Technical Challenges Involved in Managing Bulk Power System Operations with High Penetration of Renewables

An Overview of Current Activities by the
Midcontinent System Operator to Integrate Renewables

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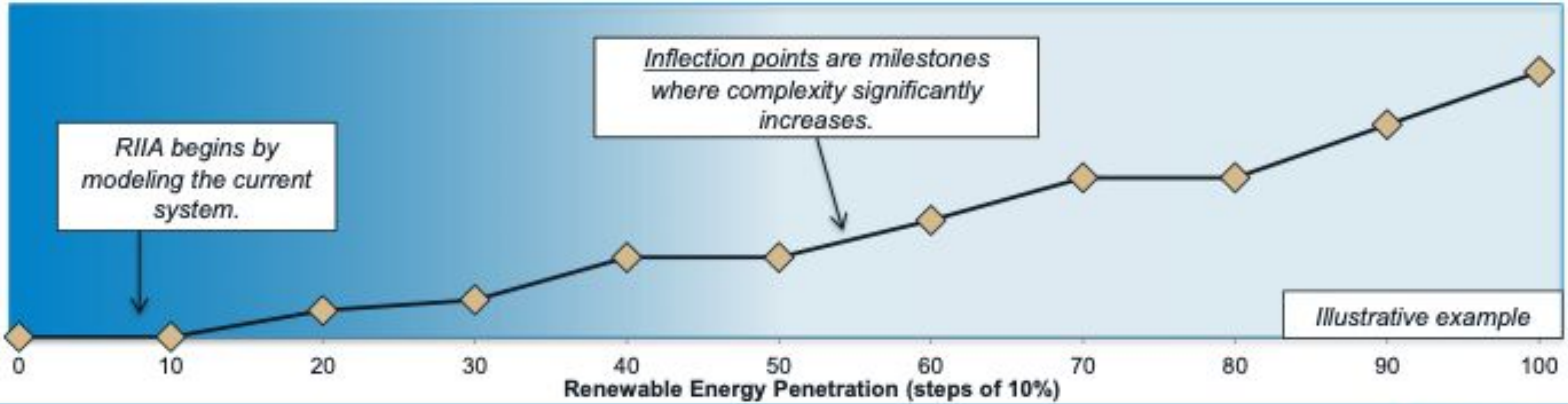
Overview

- What did MISO study and why?
- How did MISO conduct the study?
- What did MISO find?
  - Resource Adequacy
  - Energy Adequacy
  - Operating Reliability: Steady State
  - Operating Reliability: Dynamics

What did MISO study and why?

Renewable Integration Impact Assessment (RIIA) seeks to find inflection points of renewable integration complexity



Assessment goal: To better understand the impacts of renewable energy growth in MISO over the long term

This is a technical impact assessment. Nothing will be built or changed as a direct result of this effort. It is intended to provide information to shape future discussions.

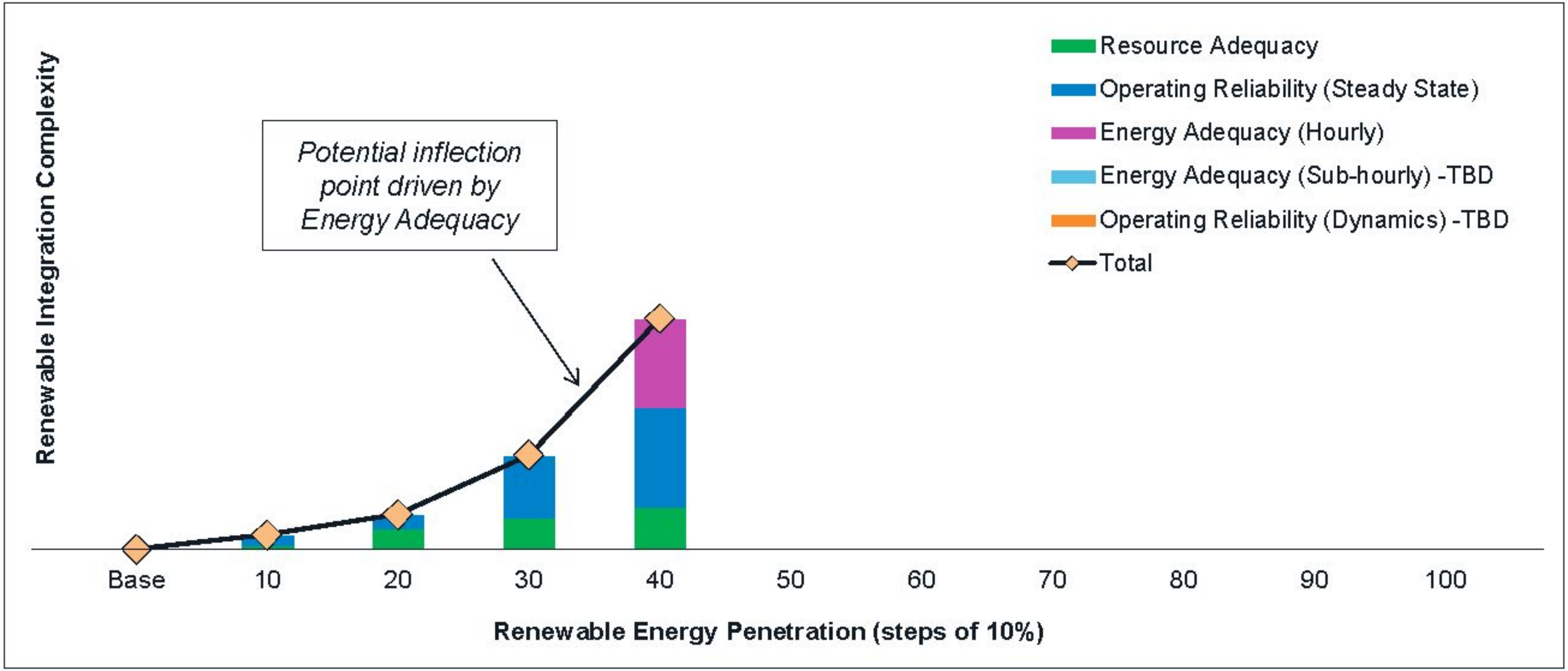
- Provide technically rigorous, concrete examples of integration issues and examine potential solutions to mitigate them
- Inform areas of focus and the sequencing of actions required as penetration increases
- Facilitate a broader conversation about renewable energy-driven impacts of fleet change on the reliability of the electric system

RIIA assesses the complexity of meeting each renewable penetration milestone

Overall objective of each milestone is to get within 5% of the energy target (e.g. 19% for the 20% renewable penetration milestone).

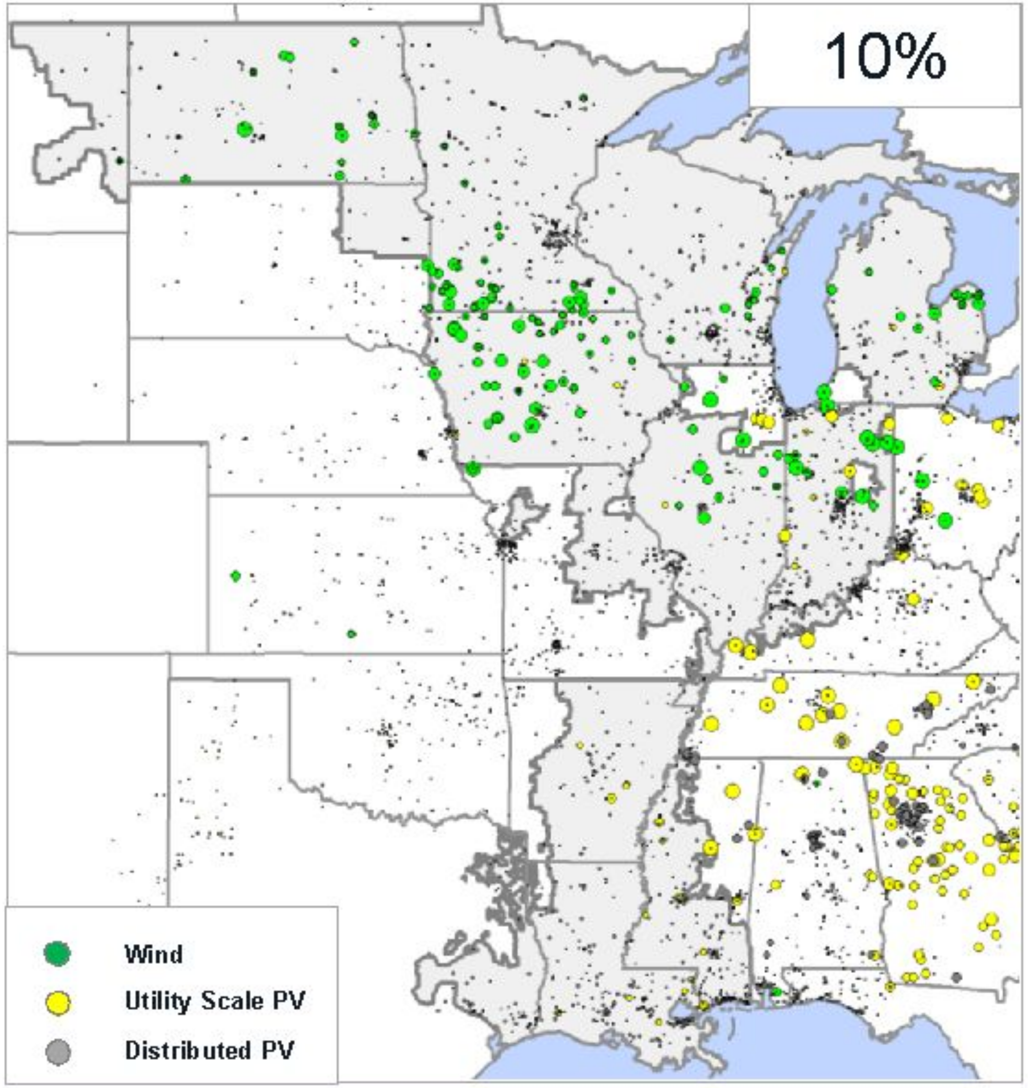
- **Resource Adequacy**
  - Ability to maintain the Planning Reserve Margin (incremental capacity needed)
- **Energy Adequacy**
  - Ability to operate within generator limits (ramp rate, min up/down time, min/max capacity), transmission limits (ratings), and system limits (energy balance, operating reserves)
- **Operating Reliability (Steady-State)**
  - Ability to operate the system within acceptable voltage and thermal limits
- **Operating Reliability (Dynamics)**
  - Ability to maintain stable frequency and voltage, and meet system performance requirements

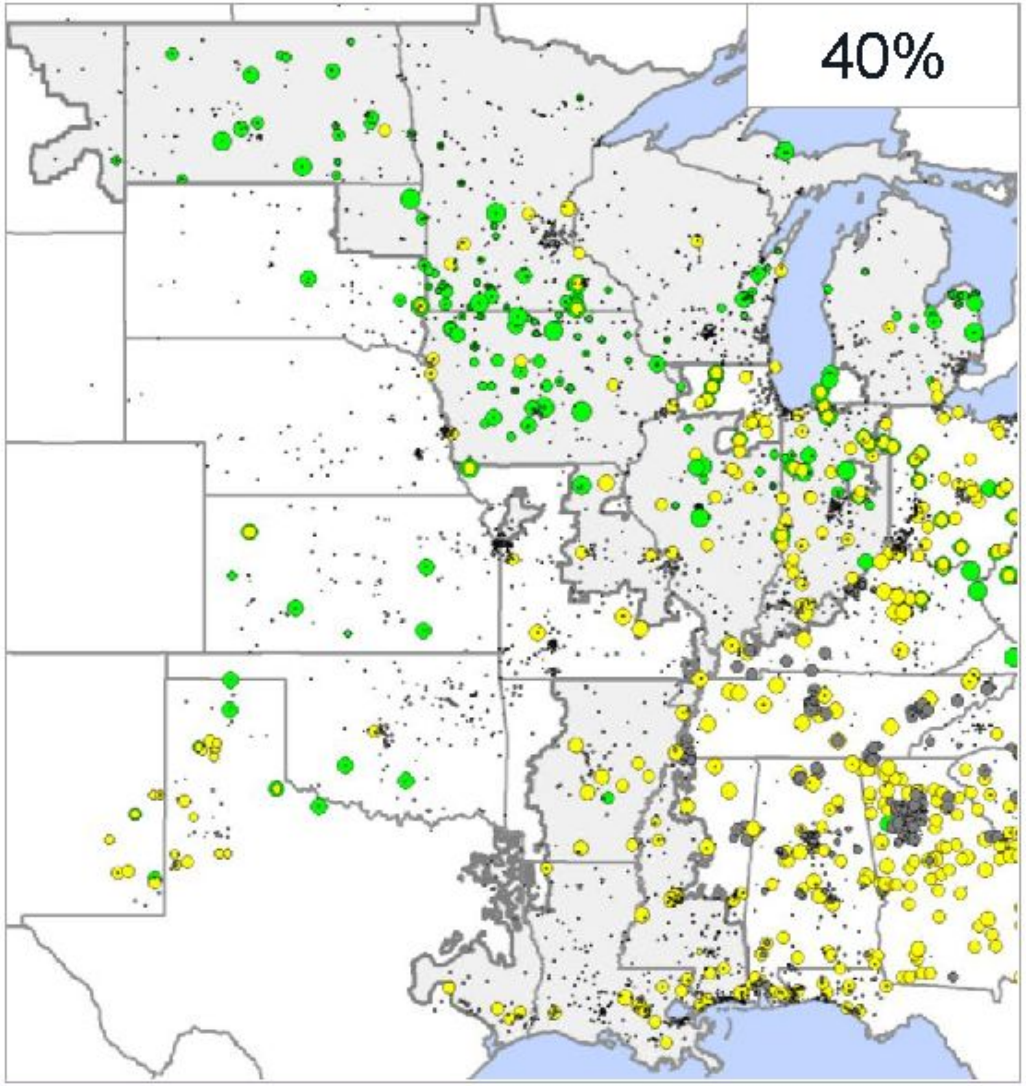
Interim results indicate integration complexity increasing sharply from 30 - 40% renewable penetration



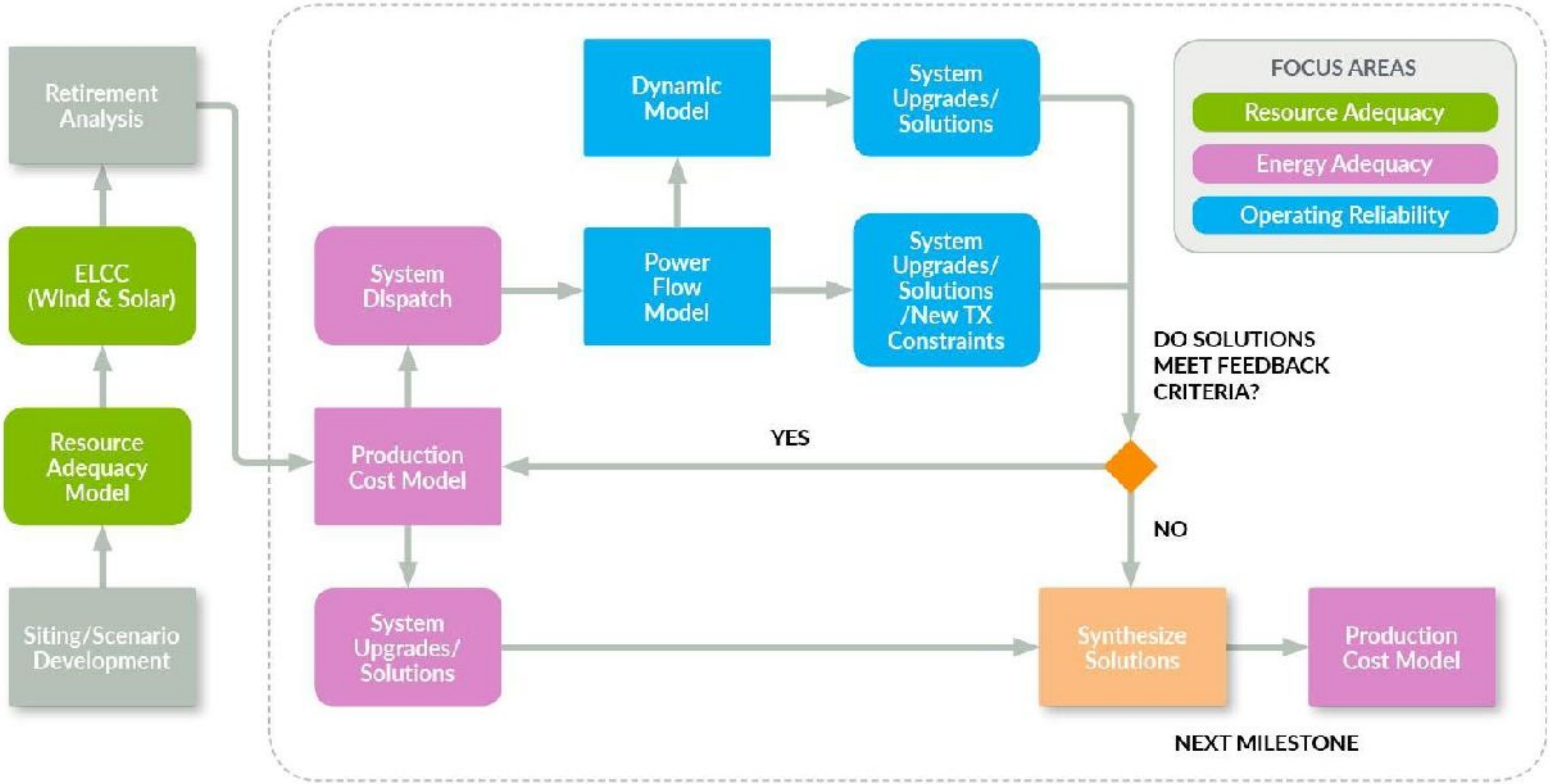
How did MISO conduct the study?

Each planning region (ISO, etc.) receives enough modeled renewable capacity to meet individual penetration milestones





Results are driven by a robust assessment process

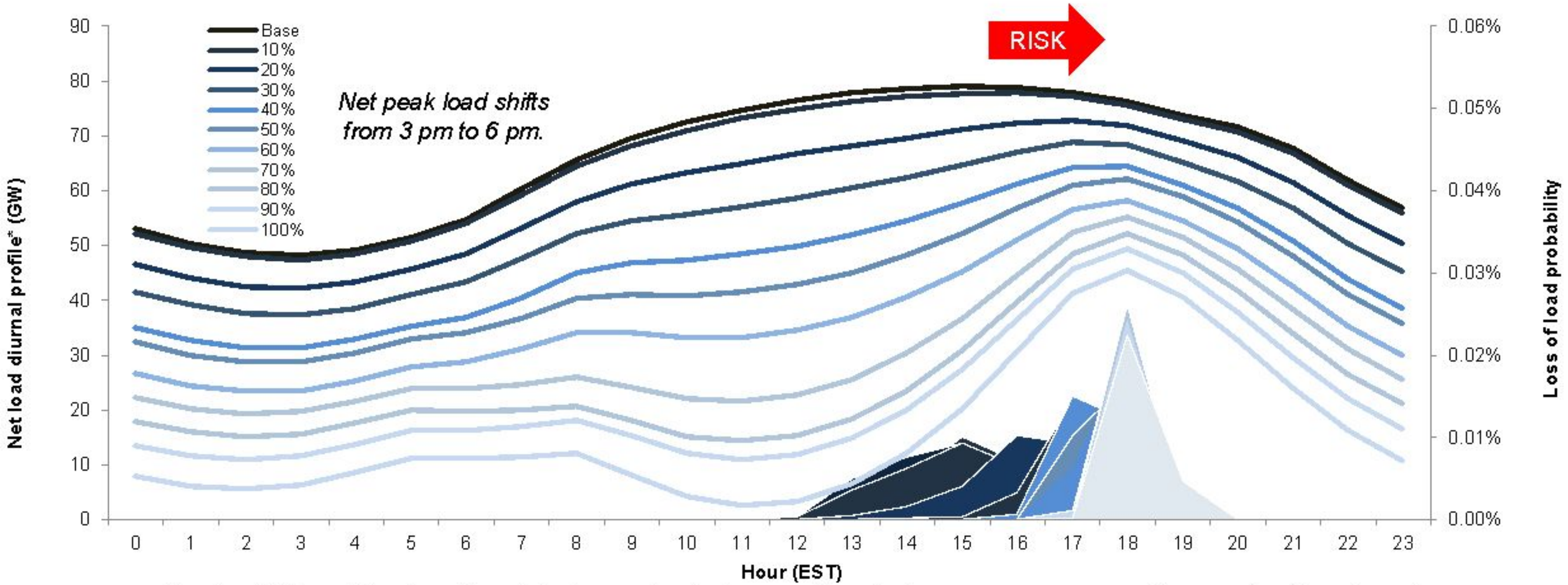


What did MISO find?

Resource Adequacy

- **Resource Adequacy**
  - Ability to maintain the Planning Reserve Margin (incremental capacity needed)

As renewable penetration increases, the risk of losing load shifts and compresses to a smaller number of hours



- Probability of losing load is targeted at one day in ten years over all penetration levels.
- While aggregate risk remains constant, the risk in particular hours increases.

**Profile shapes represent hourly averages across all days of the 6 study years.*

Resource Adequacy: Key takeaways

1. Risk of losing load compresses into a small number of hours and shifts to later in the day

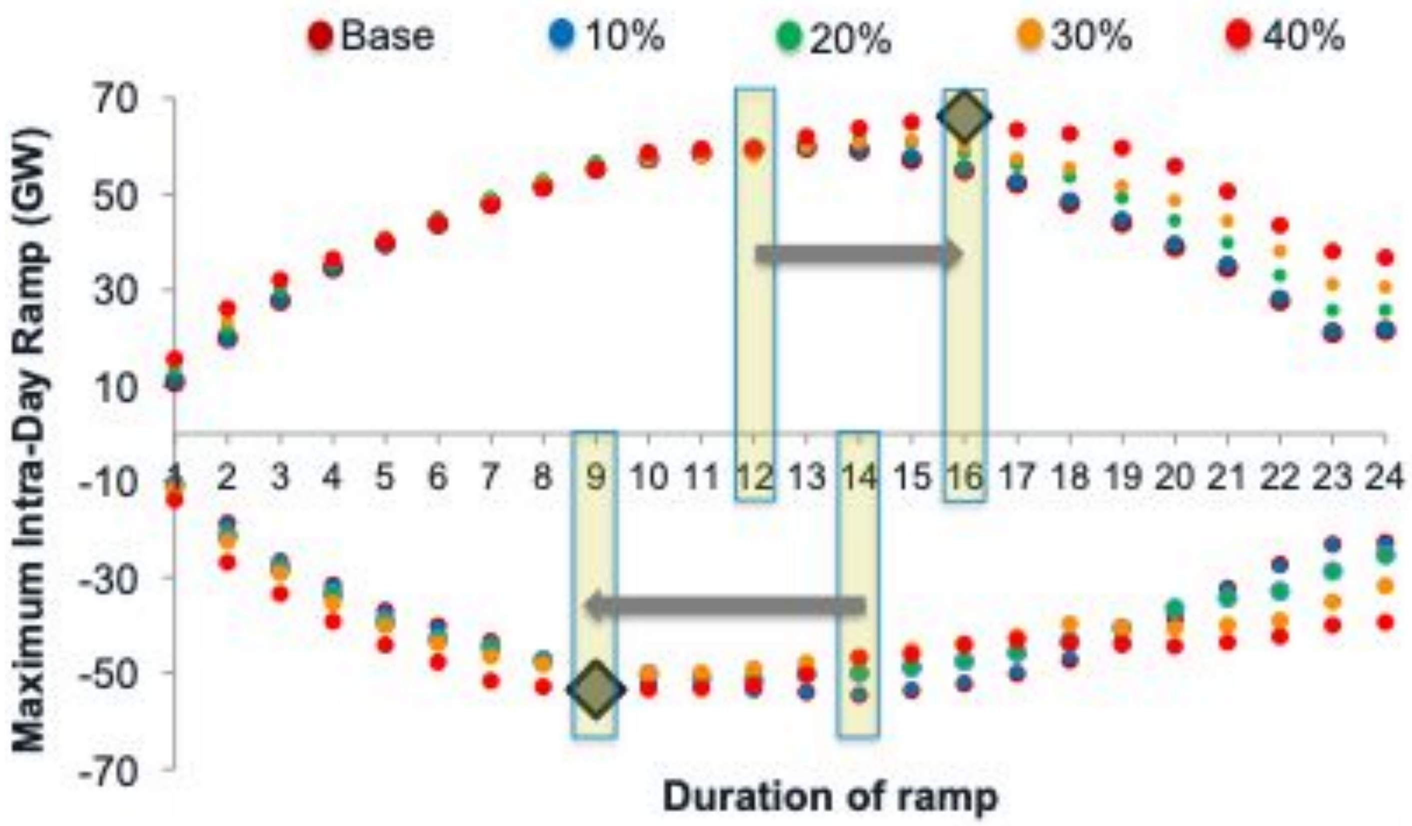
2. As a result of the shift in risk of losing load, the available energy from wind and solar during high risk hours decreases

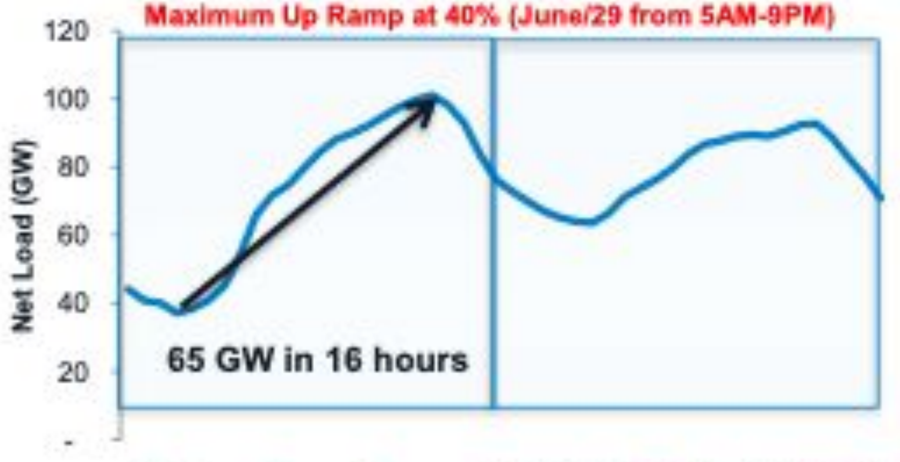
3. Diversity of technologies and geography improves the ability of renewables to meet load

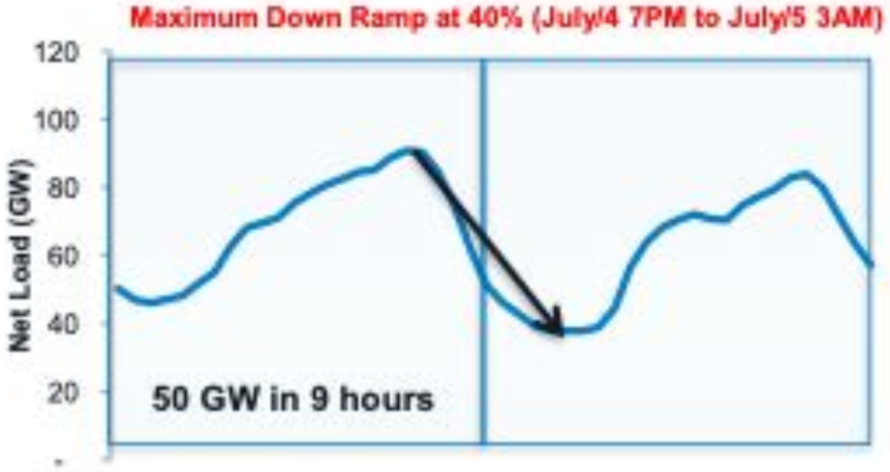
Energy Adequacy

- **Energy Adequacy**
  - Ability to operate within generator limits (ramp rate, min up/down time, min/max capacity), transmission limits (ratings), and system limits (energy balance, operating reserves)

Larger intra and inter day ramps are observed in both directions and the duration of the extreme ramp changes as the integration of renewables increases



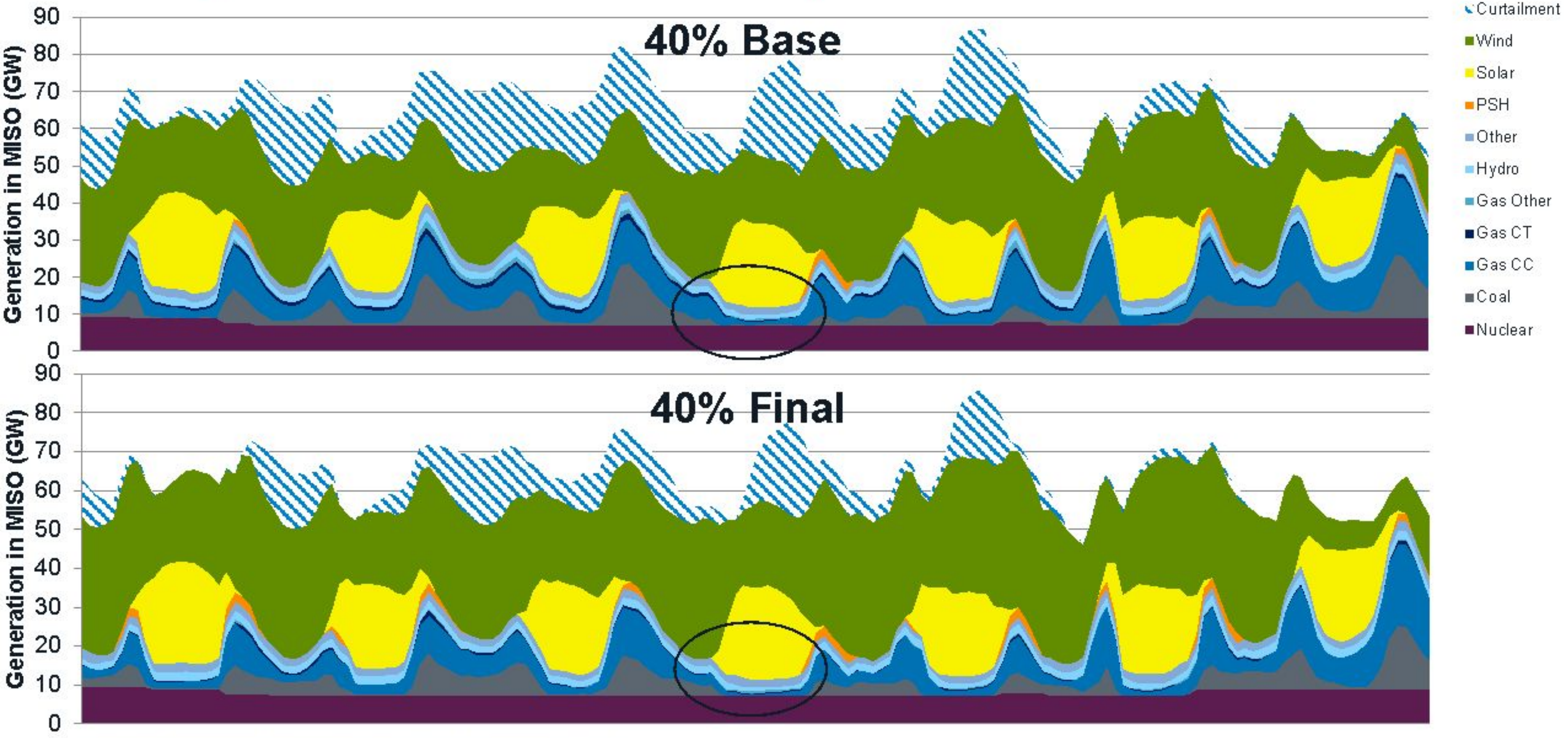




** The largest ramp up occurrence increases in both magnitude and duration at 40%*

** The duration of the largest ramp down occurrence is shorter at 40%*

Minimum generation events indicate periods with a lack of flexibility



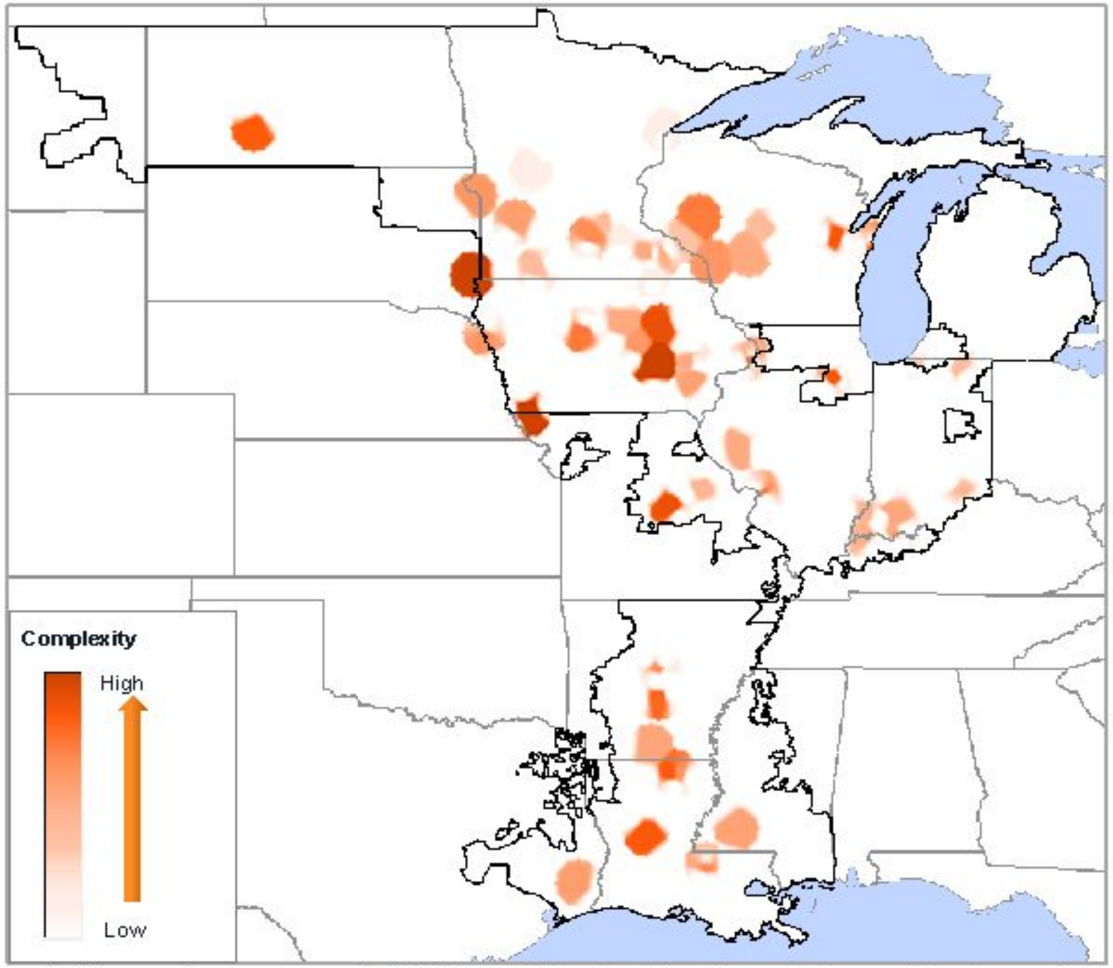
Graphs represent one week of MISO dispatch in April.

Energy Adequacy solutions developed at the 40% milestone to facilitate delivery of the diverse resources across the footprint

- Highly automated process evaluated ~11,300 candidates and their combinations in MISO, considering synergic benefit
- Selected ~80 cost effective solutions

Transmission Expansion						
kV	<200	230	345	500	765	HVDC
Ckt*Mile	266	763	1,373	316	267	408

Renewable Energy Curtailment			
	Base	Intermediate (w/ EA* solutions)	Final (w/ EA and OR** solutions)
40%	18.2%	9.6%	9.2%
Renewable Energy Penetration			
40%	34.7%	38.4%	38.5%



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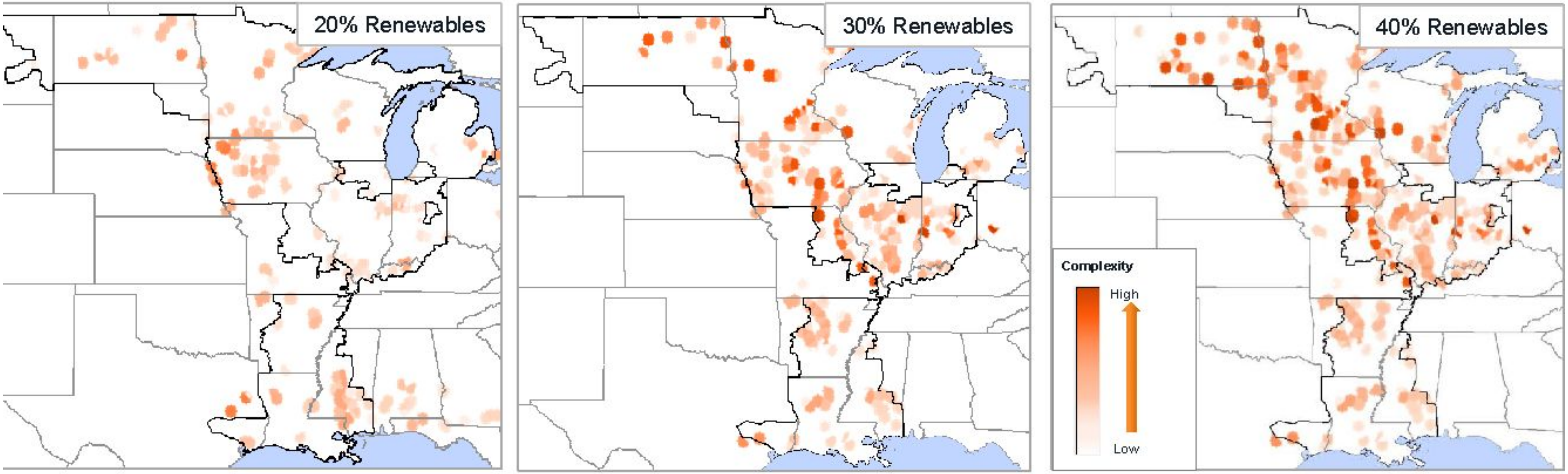
*EA – Energy Adequacy
**OR – Operating Reliability

Operating Reliability (Steady-State)

- **Operating Reliability (Steady-State)**
  - Ability to operate the system within acceptable voltage and thermal limits

Steady-state solution complexity increases with penetration level*



* Maps reflect cumulative issues across milestones

- Integration complexity is measured as the approximate cost of the transmission fixes needed for steady-state reliability issues
- Majority of integration costs is from fixes for transmission thermal violations

Operating Reliability steady-state analysis: Key takeaways

- Under RIIA assumptions, incremental integration complexity increases significantly starting from 30% renewable milestone for MISO footprint in steady-state **Operating Reliability.**

- As milestones progress, intra-MISO interchange increases and thermal overloads are seen in areas farther from renewable expansion.

Operating Reliability (Dynamics)

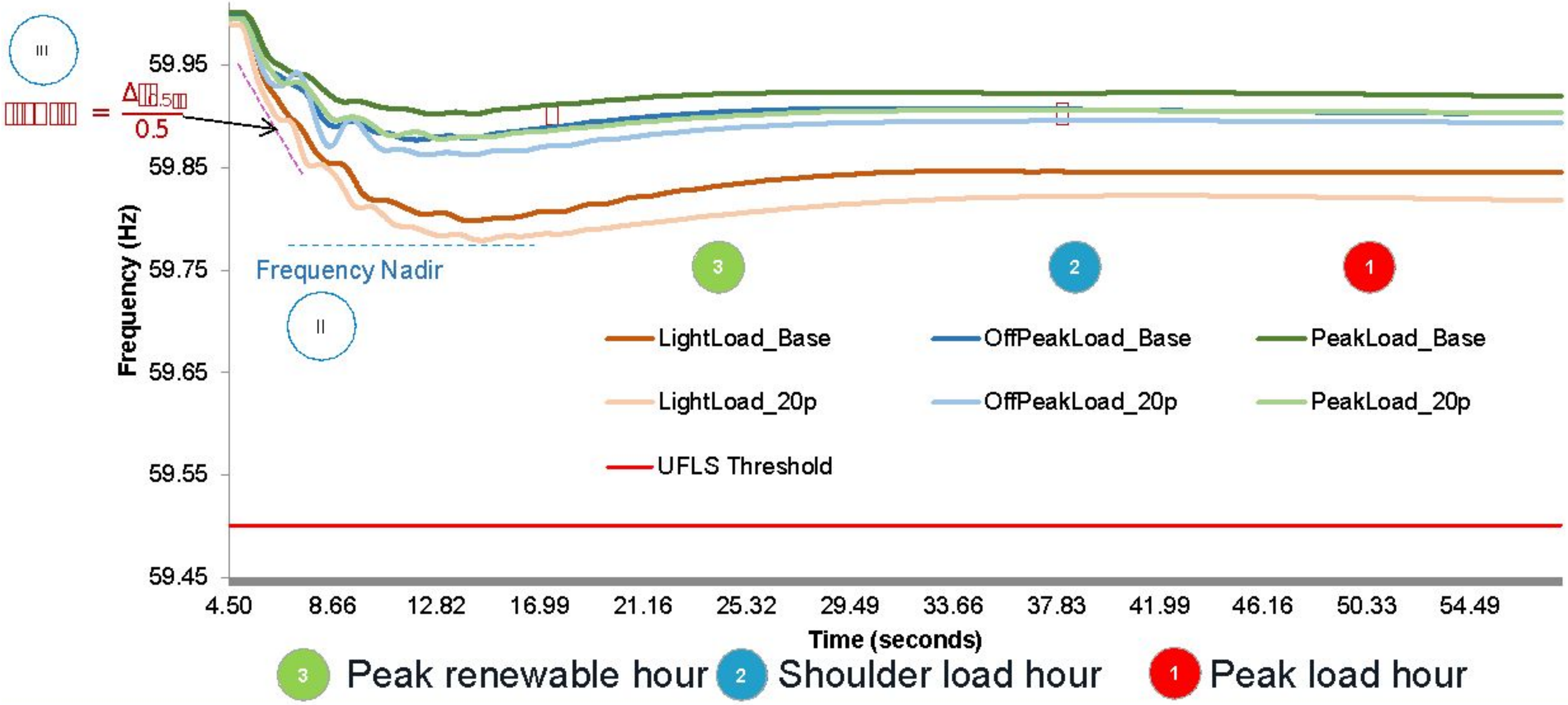
- **Operating Reliability (Dynamics)**
  - Ability to maintain stable frequency and voltage, and meet system performance requirements

Dynamic analysis focuses on four study areas

- **Key questions:**
  - What will the impact of high penetrations of renewable (inverter-based) resources be on frequency, transient and voltage stability, and local grid strength (weak areas)?
  - What actions will be required to maintain adequate performance? When will they be necessary?
- **Key metrics:**

Study area	Performance metric
1. Frequency response	Frequency nadir, rate of change of frequency (RoCoF), NERC BAL-003 obligations
2. Transient and voltage stability	TO's local planning criteria, NERC criteria
3. Weak areas	Short circuit ratio, undamped voltage and current oscillations, interactions between the controls of equipment

Frequency is stable for simultaneous loss of big generators (~4500 MW) up to 20% renewable penetration



Weak areas are identified by observing transient instability due to low short circuit ratio

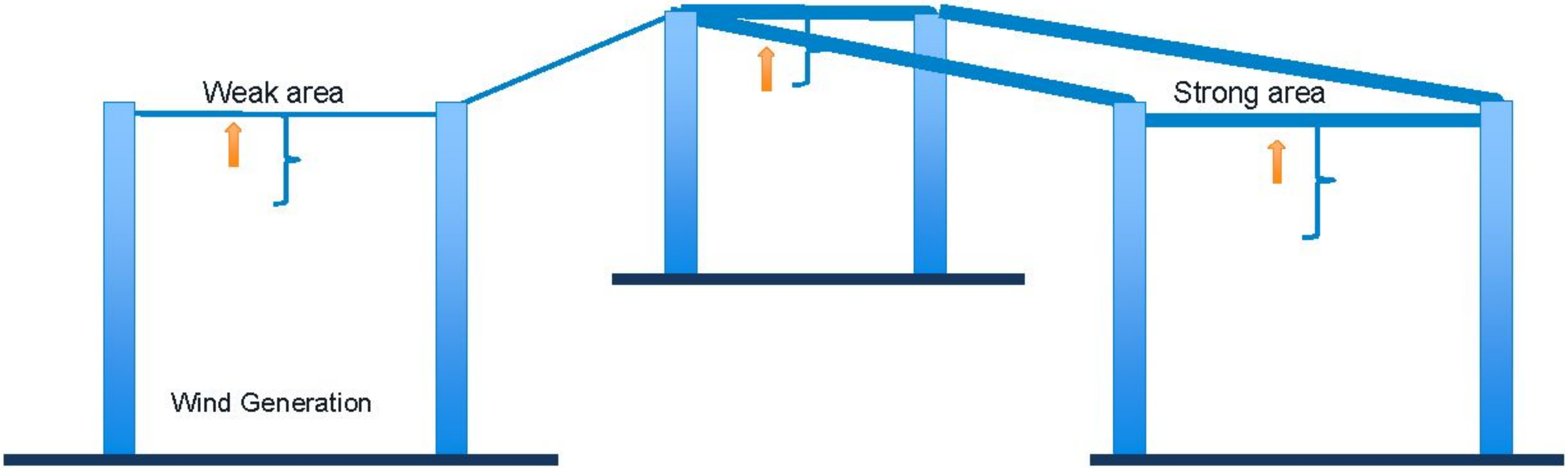
1. **Develop input files.**
    - Obtain steady-state models at each miles stone for each snapshot.
    - Determine MW injection at each milestone at selected bus (existing and new generating sites).
2. **Calculate Short Circuit Ratio (SCR) at selected buses**
    - Obtain three phase fault values using ASCC module in PSSE.
    - Use weighted SCR[1] if more than two renewable resources at one point of interconnection.

Key metrics

Performance Criteria	Threshold	Potential Solutions (if threshold is breached)
Undamped oscillations seen in transient stability study (Voltage, MW) near new or existing generating resources due to low SCR	TO's Planning or NERC Criteria	1. If oscillations originate from the new plant, then tune control parameters of wind/solar farm. 2. If tuning does not mitigate the issue, turn on nearby synchronous generation. 3. Install new synchronous condensers if #1 and #2 do not work.

[1]NERC : Integrating Inverter-Based Resources into Low Short Circuit Strength Systems Reliability Guideline, December 2017

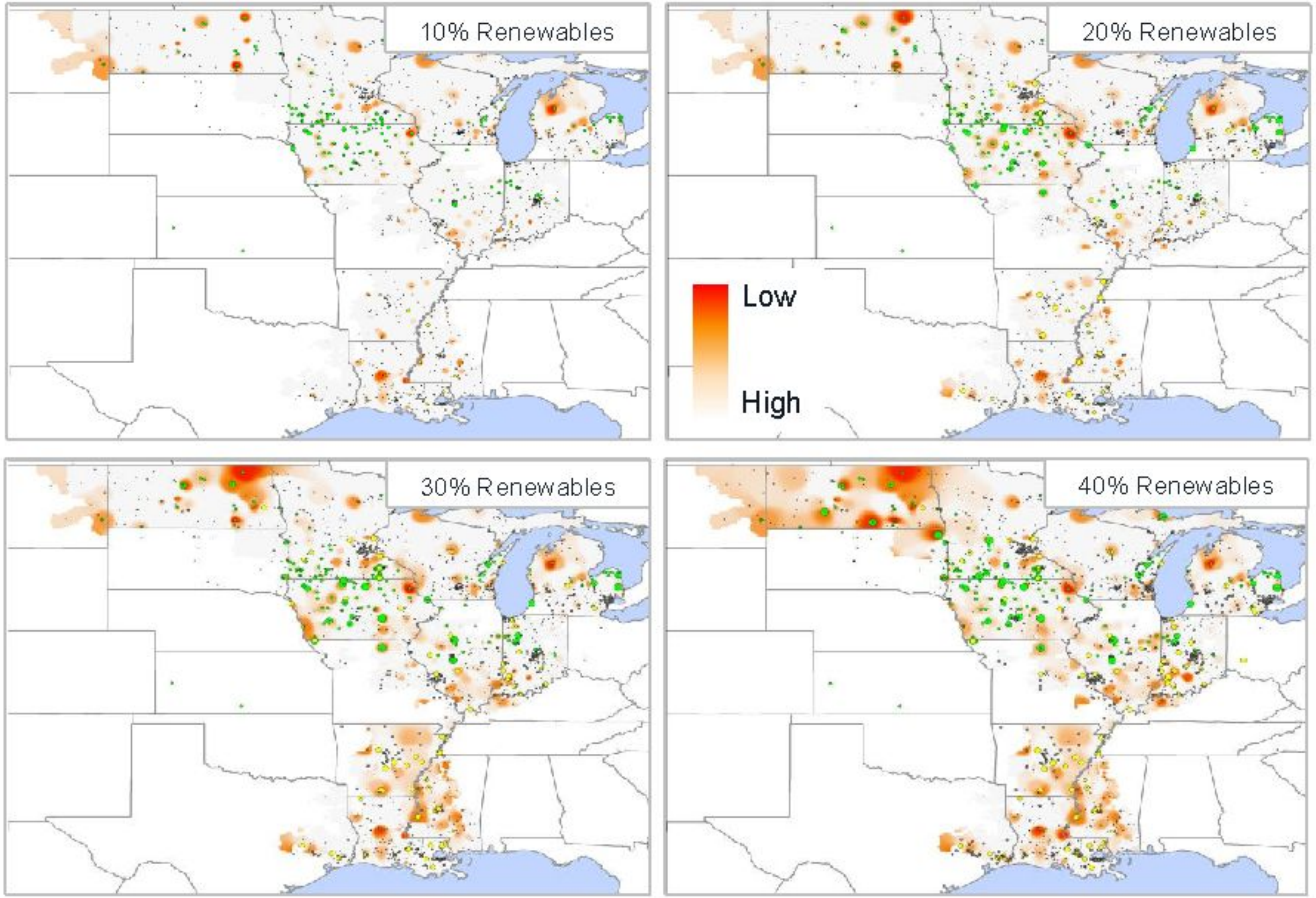
In a weak area, a resource's terminal voltage is highly sensitive to variations of current injections



Higher short circuit ratio indicates a stronger area. Short Circuit Ratio (SCR) = Fault MVA / MW injection*

*Other methods are also used to determine SCR. Refer NERC: Integrating Inverter-Based Resources into Low Short Circuit Strength Systems Reliability Guideline, December 2017

Potential system stability issues greatly increase at 40% penetration



- Number of areas with low short circuit ratios increase with renewable penetration.
- SCR at several locations decrease with an increase in penetration.

Dynamic Analysis: Key takeaways

- Frequency response is satisfactory up to 20% renewable penetration.
- Weak area issues due to low SCR are likely to appear during high renewable and low load conditions. New renewable plant controls will need to be tuned to operate over a wide range of system conditions.
- Overall the critical clearing time increases in 20% case.
- Several issues were observed during the development of 40% stability models, which indicate that dynamic issues are expected to increase. Transmission design will need to account for the dynamic stability performance metrics.

Interim results indicate integration complexity increasing sharply from 30 - 40% renewable penetration