Modeling and Applications: EMT-TS Applications for HVdc systems

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08/13/2024

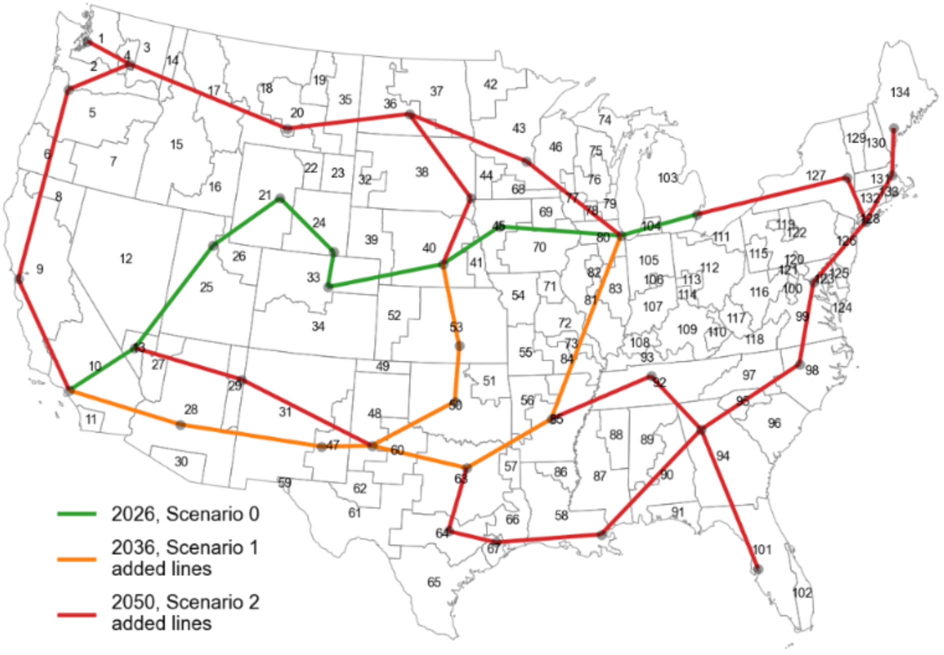
Oak Ridge National Laboratory (ORNL)

Project Team: ORNL, SCE, PSU, GIT, CAISO, SPP, OGE, FPL/NextEra

Introduction

- **Large penetration of HVdc expected**
  - Regional interconnectivity for reliability/resilience
  - Transfer generation to load centers
  - Offshore grid

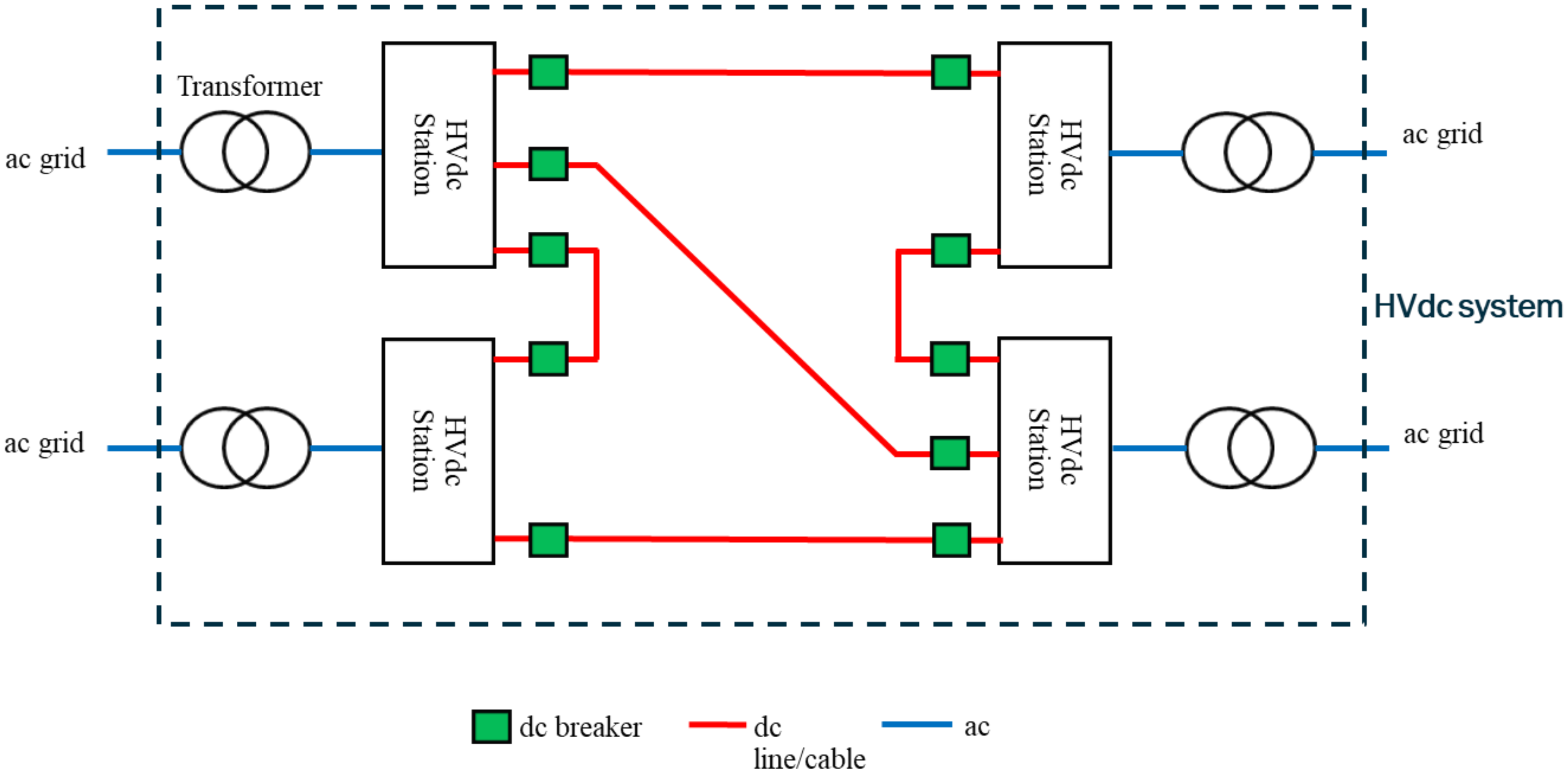
- **Drivers**
  - Reduced energy storage needs
  - Reliability/resilience needs



Scenarios

HVdc – High Voltage direct current

MTdc Architecture



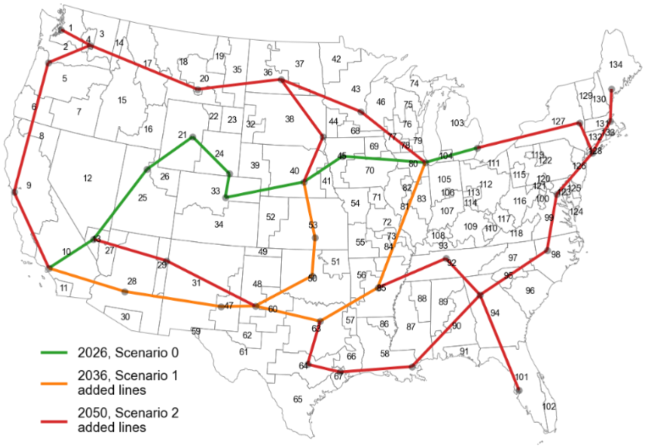
Future Scenario: 10-Terminal HVdc System in EI/WI

Scenario

- Asymmetric monopole-bipole VSC MTdc system (10-terminals)
- EI-WI system (~100,000 buses)

Use cases of interest

- Different dc fault types (line-line, line-ground, line-neutral)
- Different dc fault locations (bipole, asymmetric monopoles, junction)
- Different ac fault types (balanced, unbalanced)
- Different ac fault locations (WI, EI, boundary)



Scenario-0: Radial MTdc (green)

S. No	City	Region	HVDC station Capacity (MW)
1	Los Angeles, CA	p10	186
2	Las Vegas, NV	p13	2338
3	Salt Lake, UT	p25	2465
4	Shoshoni, WY	p21	3381
5	Cheyvenne, WY	p24	4579
6	Denver, CO	p33	5744
7	Grand Island, NE	p40	5744
8	Fort Dodge, IA	p45	2071
9	Chicago, IL	p80	4468
10	Detroit, MI	p103	4468

Lower power ratings (rows 1–4)

Higher power ratings (rows 5–10)

Scenario-0: Power rating of each station

Project Team: ORNL, NREL, PNNL

EI: Eastern Interconnection; WI: Western Interconnection

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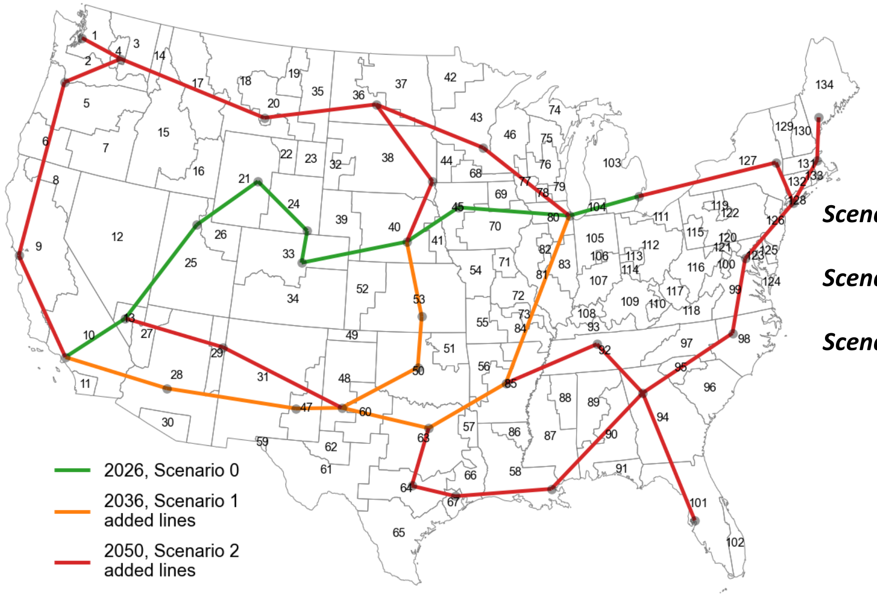
Future Scenario: EMT Simulation of 10-Terminal HVdc System in EI/WI

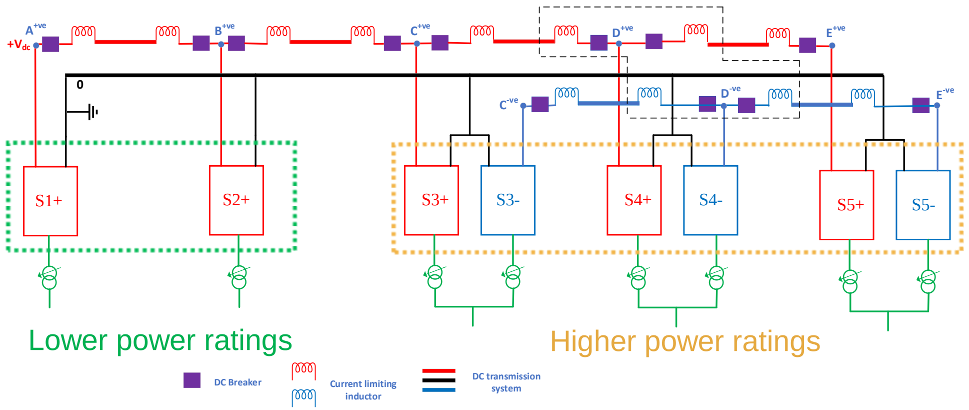


New scenarios of HVdc development

Scenario-0: Radial MTdc

Scenario-1: Meshed MTdc

Scenario-2: dc Grid



New multi-terminal dc architecture proposed*

***S. S. Jaldanki, S. Debnath, J. Zhang, P. Brown and J. Novacheck, "Mixed Monopole and Bipole MTdc Architecture," 2023 IEEE Energy Conversion Congress and Exposition (ECCE), Nashville, TN, USA, 2023, pp. 822-829**

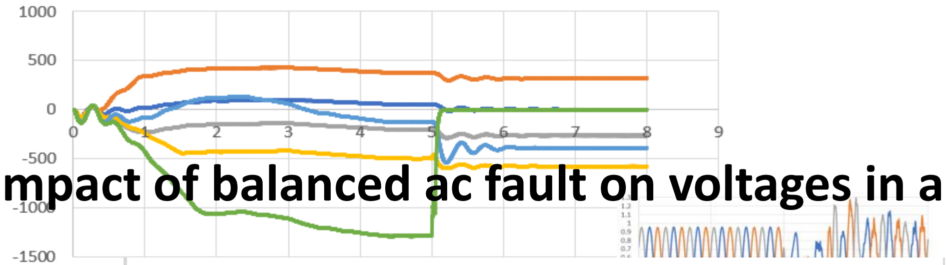
EMT models used

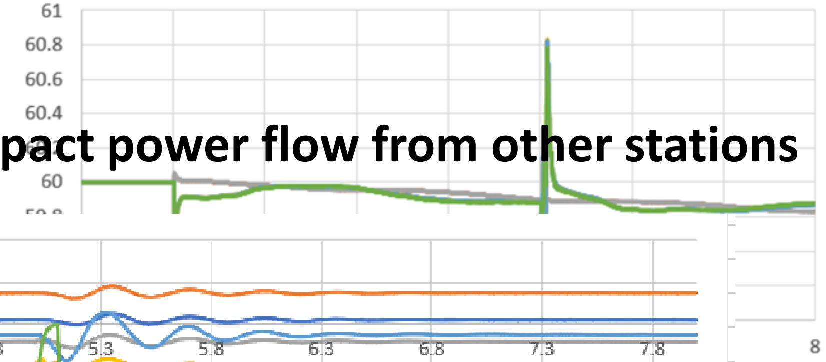
- **Scenario-0** analyzed with mixed symmetric bipole and asymmetric monopoles
- **EMT High-fidelity models**

MTdc – Multi-Terminal Direct Current

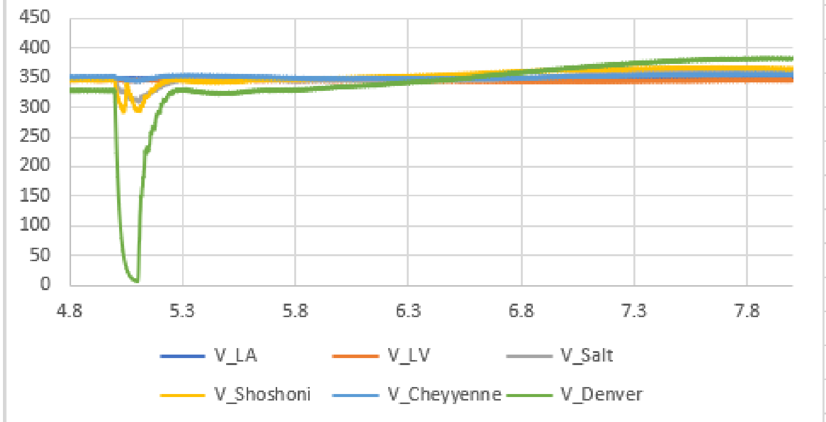
EMT-TS: 10-Terminal HVdc System + EI/WI Models

Impact of unbalanced ac fault on station and larger interconnection's frequency

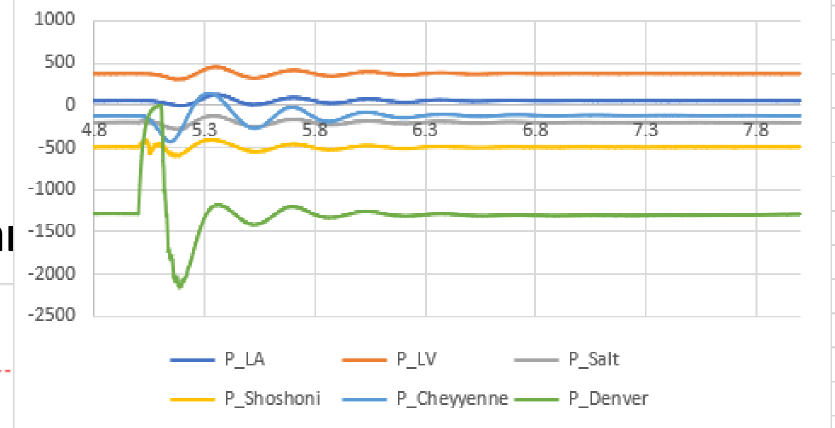




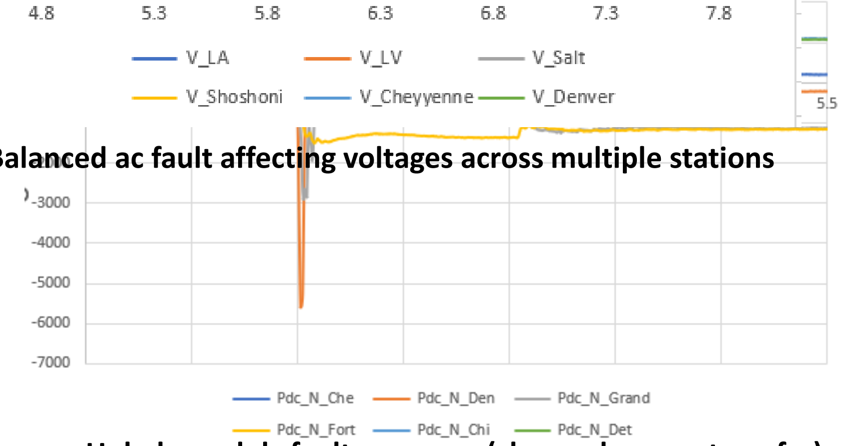
Impact of balanced ac fault on voltages in a larger region and impact power flow from other stations



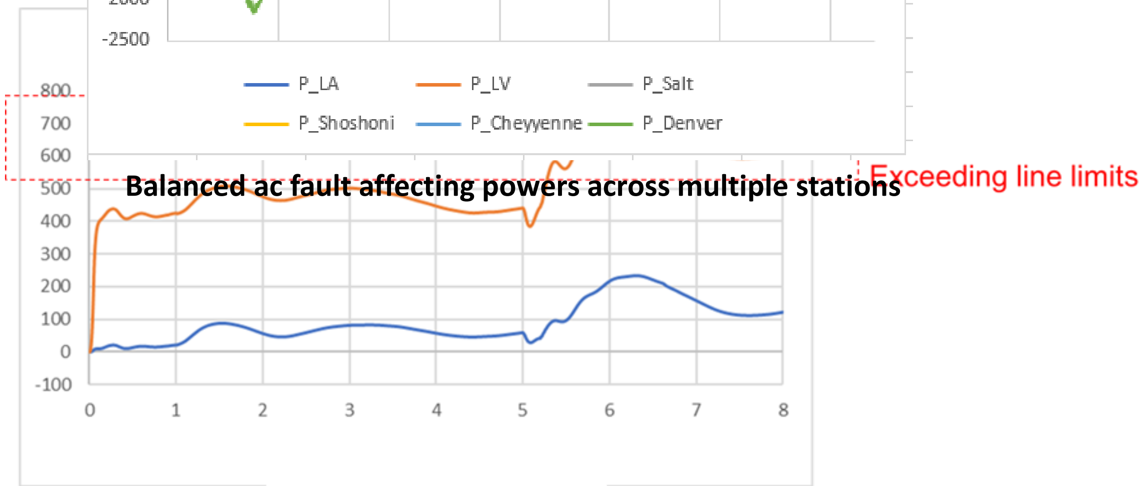
Balanced ac fault affecting voltages across multiple stations



Balanced ac fault affecting powers across multiple stations



Unbalanced dc fault response (changed power transfer)



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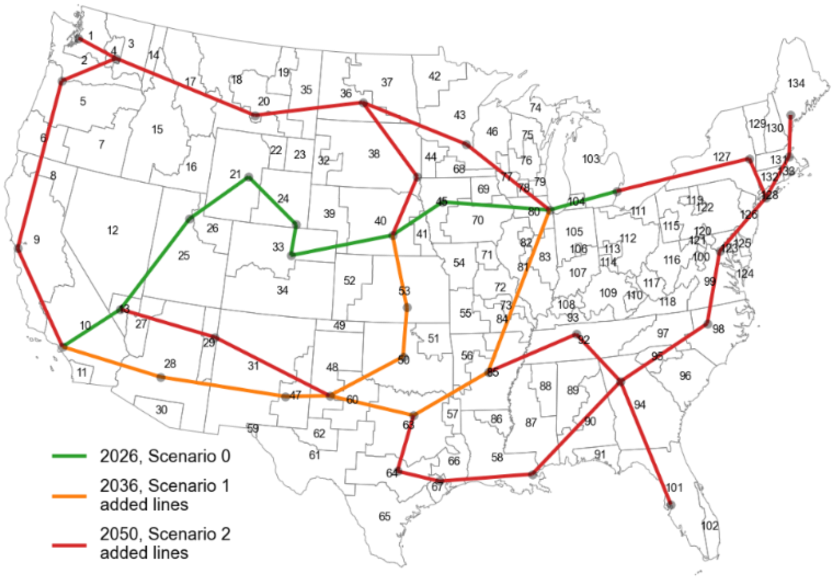
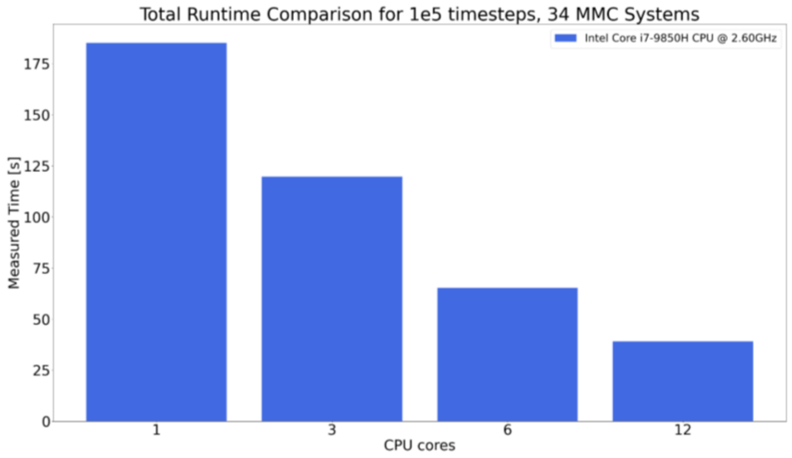
ORNL-PNNL joint research

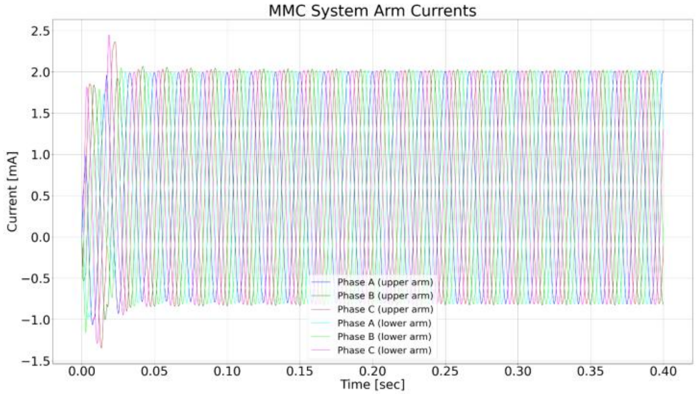
Example Scenario – Another Study

- **Challenges:** Scalability in analyzing a large number of dc stations (e.g., scenario-1)
  - Slow simulation with high-fidelity models
- **Solution:** Use of numerical simulation and HPC algorithms for scalable EMT simulation of dc



Scenario-1: Meshed MTdc (green + orange) [NREL]





High-fidelity models and HPC-based EMT simulation of large-scale dc substations [ORNL]

Enhanced capability to simulate large dc architectures in United States!

6x speed-up observed with multi-core usage enables use of more MMC substations – of the order of 34 (with greater than 2x scalability)

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Lessons Learned and Challenges

- **Lessons learned**
  - Interim value proposition of the large-scale simulation of MTdc architectures identified using EMT-TS hybrid simulation
  - Will continue to work on improving the scalability and speed of EMT simulation of MTdc architectures through simulation capabilities like RE_INTEGRATE
- **“Next set of Challenges” evaluated using EMT**
  - Scalability
  - Interoperability
  - Extra High-Voltage dc Systems (Design study)

Conclusions

- **Different HVdc architectures evaluated in EMT simulation testbeds**
  - Protection studies
  - Large ac-dc system studies (reliability studies)
- **EMT-TS hybrid simulation**
  - Design validation and reliability studies

Acknowledgment

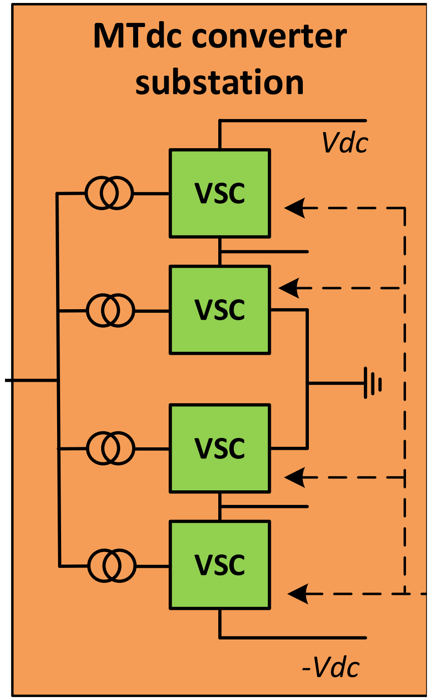
This material is based upon work supported by the U.S. Department of Energy's Office of Electricity (OE) under Transformer Resilience and Advanced Components (TRAC).

Andre Pereira from Transformer Resilience and Advanced Components (TRAC) program, Office of Electricity (OE), U.S. Department of Energy (DOE)

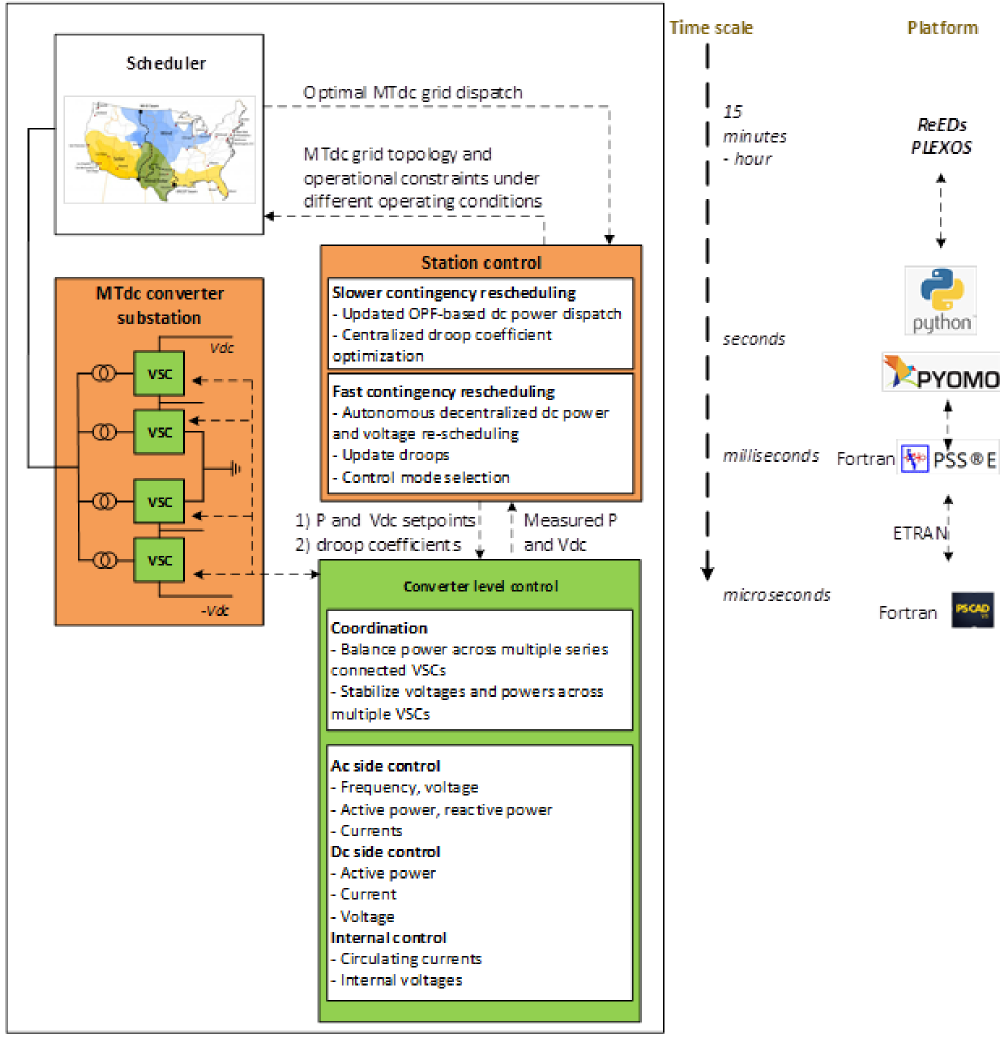
Thank You

Another Future Scenario: Extra High-Voltage dc Systems

MTdc system over long distances (EI with 4-terminal MTdc system; 24 MMCs)



Higher power rated HVdc station (series-parallel configuration)



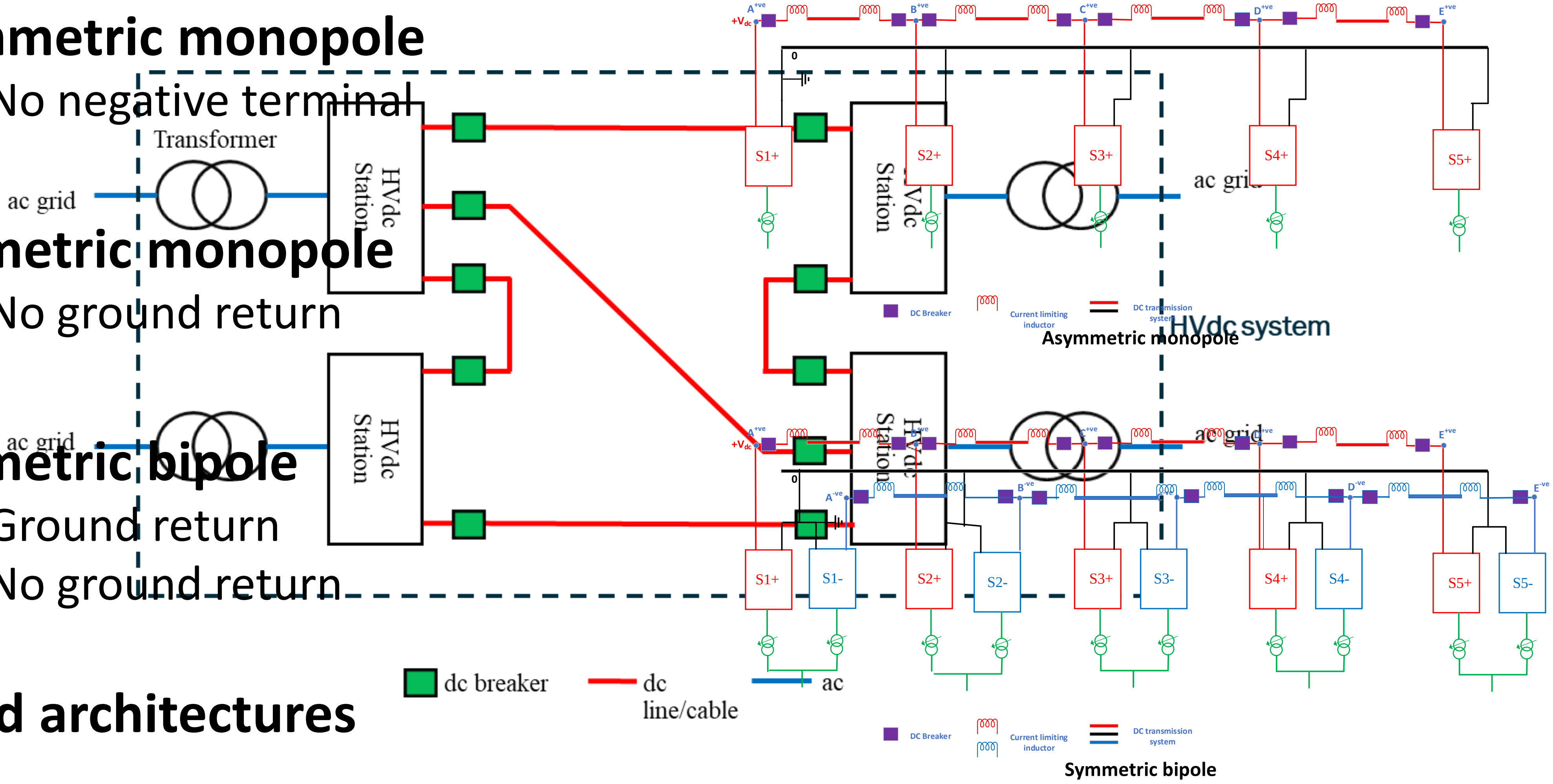
Control and protection system architecture for higher power rated HVdc

Common challenge in scalability of simulations to perform large dc-ac systems' analysis!

Project Team: ORNL, PNNL, NREL

MTdc Architectures

- **Asymmetric monopole**
  - No negative terminal
- **Symmetric monopole**
  - No ground return
- **Symmetric bipole**
  - Ground return
  - No ground return
- **Mixed architectures**



Interoperability: EMT Application

Interoperability

- **Modeling capabilities** – evaluation of interoperability or multi-vendor systems*
- **Interoperability of the systems with multiple vendors and scalability of controls** - this is an extremely challenging problem!*
- **Goal:** Enable multi-vendor MTdc systems
  - Identify key functional requirements and technical specifications
- **Approach:**
  - MTdc simulation setup at ORNL to evaluate multi-vendor systems to integrate wind (that enables plug-and-play)
  - Enable multiple (e.g., Siemens Energy and Hitachi Energy) HVdc systems in the setup using hierarchical control systems
  - Evaluate capability to integrate in different utilities and system operators
- **Target:** Improve reliability and operability of multi-vendor MTdc systems through simulation setup

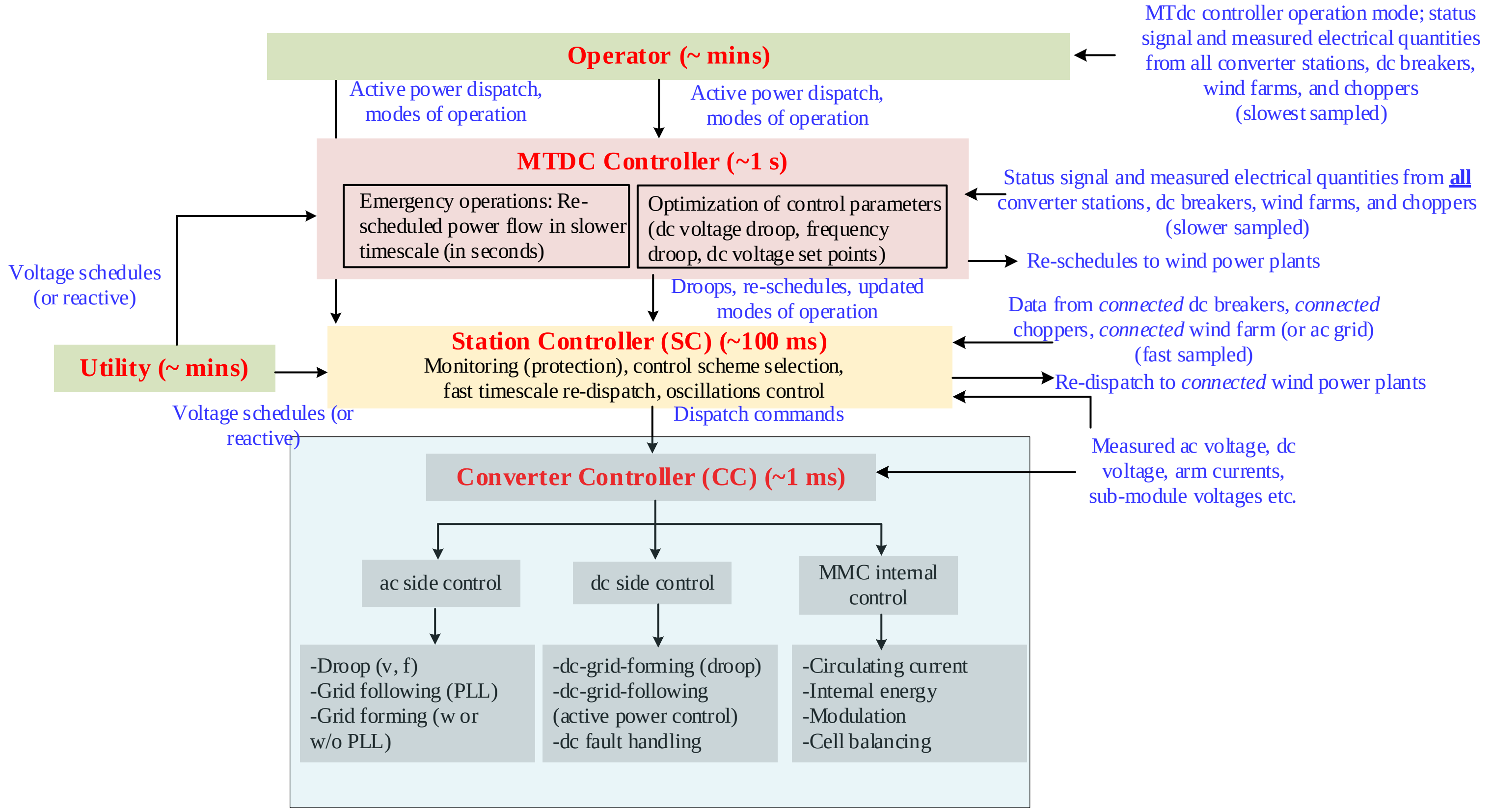
*Identified through a series of workshops and multiple engagements

[1] US DOE, “High-Voltage Direct Current (HVDC) COst REduction (CORE) Initiative”, 2023.
[2] US DOE, “HVdc Roadmap”, 2024 (expected).

Interoperability

One potential technical specification example

- Hierarchical control system to enable multi-vendor MTdc systems



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Extra High-Voltage dc Systems: Architecture

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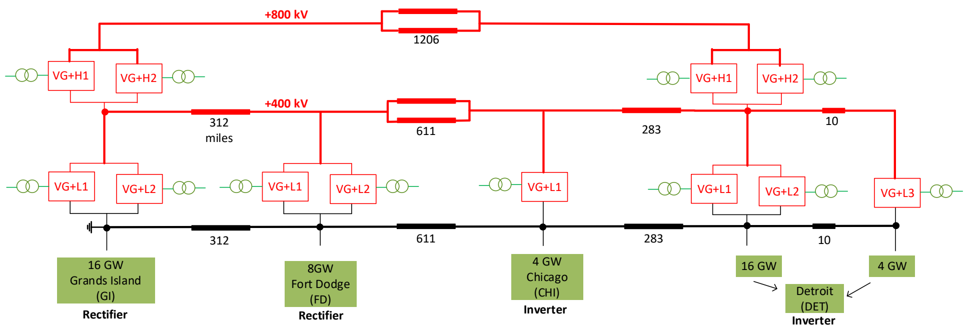
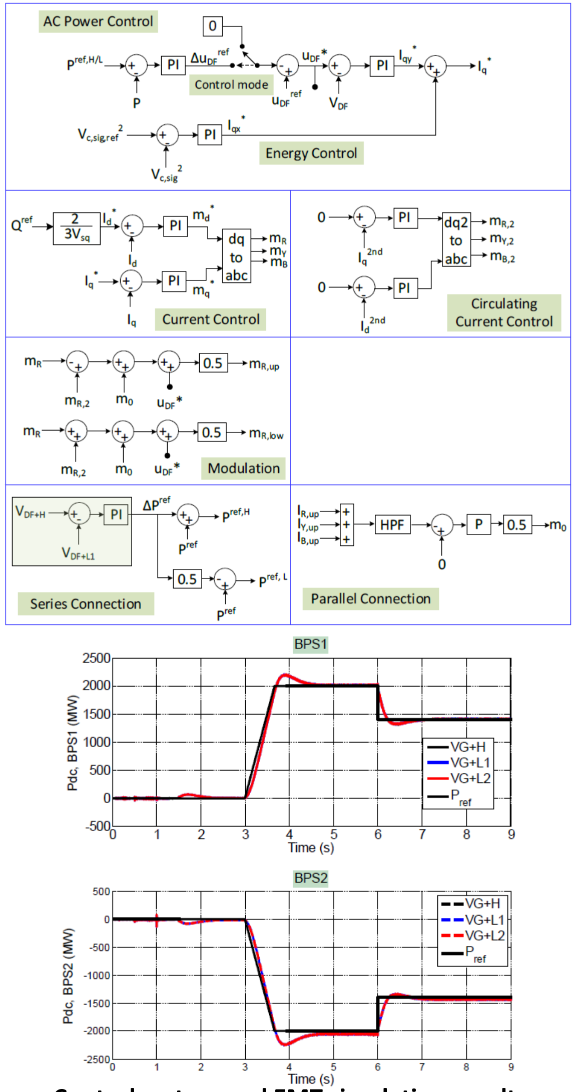


Four terminal high-voltage MTdc (800 kV)



Control system and EMT simulation results

Common challenge in scalability of simulations to perform large dc-ac systems' analysis!