

MISO's Renewable Integration Impact Assessment (RIIA)

EXECUTIVE SUMMARY - FEBRUARY 2021



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Executive Summary

A Technically Rigorous Exploration

MISO’s Renewable Integration Impact Assessment (RIIA) demonstrates that as renewable energy penetration increases, so does the variety and magnitude of the bulk electric system need and risks. Managing the system under such conditions, particularly beyond the 30% system-wide renewable level is not insurmountable and will require transformational change in planning, markets, and operations. Through coordinated action with MISO stakeholders, RIIA concludes that renewable penetration beyond 50% can be achieved.



While grid operators have managed uncertainty for decades, MISO is preparing for an unprecedented pace of change. MISO, members, regulators, and other entities responsible for system reliability all have an obligation to work together to address these challenges. MISO calls this shared responsibility the [Reliability Imperative](#), which is broken into four categories Market Redefinition, Long Range Transmission Planning (LRTP), Operations of the Future, and Market System Enhancements. RIIA is a key part of understanding the risks ahead.

RIIA is a technically rigorous systematic analysis that evaluates increasing amounts of wind and solar resources on the Eastern Interconnection bulk electric systems, with a focus on the MISO footprint. RIIA examines renewable penetration levels in 10% increments up to 50% to better understand the complexities of integration at each level. This assessment provides examples of integration issues and examines potential mitigation solutions.

RIIA is policy and pace agnostic: generation changes in the analysis are assumed to occur regardless of external drivers and timelines. As a technical impact assessment, RIIA does not directly recommend any changes to the existing electrical power system or construction of any new resources. That said, this body of work demonstrates that as renewable penetration increases, so does the variety and magnitude of system risk requiring transformational thinking and problem-solving.

“MISO, our members, and the entire industry are poised on the precipice of great change as we are being asked to rapidly integrate far more renewable resources. Given our regional Reliability Imperative, MISO must act quickly, deliberately, and collaboratively to ensure that the planning, markets, operations, and systems keep pace with these changes. We can achieve this great change if we work together.”

– Clair Moeller, MISO President



New and Changing Risks Emerge, Requiring Support

As new risks emerge, adaptation within the existing planning, market, and operations constructs will suffice only to a point. As renewable generators are added, and conventional generators retire, RIIA identifies both new and changing risks and system needs:

New Stability Risk

The grid's ability to maintain stable operation is adversely impacted, primarily when renewable resources are clustered in one region of the transmission system. As inverter-based resources displace conventional generators, the grid loses the stability contributions of physically spinning conventional units. A combination of multiple technologies — such as high-voltage direct current (HVDC) lines, synchronous condensers, motor-generator sets and emerging technology such as grid-forming inverters — are needed to provide support, along with operational and market changes to identify and react to this risk as it occurs.

Shifting Periods of Grid Stress

The periods of highest stress on the transmission system shift from peak power demand to times when renewables supply most of the energy and long-distance power transfers increase. As power flows across longer distances, local planning and operational issues become regional challenges. As renewable resources supply most of the energy, the system becomes more dependent on the stability attributes of the remaining conventional generators, increasing the system risk associated with unexpected outages of those generators. As the direction and magnitude of power flows change rapidly due to the output of renewable resources that vary with weather conditions, increased flexibility, and innovation in planning and infrastructure is needed to adapt to new and shifting periods of stress.

Shifting Periods of Energy Shortage Risk

The risk of not having enough generation to meet demand shifts from the historic times of peak power demand to other periods, specifically hot summer evenings and cold winter mornings, when low availability of wind and solar resources is coincident with high power demand. These shifts are regional in nature. The colder and windier northern states exhibit different patterns than the hotter and sunnier southern states. To address this changing risk, the system needs to ensure (1) sufficient visibility of locational risk and (2) that other energy-supplying resources are available during these new times of need, with adequate transmission to deliver across regions.

Shifting Flexibility Risk

The ability of resources to provide system flexibility will be challenged. Current flexibility is needed primarily around the morning load ramp as energy demand increases and again during the evening load ramp as demand decreases. This risk shifts as variable renewables are added. As solar resources meet a larger share of the mid-day generation needs, non-solar resources are needed to ramp down in the morning and ramp up again in the evening to balance the solar pattern. Similarly, non-wind resources will ramp up and down to balance wind patterns, which change daily. To address this shifting risk, overall flexibility need increases and shifts to align with the periods in which it is required.

Insufficient Transmission Capacity

The current transmission infrastructure becomes unable to deliver energy to load. This is especially true if renewables are concentrated in one part of the footprint while serving load in another. Without added



transmission, power flow across the footprint is hindered. The variable supply of renewables would, therefore, become much more challenging to manage, resulting in increased curtailment and markedly different operation of the remaining generators. Given how much time is typically needed to build transmission, proactive planning is necessary.

Integration Complexity Increases Sharply after 30% Renewable Penetration

In the general sense, system integration complexity is the effort needed to plan for, support, and operate new resources as they connect to the grid. In the RIIA analysis, complexity is measured quantitatively to understand its relative magnitude when comparing across various drivers.

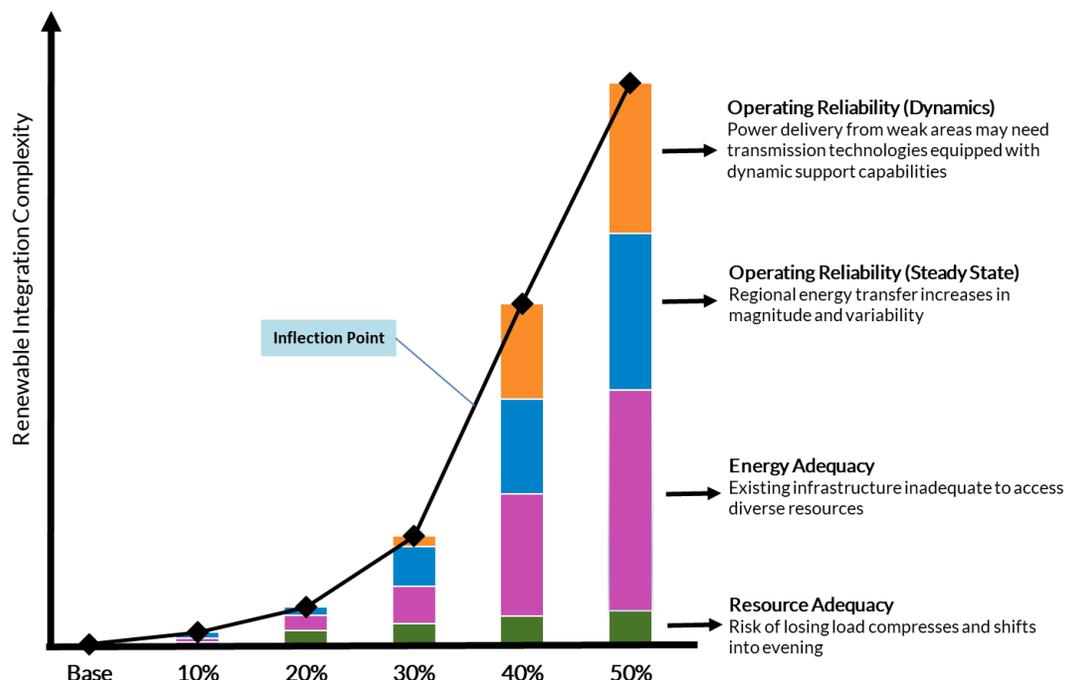


Figure 1: Increasing renewable penetration will significantly impact grid performance with complexity increasing sharply after 30% renewable penetration levels

RIIA found when the percentage of system-wide annual load served by renewable resources is less than 30%, the integration of wind and solar will require transmission expansion as well as significant changes to current operating, market, and planning practices — all of which appear manageable within MISO’s existing framework. Beyond 30%, transformative thinking and coordinated action between MISO and its members are required to prepare for the significant challenges that arise (Figure 1). It is important to note that renewable growth does not happen uniformly across the MISO footprint, or the broader interconnected system. Growth occurs fastest in areas with high quality wind and solar resources, available transmission capacity, and favorable regulatory environments. For example, when MISO reaches 30% renewable energy penetration, some Local Resource Zones are likely to be approaching 100% renewable energy penetration. Locations which experience the fastest renewable growth experience

“RIIA is the most comprehensive engineering study of the power system renewable transformation.”
— Aaron Bloom, Chair, System Planning Working Group, Energy System Integration Group



challenges first, but beyond 30% renewable penetration the system as a whole facing new and shifting risks rather than simply local issues.

Today, MISO's renewable fleet accounts for 13% of MISO's system-wide energy, and MISO operates 26 GW of wind and 1 GW of solar. Nearly 80% of MISO's renewable resources are in the northwest region of MISO, concentrating the current integration challenges to one area.

Looking ahead, as the significant pipeline of generators with executed Interconnection Agreements reach commercial operation (6 GW of new wind, 10 GW of new solar), renewables are expected to account for approximately 20% of the system-wide annual energy mix. Beyond that, [MISO Futures](#) demonstrate the 30% milestone could occur as soon as 2026.



Three Key Focus Areas, RIIA Insights and Next Steps

RIIA illustrates areas of system weakness, recognizes when those weaknesses could become problematic and identifies potential means to address them. This work has informed initiatives already underway at MISO and will serve as a key input to initiatives in the future. The assessment aims to support a broader, more informed conversation about renewable integration impacts on the reliability of the electric system within the MISO stakeholder community and the greater industry. The analysis suggests three key focus areas for MISO and stakeholders (Figure 2) and informs the sequencing of actions required to manage various renewable penetration levels.

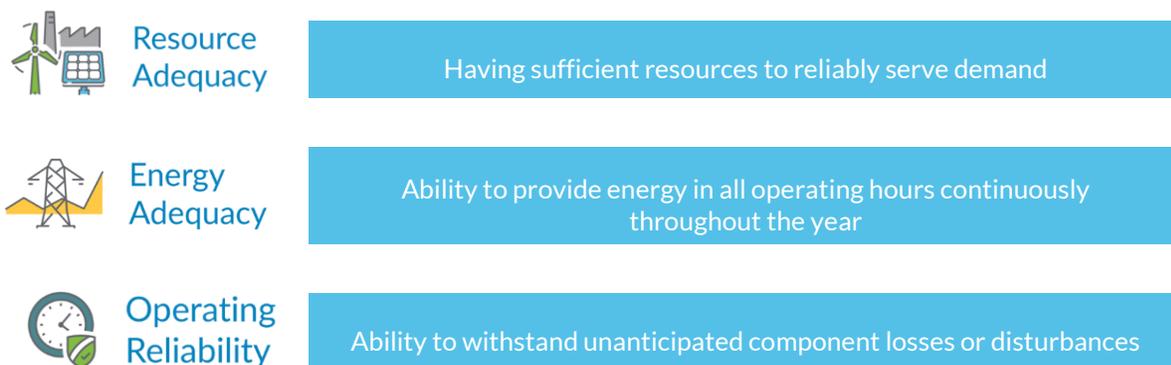


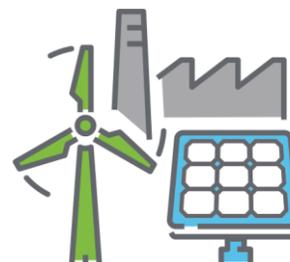
Figure 2: RIIA's three focus areas: Resource Adequacy, Energy Adequacy and Operating Reliability



Note: Where appropriate, the insights below are tied to the [Reliability Imperative](#) efforts in the categories of Market Redefinition, Long Range Transmission Planning (LRTP), Operations of the Future, and Market System Enhancements.

Resource Adequacy

Resource Adequacy is the ability of available power resources to reliably serve electricity demand when needed across a range of reasonably foreseeable conditions. Resource Adequacy complexity is defined as the effort needed to maintain capacity necessary to maintain a “one day in 10 years” loss of load expectation target.



RESOURCE ADEQUACY INSIGHTS

INSIGHT: Risk of losing load compresses into a small number of hours and shifts into the evening. The risk of not serving load shifts later into the evening and is observed for shorter durations with higher magnitude. Sensitivity analyses show risk shifting to winter and later in the evening, depending on technology and geographic mix.

NEXT STEP

- Ensure resource availability outside of traditional risk periods, both during evening hours and winter periods (Market Redefinition).

INSIGHT: Resource changes will significantly impact grid performance, with complexity increasing sharply after 30% renewable penetration levels.

NEXT STEP

- Develop and implement market solutions to identify issues prior to the system reaching 30% wind and solar penetration (Market Redefinition).

INSIGHT: Diversity of technologies and geography improves the ability of renewables to serve load. Yearly weather variations drive Resource Adequacy outcomes.

NEXT STEP

- Develop ways to increase the fidelity of renewable energy forecasts by using improved weather data.

RESEARCH STEP

- Explore ways to incentivize new resource additions to enhance technological and geographical diversity to serve MISO reliability.



Energy Adequacy

Energy Adequacy looks at the ability to operate the system continuously and deliver sufficient energy every hour of the year. Energy Adequacy complexity is defined as the effort to develop the transmission needed to maintain and deliver renewable energy during every hour of the year. The generation fleet's ability to respond to the load is limited by existing generation and transmission constraints, and new transmission costs act as a proxy to measure the additional flexibility needed to access diverse resources.



ENERGY ADEQUACY INSIGHTS

INSIGHT: With renewable penetration levels above 40 percent, there is both a greater magnitude and increased variation of ramping needed. Increasing variability due to renewable generation will require generators to perform differently than they are today.

RESEARCH STEPS

- Explore the landscape of system flexibility solutions (e.g., renewables as a solution to variability need and nuclear plant ramping).
- Explore changing risks such as the ability of the natural gas system to deliver fuel to enable gas generator flexibility, and fewer units providing needed system flexibility (due to retirements).
- Explore flexibility incentives (Market Redefinition).

INSIGHT: Existing infrastructure becomes inadequate to fully access the diverse resources across the MISO footprint. Grid technology needs to evolve as renewable penetration increases, leading to an increased need for integrated system planning.

NEXT STEP

- Educate stakeholders about complexities and opportunities of emerging technologies (LRTP).

RESEARCH STEPS

- Explore co-optimization between economic and reliability transmission needs, along with resource deployment (software, process, and data development needed).
- Explore additional opportunities to align and co-plan for system needs across the various MISO planning functions.
- Explore the gaps, opportunities, costs, and benefits of new grid technology (such as FACTS, VSC HVDC lines, grid-forming inverters) and its ability to solve emerging grid needs.

INSIGHT: Storage paired with renewables and transmission help optimize the delivery of energy.

RESEARCH STEPS

- Explore concept to understand benefits better
- Explore process changes to align benefits with outcomes



Operating Reliability

Operating Reliability studies the system's ability to withstand sudden disturbances to system stability or unanticipated loss of system components. This focus area is subdivided into "steady state" and "dynamic stability" analysis and considerations.

Steady State

Steady-state analysis examines whether the transmission system exceeds the thermal ratings of lines, transformers, and other devices following deviations from normal operating parameters occurring without warning. Complexity in steady-state analysis is defined as the effort to create the transmission needed to ensure acceptable system performance after outages.

OPERATING RELIABILITY – STEADY-STATE INSIGHTS

INSIGHT: Resource location and system conditions cause transmission risk shifting to spring and fall and increasing in frequency. Additionally, sensitivity analysis shows risk shifting to summer shoulder load periods during high solar output.

NEXT STEPS

- Align planning dispatch assumptions with shifting system conditions and risk (LRTP).
- Develop tools and processes to capture changing risks as they appear for transmission planning (LRTP).

RESEARCH STEP

- Evaluate opportunities to align and co-simulate power-flow and production cost models.

INSIGHT: Regional energy transfer increases in magnitude and becomes more variable, leading to a need for increased extra-high voltage transfer capabilities. Transmission bottlenecks shift to higher voltage lines due to increased regional energy transfers.

NEXT STEPS

- Proactively align to future needs, develop long-range, cost-effective, and least-regret transmission plans, and move construction forward (LRTP).

Dynamic Stability

Voltage stability, frequency stability, rotor angle stability, and non-oscillatory behavior of electrical quantities are considered dynamic stability issues. Dynamic stability includes maintaining operating equilibrium of three distinct elements after a disturbance in the electric grid: (a) voltage stability; (b) adequate frequency response; and (c) rotor angle stability. Complexity in the Operating Reliability – Dynamics analysis is defined as the effort to install transmission equipment and control system tuning required to ensure stable operation.

RIIA identifies potential issues with all three dynamic stability elements along with converter-driven stability, which is an additional category associated with inverter-based equipment. Concerning voltage and converter-driven stability, the assessment demonstrates that as inverter-based resources increase in penetration, there is a corresponding decrease in the online thermal generation, which intensifies reliability



issues. This is significant because commercially available inverter-based resources, such as renewables, need strong voltage connections to operate reliably and efficiently. This study identifies several approaches to address the issues, such as tuning inverter controls, re-dispatching generation, adding synchronous condensers, and using advanced technologies (FACTS, VSC HVDC). Frequency-related risks can be resolved by adding storage or maintaining online headroom from resources, including wind and solar.

OPERATING RELIABILITY – DYNAMIC STABILITY INSIGHTS

INSIGHT: Power delivery from “weak-grid” areas may need transmission technologies equipped with dynamic support capabilities.

RESEARCH STEPS

- Explore and decide ways to address “weak-grid” issues (such as improved inverter technology, new technology pilots, operational visibility, proactive and integrated transmission planning).
- Update inverter control tuning approaches as penetration of inverter technologies increases.

INSIGHT: Small signal stability issues increase in severity after 30% renewable penetration, thereby requiring power system stabilizers. Frequency response is stable up to 60% instantaneous renewable penetration but may require additional planned headroom beyond 60%.

RESEARCH STEPS

- Explore new methods to stabilize the grid, such as battery storage.
- Explore operations tools to monitor and commit power system stabilizers when needed.

INSIGHT: On average Critical Clearing Time (CCT) improves as large generating units are replaced, but new local issues emerge.

RESEARCH STEP

- Explore process to plan for new protection techniques or new transmission devices.



Additional Work Is Needed

RIIA is the culmination of four years of stakeholder collaboration and intense exploration into the impacts of increasing renewable integration in the MISO region. While the analysis is highly comprehensive, it is not finished. Additional work is needed to transform the way MISO and the power system are planned and operated to continue to maximize reliability and value creation across the region in a high renewable system. RIIA has shown that while there are challenges, the MISO region can achieve renewable penetration of at least 50% with transformational change and coordinated action amongst all participants.

“We believe it will take transformational change, including redefined markets and planning processes, to enable efficient and reliable operations in the future. Coordinated action amongst all stakeholders will be necessary to facilitate participants’ decarbonizations goals and plans for higher levels of renewable generation.”

— Richard Doying, MISO EVP Market & Grid Strategies