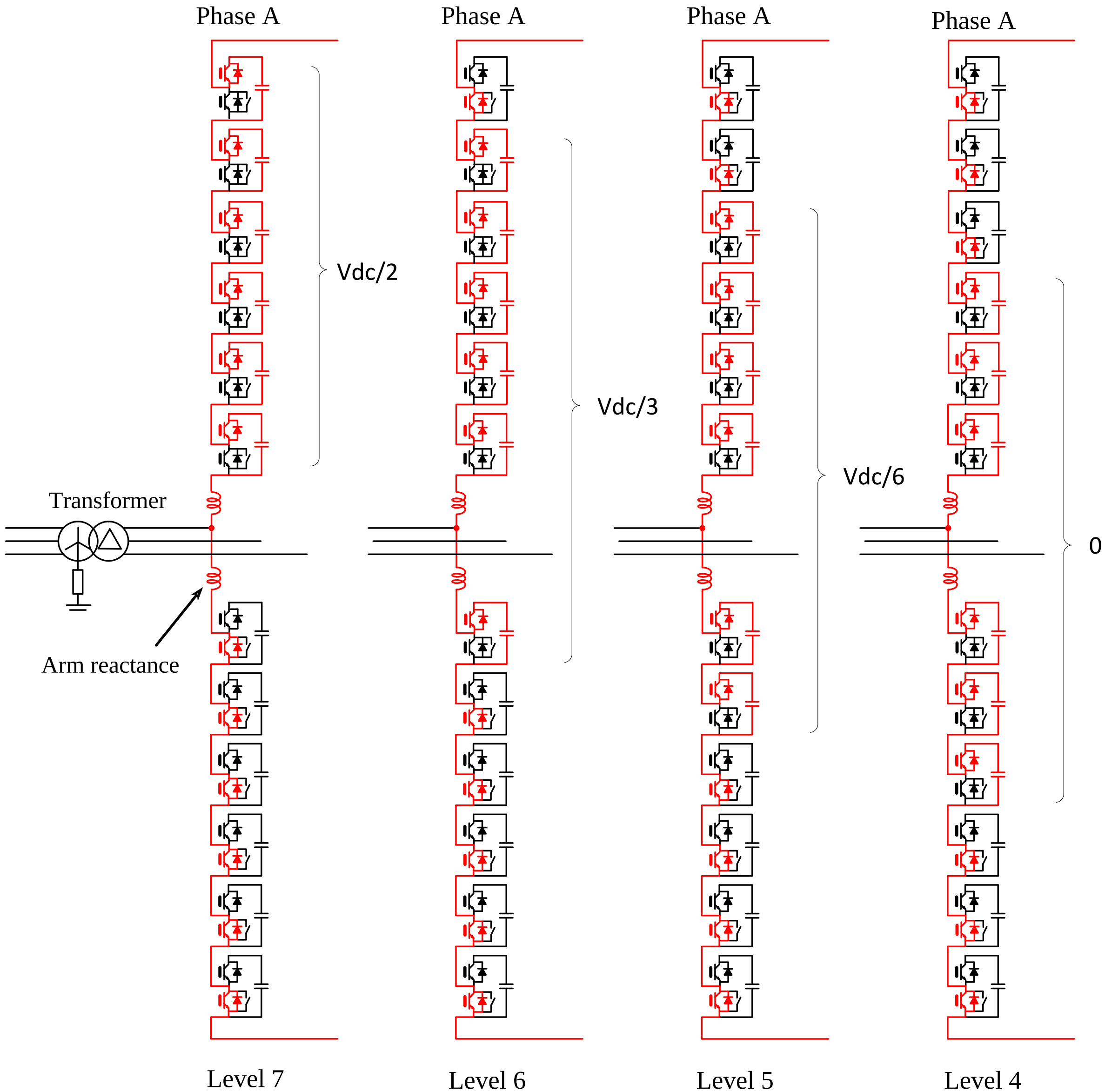


China

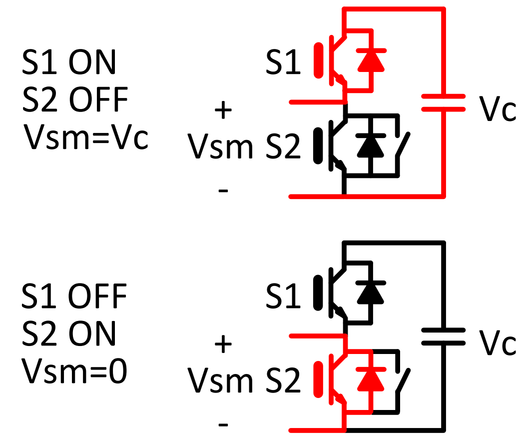
Benefits of HVDC Transmission

- More efficient power transfer over long distances
- Carrying capacity of up to 2 to 5 times that of an AC line
- Interconnection of two AC systems
- Underwater power transfer (distance longer than 50 km)
- Rapid and accurate power flow control

Modular Multilevel Converter Modeling & Control



Submodule Operation



6 submodules per arm emphasized here but 10 submodules used in simulation work

Computer Model Implementation: System Scaling

- Primary objective is to adequately scale the system from *hundreds* of submodules to ten submodules per arm.
- Ratio of the total energy stored and the rated capacity of the converter should be maintained when converter parameters are scaled.

$$\Phi = \frac{\text{(Number of arms)(Number of cells per arm)(Energy stored per arm)}}{\text{Rated Capacity of Converter}}$$

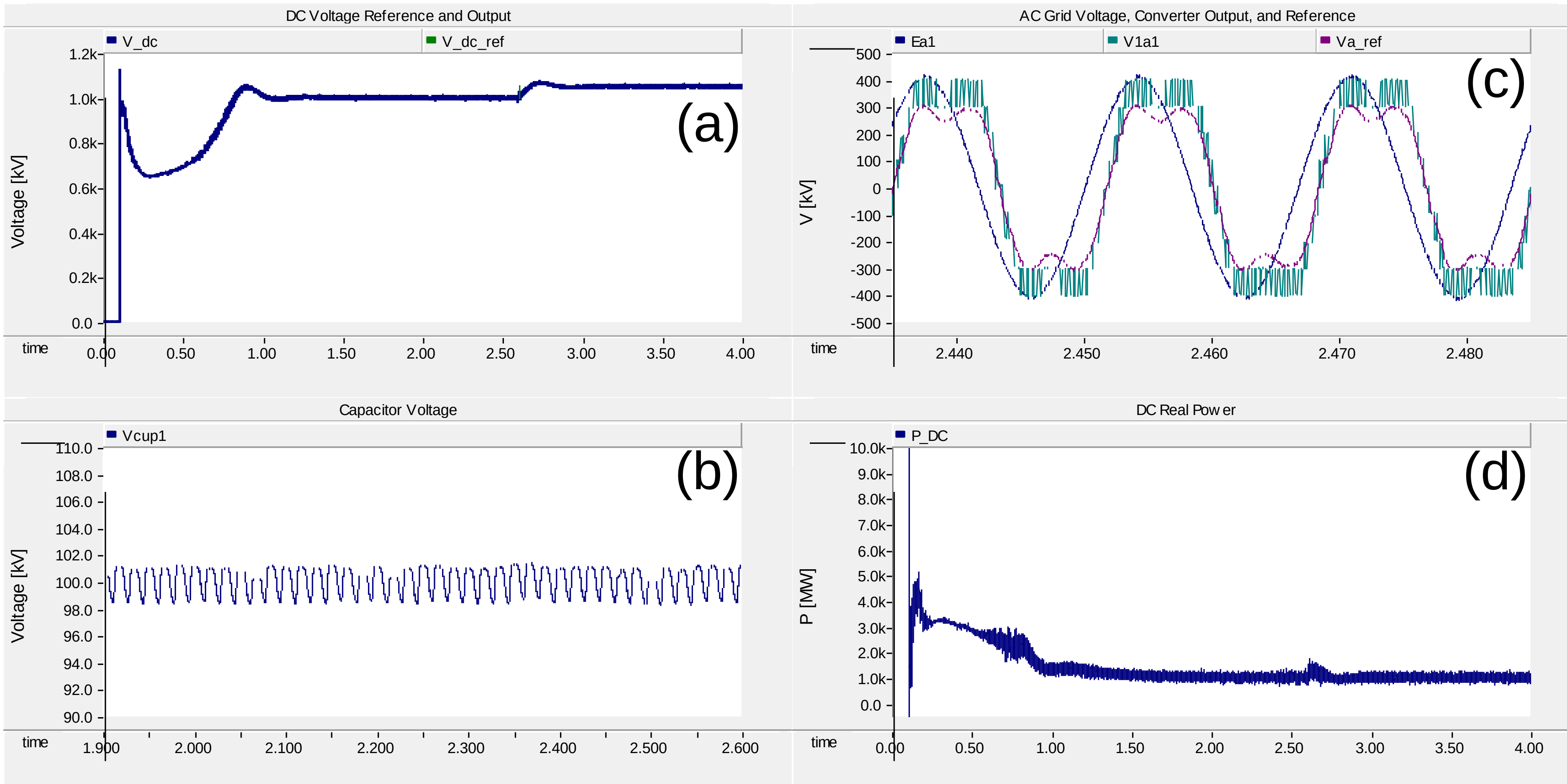
$$\Phi = \frac{3C_1V_{DC,1}^2}{N_1S_1} = \frac{3C_2V_{DC,2}^2}{N_2S_2}$$

Full Scale System Parameters

Solve for Capacitance with a Picked *N*

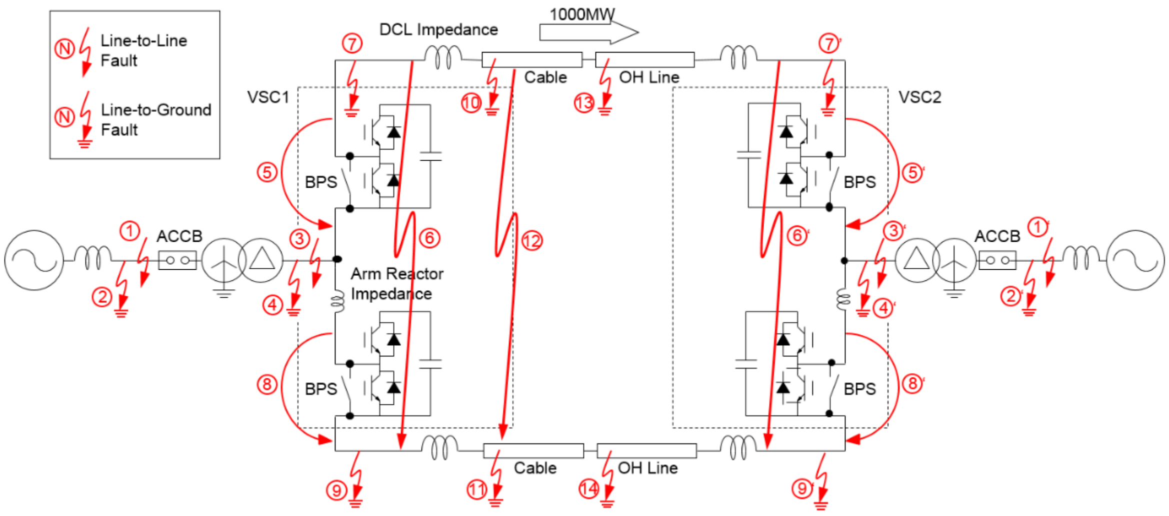
- N_2 chosen iteratively to ensure that IEEE 519-1992 standard is satisfied at the wye-side of the HVDC transformer (total THD below 1.5%).

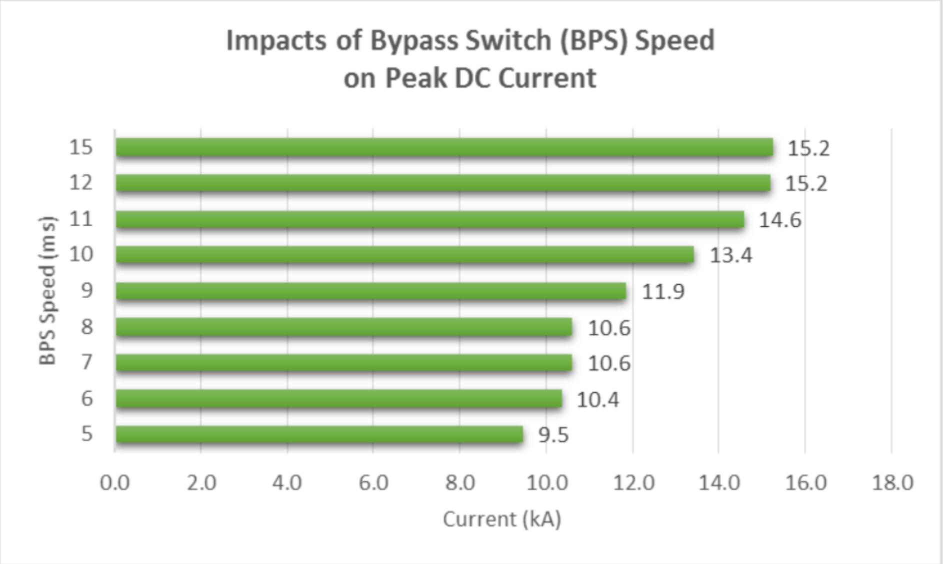
System Performance and Verification

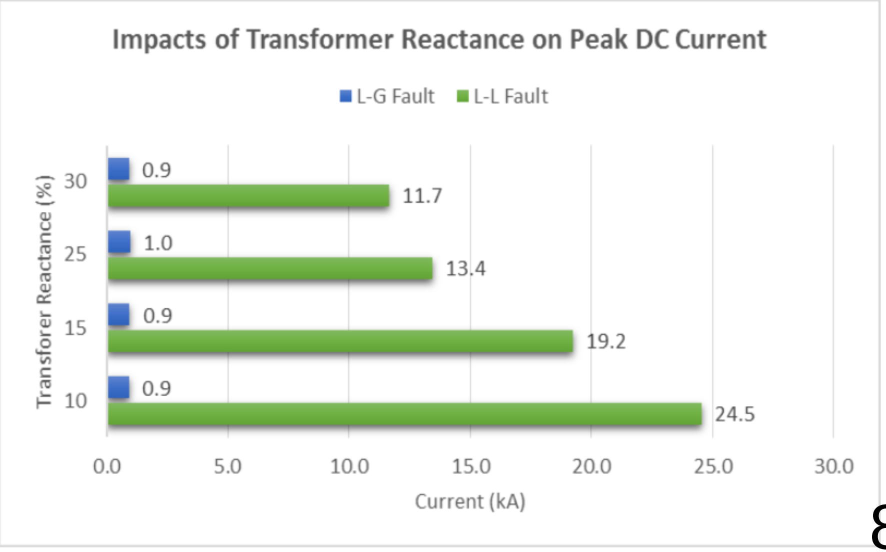


HVDC Model Waveforms: (a) DC voltage (b) Capacitor Voltage Ripple,
(c) Δ-side AC Voltage / Y-Side AC Voltage / Reference Signal and (d) Power Flow

Intense Fault Analysis and Identification







Academia Supporting Industry

5652 IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 63, NO. 9, SEPTEMBER 2016

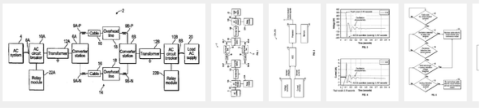
Fault Section Identification Protection Algorithm for Modular Multilevel Converter-Based High Voltage DC With a Hybrid Transmission Corridor

Communication-less fault section identification for hybrid hvdc transmission systems

Abstract

Disclosed herein are methods, systems, and devices for identifying a location of a fault in a hybrid high voltage direct current (HVDC) transmission system having a ground or underground cable section and an overhead line section. Some methods comprise determining whether a characteristic voltage oscillation is present at a cable side terminal of the HVDC transmission system, and in response, determining that the fault is located in the overhead line section. Some methods comprise determining whether a characteristic current oscillation or a terminal current exceeding a peak current threshold is present at an overhead line side terminal, and in response, determining that the fault is located in the overhead line section. The methods can be communication-less, wherein the actions are based on local measurements and/or are performed locally to where the fault is located or detected.

Images (6)



Classifications

- G01R31/085 Locating faults in cables, transmission lines, or networks according to type of conductors in power transmission or distribution lines, e.g. overhead

View 9 more classifications

US20180120367A1
United States

Download PDF | Find Prior Art | Similar

Inventor: Patrick Thomas Lewis, Brandon M. Grainger, Hashim Abbas Al Hassan, Gregory Francis Reed

Current Assignee : University of Pittsburgh

Worldwide applications

2016 · WO US

Application US15/576,650 events

- Priority claimed from US201562166869P
- 2016-05-19 • Application filed by University of Pittsburgh
- 2016-05-19 • Priority to US15/576,650
- 2017-11-22 • Assigned to UNIVERSITY OF PITTSBURGH - OF THE COMMONWEALTH SYSTEM OF HIGHER EDUCATION
- 2018-05-03 • Publication of US20180120367A1
- 2020-08-04 • Application granted
- 2020-08-04 • Publication of US10732214B2
- Status • Active
- 2037-02-23 • Adjusted expiration

Info: Patent citations (11), Cited by (17), Legal events, Similar documents, Priority and Related Applications

External links: USPTO, USPTO PatentCenter, USPTO Assignment, Espacenet, Global Dossier, Discuss

Mitsubishi Electric Power Products, Inc. – Solutions for high voltage transmission

Published May 4, 2020

Section 2:

Medium Voltage Power Electronics and Success Stories in Practice

Motor Drive Case

MMC Converter Penetration in Motor Drives

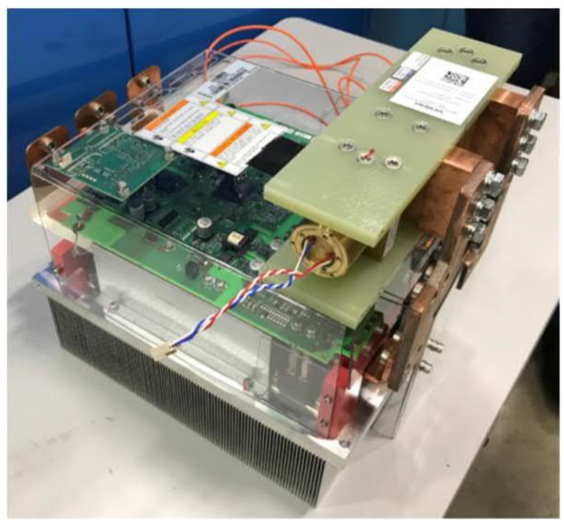
In 1994, **Pete Hammond** of Robicon introduced a new concept in Medium Voltage Drive technology based on what would be called Cascaded H-Bridge (CCH).

- ✓ Siemens would later introduce this as the GH180 product family.

10 years later in 2003, **Rainer Marquardt** of Siemens / University of Munich would introduce a bridge based version of modular cells for High Voltage DC applications which would be called Modular Multilevel Converter (M2C).

- ✓ Siemens would later introduce this for Large Drive Applications as the GH150 product family. **This technology is just beginning to penetrate the Large Drives arena (stated in 2019).**

24 Cell Proof of Concept (10MVA / 4160V) from Siemens



From 2019

35 MW, Air-Cooled, 12.5kV, 60/25 Hz M2C for New Orleans

Current and being built in Pittsburgh

Segment 3:
Control and Architectures of Multiport Dual-Active Bridge Based Converters

What is being evaluated in Academia?

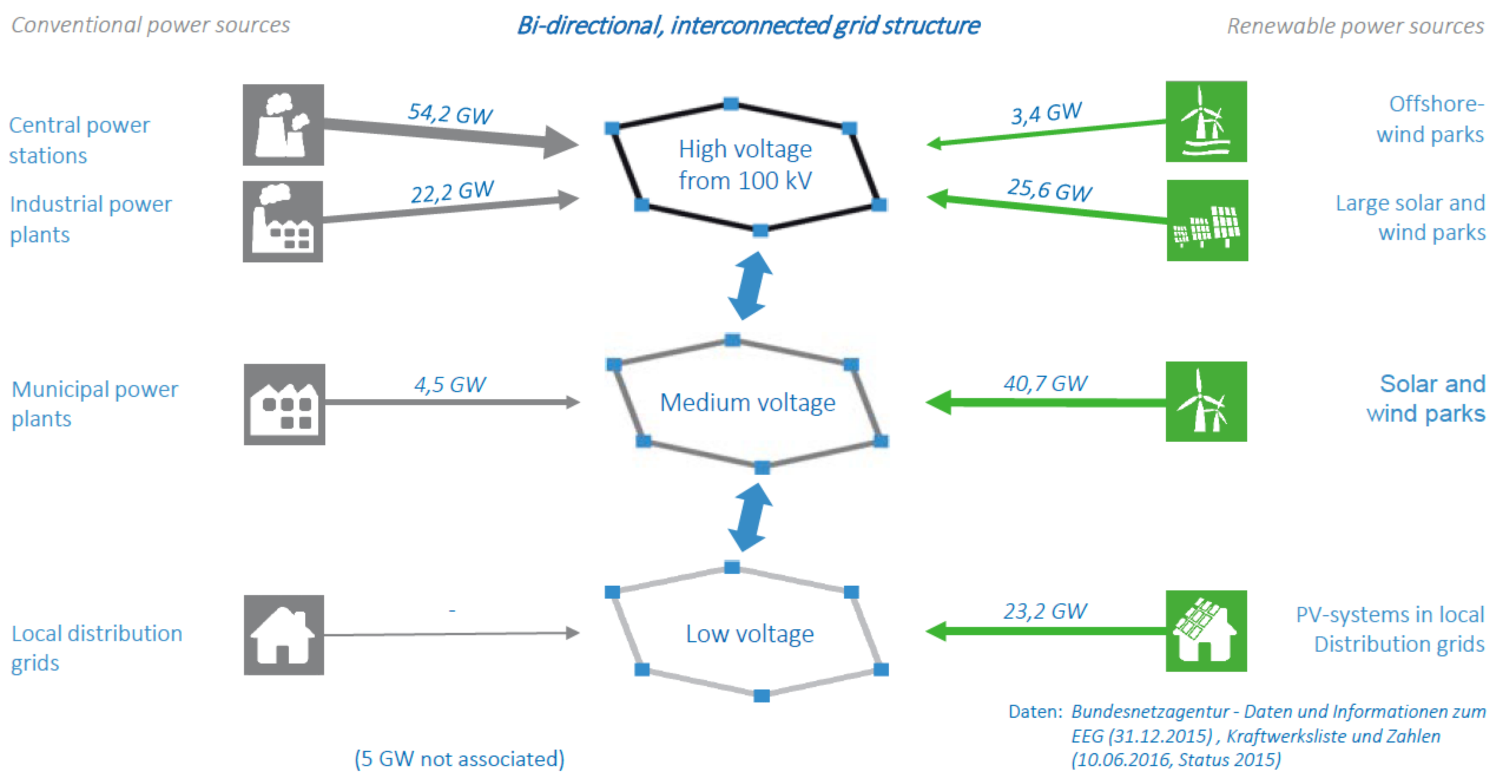
Z. T. Smith and B. M. Grainger, "Analytical Treatment of the Power Transfer Relationships for a Coupled, Current-Fed, Multi-Port Dual Active Bridge Converter," *2019 IEEE Electric Ship Technologies Symposium (ESTS)*, 2019, pp. 562-568

Z. T. Smith and B. M. Grainger, "Medium Voltage Ring-Bus Grid Design Employing Current-Fed, Three-Port Dual Active Bridge Converters with Average Power Flow Control," *2021 IEEE Electric Ship Technologies Symposium (ESTS)*, 2021, pp. 1-7.

Z. T. Smith, M. L. McIntyre, P. R. Ohodnicki and B. M. Grainger, "A Parameter Estimator for Inductance within a Dual Active Bridge Converter," *2022 IEEE Energy Conversion Congress and Exposition (ECCE)*, 2022, pp. 1-6

Z. T. Smith, R. B. Beddingfield and B. M. Grainger, "Power Flow Control for Decoupled Load Performance of Current-Fed Triple Active Bridge Converter," in *IEEE Open Journal of Power Electronics*, vol. 4, pp. 319-329, 2023

New Architectures: MVDC Distribution Grids



Future grids cannot ignore the energy feed-in in medium- and low-voltage distribution grids and must become interconnected

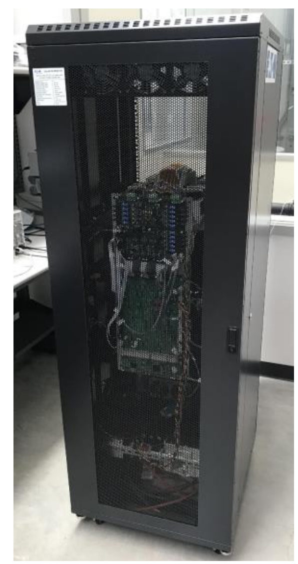
RWTH AACHEN UNIVERSITY Campus Cluster Sustainable Energy
Forschungscampus Elektrische Netze der Zukunft

Dual-Active Bridge Based Solid State Transformers (SST)

Traditional Transformer Designs

- **Traditional Transformers:** Economical, Reliable, Easier for Technicians to maintain but no intelligence
- **Solid State Transformers:** Intelligent control (Regulate current, voltage, etc), Magnetic weight reduction, Increased complexity

Traditional Pole-Mounted Transformer
(No Power Electronics)



Solid State Transformer
(Silicon Carbide Based Power Electronics)

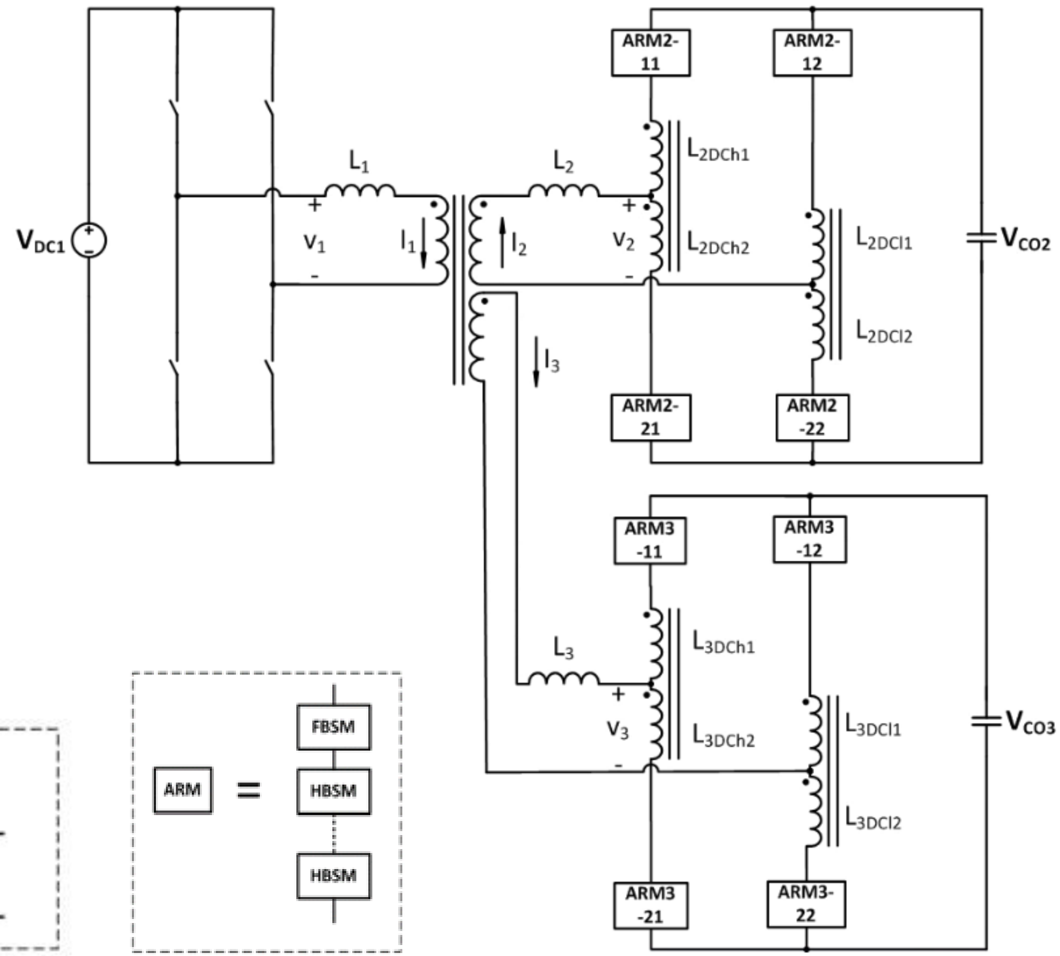
Dual-Active Bridge Based Solid State Transformers (SST)

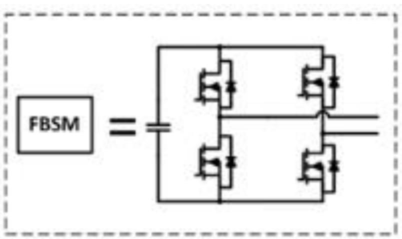
Multiport Topology Studied

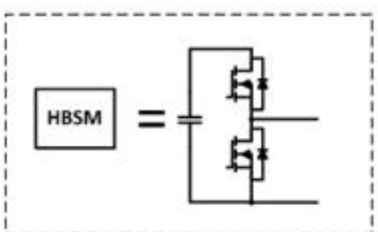
Multiport Topology

- 1 LV port, 2 MV ports
- Arms consist of half and full bridge submodules, with a capacitor
- Mutual inductors at MV ports

$$P = \frac{V_1 V_2}{n\omega L}\varphi\left(1 - \frac{|\varphi|}{\pi}\right)$$







Dual-Active Bridge Based Solid State Transformers (SST)

Dynamic Analysis

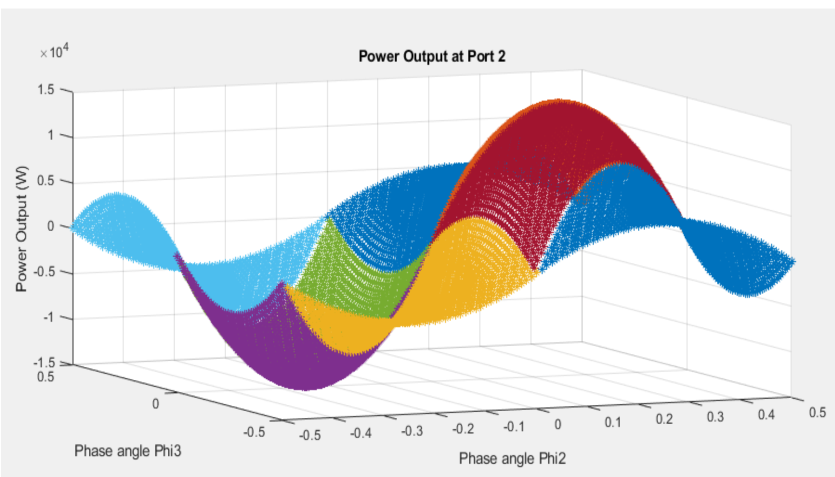
Power Flow Analysis

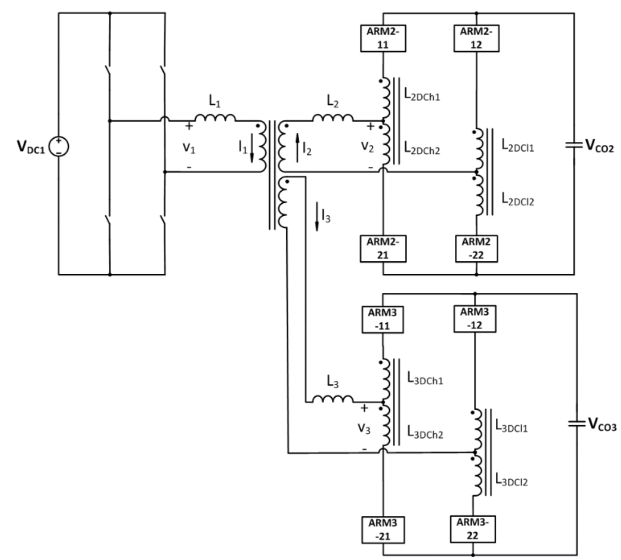
- State-Space Form $\dot{\boldsymbol{x}} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{B}\boldsymbol{u}$:

$$\boldsymbol{x} = [i_{L1}\ i_{L2}\ i_{L3}\ v_{Co2}\ v_{Co3}\ v_{Carm2-11}\ v_{Carm2-12}\ v_{Carm2-21}\ v_{Carm2-22}\ \cdots$$
$$\cdots\ i_{2dch1}\ i_{2dcl1}\ i_{2dch2}\ i_{2dcl2}\ v_{Carm3-11}\ v_{Carm3-12}\ \cdots$$
$$v_{Carm3-21}\ v_{Carm3-22}\ i_{3dch1}\ i_{3dcl1}\ i_{3dch2}\ i_{3dcl2}]^T$$

- Control Inputs:

$$\boldsymbol{u} = [V_1\ I_{DC2}\ I_{DC3}]^T$$



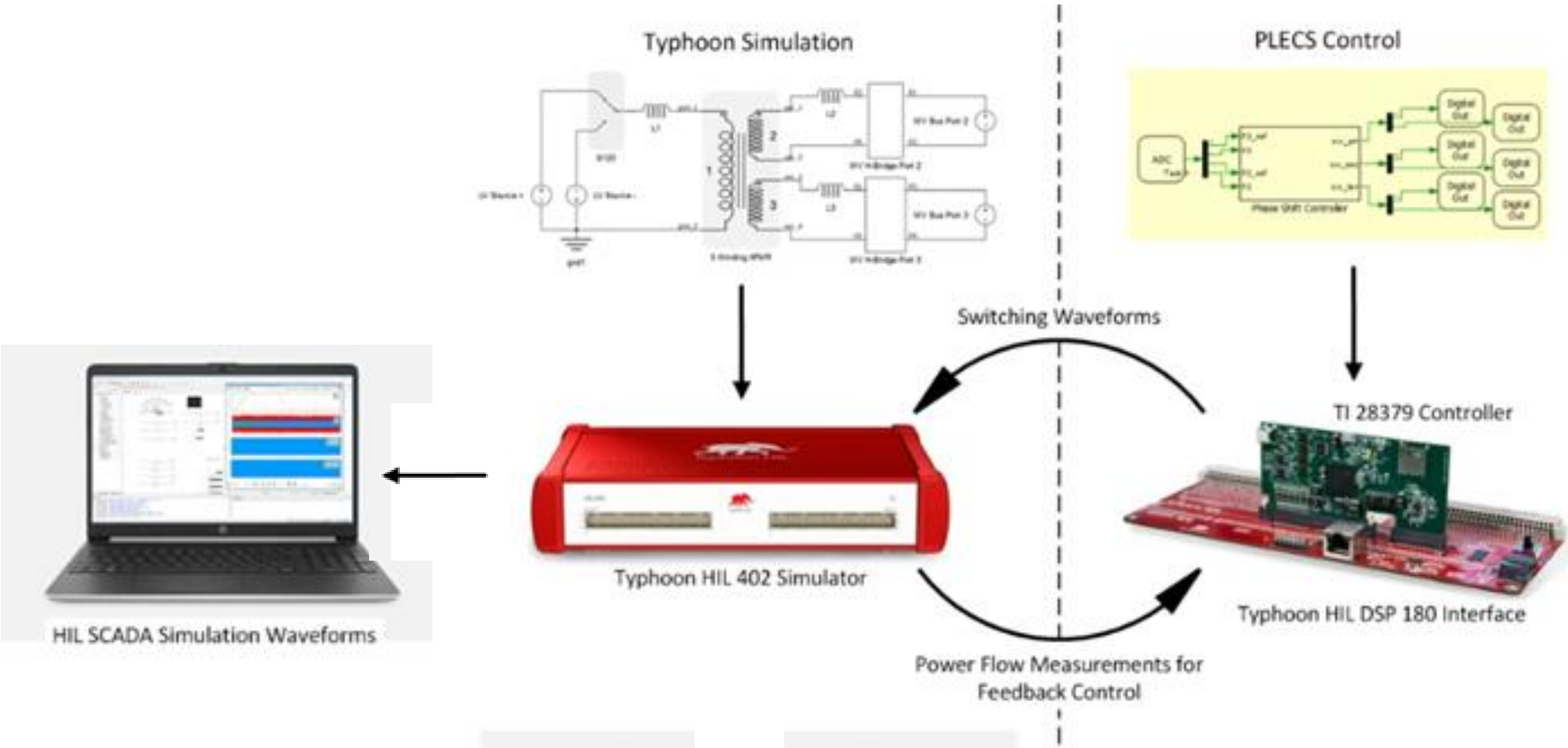


Each color is a different mode of operation

Dual-Active Bridge Based Solid State Transformers (SST)

Control Hardware-in-the-Loop

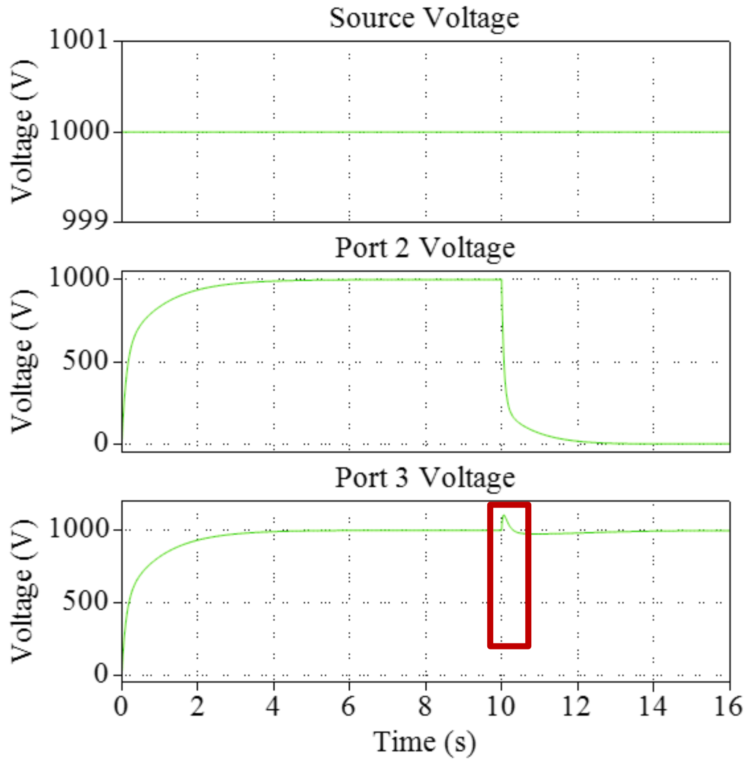
Research Question: If one port is disturbed, prevent the other port from being disturbed?



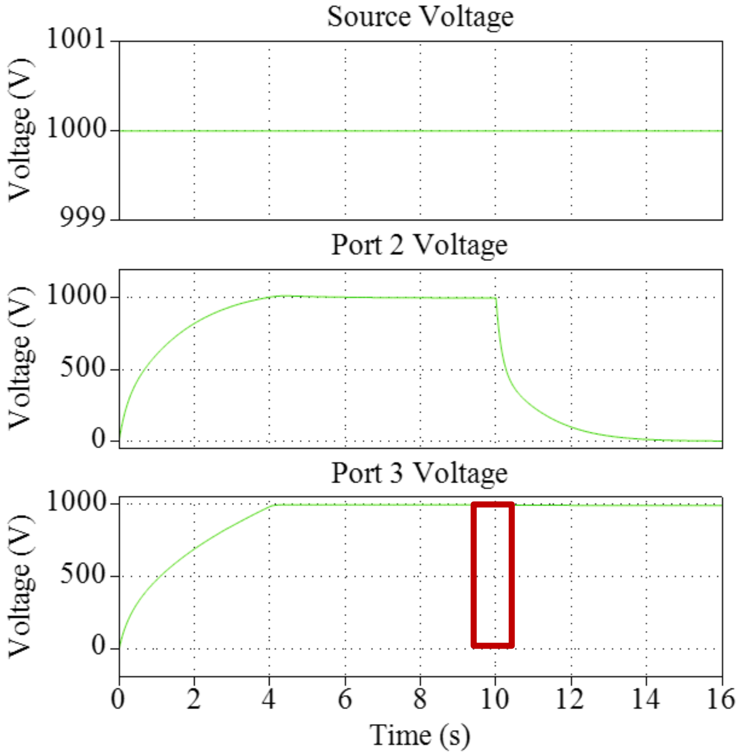
Dual-Active Bridge Based Solid State Transformers (SST)

Hardware Results Mapped into Software Simulator

Performance of Designed Controller



Traditional PI



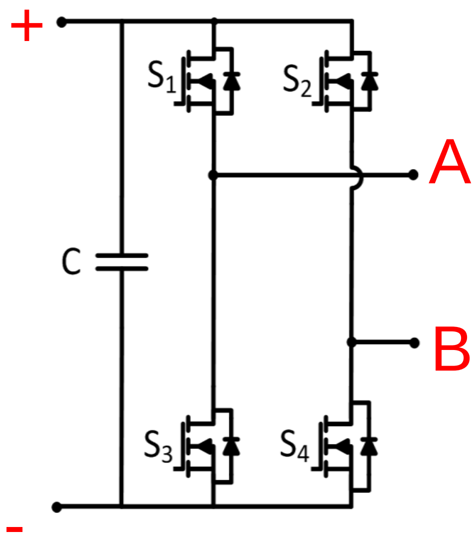
Proposed Control

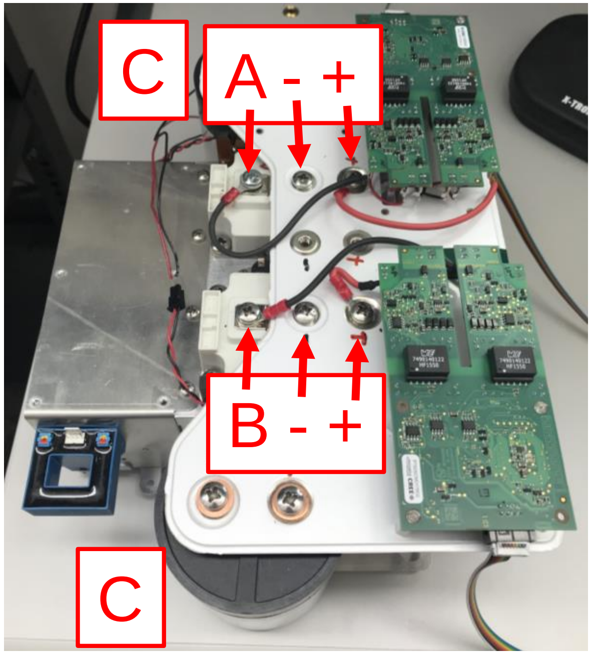
Dual-Active Bridge Based Solid State Transformers (SST)

Hardware Implementation

Experimental Prototype of Full Power Electronics System

- H Bridge Setup





Single H-Bridge

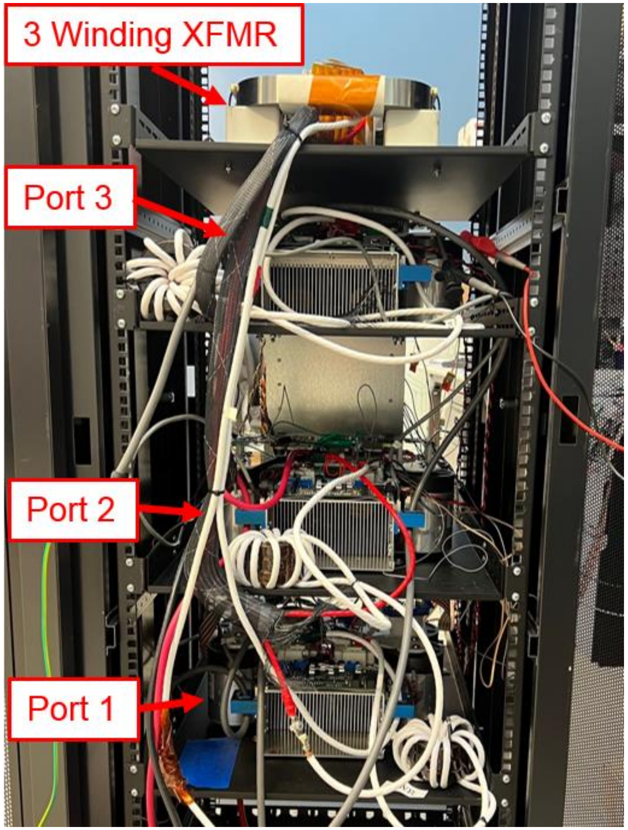
Full Cabinet

---, "Final technical report DE-EE00031004 combined PV/battery grid integration with high frequency magnetics enabled power electronics", pp. 1-50, May 2019 [DoE SunShot Program]

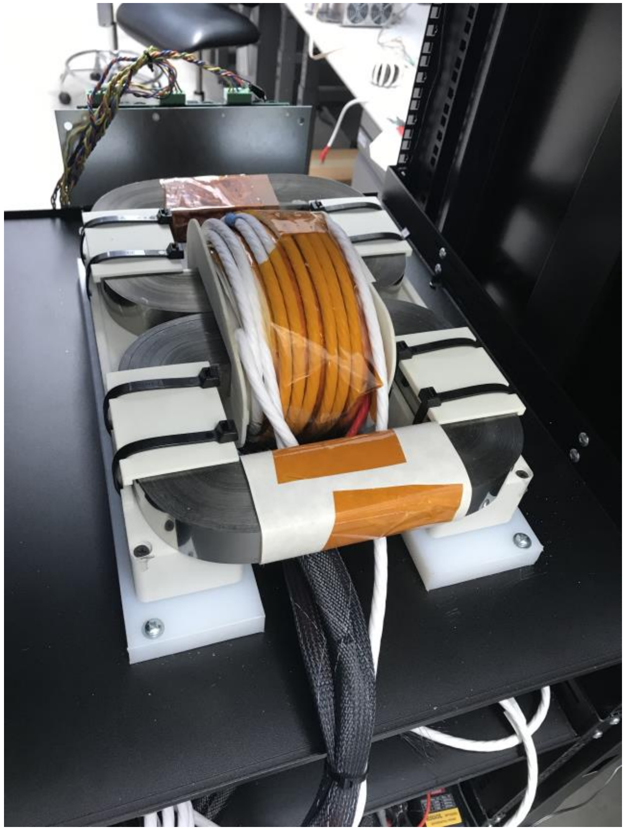
Dual-Active Bridge Based Solid State Transformers (SST)

Hardware Implementation

Experimental Prototype Continued



3 H-Bridges

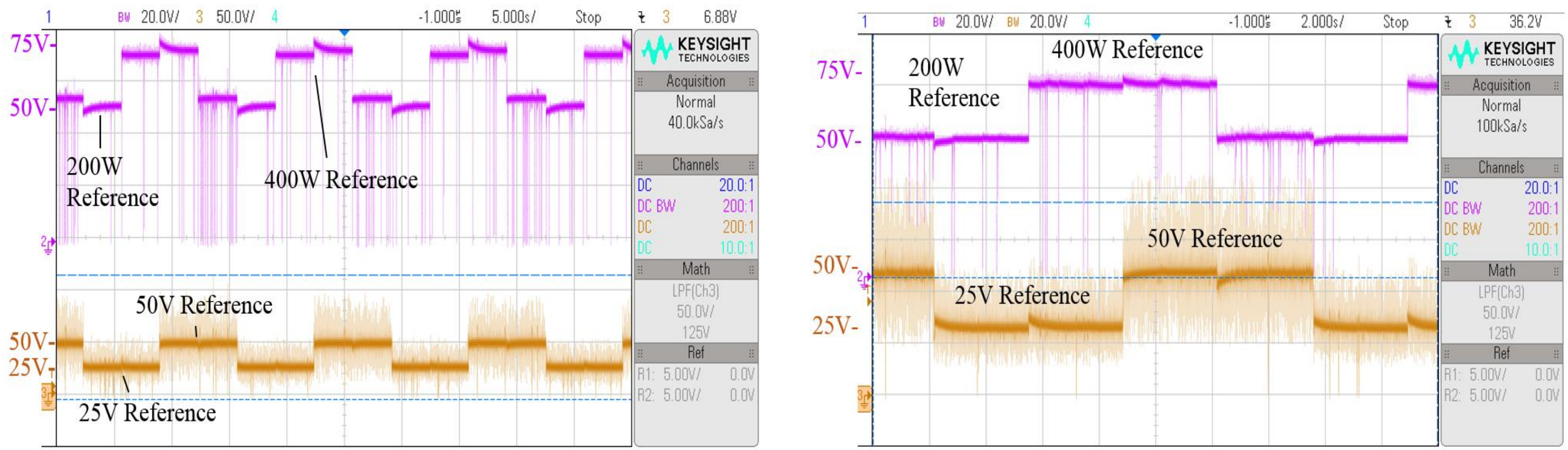

3 Winding XFMR

Dual-Active Bridge Based Solid State Transformers (SST)

Hardware Implementation

Testing Results

- Control sensitivity to inductance value



(a) Untuned Power Flow Control (port 2) PI Control (port 3)

(b) Tuned Power Flow Control (port 2) PI Control (port 3)

DC Bus Voltages: Port 2 Voltage (Purple), Port 3 Voltage (Orange)

Acknowledgements

DoE Sunlamp Program

DLC DUQUESNE LIGHT CO.

H HILLMAN FAMILY FOUNDATIONS

Segment 4:
Where are the medium voltage lab facilities?

University of Pittsburgh Advanced Research Facilities at the Energy Innovation Center

Electric Power Technologies Lab

- Dr. Brandon Grainger – ECE
- Medium-Voltage/High-Power AC Grid Facility

Advanced Magnetics for Power & Energy Development (AMPED)

- Dr. Paul Ohodnicki – MEMS
- Dr. Brandon Grainger – ECE
- Magnetic Materials Processing and Manufacturing

Energy Storage Technologies Lab

- Dr. Prashant Kumta – BioE, ChemE
- Nano-Materials for Conversion and Energy Storage

Energy Innovation Center – Downtown/Lower Hill District, Pittsburgh

High-Temperature Corrosion Testing Lab

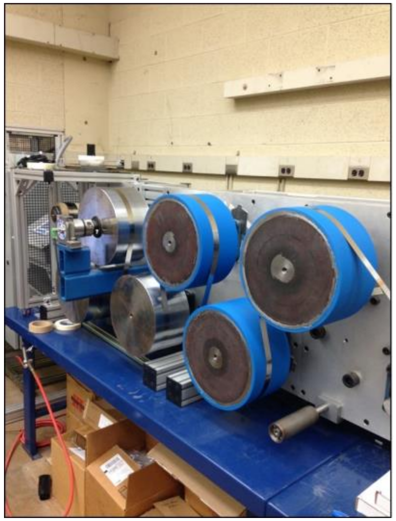
- Dr. Brian Gleeson – MEMS
  Harsh-Environment, High-Temperature Materials Testing

Energy-Related University Incubator Space

- Lab Spaces for Start-up/Commercialization Activities

Allows INDUSTRY to work COLLABORATIVELY on product research, development, demonstration, & early-STAGE deployment

Pitt Advantage with Facilities

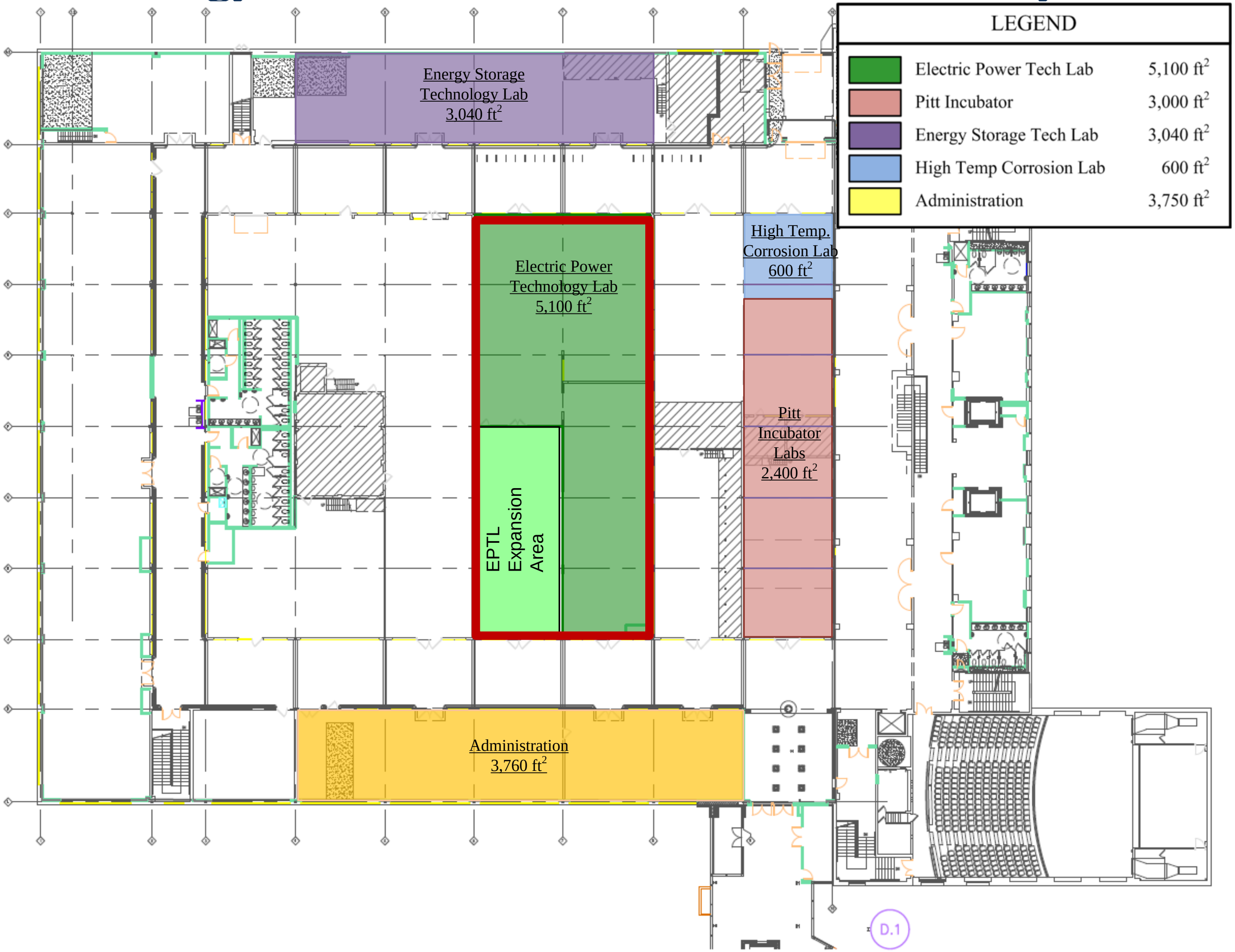


Materials Science → Electrical Product Development → High Power Testing

Multidisciplinary ecosystem between materials science and electrical engineering to develop and test medium voltage electrical products.

Recall the Battelle consulting study that launched the Center for Energy in 2012 that showcased that Pitt could develop strengths in harsh environment materials and electric power engineering.

University of Pittsburgh, Center for Energy/ GRID Institute Energy Innovation Center – Facilities Layout



LEGEND

Electric Power Tech Lab	5,100 ft²
Pitt Incubator	3,000 ft²
Energy Storage Tech Lab	3,040 ft²
High Temp Corrosion Lab	600 ft²
Administration	3,750 ft²

Electric Power Technologies Laboratory Layout Plan, Features, and Capabilities

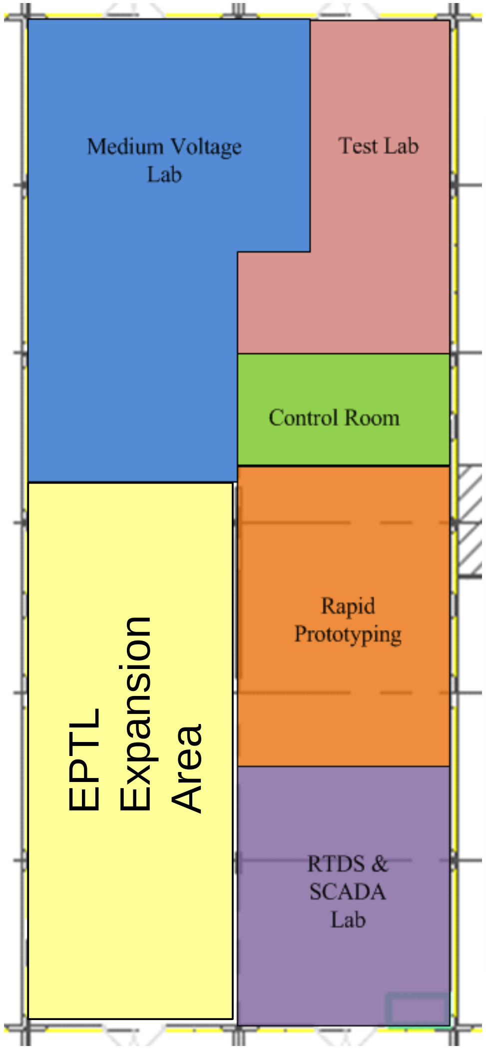
EPTL Layout

Power Distribution Areas

- **MV Grid Lab**: Reconfigurable lab for traditional projects. Designed using Eaton utility-grade distribution equipment.
- **Test Lab**: Isolated testing facility for safe testing of industry technologies, and EPTL research projects.
- **AC Flexibility**: Flexible power architecture capabilities through Eaton reclosers

General Areas of Map

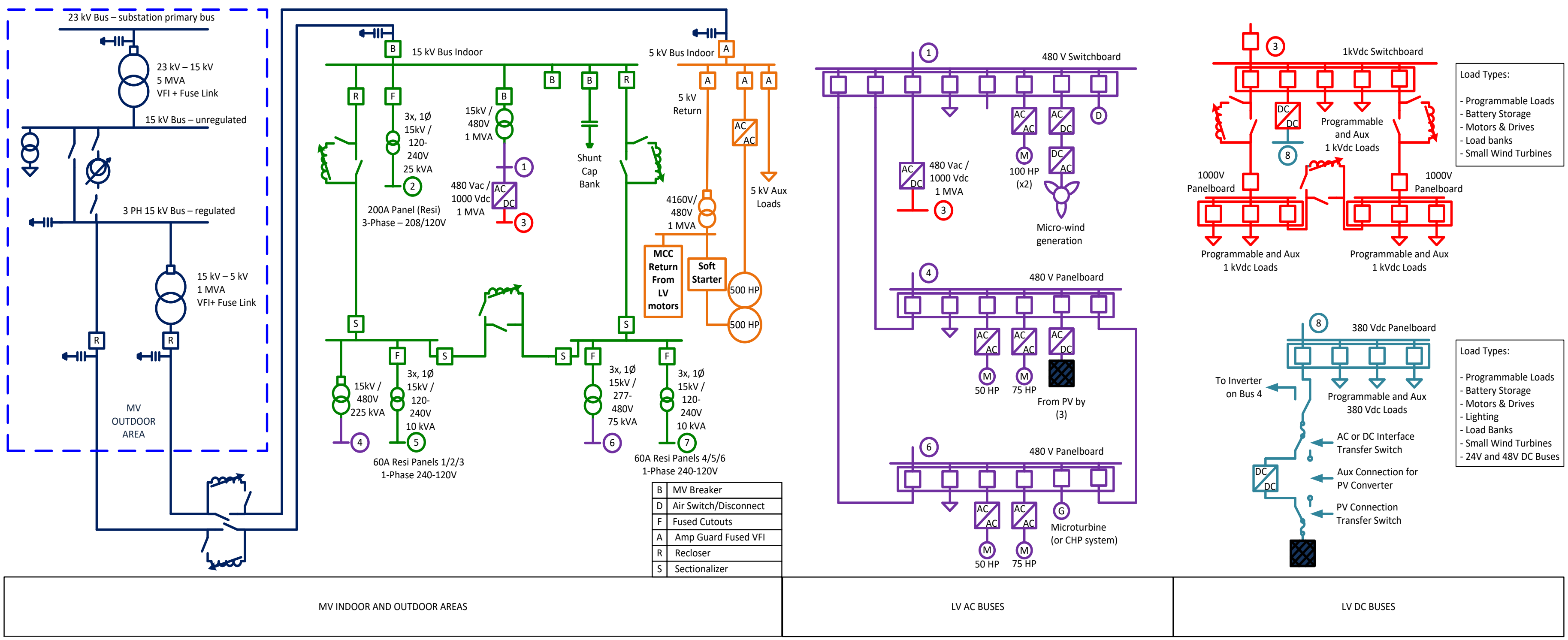
- **Rapid Prototyping**: Advanced machine shop for development of professional grade components and projects (Planning)
- **SCADA Center**: Automation, metering, and control for distribution network.
- **Relaying and Controls**: Protective relaying technologies and advanced control
- **RTDS Center**: Real-Time Digital Simulator and hardware in the loop capabilities – research and testing on industry leading equipment.



Laboratory Ratings and Features

- 15 kV-ac, 5 MVA capacity
- Microgrid Environment at Electric Utility Distribution Level
- Distributed Energy Resource and Load Integration
- Renewable Technologies (50kW Solar PV)
- Energy Storage, Electric Vehicle-2-Grid
- Real Time Digital Simulator (RTDS)
- SCADA and Systems Operations through Emerson Ovation Platform
- Protective Relaying and Substation Automation (Schweitzer and ABB Products)
- Advanced Control and Communications
- Modeling, Simulation, and Analysis through ANSYS
- FACTS and HVDC Control Systems (Planned)
- Medium Voltage Power Electronics Converters (and other power technologies development, prototyping, and testing -- e.g., IEEE 1547 certification)
- Technology testing and certification

Electric Power Technologies Laboratory
Electrical One-Line Diagram



Electric Power Technologies Lab: One-Line Diagram

(AC network: 23-kV/15-kV/4.16-kV/480-V > system)

GRID – Outside of the EIC

Eaton MITS Substation

23kV to 13.8kV and 5kV

Electric Power Technologies Laboratory

Medium Voltage Features

- 13.8kV, 4.16kV, 480V, and 208V AC voltage rails.
- Rated to handle 5MVA of power capacity.
- System is reconfigurable through Eaton reclosures to isolate parts of the lab OR create a ring architecture.

Notable Equipment Provided In-Kind

- Eaton MITS, MV circuit breakers, reclosers, power transformers, 500HP motor drive, LV motor drives, and ground fault indicator (**Donated by Eaton**).
- **Emerson Ovation** platform communicates with all major equipment.
- All equipment installed by **Sargent Electric.**

Virtual Tour of Medium Voltage Lab

https://my.matterport.com/show/?m=p85qmPtaFx

Questions???

Contact Information

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