LARGE POWER INTERVENORS

Utility Information Request

Docket Numbers: E015/CN-22-607; E015/TL-22-611 Date of Request: November 7, 2023

Requested From: Minnesota Power Response Due: November 17, 2023
Extension Granted to: December 8, 2023

By: Large Power Intervenors (Andrew P. Moratzka, Amber S. Lee)

Information Request No. 5

Please provide all Company communications with MISO regarding this Project.

Objection:

Minnesota Power objects to this information request as overly broad and unduly burdensome. Notwithstanding and without waiving this objection, Minnesota Power is providing all presentations or reports delivered to MISO related to the HVDC Project prior to the filing of the Application with the Minnesota Public Utilities Commission.

Response:

Please see the attached documents:

- LPI IR 005.01 Attach: *2022.06.09 MP-MISO HVDC Discussion.pdf,* Minnesota Power update to MISO on planning for the HVDC Modernization Project.
- LPI IR 005.02 Attach: *2022.10.17 MP Response to MISO Concepts.pdf,* Minnesota Power presentation during a meeting of MISO and Minnesota-Dakotas-Wisconsin Transmission Owners on the scope of LRTP Tranche 2.
- LPI IR 005.03 Attach: *2023.01.17 MP-MISO Meeting*, Minnesota Power meeting with MISO to provide an update on planning for the HVDC Modernization Project and discuss the status of the LRTP Tranche 2 study. Please note that information discussing a project that is not the HVDC Modernization project has been redacted due to relevance.

Response by: Christian Winter

Title: Manager-Regional Transmission Planning

Department: Delivery Support Operations

Telephone: 218-355-2908

As to Objection: David Moeller

Title: Senior Regulatory Counsel

Department: Legal

Telephone: (218) 723-3963

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- LPI IR 005.04 Attach: *2023.03.09 VSC HVDC vs 765kV AC_Draft Summary.pptx,* Minnesota Power, American Transmission Company, and MISO discussion on HVDC modeling and technology considerations for LRTP Tranche 2.
- LPI IR 005.05 Attach: *Square_Butte_HVDC_Upgrade_Facilities_Study_F118.pdf,* Minnesota Power Facilities Study Report for MISO Transmission Service Requests on the HVDC Line.
- LPI IR 005.06 Attach: *2023.05.31 MP-RBJ VSC-HVDC,* Minnesota Power and RBJ Engineering presentation during MISO Planning Advisory Committee stakeholder workshop on technology considerations for LRTP Tranche 2.

Response by: Christian Winter	As to Objection: David Moeller
Title: Manager-Regional Transmission Planning	Title: Senior Regulatory Counsel
Department: Delivery Support Operations	Department: Legal
Telephone: 218-355-2908	Telephone: (218) 723-3963

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Square Butte HVDC

Upgrade & Modernization Planning Update

MP-MISO DISCUSSION
June 9, 2022

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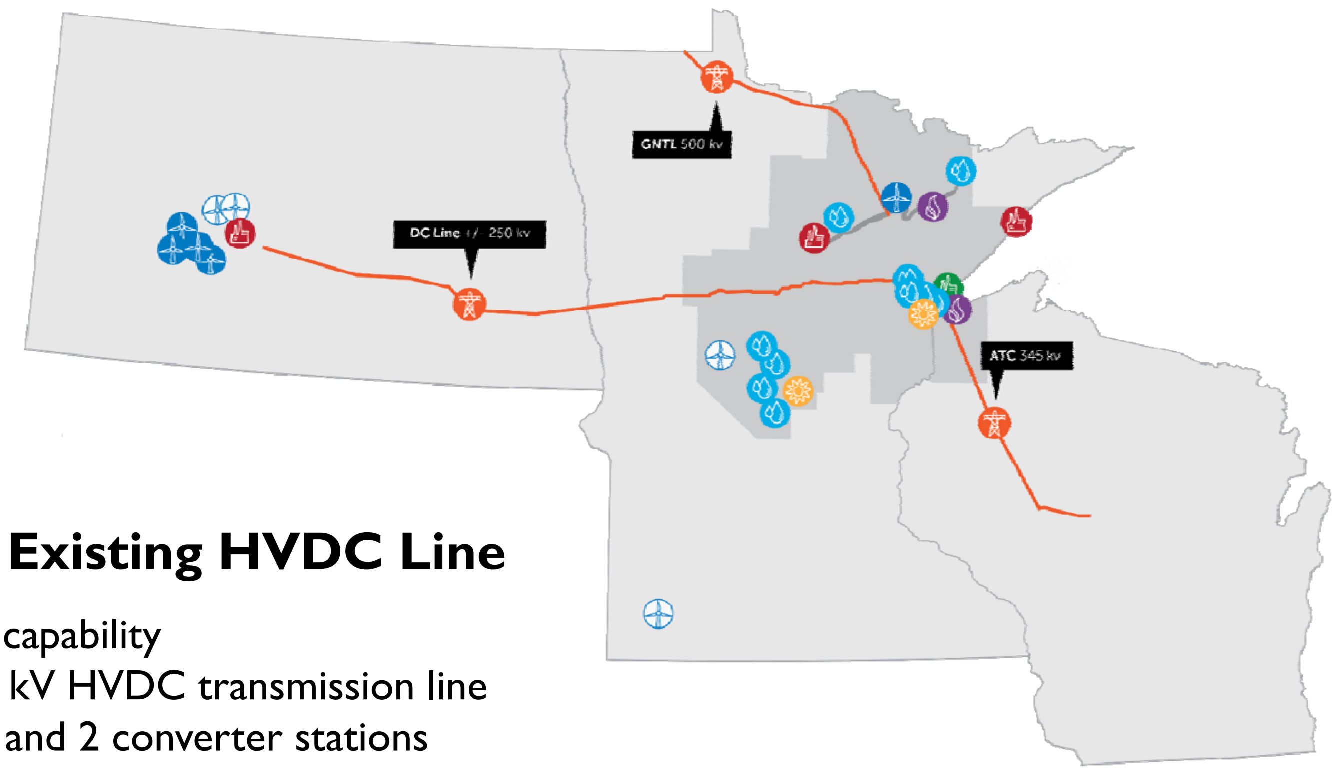
The Square Butte HVDC Corridor:
A Foundation for the Clean Energy Future



By the numbers: Existing HVDC Line

- 550 MW of existing capability
- 465 miles of +/- 250 kV HVDC transmission line
- 3200 line structures and 2 converter stations
- Put in service in 1977 to deliver "coal by wire" from ND coal fields to MP customers in NE Minnesota
- Acquired by MP in 2009 and repurposed to deliver wind and valuable energy to MP customers
- It is in need of modernization and has multiple potential opportunities to upgrade

When it was originally commissioned, Square Butte was the first long-distance project in North America to implement 12-pulse thyristor technology

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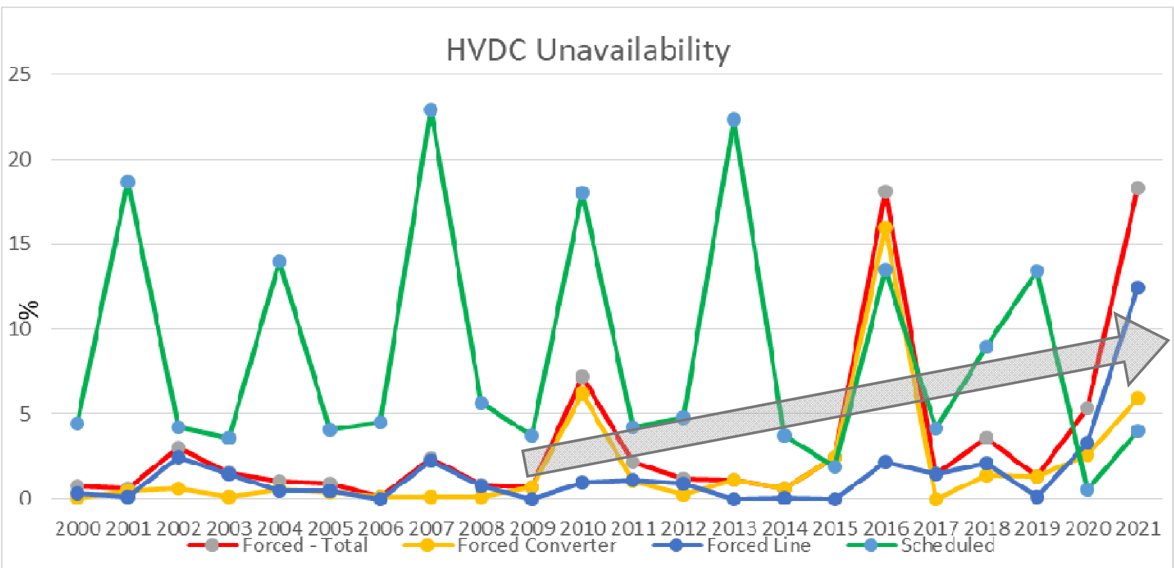
HVDC Modernization Urgency

Converter Station Modernization & Asset Renewal Needs

- **Control System:** Last upgrade was 2004, and those computer systems and components are now failing. Could result in an extended single pole outage, cutting HVDC capacity in half.
- **Power Modules:** Original pulse transformers no longer produced or supported by any manufacturer. Design specs destroyed/lost when GE originally exited from HVDC business. Limited spares available, and when we run out we will be in extended single pole outage.
- **Converter Transformers:** Three failures in last seven years, often associated with wear and tear caused by LTC operations. Limited refurbishment options. Failures more likely to be catastrophic and cause collateral damage. Could result in loss of one or both poles for an extended period of time depending on failure mode.



Forced outage rates are generally increasing, even as MP continues to diligently maintain the Square Butte HVDC system

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HVDC Upgrade Project Goals

1. **Modernization:** Address asset renewal needs by replacing existing converter stations ASAP
2. **Optimize Capacity:** Design converters to optimize capacity of existing HVDC transmission line. Max capacity for existing conductor on majority of line (2839 ACSR) is 900 MW
3. **Long-Term Technology:** Implement converter technology that does not become obsolete or un-upgradeable prior to normal end-of-life (35-40 years)
4. **Future Proof:** Robust to navigate changes in the surrounding transmission system, particularly for weaker transmission systems with high penetration of inverter-based resources
5. **Performance Features:** Self-sufficient in reactive power requirements, bi-directional dispatch capability, smooth & continuous control range, sub-hourly dispatchability, blackstart capable
6. **Expandability:** Designed to meet present maximum capacity (900 MW) with staged or modular expansion to meet future regional needs (3000 MW)

How to Develop a Solution?

Minnesota Power brought in RBJ Engineering to develop a robust HVDC Technology Assessment and recommendations on optimal near/term long-term solutions

RBJ Engineering Corporation

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HVDC Technology Assessment

1. **Development of Configurations:** Four basic configurations were developed by RBJ Engineering for investigation in the tech assessment:
   A. Initial 1500 MW Symmetric Monopole VSC with Future Expansion to 3000 MW Bipole
   B. Initial 1500 MW Bipole VSC with Future Expansion to 3000 MW Bipole
   C. Initial 900 MW Non-Expandable Bipole VSC with Future 3000 MW Bipole #2 Addition
   D. Initial 1500 MW Bipole LCC with Future Expansion to 3000 MW Bipole

   More information on each configuration is provided in Appendices

2. **Supplier Workshops:** A questionnaire with 40 specific questions was developed to accompany the configurations and three major suppliers – Siemens, Hitachi, and GE – were invited to join MP & RBJ for individual one-day technical workshops to discuss the questionnaire and configurations. Suppliers were also asked to respond in writing to the questionnaire, propose modifications or alternatives to the basic configurations, and provide indicative pricing for the initial and future stages of each configuration.

3. **Technology Assessment Report:** Following the supplier workshops, RBJ Engineering produced a detailed evaluation of technology options, configurations, performance and cost considerations, including recommendations for a preferred configuration.

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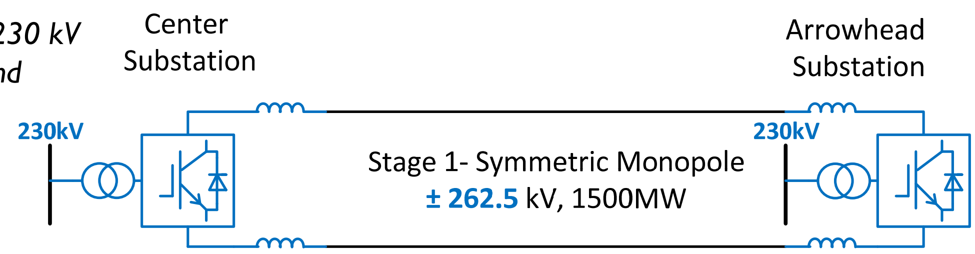
Preferred Expandable Solution
Expandable Symmetric Monopole

Relocate & replace existing converter stations with one 525 kV half-bridge VSC converter on each end, operated as a +/- 250 kV symmetric monopole using the existing HVDC line. Converter designed for 1500 MW capacity, operated initially at 900 MW or less based on line capacity limit. At this stage, Square Butte is converted to a single 900 MW HVDC line.

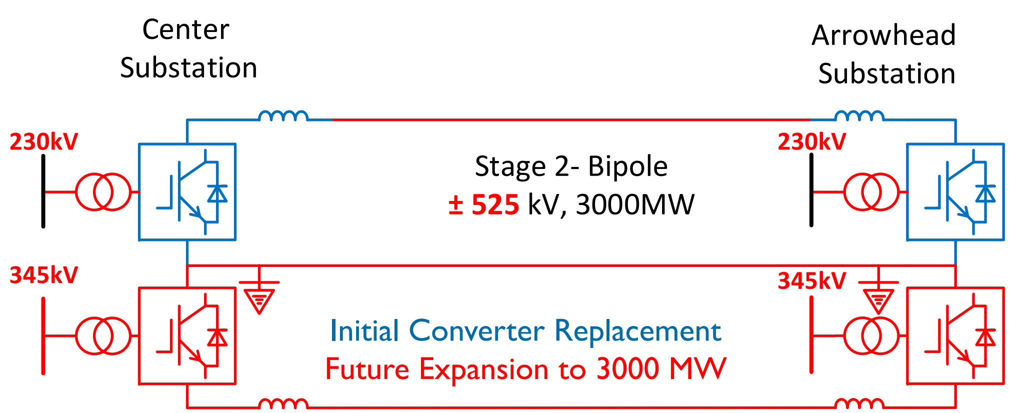
Initial AC interconnection voltage can be either 230 kV or 345 kV and can be different for each end



Expandability Options

I. Rebuild & reconductor existing HVDC line (465 miles) for 3000 MW capacity and +/- 525 kV bipole operation. Operate initially as a 1500 MW symmetric monopole (as shown above)

II. Add a second set of 525 kV converters on each end and modify existing 525 kV converter to operate as +/- 525 kV bipole HVDC with total capacity of 3000 MW (1500 MW per pole)



Initial converter preferably stays connected to same AC bus (230 kV or 345 kV) Future converter interconnects at 345 kV to tie in with complementary regional transmission.

HVDC control system and transmission line can be designed with future multi-terminal operation in mind, but HVDC suppliers generally discouraged multi-terminal

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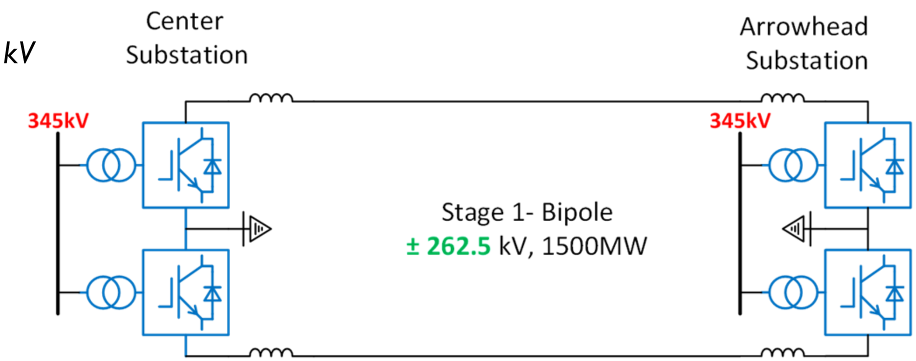
Alternative Expandable Solution
Expandable Bipole

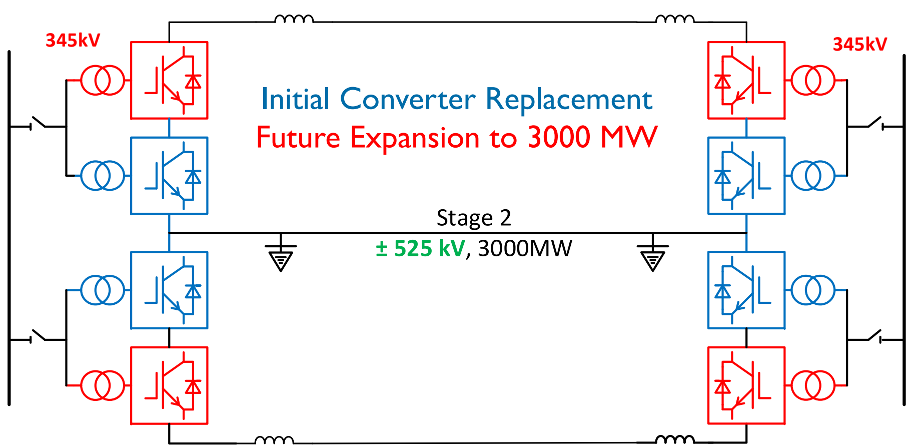
Relocate & replace existing converter stations with two 262.5 kV converters on each end, operated as a +/- 250 kV bipole similar to today's configuration. Initial bipole designed for 1500 MW capacity, operated initially at 900 MW or less based on line capacity limit.

Initial AC interconnection voltage can be either 230 kV or 345 kV and can be different for each end



Expandability

The most straightforward way to expand the bipole configuration is to add a second set of series-connected converters in each pole, located in adjacent buildings, to extend it to +/- 525 kV and 3000 MW total. This configuration may drive a preference for full-bridge converters.



Additional buildings, transformers, control system equipment, and potentially full bridge converters all drive up the cost and complexity of this configuration significantly

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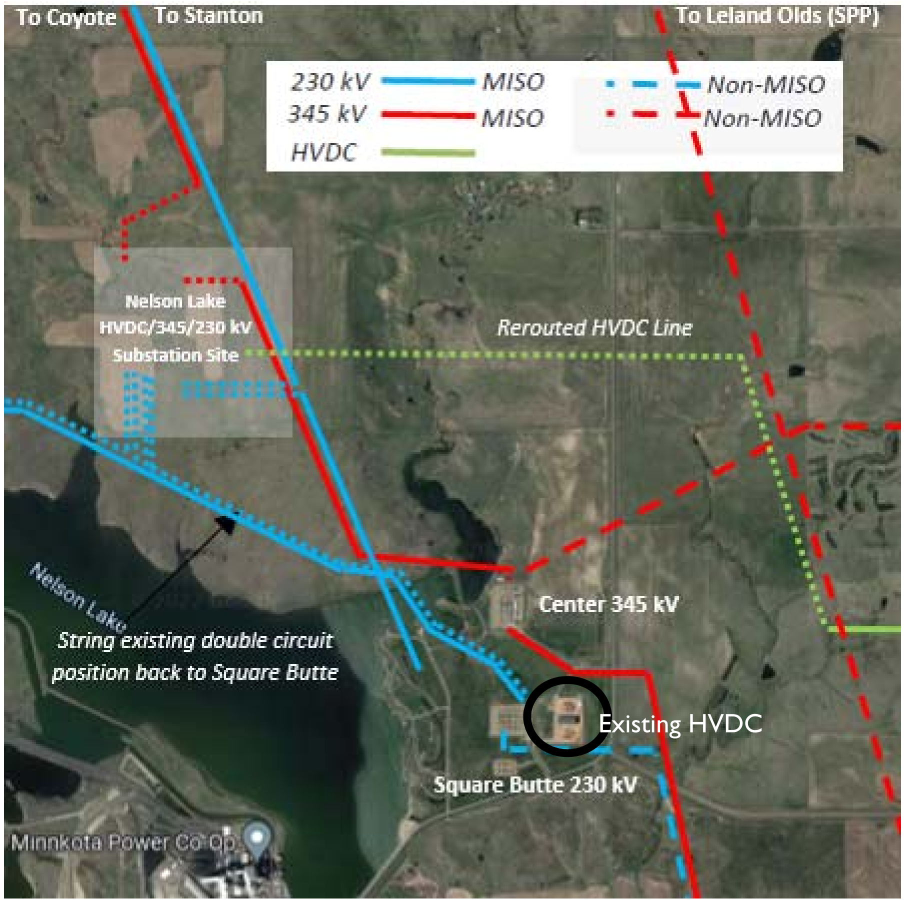
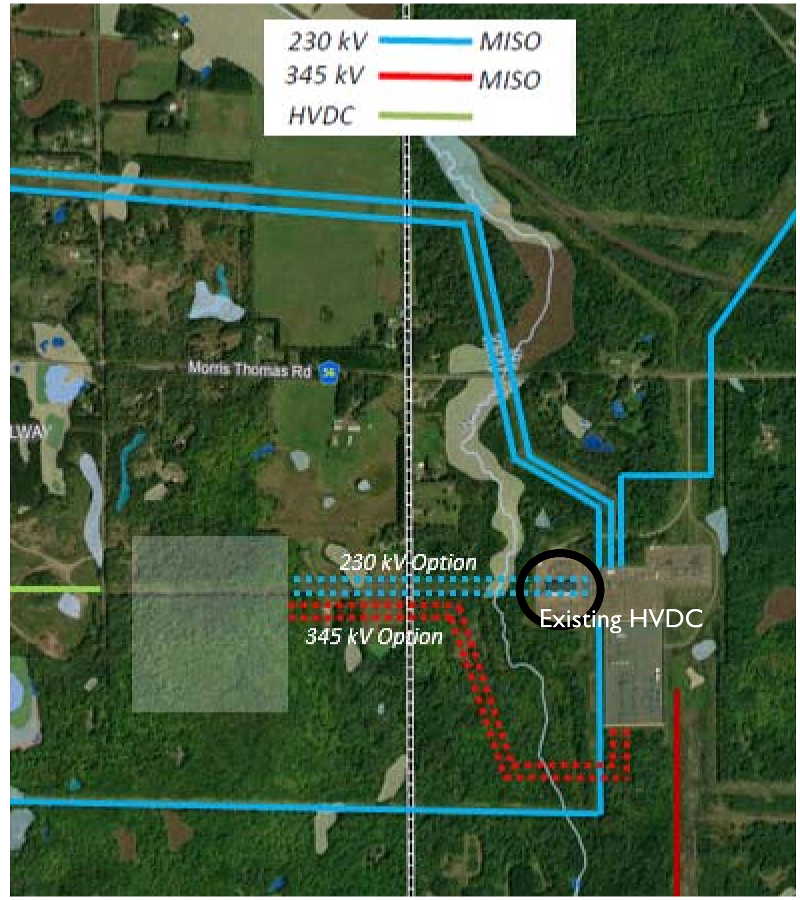
Converter Station Relocations





North Dakota: Nelson Lake Substation

Relocate converter & HVDC line to north side of Nelson Lake, tie in existing 230 kV system. Opportunity to bridge MPC seams that cause issues for MP, GRE, and OTP. Space for future 345 kV expansion to facilitate regional transmission network development.

Minnesota: St Louis County Substation

Relocate converter just west of Arrowhead Substation, tie in to existing Arrowhead 230 kV or 345 kV bus. Space for future 345 kV expansion to facilitate regional transmission network development. (Existing Arrowhead Substation has limited expandability)

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Cost Implications of Expandability

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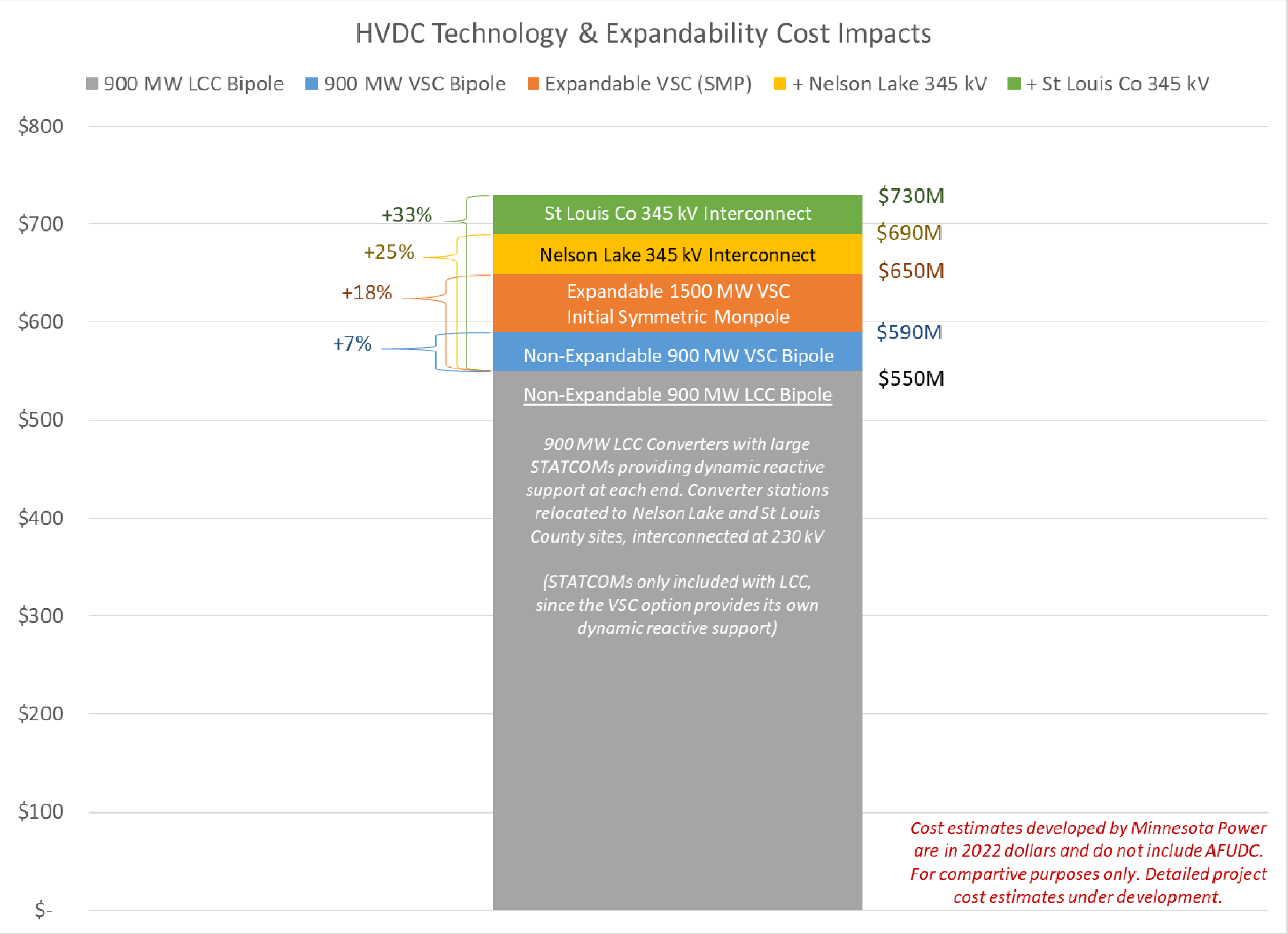

UMEX & LRTP Coordination

Moving Forward

MP has an urgent need to modernize the existing HVDC converters and is making plans to move forward with the converter station upgrades later in 2022. The project is being branded "Upper Midwest Express" (UMEX) and will be developed to meet MP's near-term needs, incorporating expandability only to the extent the incremental costs can be justified or offset. Anticipated best possible in-service date is 2027 based on HVDC supplier leadtimes.

How Should MP Coordinate with MISO Going Forward?

- Several near-term decisions about the scope of UMEX are critical to building expansion capability into the existing Square Butte HVDC corridor:
  - Technology Selection: VSC vs LCC
  - Configuration: Expandable Symmetric Monopole vs Non-Expandable Bipole
  - AC Interconnection Voltage: 345 kV vs 230 kV
- Does MISO wish to evaluate an incremental upgrade of the Square Butte HVDC as part of LRTP Tranche 2? Which increments are of interest (900 MW / 1500 MW / 3000 MW)? What is the timing for this evaluation and when will there be more certainty around whether or not the project can be justified for inclusion in LRTP Tranche 2? What can MP do to assist MISO's evaluation of the project? Can MISO assist MP with replicating the LRTP business justification metrics so that we can evaluate the project for ourselves?
- What other HVDC-related issues need to be resolved? How do we make progress on those?

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MISO LRTP Tranche 2

Minnesota Power Response to MISO Concepts

October 17, 2022

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Outline of Comments

1. **General Comments**
   - Go big, recognize where futures are headed
   - Consider RIIA findings, expand study concepts & analysis

2. **LRTP Futures & Modeling Assumptions**
   - Latest assumptions & models are not available for review
   - Western North Dakota needs attention
   - Regional transfer assumptions, particularly Manitoba Hydro

3. **Account for Existing TO Plans**
   - MP HVDC Modernization & Upgrade Project

4. **LRTP Tranche 2 Concepts**
   - Response to MISO's Northern Minnesota Concepts
   - Minnesota Power's Northern Minnesota Concepts
   - Minnesota Power's Western North Dakota Concepts

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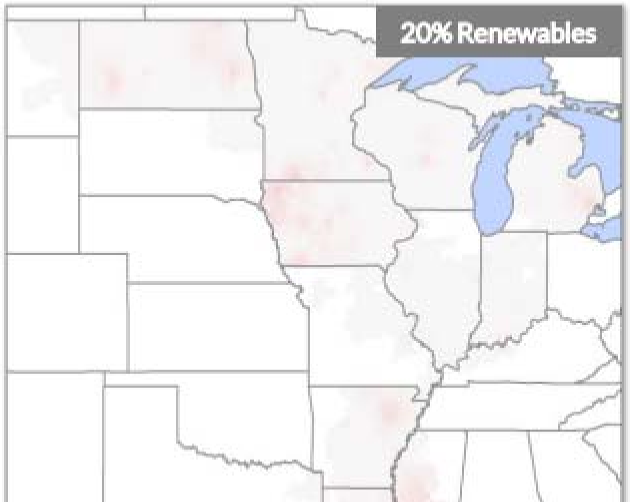
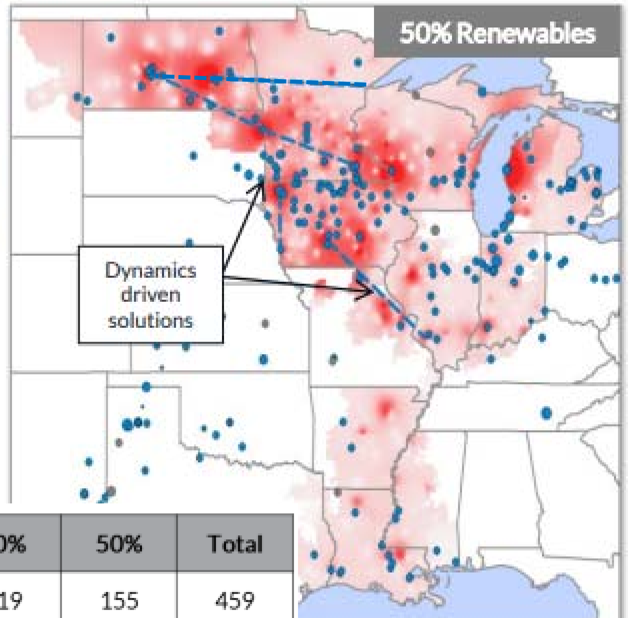
Consider RIIA Findings

Several locations may need mitigation for dynamic stability issues beyond 20% milestone





# of equipment per milestone	10%	20%	30%	40%	50%	Total
Switched Shunts	6	10	169	119	155	459

# of equipment per milestone	MISO Only			
	30%	40%	50%	Sub-total
Batteries (30min)	-	-	118	118
Controls Tuning	-	-	319	319
Dispatch Adjustment	-	60	17	77
HVDC	1	4	-	5
Power System Stabilizer	-	-	4	4
STATCOMs	25	8	5	38
Switched Shunts	-	-	-	-
Synchronous Condenser	2	10	163	175

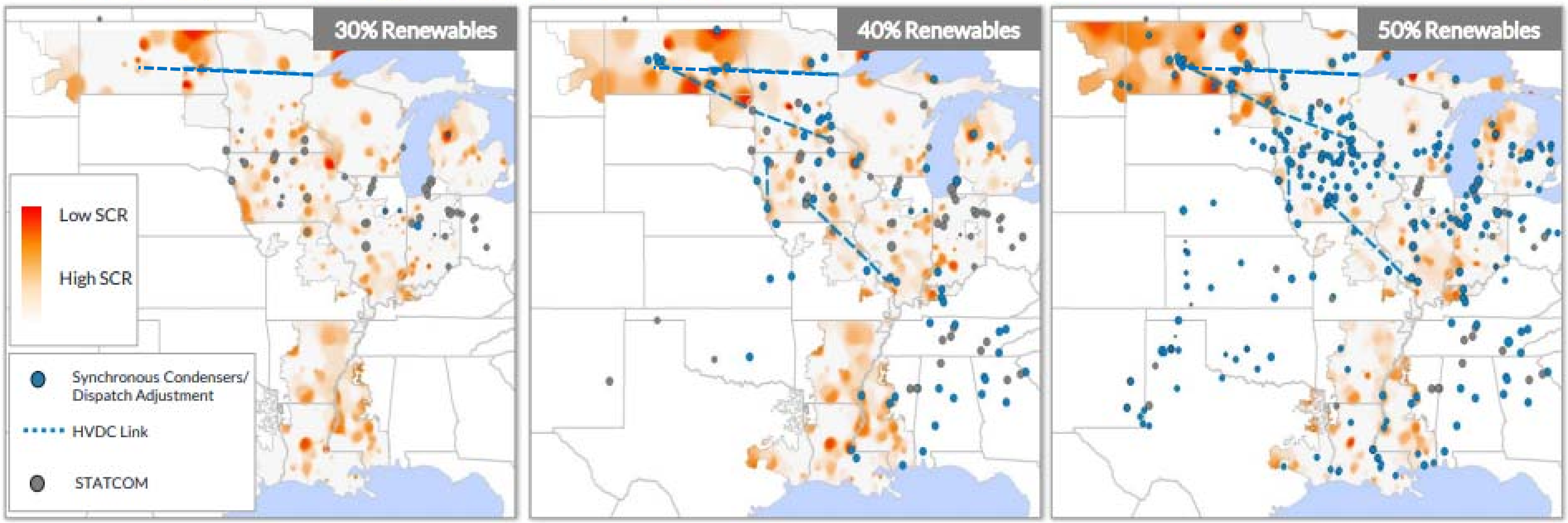
- Renewable penetration causes displacement and different dispatch patterns of conventional generators, leading to several dynamic issues.
- Power delivery from low short circuit areas may need transmission technologies equipped with dynamic support capabilities.
- Frequency response is stable up to 60% instantaneous renewable penetration, but may require additional planned headroom beyond

Go Big Where & How Needed

- RIIA identified inflection points, such as the jump from 20% to 30%
- **MISO says 2030 is the new 2040 and Future 3 is coming faster than expected**
- Tranche 2 needs to reflect those realities

Expand LRTP Concepts & Analysis

Starting at 40%, system-wide voltage stability is the main driver of dynamic complexity and requires transmission technologies equipped with dynamic-support capabilities



* Maps reflect cumulative solutions across milestones

Expand Concepts & Analysis for Tranche 2

- Voltage and transient stability need to be considered
- Reactive resources, STATCOMs, and Synch Condensers need to be considered
- VSC-HVDC needs be considered *(RIIA pointing to HVDC as early as 30% renewables)*

Addressing North Dakota Holistically

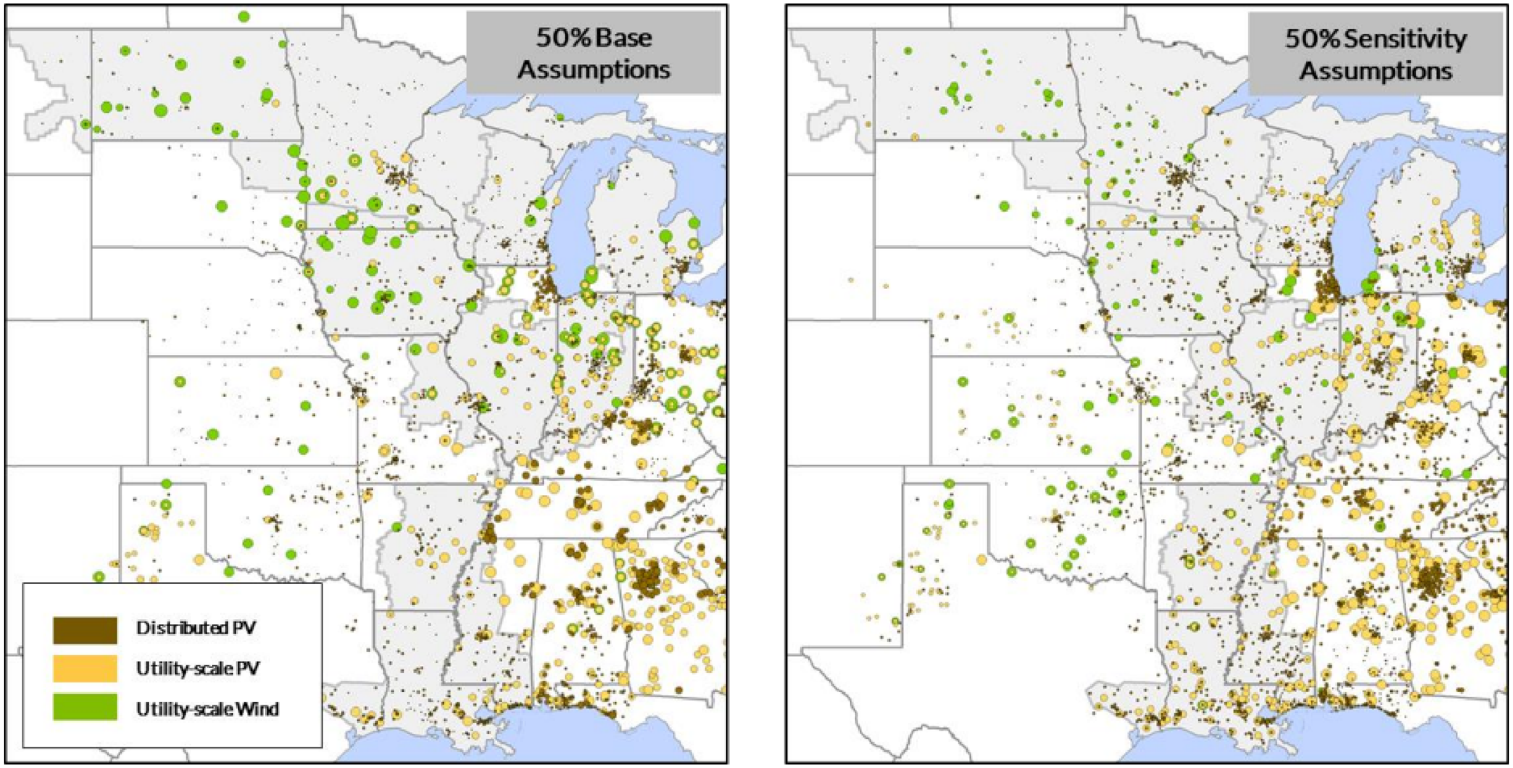
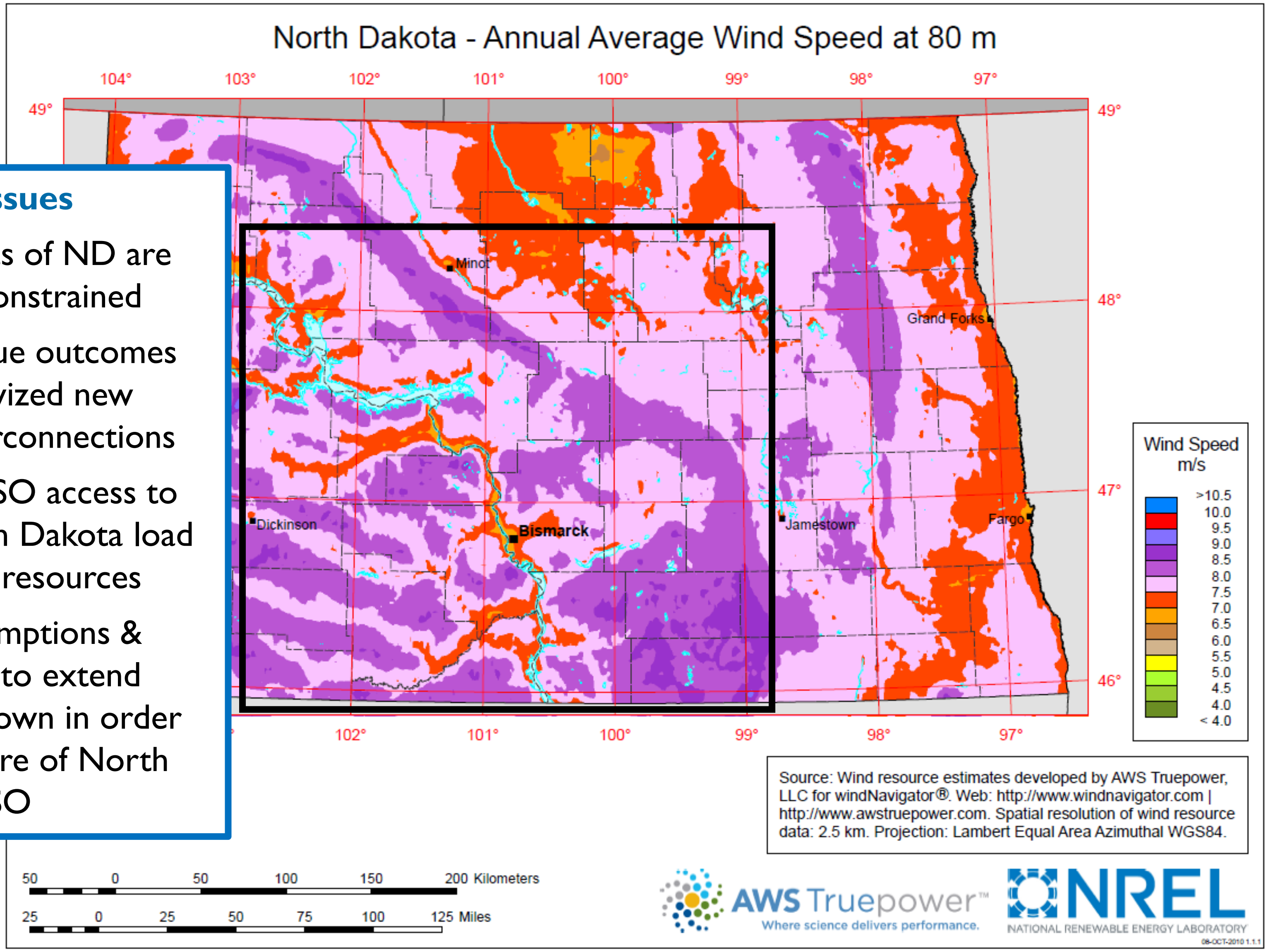


Figure TA-2: Geographic Distribution of Renewables Under Base and Sensitivity Assumptions

North Dakota Renewable Siting

- RIIA siting methodology showed an even distribution of new interconnections in North Dakota regardless of Regional or Local siting philosophy use.
- Tranche 2 assumptions and concepts should also address North Dakota holistically
- MISO should spread RRF generation out evenly in North Dakota, not stacked in Eastern Dakotas

Opening Up North Dakota for MISO



North Dakota Issues

- Wind-rich areas of ND are transmission-constrained
- Recent GI queue outcomes have disincentivized new generator interconnections
- Seams limit MISO access to Western North Dakota load and renewable resources
- Tranche 2 assumptions & concepts need to extend west of Jamestown in order to open up more of North Dakota for MISO

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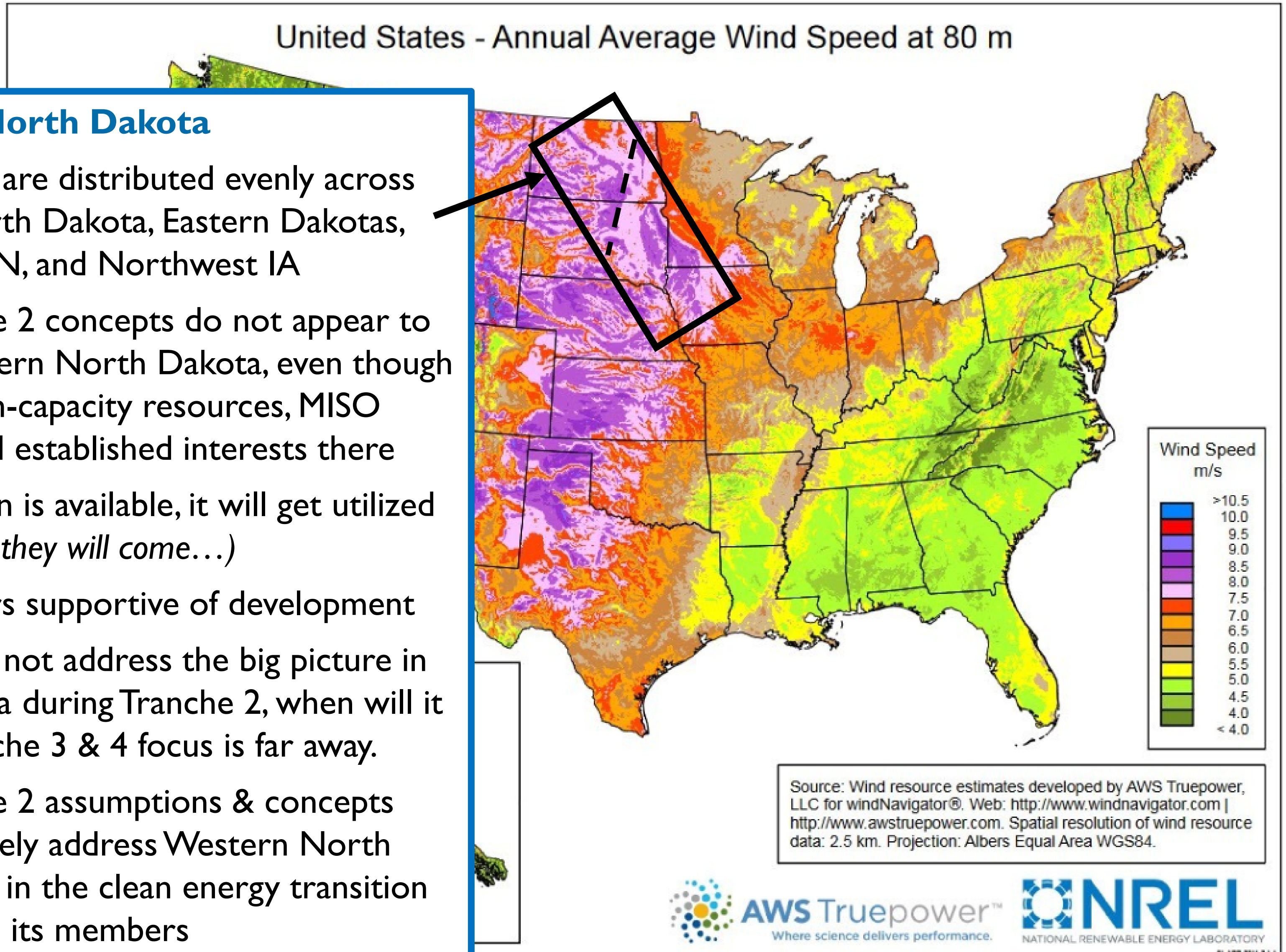
North Dakota in the Bigger Picture



MISO Needs North Dakota

- Wind speeds are distributed evenly across Western North Dakota, Eastern Dakotas, Southwest MN, and Northwest IA
- MISO Tranche 2 concepts do not appear to address Western North Dakota, even though there are high-capacity resources, MISO members, and established interests there
- If transmission is available, it will get utilized *(if you build it, they will come…)*
- ND regulators supportive of development
- If MISO does not address the big picture in North Dakota during Tranche 2, when will it happen? Tranche 3 & 4 focus is far away.
- MISO Tranche 2 assumptions & concepts must adequately address Western North Dakota's role in the clean energy transition for MISO and its members

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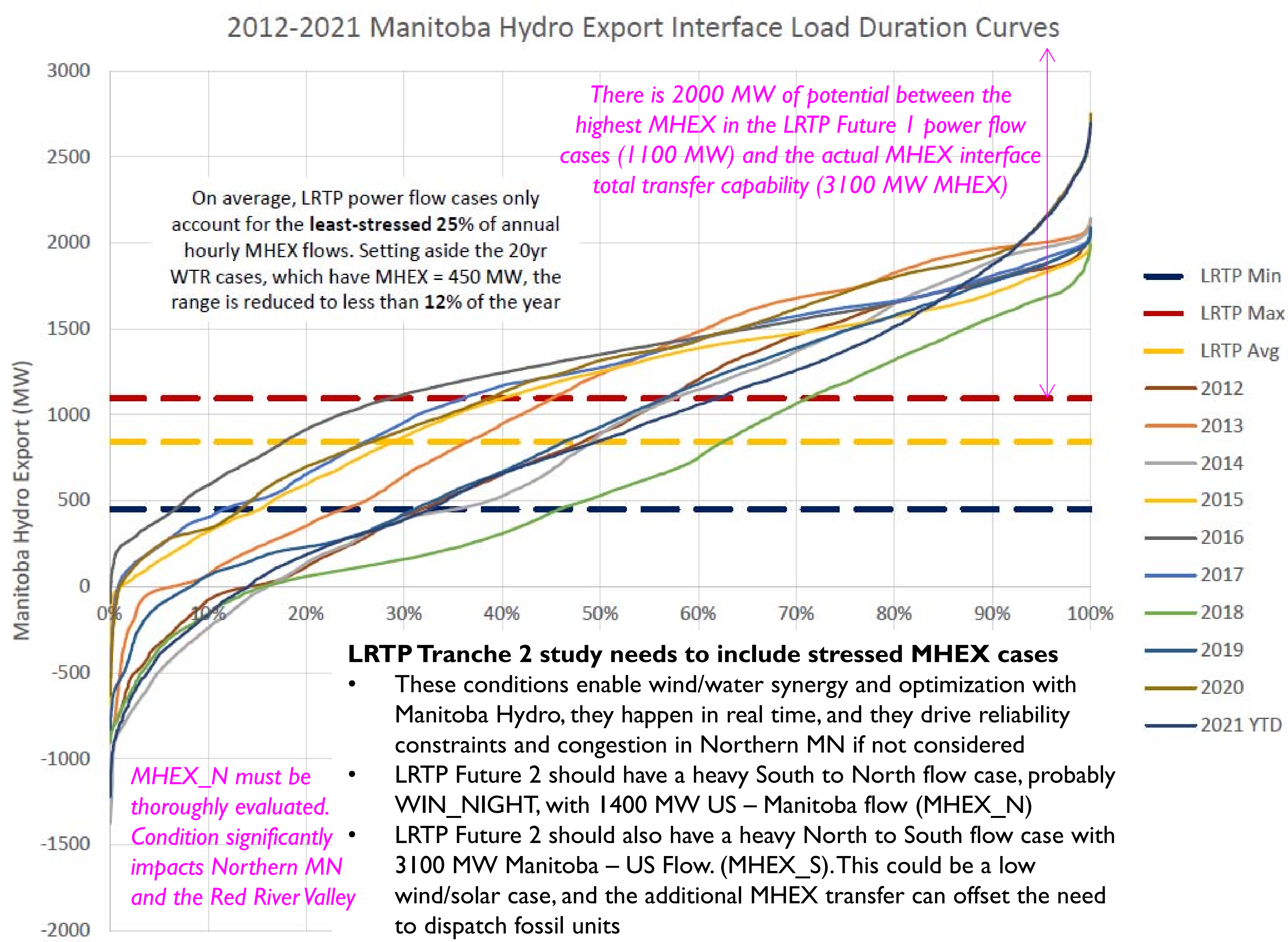
Manitoba Hydro Assumptions



LRTP Tranche 2 study needs to include stressed MHEX cases

- These conditions enable wind/water synergy and optimization with Manitoba Hydro, they happen in real time, and they drive reliability constraints and congestion in Northern MN if not considered
- LRTP Future 2 should have a heavy South to North flow case, probably WIN_NIGHT, with 1400 MW US – Manitoba flow (MHEX_N)
- LRTP Future 2 should also have a heavy North to South flow case with 3100 MW Manitoba – US Flow. (MHEX_S). This could be a low wind/solar case, and the additional MHEX transfer can offset the need to dispatch fossil units

MP HVDC Upgrade Project

Moving Forward

- MP has an urgent need to modernize the existing Square Butte HVDC converters and is moving forward with the converter station upgrade project as rapidly as possible
- The project will be developed to meet MP's near-term needs by implementing VSC technology, with options to incorporate future expandability to be explored as the project is designed
- The project requires that both converter stations be relocated to adjacent properties, establishing new facilities nearby to Center and Arrowhead to be known as **Nelson Lake** (ND) and **St Louis County** (MN), respectively
- Anticipated best-possible in-service date is 2027 based on HVDC supplier leadtimes. **Project is currently out to bid.**

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Comments on MISO Tranche 2 Concepts

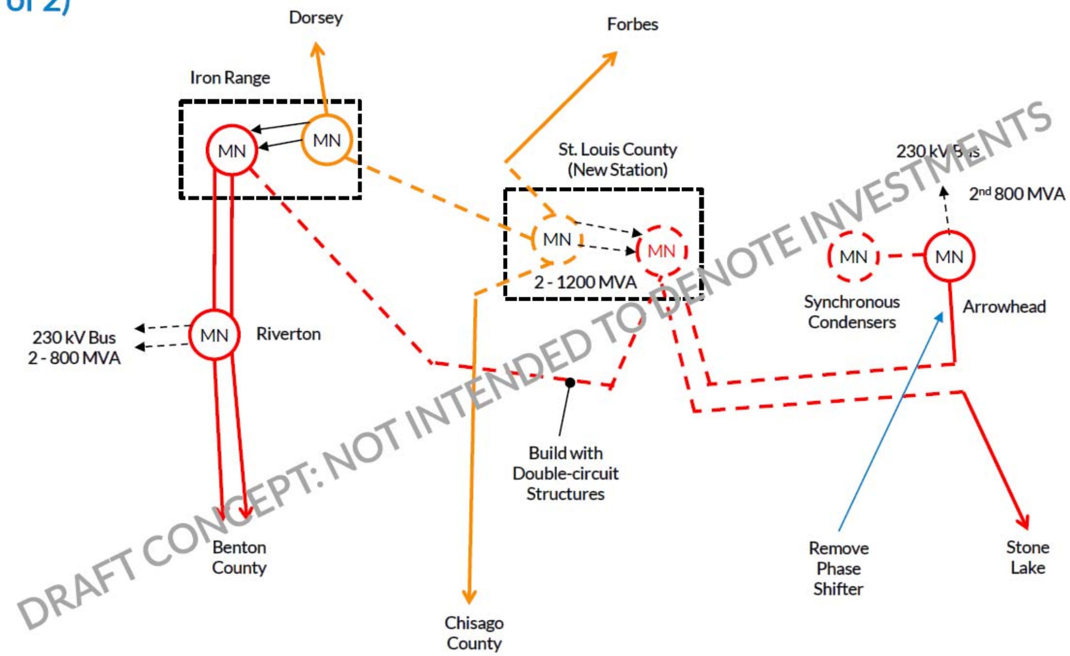
MISO's St Louis County concept needs to be split between Forbes and Arrowhead / MP's Planned St Louis County Converter Station

MISO's concept of segmenting the series-compensated Forbes – Chisago 500 kV Line is technically problematic. The south segment of the line would end up over-compensated by the Chisago series capacitors

MISO's concepts should focus on existing hubs in Northern MN rather than creating new ones (Iron Range, Forbes, and Arrowhead / St Louis County)

MISO's concepts should focus on double circuit capable 345 kV for new transmission lines rather than adding more 500 kV lines

Tranche 2 MN Concept 3
Central and Northern Minnesota Reinforcements
(1 of 2)



MISO's concepts should focus on replacement or colocation with existing 230 kV corridors connecting the existing major Northern MN hubs

MISO's conceptual synchronous condenser at Arrowhead will not be necessary because MP will be adding VSC-HVDC. A better location for dynamic reactive support is near the large load centers on the Iron Range

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MP Proposed Tranche 2 Concepts

Minnesota

1.) Consider using MP's planned St Louis County Substation to enhance connectivity in Northern MN
2.) Connect & Strengthen Major Hubs to Optimize Transfer Capability
   ++ Iron Range – Forbes – St Louis County – Arrowhead 345 kV
3.) Consider Reactive Resource Needs: STATCOMs or synchronous condensers
   ++ Iron Range STATCOM / Synch Condenser
4.) Consider West-East Transfer Constraints
   ++ Riverton 345/230 kV Transformer
   ++ Riverton – Maple River 345 kV
5.) Consider VSC-HVDC
   ++ MP's VSC-HVDC Converters can be expanded to increase capacity, HVDC Line would need to be rebuilt

Western North Dakota

1.) Consider North Dakota **Holistically** – Include Western North Dakota concepts
2.) Consider using MP's planned Nelson Lake Substation to establish greater MISO connectivity in ND
3.) Develop New MISO Connections to bridge seams, add redundancy & create transfer capability
   ++ Center – Nelson Lake – Coal Creek 345 kV
   ++ Nelson Lake – Ellendale – Hankinson 345 kV
4.) Consider Reactive Resource Needs: STATCOMs or synchronous condensers
   ++ STATCOM or Synch Condensers at Jamestown, Wahpeton, Fargo, Grand Forks, and/or Winger
5.) Consider VSC-HVDC
   ++ MP's VSC-HVDC Converters can be expanded to increase capacity, HVDC Line would need to be rebuilt

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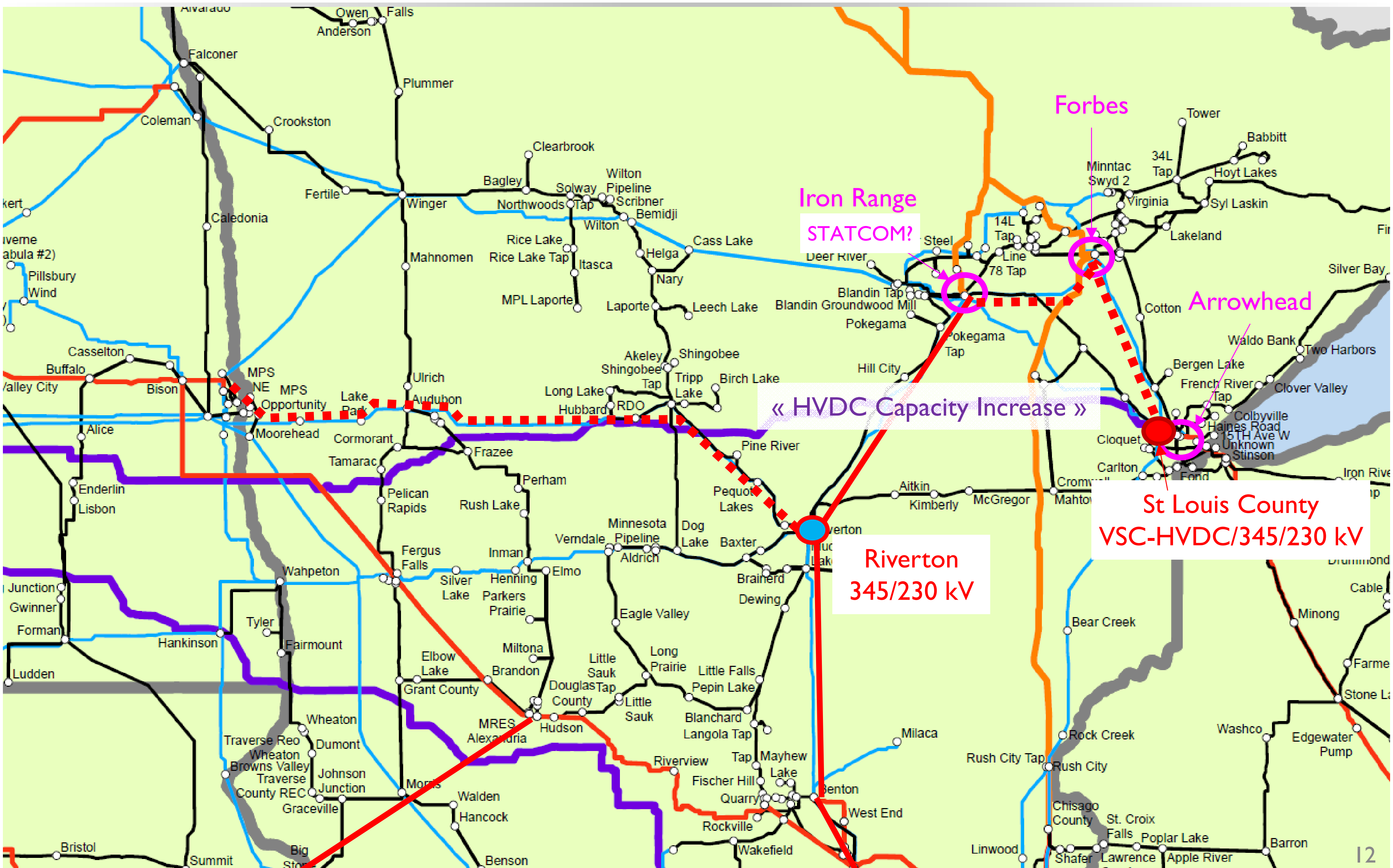
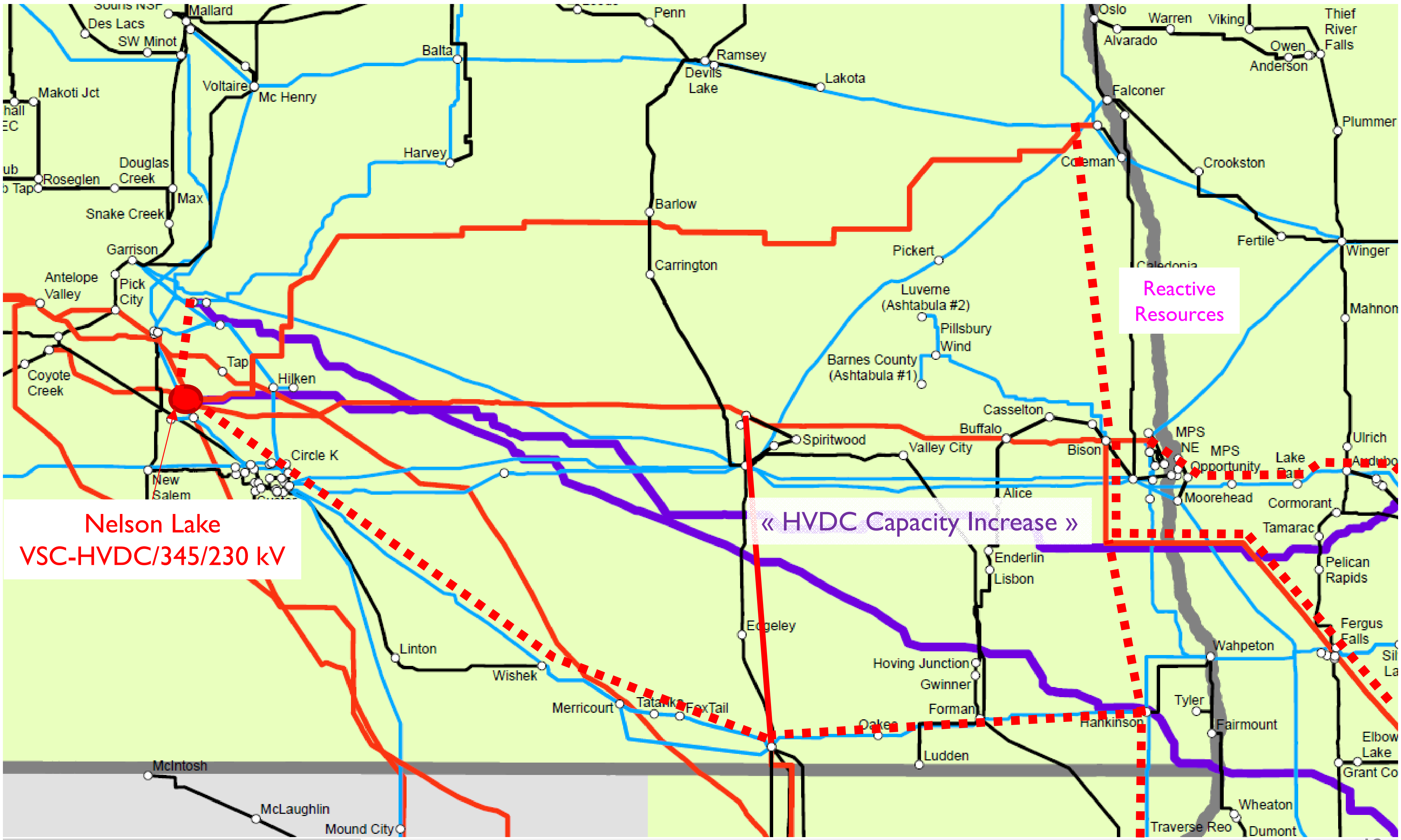
Tranche 2 Concepts – Northern MN



Tranche 2 Concepts – Western ND



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MP-MISO LRTP Tranche 2 Discussion

January 17, 2023

Today's Purpose

1. Focus of 1/27 LRTP Tranche 2 Workshop
2. HVDC Modernization Project Update
3. [redacted]
4. North Dakota Considerations
5. Modeling Assumptions
6. Next Steps

MP believes that collaboration is key to the success of LRTP Tranche 2 and wants to partner with MISO. How can MP support MISO Tranche in its efforts?

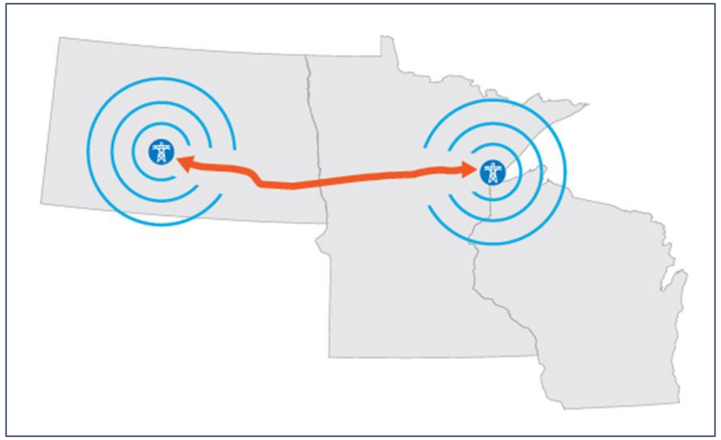
Focus of 1/27 LRTP Tranche 2 Workshop

HVDC Modernization Project Overview

HVDC Modernization Project: Preparing for the Future

Project Attributes:

- Upgrade the existing line capacity by 40% (900MW line, 1500MW capable terminals)
- Leverages existing infrastructure and positions it for further development with expandable, modular technology (VSC).
- Establish the transmission corridor as an essential building block for reliably moving energy across the Upper Midwest.



Project Benefits:

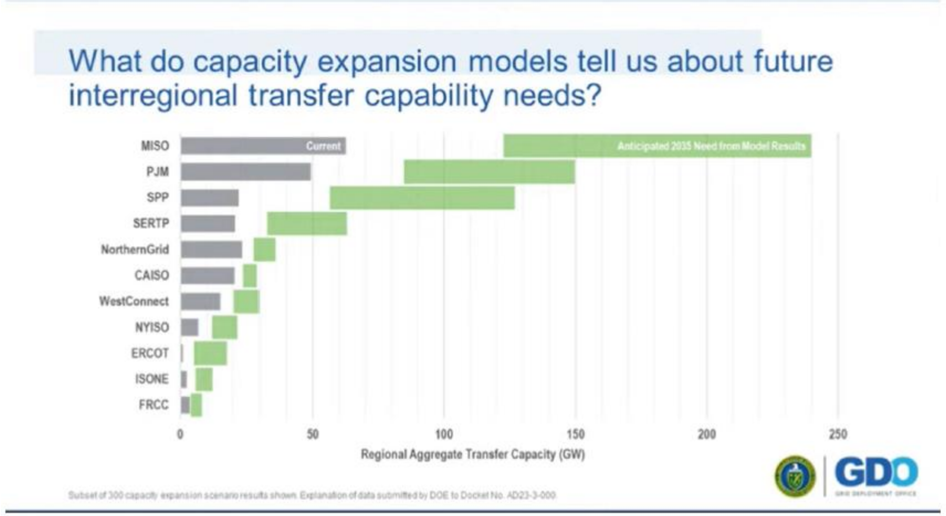
- Augment reliability and system stability in largely rural North Dakota and Minnesota.
- Increase access to additional clean energy transfer with limited land impact.
- Optimize energy resources in North Dakota and Minnesota with bidirectional power flow.
- Ensures continued access to affordable clean energy for MP customers.
- Align with State (MN), MISO, FERC and Department of Energy goals for regional transmission expansion.

HVDC Modernization Project: Increasing Transfer Capacity

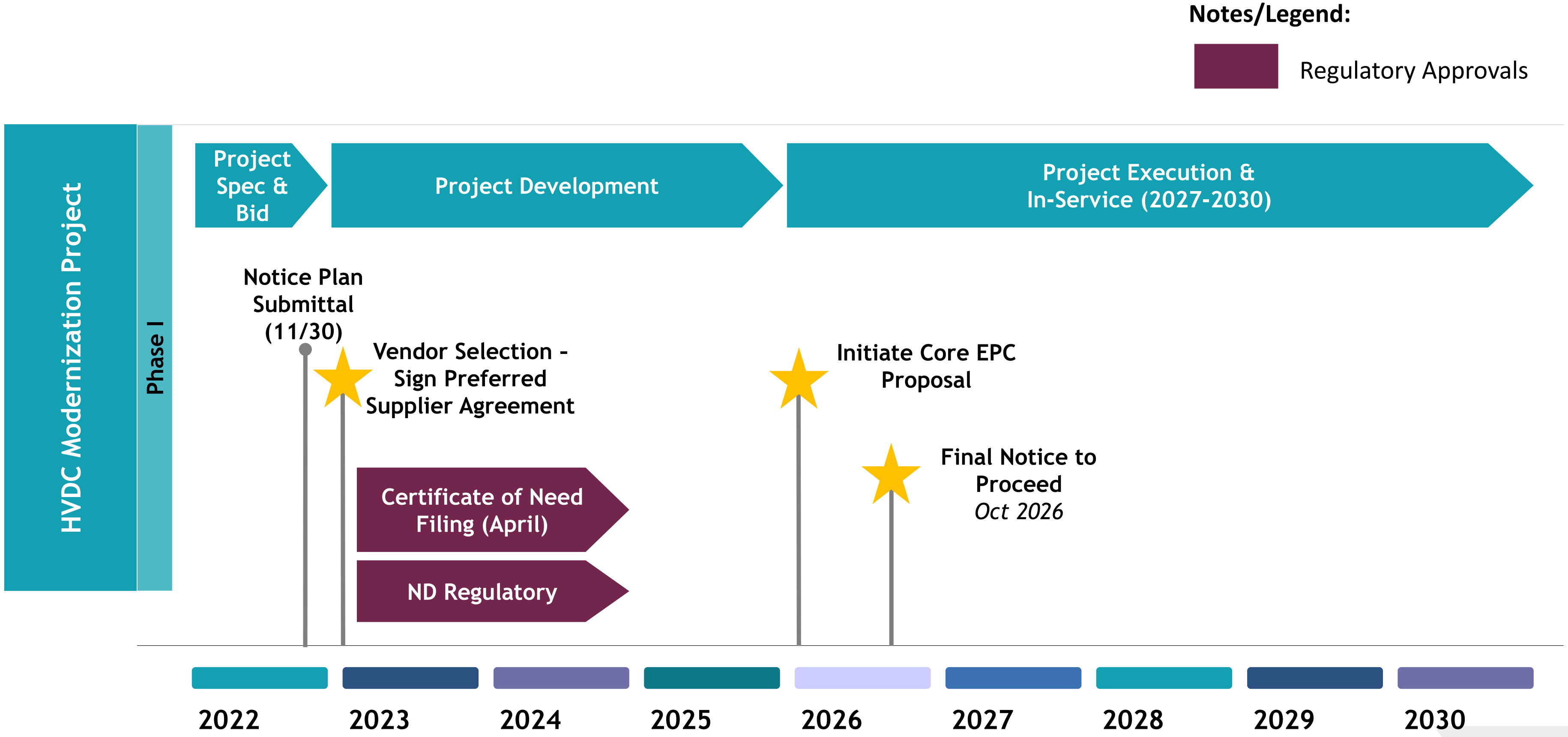
Benefits

- Accelerates development of renewable energy to help meet decarbonization goals in MISO.
- Facilitates movement of renewables from high energy areas to load centers.
- Aligned with MISO Futures 2 and 3 (MISO Futures identify the need for 7000 MWs of wind out of ND)
- Anticipates expected significant increase in need for inter-regional transfer capacity in MISO.
- Resilience and reliability benefits are inherent in HVDC design.
- Increases optionality.

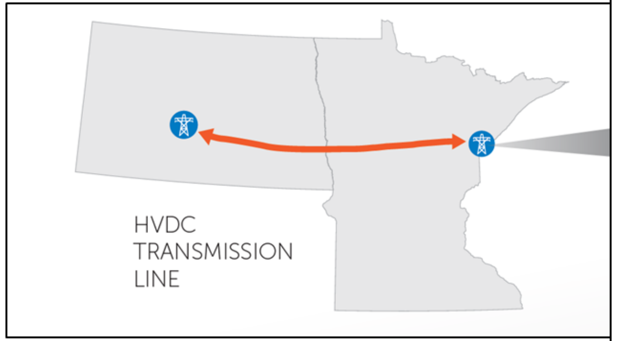
DOE Study Identifies that MISO Needs to Increase Interregional Transfer Capability



HVDC Modernization Project: Timeline



Federal Funding & State Funding Requests to Support HVDC Modernization Project Expandability



Terminals upgrade and expand transfer capacity

- Federal funding: $50 million with US Department of Energy
- States funding: **$25 million MN** and $25 million ND State matches

Future expandability being designed into project.

PROJECT BENEFITS

Enhanced reliability and system control	Increased transfer capacity between ND and MN	Bidirectional flow to expand renewable energy access

[redacted]

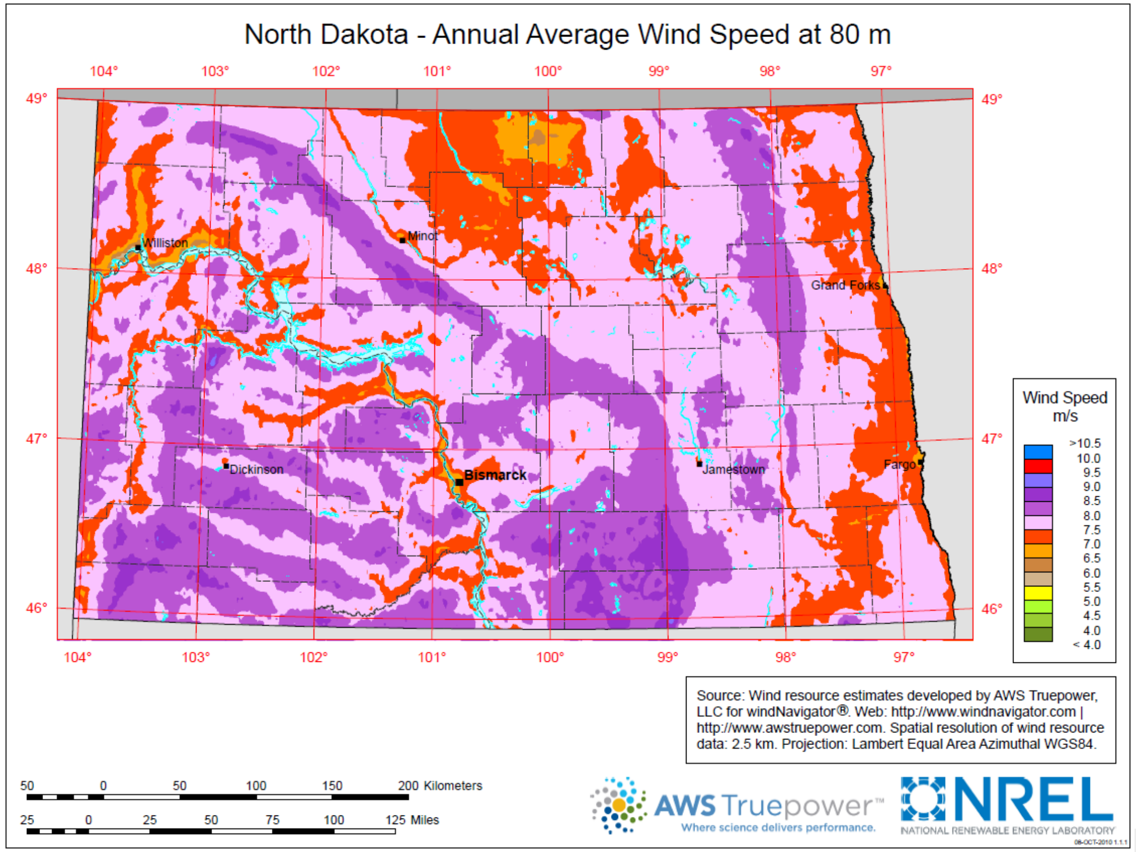
[redacted]

North Dakota Considerations

Opening Up North Dakota for MISO

North Dakota Issues

- Wind-rich areas of ND are transmission-constrained
- Recent GI queue outcomes have dis-incentivized new generator interconnections
- Seams limit MISO access to Western North Dakota load and renewable resources
- Tranche 2 assumptions & concepts need to extend west of Jamestown in order to open up more of North Dakota for MISO



North Dakota in the Bigger Picture

MISO Needs North Dakota

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- MISO Tranche 2 concepts do not appear to address Western North Dakota, even though there are high-capacity resources, MISO members, and established interests there
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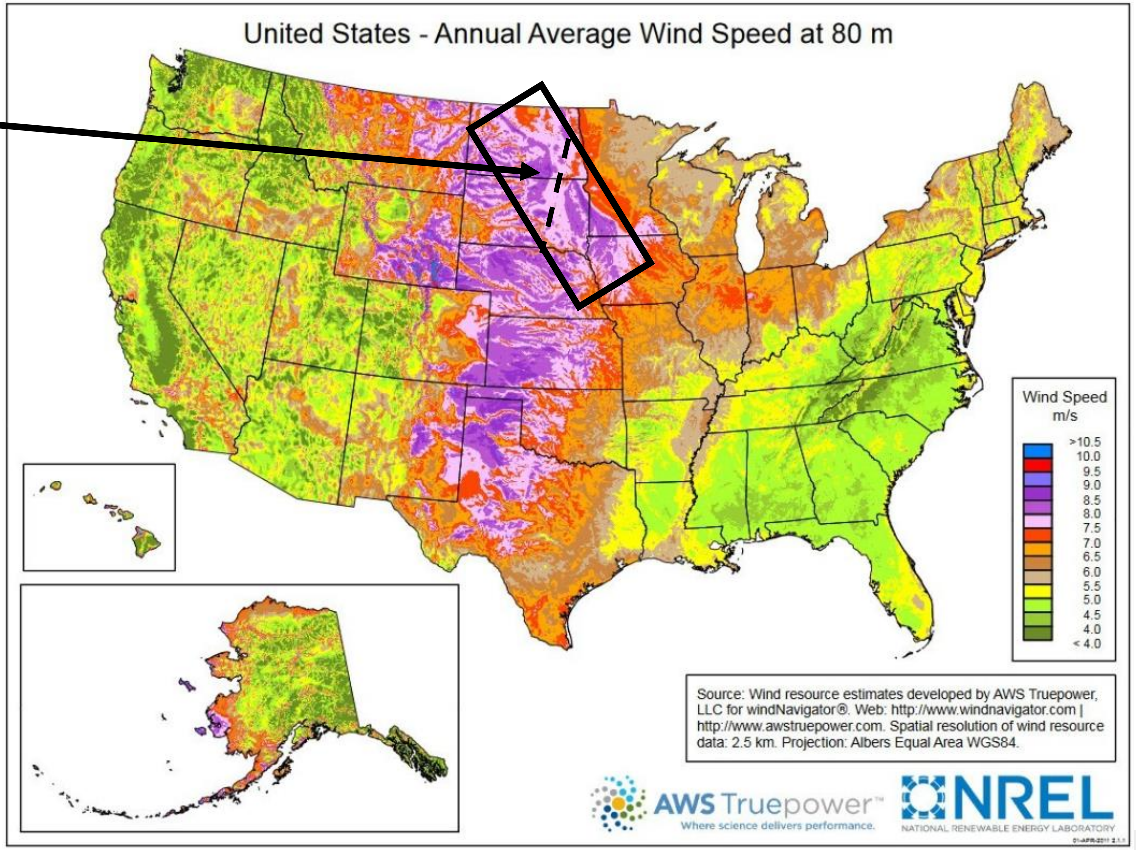
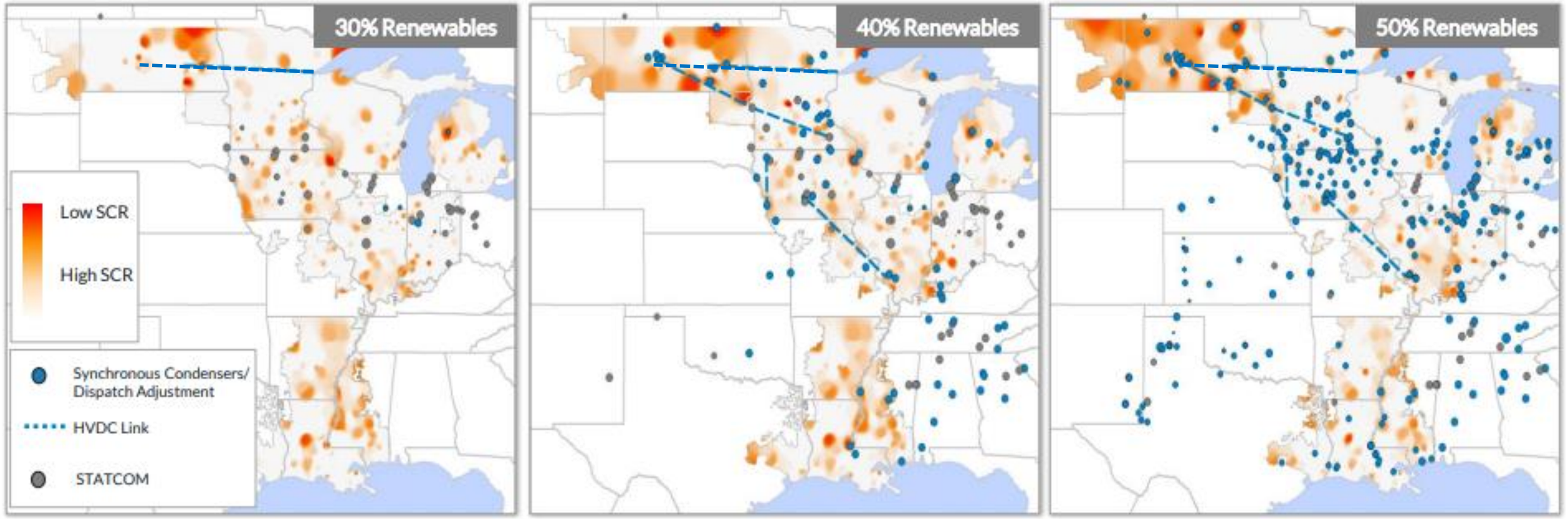


Modeling Assumptions

Expand LRTP Concepts & Analysis

Starting at 40%, system-wide voltage stability is the main driver of dynamic complexity and requires transmission technologies equipped with dynamic-support capabilities



* Maps reflect cumulative solutions across milestones

Expand Concepts & Analysis for Tranche 2

- Voltage and transient stability need to be considered
- Reactive resources, STATCOMs, and Synch Condensers need to be considered
- VSC-HVDC needs be considered *(RIIA pointing to HVDC as early as 30% renewables)*

Addressing North Dakota Holistically

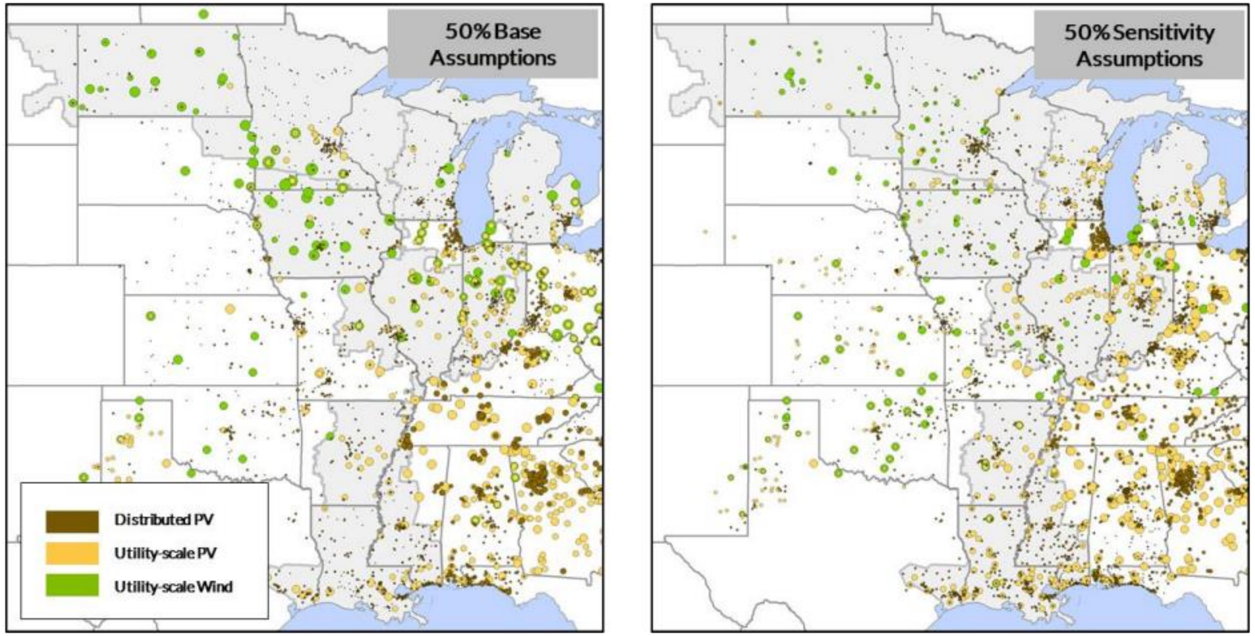


Figure TA-2: Geographic Distribution of Renewables Under Base and Sensitivity Assumptions

North Dakota Renewable Siting

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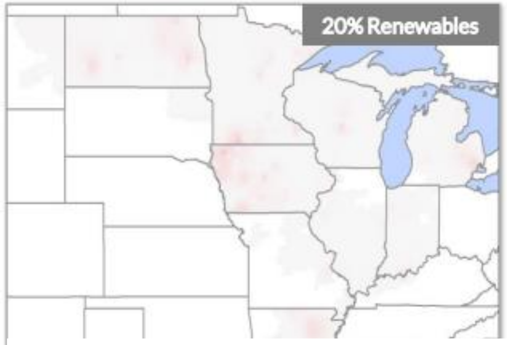
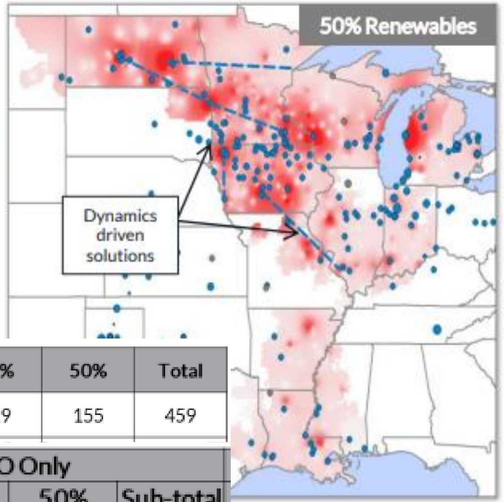
- MISO should spread RRF generation out evenly in North Dakota, not stacked in Eastern Dakotas

Consider RIIA Findings

Several locations may need mitigation for dynamic stability issues beyond 20% milestone





# of equipment per milestone	10%	20%	30%	40%	50%	Total
Switched Shunts	6	10	169	119	155	459

# of equipment per milestone	MISO Only			
	30%	40%	50%	Sub-total
Batteries (30min)	-	-	118	118
Controls Tuning	-	-	319	319
Dispatch Adjustment	-	60	17	77
HVDC	1	4	-	5
Power System Stabilizer	-	-	4	4
STATCOMs	25	8	5	38
Switched Shunts	-	-	-	-
Synchronous Condenser	2	10	163	175

- Renewable penetration causes displacement and different dispatch patterns of conventional generators, leading to several dynamic issues.
- Power delivery from low short circuit areas may need transmission technologies equipped with dynamic support capabilities.
- Frequency response is stable up to 60% instantaneous renewable penetration, but may require additional planned headroom beyond

Go Big Where & How Needed

- RIIA identified inflection points, such as the jump from 20% to 30%
- **MISO says 2030 is the new 2040 and Future 3 is coming faster than expected**
- Tranche 2 needs to reflect those realities

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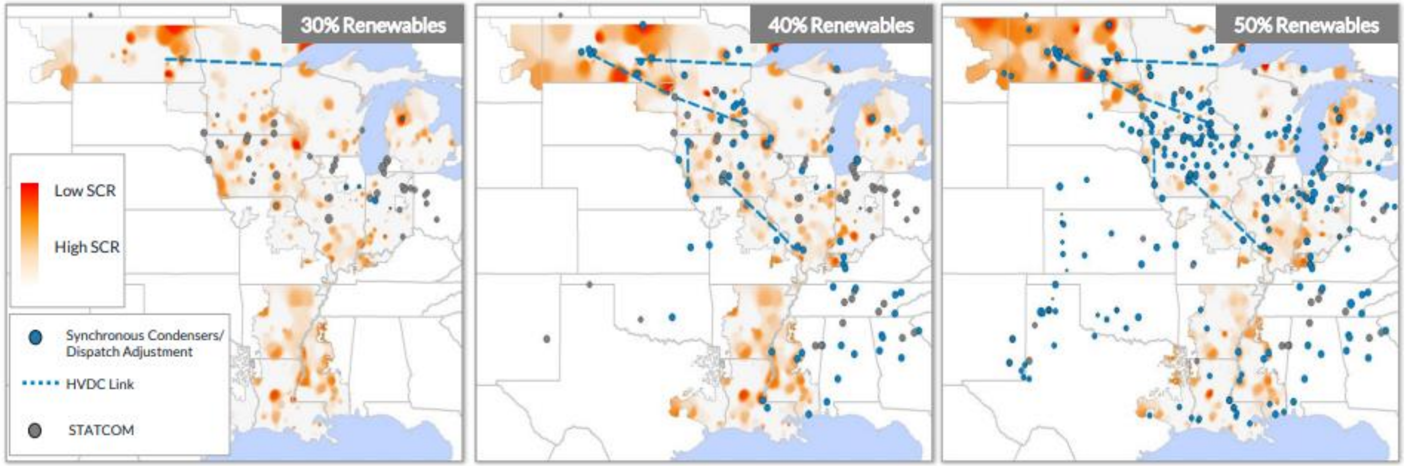

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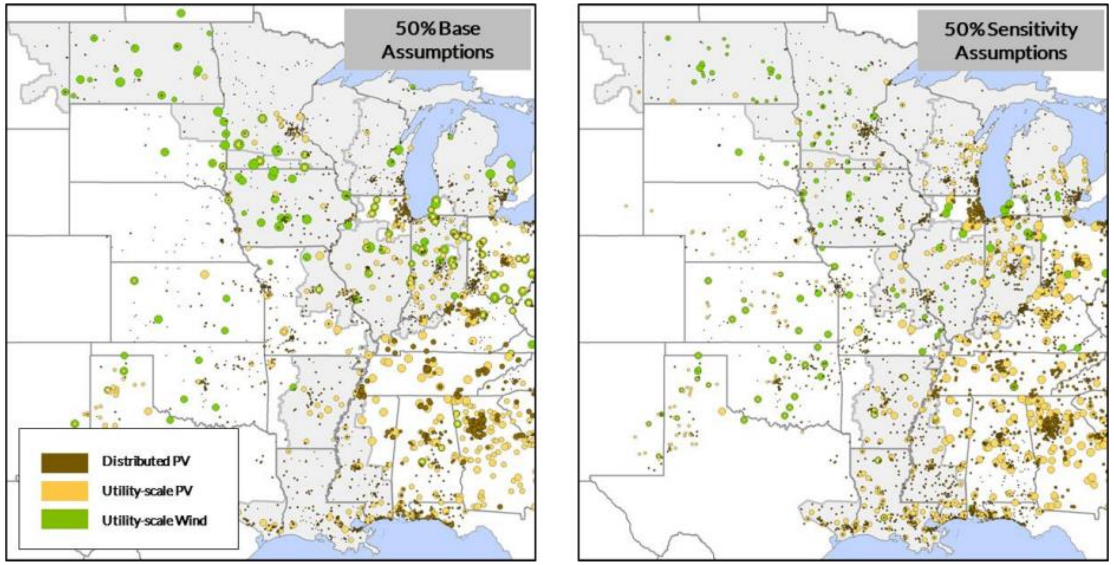

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Next Steps

Next Steps

- MP would like time on the 1/27 LRTP Tranche 2 Workshop Agenda
- Continued dialogue and collaboration with MISO on HVDC
- MP sponsored educational session regarding the purpose and value of HVDC – open to MISO staff, OMS, and stakeholders

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Thank you

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Appendix

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MISO LRTP Tranche 2

Minnesota Power Response to MISO Concepts

October 17, 2022

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Outline of Comments

1. **General Comments**
    - Go big, recognize where futures are headed
    - Consider RIIA findings, expand study concepts & analysis

2. **LRTP Futures & Modeling Assumptions**
    - Latest assumptions & models are not available for review
    - Western North Dakota needs attention
    - Regional transfer assumptions, particularly Manitoba Hydro

3. **Account for Existing TO Plans**
    - MP HVDC Modernization & Upgrade Project

4. **LRTP Tranche 2 Concepts**
    - Response to MISO's Northern Minnesota Concepts
    - Minnesota Power's Northern Minnesota Concepts
    - Minnesota Power's Western North Dakota Concepts

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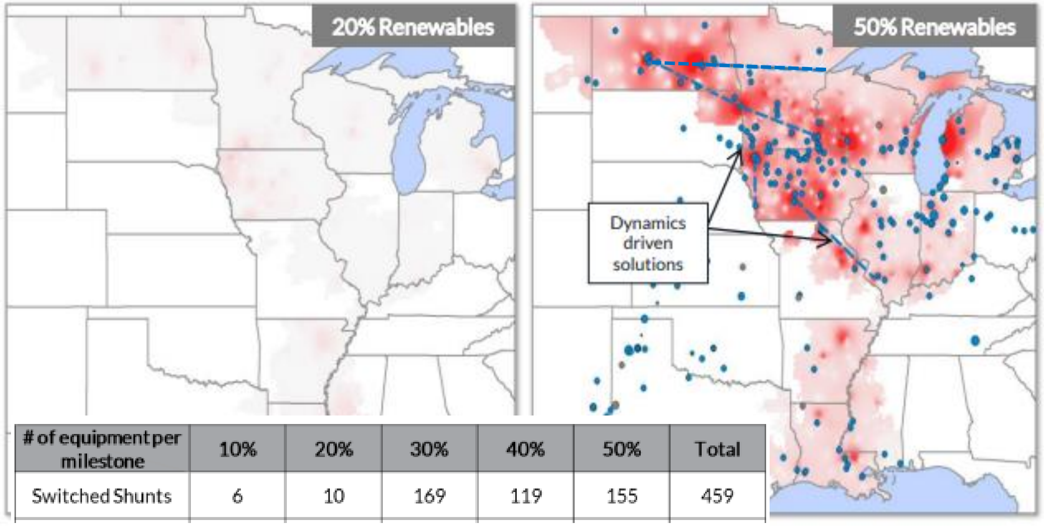

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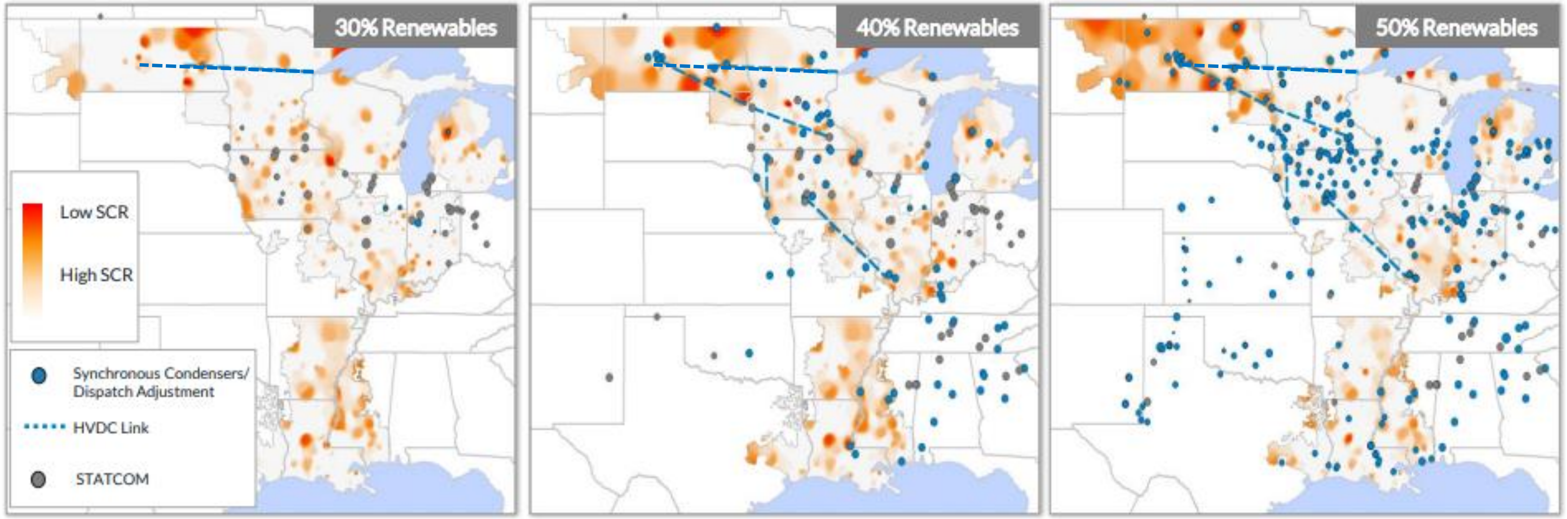

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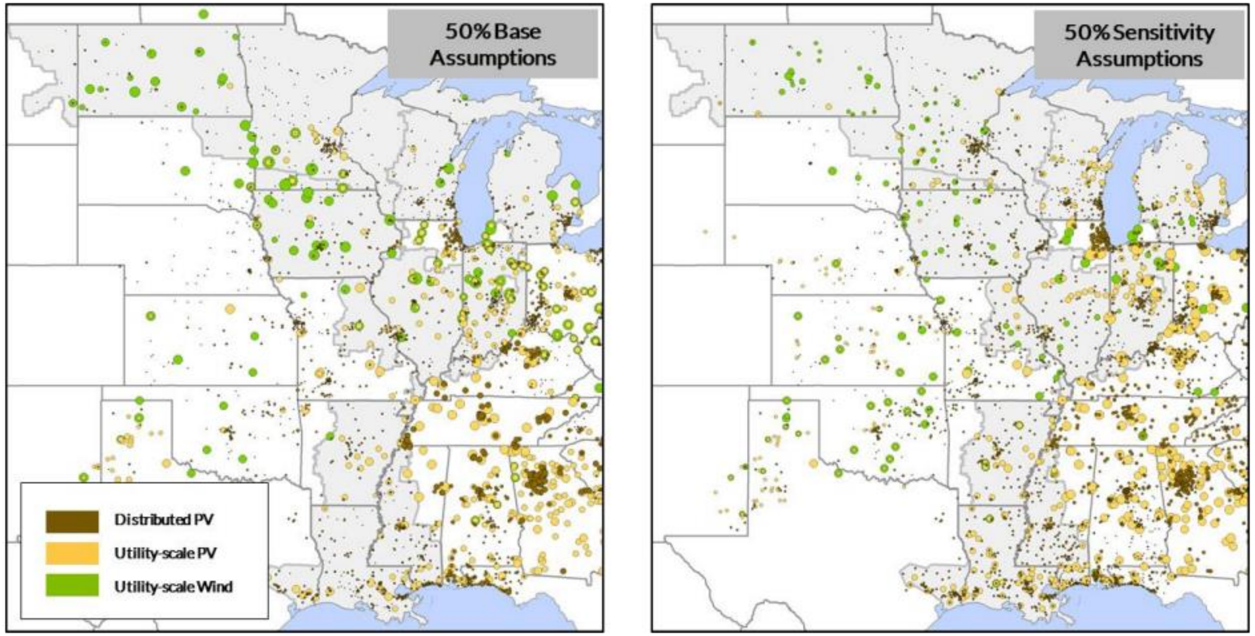

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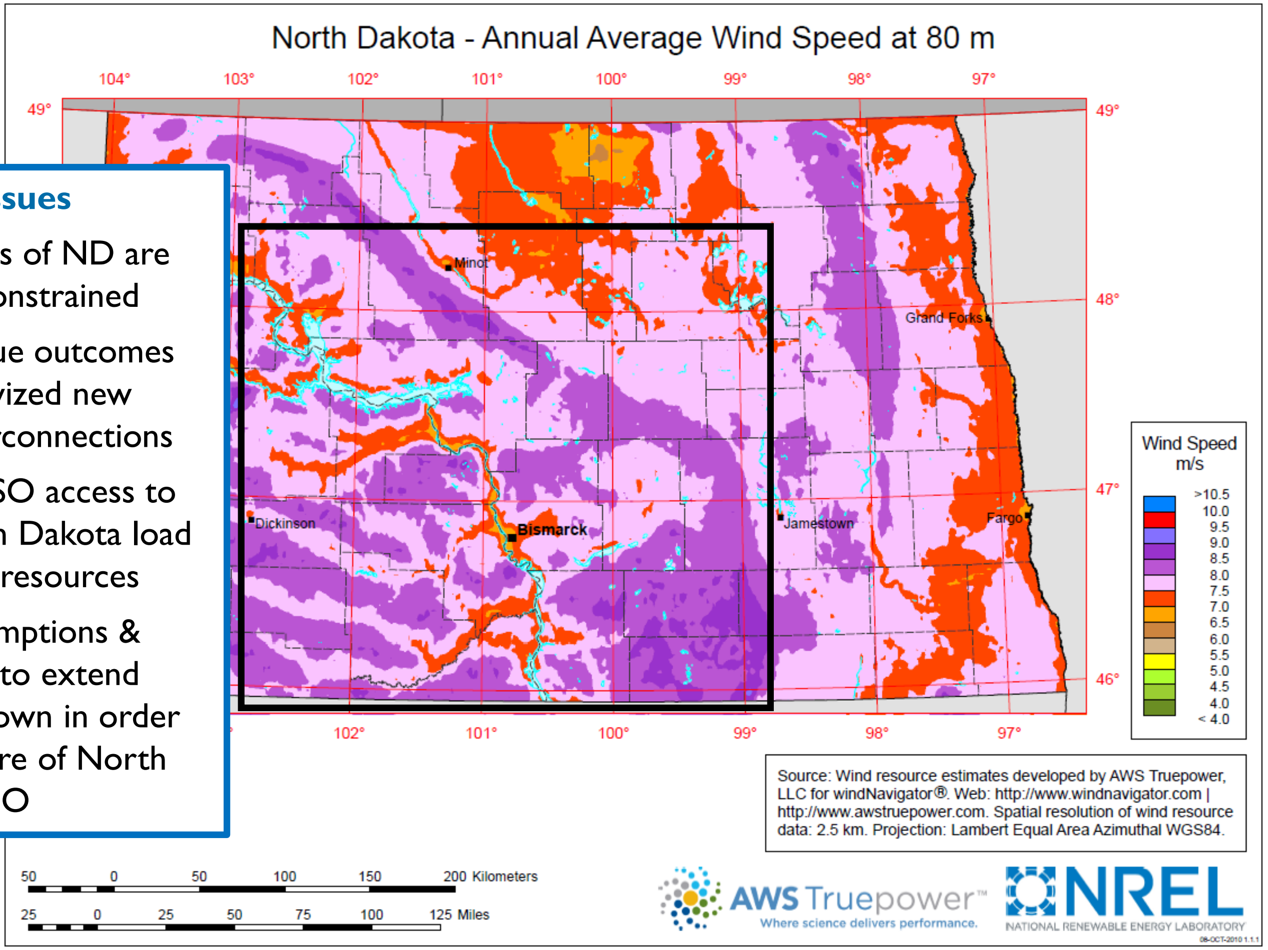
Opening Up North Dakota for MISO

North Dakota Issues

- Wind-rich areas of ND are transmission-constrained
- Recent GI queue outcomes have disincentivized new generator interconnections
- Seams limit MISO access to Western North Dakota load and renewable resources
- Tranche 2 assumptions & concepts need to extend west of Jamestown in order to open up more of North Dakota for MISO



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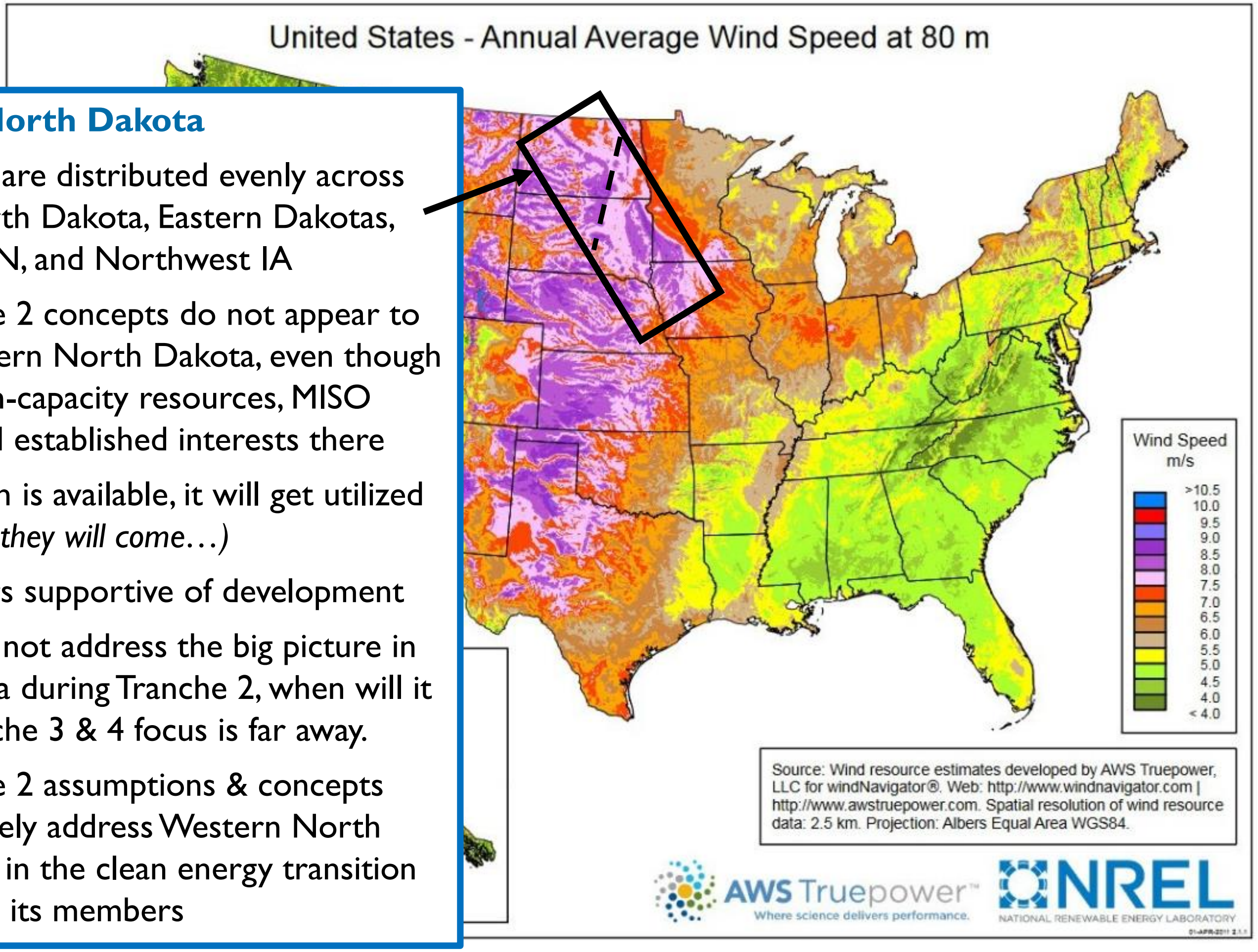
North Dakota in the Bigger Picture



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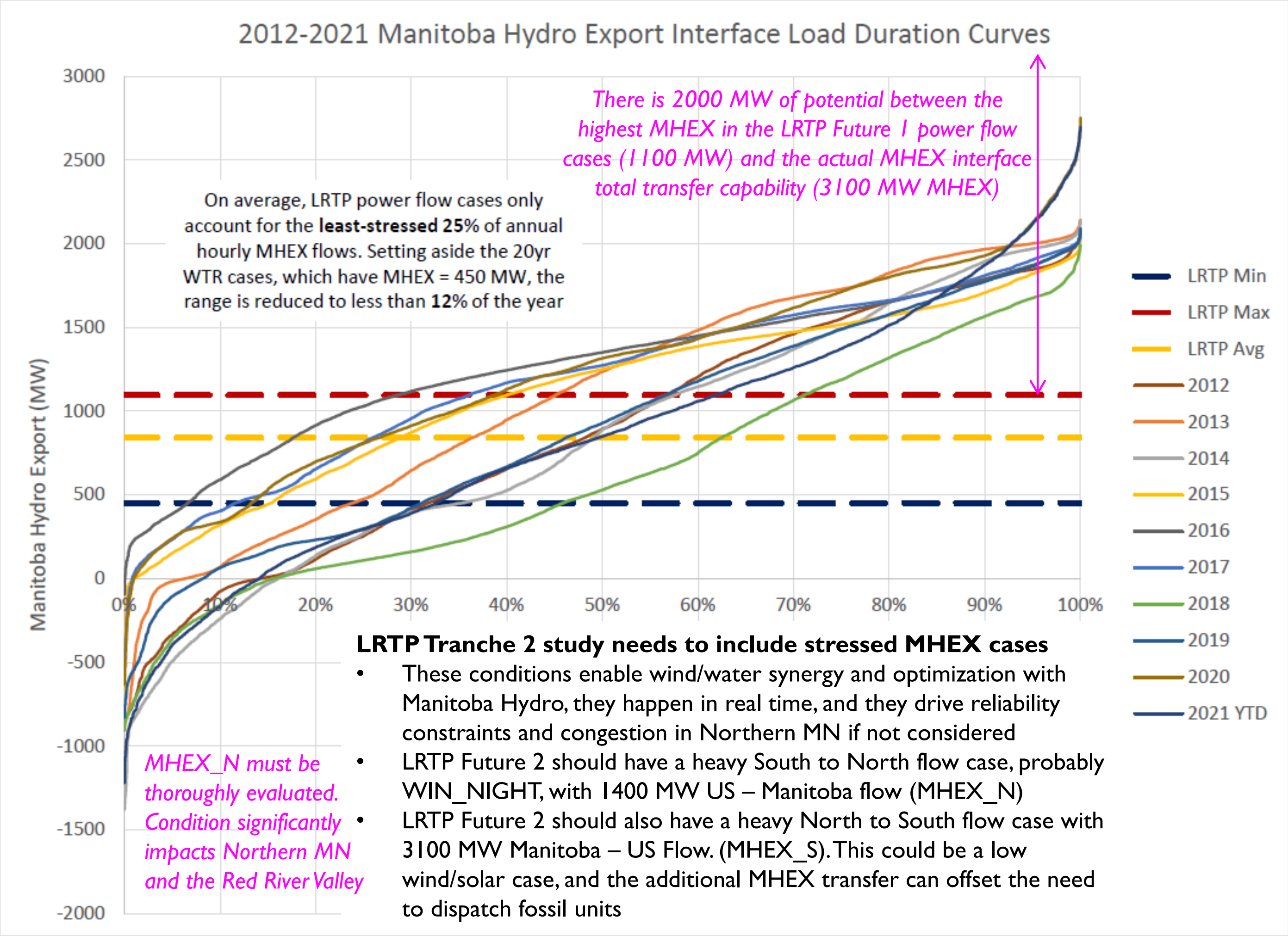
Manitoba Hydro Assumptions



LRTP Tranche 2 study needs to include stressed MHEX cases

- These conditions enable wind/water synergy and optimization with Manitoba Hydro, they happen in real time, and they drive reliability constraints and congestion in Northern MN if not considered
- LRTP Future 2 should have a heavy South to North flow case, probably WIN_NIGHT, with 1400 MW US – Manitoba flow (MHEX_N)
- LRTP Future 2 should also have a heavy North to South flow case with 3100 MW Manitoba – US Flow. (MHEX_S). This could be a low wind/solar case, and the additional MHEX transfer can offset the need to dispatch fossil units

MP HVDC Upgrade Project

Moving Forward

- MP has an urgent need to modernize the existing Square Butte HVDC converters and is moving forward with the converter station upgrade project as rapidly as possible
- The project will be developed to meet MP's near-term needs by implementing VSC technology, with options to incorporate future expandability to be explored as the project is designed
- The project requires that both converter stations be relocated to adjacent properties, establishing new facilities nearby to Center and Arrowhead to be known as **Nelson Lake** (ND) and **St Louis County** (MN), respectively
- Anticipated best-possible in-service date is 2027 based on HVDC supplier leadtimes. **Project is currently out to bid.**

Comments on MISO Tranche 2 Concepts

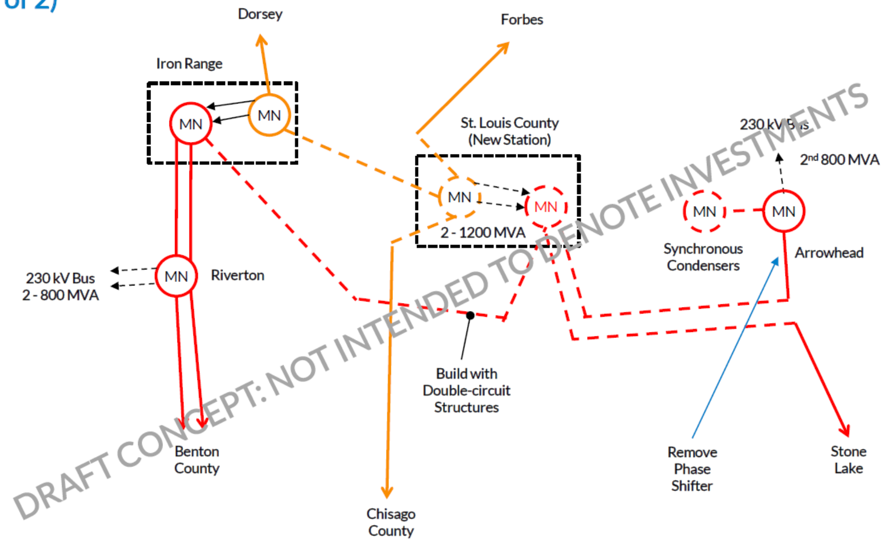
MISO's St Louis County concept needs to be split between Forbes and Arrowhead / MP's Planned St Louis County Converter Station

MISO's concept of segmenting the series-compensated Forbes – Chisago 500 kV Line is technically problematic. The south segment of the line would end up over-compensated by the Chisago series capacitors

MISO's concepts should focus on existing hubs in Northern MN rather than creating new ones (Iron Range, Forbes, and Arrowhead / St Louis County)

MISO's concepts should focus on double circuit capable 345 kV for new transmission lines rather than adding more 500 kV lines

Tranche 2 MN Concept 3
Central and Northern Minnesota Reinforcements
(1 of 2)



MISO's concepts should focus on replacement or colocation with existing 230 kV corridors connecting the existing major Northern MN hubs

MISO's conceptual synchronous condenser at Arrowhead will not be necessary because MP will be adding VSC-HVDC. A better location for dynamic reactive support is near the large load centers on the Iron Range

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MP Proposed Tranche 2 Concepts

Minnesota

1.) Consider using MP's planned St Louis County Substation to enhance connectivity in Northern MN
2.) Connect & Strengthen Major Hubs to Optimize Transfer Capability
++ Iron Range – Forbes – St Louis County – Arrowhead 345 kV
3.) Consider Reactive Resource Needs: STATCOMs or synchronous condensers
++ Iron Range STATCOM / Synch Condenser
4.) Consider West-East Transfer Constraints
++ Riverton 345/230 kV Transformer
++ Riverton – Maple River 345 kV
5.) Consider VSC-HVDC
++ MP's VSC-HVDC Converters can be expanded to increase capacity, HVDC Line would need to be rebuilt

Western North Dakota

1.) Consider North Dakota **Holistically** – Include Western North Dakota concepts
2.) Consider using MP's planned Nelson Lake Substation to establish greater MISO connectivity in ND
3.) Develop New MISO Connections to bridge seams, add redundancy & create transfer capability
++ Center – Nelson Lake – Coal Creek 345 kV
++ Nelson Lake – Ellendale – Hankinson 345 kV
4.) Consider Reactive Resource Needs: STATCOMs or synchronous condensers
++ STATCOM or Synch Condensers at Jamestown, Wahpeton, Fargo, Grand Forks, and/or Winger
5.) Consider VSC-HVDC
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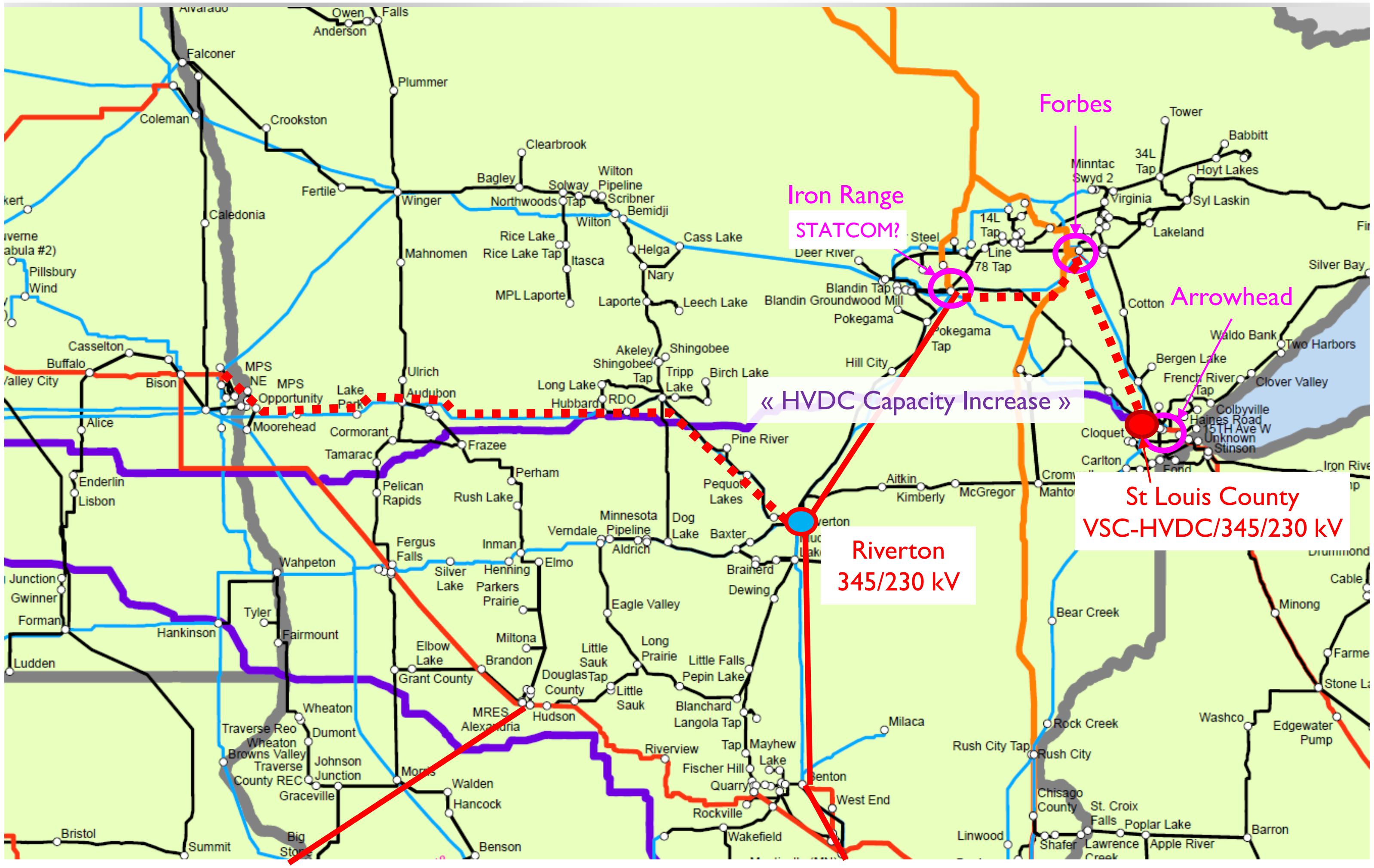
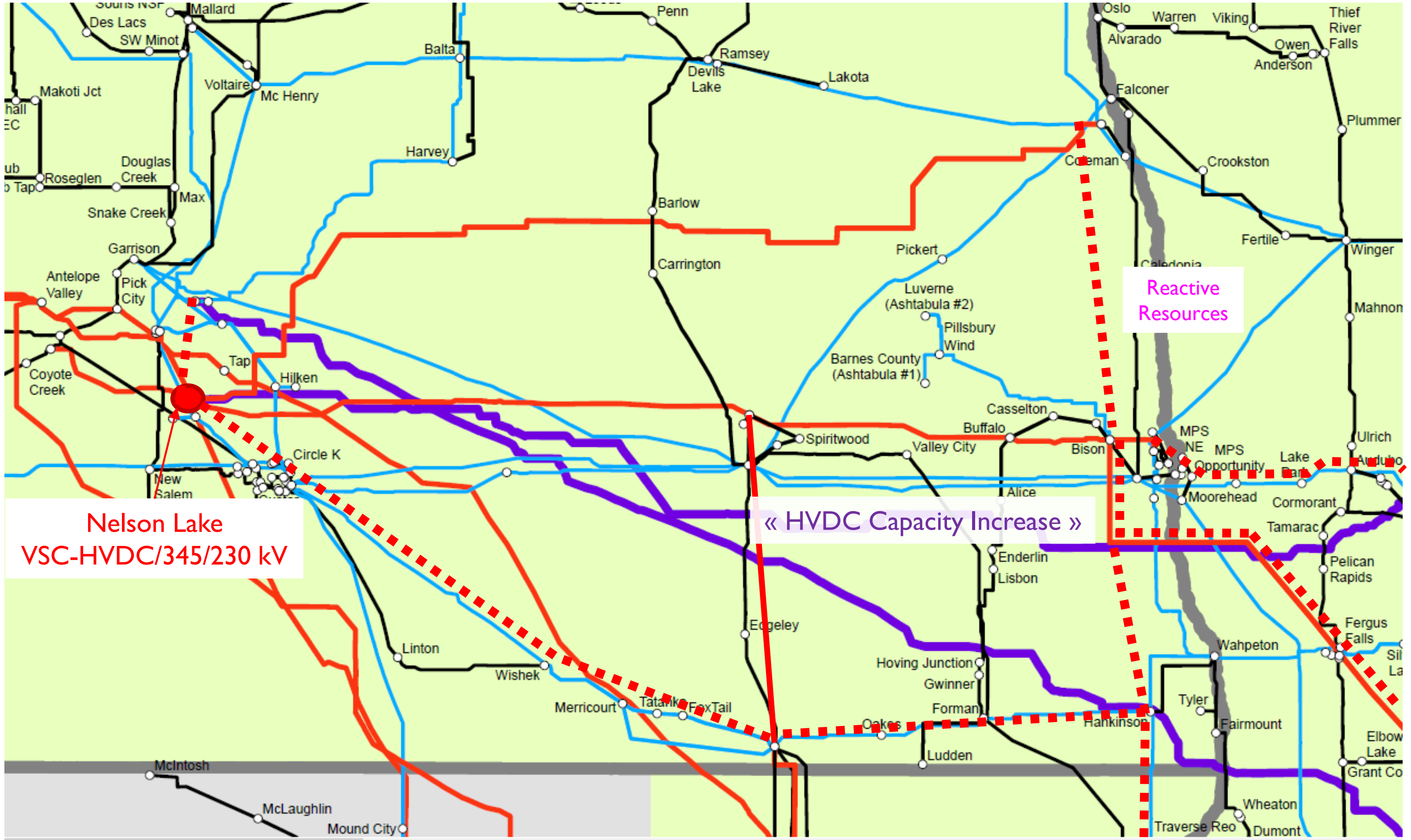
Tranche 2 Concepts – Northern MN



Tranche 2 Concepts – Western ND



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HVDC Modeling Discussion

March 9, 2023

AGENDA

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1. MISO Study Process for HVDC in LRTP Tranche 2
   – Description of MISO's approach for analyzing HVDC facilities.
   – Types of analysis, including reliability and the different types of reliability analysis needed?
   – Tools and tactics that have been used in ProMod and other tools to enable HVDC evaluation.
   – Challenges with existing methodology – does MISO have the tools that they need in order to model HVDC effectively?
2. MP HVDC Modernization Project Update; technical insight on how HVDC systems are designed to connect to the grid

HVDC MODELING IN PROMOD

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- Operational Inconsistencies
  - Flows on HVDC lines in PROMOD are optimized to reduce production cost for each defined region. It does not accurately reflect how an HVDC line owner may control the dispatch on the line.
  - If HVDC connects areas across pools (MISO to SPP), PROMOD may not replace higher cost generation on one side of the line with low cost generation from the other.
- Dispatch Methodology – PROMOD optimizes line flow on monitored transmission elements to minimize line losses within pools.
- Ancillary support benefits
  - Additional benefits associated with HVDC lines such as frequency response and dynamic voltage support are not captured in PROMOD
- Congestion mitigation in the Real Time
  - Additional benefits of dispatching the HVDC to minimize congestion caused by load and renewable forecast error is not captured.

HVDC ANALYTICAL TOOLS – WHAT WILL BE USED IN TRANCHE 2?

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Reliability		Production Cost		Interregional Flow
PowerFlow	Dynamic Reactive			

Reliability
- PSS/e
- TARA
- Other?

Production Cost
- PROMOD
- Aurora
- PSO
- EnCompass
- GridView

HVDC MODERNIZATION PROJECT: CURRENT STATE

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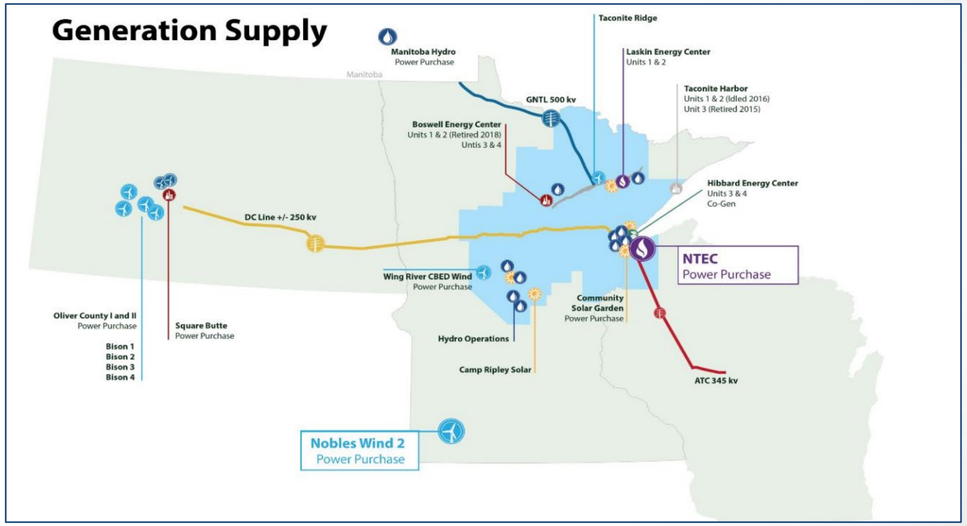
About the Line

- Commissioned in May 1977 and originally tied to North Dakota coal under joint ownership by Minnkota Power Cooperative and Minnesota Power.
- In 2010, Minnesota Power purchased the DC Line from Minnkota.
- The Line now transports about 600 MWs of MP owned and purchased variable wind energy from one of the best wind resource areas in ND and the US to Minnesota Power's load, benefitting customers.
- +/-250kV 1100A (550MW) capacity; 465miles from Center, ND to Arrowhead substation (Hermantown, MN).

Map



HVDC MODERNIZATION PROJECT: PREPARING FOR THE FUTURE

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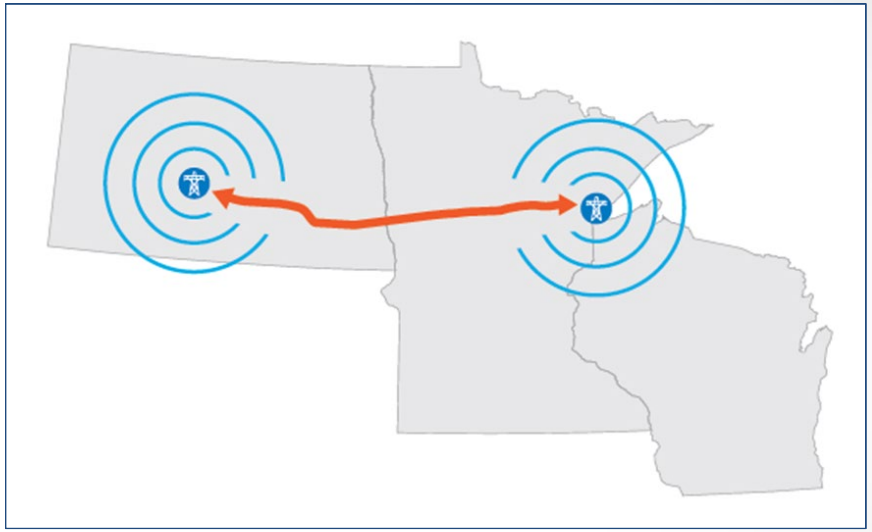
Project Attributes:

- Upgrade the existing line capacity by 40% (900MW line, 1500MW capable terminals)
- Leverages existing infrastructure and positions it for further development with expandable, modular technology (VSC).
- Establish the transmission corridor as an essential building block for reliably moving energy across the Upper Midwest.
- Create new construction jobs and additional long-term tax base in North Dakota and Minnesota.



Project Benefits:

- Augment reliability and system stability in largely rural North Dakota and Minnesota.
- Increase access to additional clean energy transfer with limited land impact.
- Optimize energy resources in North Dakota and Minnesota with bidirectional power flow across the line.
- Ensures continued access to affordable clean energy for MP customers.
- Align with State (MN), MISO, FERC and Department of Energy goals for regional transmission expansion

HVDC MODERNIZATION PROJECT: INCREASING TRANSFER CAPACITY

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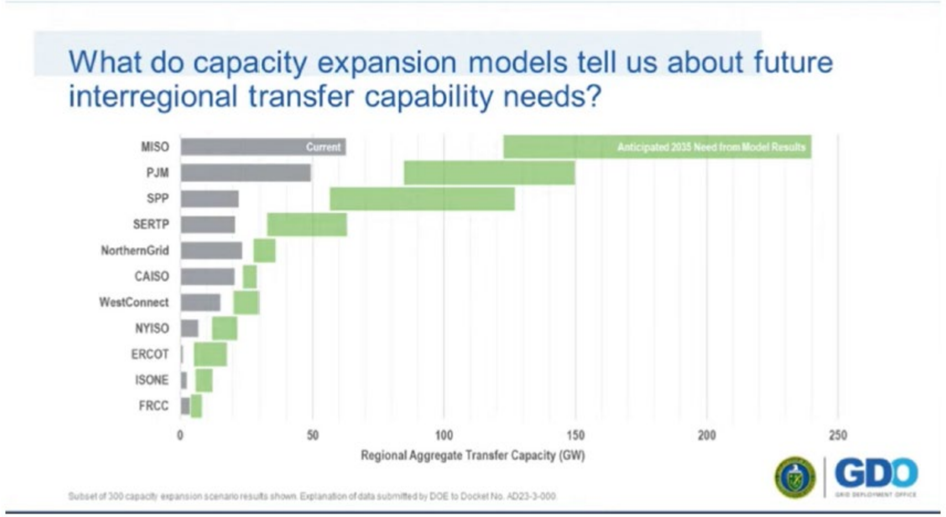
Benefits

- Accelerates development of renewable energy to help meet decarbonization goals in MISO.
- Facilitates movement of renewables from high energy areas to load centers.
- Aligned with MISO Futures 2 and 3 (MISO Futures identify the need for 7000 MWs of wind out of ND)
- Anticipates expected significant increase in need for inter-regional transfer capacity in MISO.
- Resilience and reliability benefits are inherent in HVDC design.
- Increases optionality.

DOE Study Identifies that MISO Needs to Increase Interregional Transfer Capability



HVDC MODERNIZATION PROJECT TIMELINE

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Project design, land acquisition, and initial public engagement

Project permitting, additional community engagement, and vendor negotiations

Engineering, equipment purchases and site preparation

Construction

COD

2022 | 2023 | 2024 | 2025 | 2026 | 2027-2030

Notice Plan and Exemption Request Filing

Certificate of Need & Route Permit Filings (MN)

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Advantages of VSC-HVDC Technology for the Future Power System

March 2023

INITIAL LANDSCAPE CONSIDERATIONS

Long-Term regional overlay solutions depend heavily on the nature of the grid in the future.

Decisions made today will define the transmission development path over the next several decades.

Critical Considerations:

- A highly variable, low baseload generation system is very different from what exists today
- *AC transmission solutions* depend more heavily on system strength and voltage regulation from traditional generation or other devices (e.g. synchronous condensers, STATCOMs) requiring more technology additions
- *VSC HVDC transmission solutions* are less dependent on system strength and provide their own voltage regulation and controllability – which makes it better suited for a grid with large amounts of variable generation

System strength and voltage support, as well as additional underlying system requirements for AC-only solutions, tend to levelize the holistic cost comparison between HVDC and AC when considering the future, renewable-heavy power system.

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GENERAL ADVANTAGES OF VSC HVDC TECHNOLOGY

Broad HVDC advantages

- Can interconnect asynchronous AC systems without inadvertent power flow or transient stability concerns
- At a similar voltage level, a DC line can transmit more than double the power at around half the losses versus an AC line
- Narrower right-of-way footprint than for comparable capacity AC lines—one third to one half of the width for the same capacity
- Lower cost than AC for long-distance transmission—exact breakeven factor varies based on project details
- No increase in short-circuit power (less impact on underlying system)
- Fast control of power flow and ability to schedule flows
- Low outage rates and option for redundancy in case of faults
- Capacity is limited only by thermal limit, rather than an additional safe loading limit

Key attributes of VSC technology

- Independent and flexible active and reactive power control—improves power quality and avoids overloads on AC networks
- Optional Power oscillation damping—can help stabilize AC networks
- Black start capability: during AC network restoration VSC technology can provide system recovery ancillary service
- Firewall against cascading system disturbances
- Ideal support for AC grids with low short-circuit levels and for the supply of fully passive systems
- Grid forming capability and compatibility with inverter-based resources

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COMPARING VSC HVDC TO 765 KV AC

KEY VARIABLES DEPEND ON SYSTEM INTEGRATION NEEDS

Attribute	765 kV AC Line	VSC HVDC (±525 kV) Line
Estimated Max. Capacity	3,000 MW	3,000 MW**
Single Largest Contingency	3,000 MW	1,500 MW (loss of one pole)
Flexible Power Flow Control	No	Yes
Black Start Capability	No	Yes
Dynamic Voltage Response Support	No	Yes
Inertial Response***	No	Yes
Losses per 100 miles	<~1%	<~1%
Transmission Line Cost*	$4.7-5.7M/mile	$2.2-3.0M/mile

*Excludes converter station costs for HVDC, which cost $400-500M per converter. All-in system cost is dependent on line length, number of substations/converter terminals, and (in the case of 765 kV AC) additional technologies needed for AC system integration
** Present transfer capacity and may increase in the future depending on the transistor current capacity.
*** Inertial response with VSC HVDC requires additional capacitors on the DC side and corresponding control system features

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COMPARING VSC HVDC TO 765 KV AC

CRITICAL ATTRIBUTES FOR SYSTEM INTEGRATION

Attribute	765 kV AC	VSC HVDC (±525 kV)
Power Transfer Capability	▪ Decreases substantially with line length/distance ▪ Enhanced with series/shunt reactive compensation	▪ Generally independent of line length/distance ▪ Main limitations associated with equipment ratings
Reactive Support and Voltage Control	▪ Generates large amount of reactive power at light load ▪ Consumes large amount of reactive power at high load ▪ Drastic swings require additional technologies & coordination (e.g. shunt reactors/capacitors, STATCOMs)	▪ Designed to produce or absorb reactive power at both converter stations ▪ Controls AC terminal voltages automatically for steady state and dynamic voltage regulation
Fault Performance: General AC System Faults External to the Transmission Line	▪ Generally do not trip for AC system faults but also do not provide significant additional support ▪ Low voltages may cause significant tripping of nearby renewable generation with long restart time	▪ Rides through AC system faults without blocking ▪ Designed to provide dynamic support during AC system faults, which can support improved system response ▪ Improved voltage response results in less tripping of nearby renewable generation
Fault Performance: Faults on the Transmission Line (765 kV or VSC HVDC)	▪ Fault impact will be seen broadly through the system ▪ Tripping results in significant rerouting of power onto the underlying system, increasing reactive requirements and potentially leading to overloading or voltage collapse ▪ Tripping the line results in loss of short circuit level in the area near the line, weakening the AC system	▪ Direct fault impact on AC system is minimized by HVDC connection configurations ▪ Vast majority of faults are single pole, meaning the remaining pole can continue to transfer real power and produce/absorb reactive power to support AC system ▪ Loss of VSC HVDC pole does not result in significant loss of system short circuit level

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CAPITAL INVESTMENT COST - INTEGRATION COMPLEXITY

765 kV AC	VSC HVDC

For fair comparison of HVDC link costs versus 765kV AC, all costs associated with the 765kV system integration need to be considered:
▪ New interconnection facilities:
  ▪ 765kV and 345kV substations, buswork, circuit breakers, and instrument transformers
  ▪ New 765kV/345kV autotransformers
▪ Voltage and reactive power control
  ▪ Line shunt reactors, shunt capacitors
  ▪ Series compensation, (if applicable)
  ▪ STATCOMs or synchronous condensers
▪ Power flow control
  ▪ Phase shifters or other technology
▪ Underlying system impacts
  ▪ Short circuit level increases may require lower-kV circuit breakers to be replaced
  ▪ Underlying AC transmission line upgrades
 	
Final investment cost of 765kV could exceed that of VSC HVDC when all necessary support is considered.
	VSC HVDC is considered costly primarily due the high cost of HVDC converters, however there is significantly less additional system integration support required:
	▪ New interconnection facilities:
	  ▪ AC (345kV) substations, buswork, circuit breakers, etc…
	▪ New HVDC converter stations on each end
	  ▪ Inherent voltage and reactive power control
	  ▪ Inherent power flow control
	▪ Underlying system impacts
	  ▪ No impact on short circuit level
	  ▪ Limited impacts on underlying AC transmission system due to controllability and other features
	
	System integration of VSC HVDC is much less complex. It has inherent value-added attributes and can usually be integrated with fewer changes to the existing system.

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FUTURE CONVERSION FROM 765KV AC TO VSC HVDC

- Conversion of 765kV AC Line to HVDC is theoretically possible but:
  - It requires acquisition of more right of way (e.g. land owner impact) than ultimately will be needed for the future HVDC line
  - It requires initial over-investment to include HVDC insulators on the AC line, as well as reactive support resources such as STATCOMs or synchronous condensers that are necessary to integrate 765kV transmission but not necessary for VSC HVDC
  - Where 765kV AC is not already present, it requires the development of design standards, spare equipment programs, and maintenance programs for 765kV equipment that is not intended to be a long-term solution
  - Upon conversion to HVDC, it may require the abandonment of 765kV equipment associated with the new line such as shunt reactors, circuit breakers, entire switchyards and large step up transformers (e.g. additional stranded investment)
  - It may negate or devalue investment in other 765kV AC lines if one line is converted for HVDC operation; or subsequent segmentation of the new 765kV line may inhibit future conversion to HVDC

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SUMMARY

- Two factors are commonly cited for selecting 765kV AC rather than VSC HVDC
  - 765kV lines are less costly for short lines than VSC HVDC line plus converters
  - Fault clearing and power recovery time is faster with 765kV
- This presentation indicates these arguments are not necessarily compelling or correct and each situation needs to be evaluated on a case-by-case basis.
- VSC HVDC offers additional benefits that are not provided by 765kV AC
  - Lower integration complexity
  - Inherent redundancy in bipolar configuration
  - Flexible power flow control
  - Steady state and dynamic reactive power/AC voltage control
  - Reduced fault current and thus lower impact on system voltage
  - Black start capability
  - Frequency control on isolated subsystems
  - Grid-forming control
  - Lower losses
  - Virtual inertia control (possible with energy storage)
- Initial construction of a 765kV line for later conversion to VSC HVDC is unlikely to be technically or economically attractive.

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PATH FORWARD/NEXT STEPS

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- Path Forward/Next Steps –
- Ensure HVDC modeling/analysis is ready to be considered as part of Tranche 2 study.
  - Timeline of key activities related to analyzing HVDC options, including those identified in MISO's project concepts and additional ones still to be identified.
- How best can MP, ATC and other TOs support MISO?
  - Approach for including other interested TOs in effort.
- Future interactions/third party support for LRTP transmission planning, especially as it relates to analyzing HVDC options.

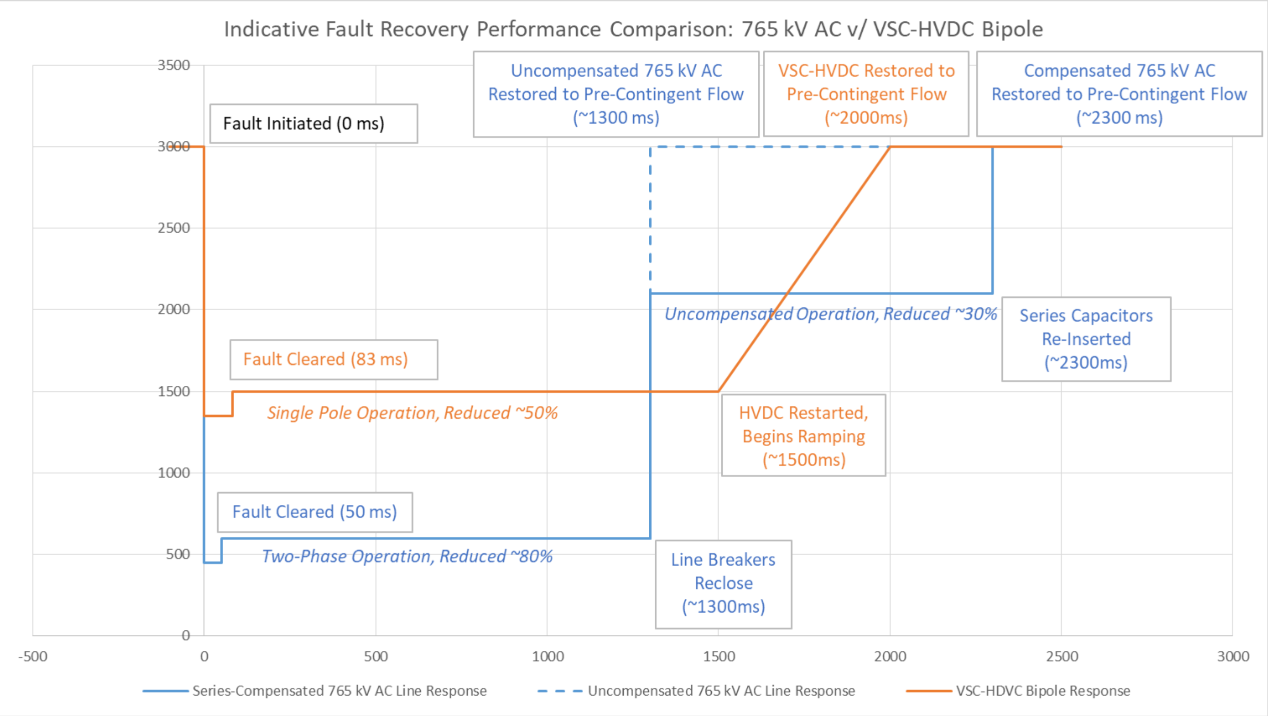
APPENDIX

FAULT RECOVERY: ILLUSTRATIVE EXAMPLE

Attribute	765 kV AC	VSC HVDC (±525 kV)
Clearing Time	50 ms	83 ms
Power Transfer Reduction[1]	~80 percent	~ 50 percent
Reclose[2]/Restart	1300 ms	1500 ms
Return to Full Power[3] (Uncompensated)	~1300 ms	2000 ms
Return to Full Power (Compensated[4] AC Line)	2300 ms	N/A

Notes

1. Assuming single line to ground AC / single pole HVDC fault
2. Single pole trip and reclose time for 765 kV AC subject to detailed design studies to ensure full dissipation of induced currents. HVDC restart time based on half-bridge VSC converters.
3. Return to full power for 765 kV AC depends on surrounding system impacts. Generator tripping may reduce post-fault flow
4. For series-compensated AC transmission, series capacitor re-insertion is typically delayed from reclosing. Estimated about ~30% reduction in power transfer until series capacitors are restored to service



Conclusion: Fault clearing & recovery for VSC-HVDC is not significantly worse compared to 765 kV AC. In fact, some attributes of VSC-HVDC are better than 765 kV AC

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REFERENCES

1) MISO's renewable integration impact assessment (RIIA)
2) Cigre TB 450 – Grid integration of Wind Generation
3) Cigre TB 671 – Connection of wind farms to weak AC networks
4) Ph.D Thesis – Integration of wind farms into weak AC grids – Manal Hussein Nawir 2017, Cardiff University
5) Connecting Eastern and Western Grids; Macrogrid Design – a Strategic US infrastructure Investment, University of Washington Clean Energy Institute, James McCalley
6) Inertia emulation control strategy for VSC HVDC transmission systems

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