HVDC Transmission: Multi-Value Planning Considerations and Experience

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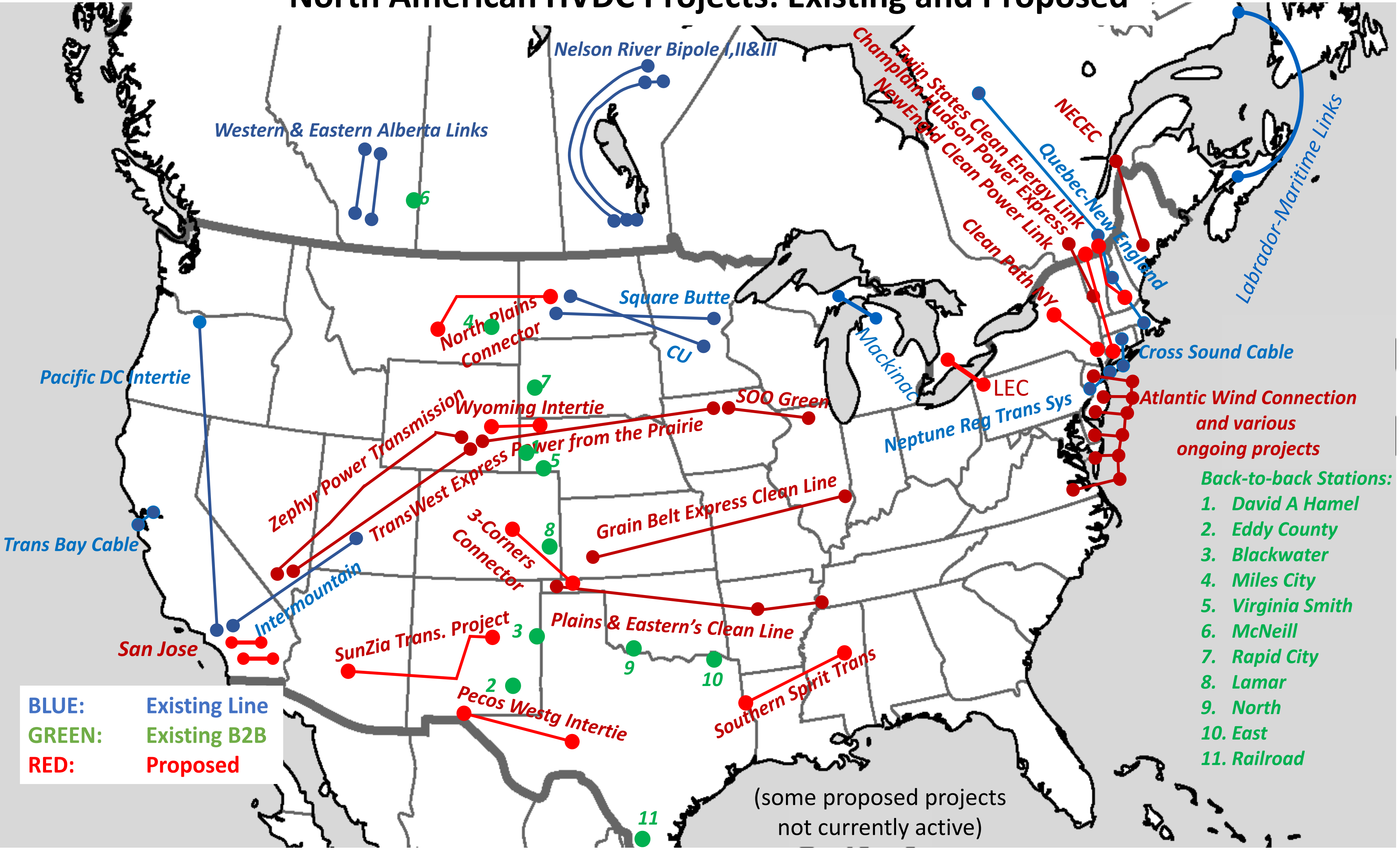
Source: Siemens

Contents

Significant HVDC Experience, including with rapidly-growing number of VSC projects in the U.S. and worldwide

North American HVDC Projects: Existing and Proposed



Source: Jim McCalley, Iowa State University

Rte's HVDC-VSC Newsletter documents world-wide experience in great detail:

- **53** existing HVDC-VSC projects (as of May 2023)
- **26** new HVDC-VSC projects online before the end of 2025
- **102** new HVDC-VSC projects through 2032

HVDC technology provides MISO with unique opportunities for multi-value transmission planning

MISO is leading the country with its LRTP and MVP transmission planning processes. Given the substantial regional transmission needs and challenges MISO has identified, new HVDC technology can provide effective solutions.

- MISO's RIIA studies have noted the unique capabilities and **benefits of new VSC-based HVDC** technology:
  - Lower costs for high-capacity, long-distance transmission, particularly from/to weak grid locations
  - Valuable grid-forming/supporting capabilities: power flow control, reactive/voltage support, dynamic stability, synthetic inertia, system restoration, and various other reliability attributes and grid services
- VSC technology has become the dominant HVDC application, with substantial commercial and quickly **growing experience** in offshore, onshore, embedded , and multi-terminal applications
- The industry has already gained substantial **HVDC transmission planning experiences**
  - For example: IEEE Planning for HVDC (2021-22), 3/24/23 EPRI presentation to SPP, CIGRE, ENTSO-E, CAISO 2021 and 2022 TPPs (discussed later)
- The "Tranche 2" MVP planning effort offers a **unique opportunity for MISO** to gain the necessary planning, market integration, and operational experience with VSC HVDC technology for possible larger-scale future deployments

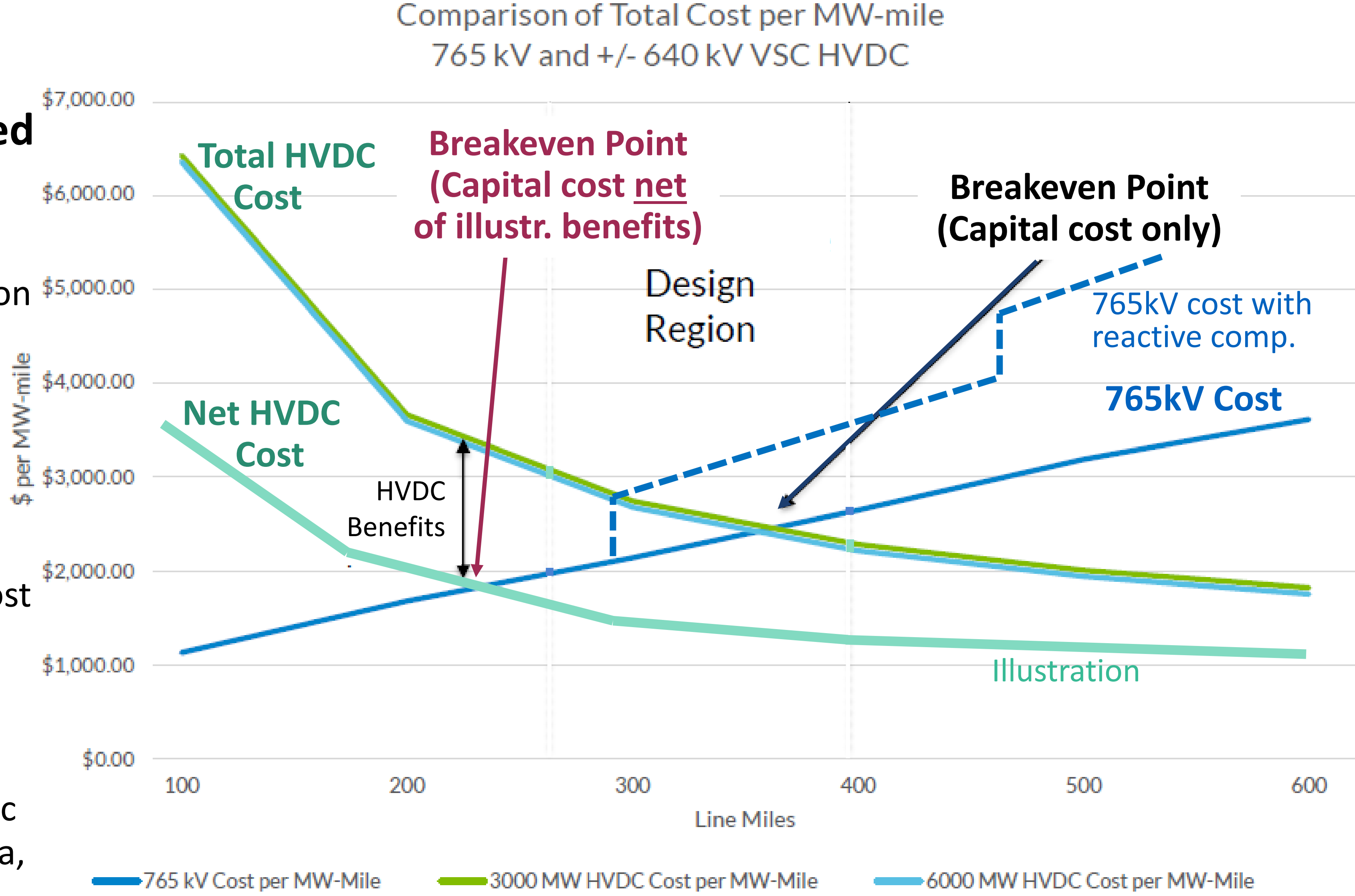
Recognizing HVDC VSC benefits in multi-value planning

HVDC-VSC Capability	Planning Benefits / Options for Quantification
1. Flow control/market optimization	• Estimate value of congestion relief and loss reduction on AC grid with nodal production cost model that can optimize HVDC
2. Dynamic reactive power and voltage control	• Avoided cost of STATCOMs, SVCs, or synchronous condensers
3. Lower long-distance transfer losses	• Market value of avoided losses on transmitted energy
4. Smaller footprint/right-of-way (ROW), including for undergrounding option	• Lower cost for right-of-way (e.g., 50ft less than for 765kV AC); lower cost of undergrounding; lower permitting risks
5. Reliability benefits (fault ride-through, lower N-1 contingency for bipoles, voltage support)	• Increased transfer capacity; reduced cost of contingency reserves; avoided AC equipment costs (e.g., additional lines, STATCOMs)
6. AC dynamic stability; power oscillation dampening; mitigate stability constraints on AC grid	• Avoided cost of power system stabilizers/supplemental power oscillation damping (POD) controllers on batteries, SVCs, STATCOMs, switched shunt equipment, synchronous condensers, etc. • Value of congestion relief on proxy constraints
7. Grid forming, grid services, synthetic inertia, blackstart/restoration, etc.	• Market value or avoided cost of providing the grid services through conventional means

MISO's 3/8/23 PAC presentation is helpful starting point for applying a multi-value planning framework to new lines

HVDC solutions can offer additional benefits (and avoided AC facilities cost), that lower their net cost:

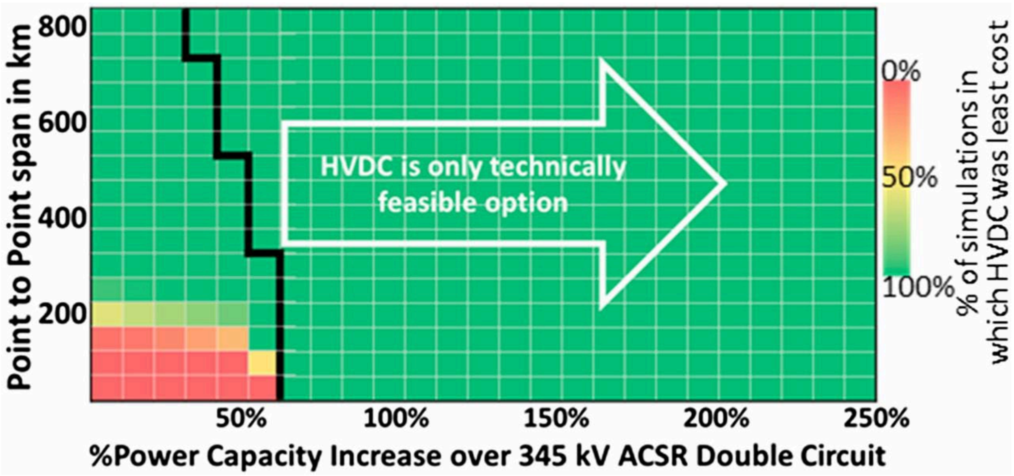
1. Flow control and market optimization (to reduce AC grid congestion and losses)
2. Dynamic reactive power/voltage control
3. Lower transfer losses
4. Lower ROW and undergrounding cost
5. Lower N-1 contingency
6. AC system dampening; mitigate stability constraints
7. Grid forming, grid services, synthetic inertia, blackstart/restoration inertia, etc.

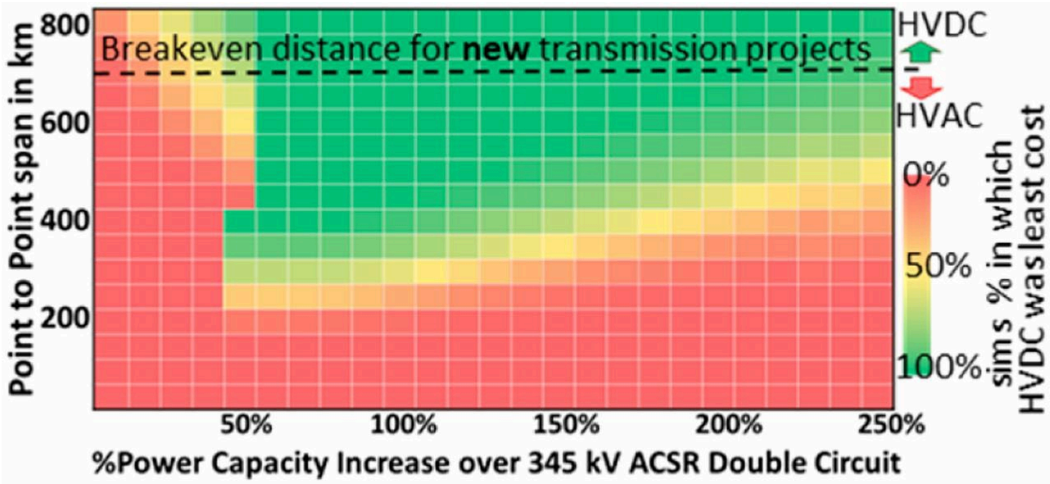


This is a modified version of the chart in slide 29 of MISO, Discussion of Legacy, 765kV, and HVDC Bulk Transmission, March 8, 2023.

Planning HVDC conversions/upgrades of existing lines may offer substantially lower-cost options

2019 Article: Converting existing transmission corridors to HVDC to increase transmission capacity | PNAS





If an existing double-circuit 345kV line has to be upgraded and ROW cannot be expanded:

- AC solutions cannot increase capacity by more than 60%
- HVDC conversion is least cost if the transfer capability needs to be increased by more than 60% or the distance is more than 200 km (135 miles)
- Example does not even consider VSC-related benefits

If multiple 345kV or 500kV lines are possible:

- HVDC conversion is preferable if capability needs to be increased by more than 60% and the distance is more than 300 km (185 miles) … even though the break-even distance for new transmission may be 700 km (430 miles)

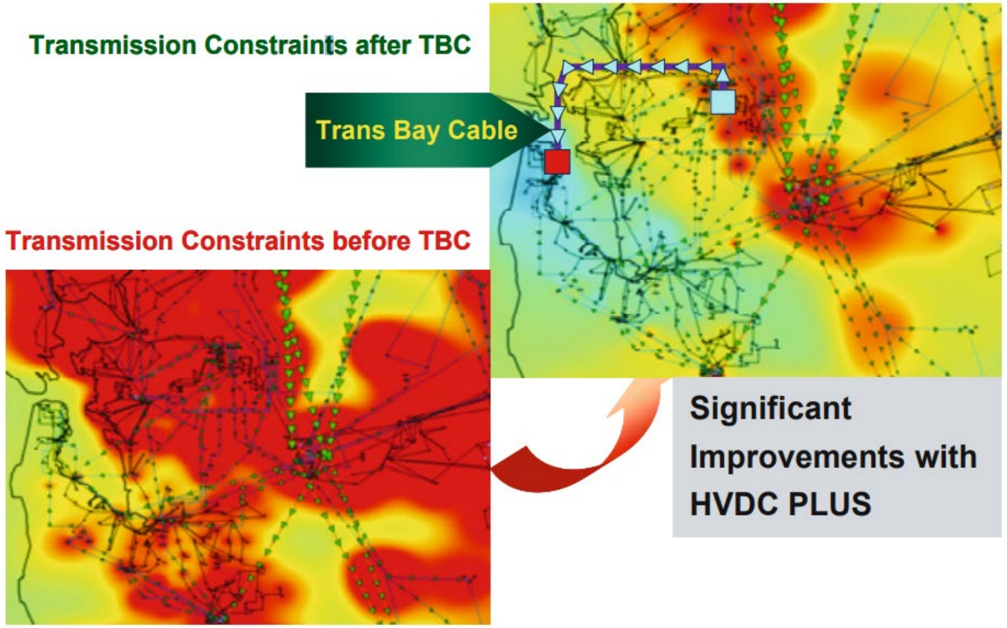
Similar analyses can be done for upgrading existing HVAC or HVDC lines at different voltage levels

CAISO Case Study: HVDC solutions in transmission planning

CAISO has been a leader in considering HVDC solutions in transmission planning:

- Transbay Cable (TBC), CAISO's first internal HVDC-VSC line, operational since 2013 (1st in North America)
- In its recent Transmission Planning Processes (TPPs), CAISO considered a dozen HVDC solutions and approved two (all VSC, some multi-terminal):

  For example: "the HVDC alternatives resulted in better performance from the power flow perspective as a result of controllability of the HVDC source. The HVDC alternative also provides benefits in reducing local capacity requirements in the San Jose subarea and overall Greater Bay Area that reduces reliance on the local gas generation."



Source: HVDC PLUS – Basics and Principle of Operation, Siemens

- Improvements in California planning studies for HVDC continue:
  - CAISO continues efforts of finding and promoting standard models and approaches for assessing HVDC VSC
  - For example, CAISO is in the process of assessing applicable models for dynamic stability analysis
  - Cal Western has been working with industry experts to develop dynamic stability models for HVDC VSC lines and to find modeling solutions that work in a PSLF environment; they are now able to do dynamic analysis of HVDC VSC lines using PSLF.

Examples of HVDC benefits considered in CAISO’s TPPs

CAISO’s 2022 TPP Report discusses a number of VSC-HVDC-related benefits that are considered in its Transmission Planning Process:

- “Transmission over long distances with overhead lines or underground/subsea cables; there is no practical limit on how far power could be transmitted with HVDC lines”
- “smaller rights-of-way”
- “Power flow on the line is set by the operator”
- “The AC system the VSC-HVDC converters are connected to does not need specific minimum short circuit levels”
- “Does not require reactive power support at the converter station”
- “Multi-terminal configuration is less complicated”
- “VSC-HVDC is suitable for delivering power to urban areas and systems with low short-circuit levels”
- “The converter stations are physically smaller compared to LCC HVDC stations and therefore more suitable to deliver power to urban centers”
- VSC HVDC lines can be combined with other technologies: e.g., to create a “hybrid AC and HVDC solution” to connect 14,428 MW of wind with two VSC-HVDC, two LCC-HVDC, and two 500kV AC lines

Source: ISOBoardApproved-2021-2022TransmissionPlan (caiso.com)

Example: HVDC solutions considered in CAISO's recent TPP

CAISO's 2023 TPP considered ten VSC-HVDC solutions for addressing identified reliability needs in southern California:

1. Three variants of a Diablo South Multi-Terminal HVDC VSC Line:
   - 2000 MW at Diablo Canyon, 1000 MW at Alamitos, and 1000 MW at Huntington Beach
   - 2000 MW at Diablo Canyon, 1000 MW at Redondo Beach, 1000 MW at Encina
   - 2000 MW at Diablo Canyon, 500 MW at Redondo Beach, 750 MW at Alamitos, 750 MW at San Onofre
4. Alberhill – Suncrest HVDC VSC Line (1000 MW)
5. Vincent – Del Amo HVDC VSC line (1000 MW)
6. Imperial Valley – Serrano HVDC VSC line (2000 MW)
7. Devers – La Fresa HVDC VSC line (1000 MW)
8. Imperial Valley – Del Amo HVDC VSC line (2000 MW)
9. Two variants of an Imperial Valley multi-terminal HVDC VSC:
   - Imperial Valley (2000 MW) – Inland (normal flow at 1000 MW with converter capability up to 2000 MW for emergency condition) – Del Amo (1000 MW normal flow with converter capability up to 2000 MW for emergency condition)
   - Multi-terminal HVDC VSC: Imperial Valley (2000 MW) – Sycamore Canyon (1000 MW normal flow with converter capability up to 2000 MW for emergency condition) – Del Amo (1000 MW normal flow with converter capability up to 2000 MW for emergency condition)

Source: [Presentation-2022-2023-Transmission-Planning-Process-Nov 17, 2022.pdf (caiso.com)]

CAISO and NYISO initiatives to capture HVDC planning benefits

To ensure that the multiple benefits of HVDC lines (as considered in planning) can actually be captured, CAISO and NYISO have both initiated and implemented several adjustments to their wholesale market design and operations:

- As part of CAISO's Market & Operational Excellence effort, **optimization of controllable transmission devices"** (e.g., HVDC lines and phase shifters) was added to the CAISO DA+RT markets in 2017:
  - Section 3.2.12: "The CAISO market system [now] optimizes the controllable transmission devices as part of its security constrained economic dispatch and security constrained unit commitment. The CAISO market system will calculate and issue the optimal position for the controllable device to the transmission owner."
- NYISO is implementing optimization of "**Internal Controllable Lines**" in its energy and capacity markets after the Clean Path NY line was selected in part because of its congestion-relief benefits to the AC grid
- The Western EIM (and the proposed new Extended DA Market) is able to fully **co-optimize the dispatch of interregional HVDC lines** (and phase shifters) between the 19 BAs who now participate in EIM (and some soon in EDAM)
  - The Western EIM and EDAM use CAISO's RT+DA market engine to achieve interregional optimization
- CAISO is now in process of finishing its Subscriber PTO (SPTO) framework for full DA+RT market integration of unscheduled capacity on interregional **merchant HVDC lines**

Takeaways

1. **HVDC VSC transmission**, now the dominant HVDC technology, offers substantial advantages in addressing many of MISO's transmission needs, including dispatchable flow-control and other AC-grid enhancements, at lower cost
2. HVDC VSC benefits are particularly pronounced in **MISO's footprint** due to the large supply of low-cost renewable generation in areas with a weak AC grid that are very distant from major load centers
3. MISO's **multi-value planning framework** is uniquely well-suited to consider the multiple benefits (and avoided AC upgrade costs) offered by HVDC VSC transmission
4. MISO now has a **unique opportunity** to fast-track cost-effective HVDC upgrades in Tranche 2 of its LRTP and quickly gain the necessary planning, operational, and market-integration experience (incl. by learning from others)
5. Gaining HVDC experience quickly will be invaluable for integrating and optimizing future **intra-regional and inter-regional** HVDC (and 765kV) transmission projects

About the Speaker

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Johannes (Hannes) Pfeifenberger, a Principal at The Brattle Group, is an economist with a background in electrical engineering and over twenty-five years of experience in wholesale power market design, renewable energy, electricity storage, and transmission. He also is a Visiting Scholar at MIT's Center for Energy and Environmental Policy Research (CEEPR), a Senior Fellow at Boston University's Institute of Sustainable Energy (BU-ISE), a IEEE Senior Member, and currently serves as an advisor to research initiatives by the U.S. Department of Energy, the National Labs, and the Energy Systems Integration Group (ESIG).

Hannes specializes in wholesale power markets and transmission. He has analyzed transmission needs, transmission benefits and costs, transmission cost allocations, and renewable generation interconnection challenges for independent system operators, transmission companies, generation developers, public power companies, industry groups, and regulatory agencies across North America. He has worked on transmission matters in SPP, MISO, PJM, New York, New England, ERCOT, CAISO, WECC, and Canada and has analyzed offshore-wind transmission challenges in New York, New England, and New Jersey.

He received an M.A. in Economics and Finance from Brandeis University's International Business School and an M.S. and B.S. ("Diplom Ingenieur") in Power Engineering and Energy Economics from the University of Technology in Vienna, Austria.

Examples of Brattle Reports on Regional and Interregional Transmission Planning and Benefit-Cost Analyses

Additional Reading on Transmission

Pfeifenberger, DeLosa, et al., The Benefit and Urgency of Planned Offshore Transmission, for ACORE, ACP, CATF, GridLab, and NRDC, January 24, 2023.

Brattle and ICC Staff, Illinois Renewable Energy Access Plan: Enabling an Equitable, Reliable, and Affordable Transition to 100% Clean Electricity for Illinois, December 2022.

Pfeifenberger et al., New Jersey State Agreement Approach for Offshore Wind Transmission: Evaluation Report, October 26, 2022.

Pfeifenberger, DeLosa III, Transmission Planning for a Changing Generation Mix, OPSI 2022 Annual Meeting, October 18, 2022.

Pfeifenberger, Promoting Efficient Investment in Offshore Wind Transmission, DOE-BOEM Atlantic Offshore Wind Transmission Economics & Policy Workshop, August 16, 2022.

Pfeifenberger, Generation Interconnection and Transmission Planning, ESIG Joint Generation Interconnection Workshop, August 9, 2022.

Pfeifenberger and DeLosa, Proactive, Scenario-Based, Multi-Value Transmission Planning, Presented at PJM Long-Term Transmission Planning Workshop, June 7, 2022.

Pfeifenberger, Planning for Generation Interconnection, Presented at ESIG Special Topic Webinar: Interconnection Study Criteria, May 31, 2022.

RENEW Northeast, A Transmission Blueprint for New England, Prepared with Borea and The Brattle Group, May 25, 2022.

Pfeifenberger, New York State and Regional Transmission Planning for Offshore Wind Generation, NYSERDA Offshore Wind Webinar, March 30, 2022.

Pfeifenberger, The Benefits of Interregional Transmission: Grid Planning for the 21st Century, US DOE National Transmission Planning Study Webinar, March 15, 2022.

Pfeifenberger, 21st Century Transmission Planning: Benefits Quantification and Cost Allocation, for NARUC members of the Joint Federal-State Task Force on Electric Transmission, January 19, 2022.

Pfeifenberger, Spokas, Hagerty, Tsoukalis, A Roadmap to Improved Interregional Transmission Planning, November 30, 2021.

Pfeifenberger, Tsoukalis, Newell, "The Benefit and Cost of Preserving the Option to Create a Meshed Offshore Grid for New York," Prepared for NYSERDA with Siemens and Hatch, November 9, 2022.

Pfeifenberger, Transmission–The Great Enabler: Recognizing Multiple Benefits in Transmission Planning, ESIG, October 28, 2021.

Pfeifenberger et al., Transmission Planning for the 21st Century: Proven Practices that Increase Value and Reduce Costs, Brattle-Grid Strategies, October 2021.

Pfeifenberger et al., Initial Report on the New York Power Grid Study, prepared for NYPSC, January 19, 2021.

Van Horn, Pfeifenberger, Ruiz, "The Value of Diversifying Uncertain Renewable Generation through the Transmission System," BU-ISE, October 14, 2020.

Pfeifenberger, Newell, Graf and Spokas, "Offshore Wind Transmission: An Analysis of Options for New York", prepared for Anbaric, August 2020.

Pfeifenberger, Newell, and Graf, "Offshore Transmission in New England: The Benefits of a Better-Planned Grid," prepared for Anbaric, May 2020.

Tsuchida and Ruiz, "Innovation in Transmission Operation with Advanced Technologies," T&D World, December 19, 2019.

Pfeifenberger, "Cost Savings Offered by Competition in Electric Transmission," Power Markets Today Webinar, December 11, 2019.

Chang, Pfeifenberger, Sheilendranath, Hagerty, Levin, and Jiang, "Cost Savings Offered by Competition in Electric Transmission: Experience to Date and the Potential for Additional Customer Value," April 2019 and "Response to Concentric Energy Advisors' Report on Competitive Transmission," August 2019.

Ruiz, "Transmission Topology Optimization: Application in Operations, Markets, and Planning Decision Making," May 2019.

Chang, Pfeifenberger, "Well-Planned Electric Transmission Saves Customer Costs: Improved Transmission Planning is Key to the Transition to a Carbon-Constrained Future," WIRES&Brattle, June 2016.

Newell et al. "Benefit-Cost Analysis of Proposed New York AC Transmission Upgrades," on behalf of NYISO and DPS Staff, September 15, 2015.

Pfeifenberger, Chang, and Sheilendranath, "Toward More Effective Transmission Planning: Addressing the Costs and Risks of an Insufficiently Flexible Electricity Grid," WIRES and Brattle, April 2015.

Chang, Pfeifenberger, Hagerty, "The Benefits of Electric Transmission: Identifying and Analyzing the Value of Investments," on behalf of WIRES, July 2013.

Chang, Pfeifenberger, Newell, Tsuchida, Hagerty, "Recommendations for Enhancing ERCOT's Long-Term Transmission Planning Process," October 2013.

Pfeifenberger and Hou, "Seams Cost Allocation: A Flexible Framework to Support Interregional Transmission Planning," on behalf of SPP, April 2012.

Pfeifenberger, Hou, "Employment and Economic Benefits of Transmission Infrastructure Investment in the U.S. and Canada," on behalf of WIRES, May 2011.

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