Renewable Integration Impact Assessment: The MISO Experience

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See footnotes at end of text.

Midcontinent Independent System Operator (MISO) is a not-for-profit member-based reliability organization that ensures reliable, least-cost delivery of electricity across all or parts of 15 U.S. states and one Canadian province (Figure 1). Driven by economics, environmental regulations, technological innovation and aging infrastructure, the types of generating resources in the MISO footprint are changing in a profound way. Many of the legacy power plants that generated the bulk of the region's electricity for decades have either retired in recent years or been replaced by natural gas-fired resources and renewable energy facilities. Energy efficiency initiatives, demand-side programs, energy storage, and distributed energy systems are also growing in popularity. These changes represent a shift away from long-standing power system design and operational practices, and call for a detailed exploration of assumptions regarding the way the electrical grid will work in the future.

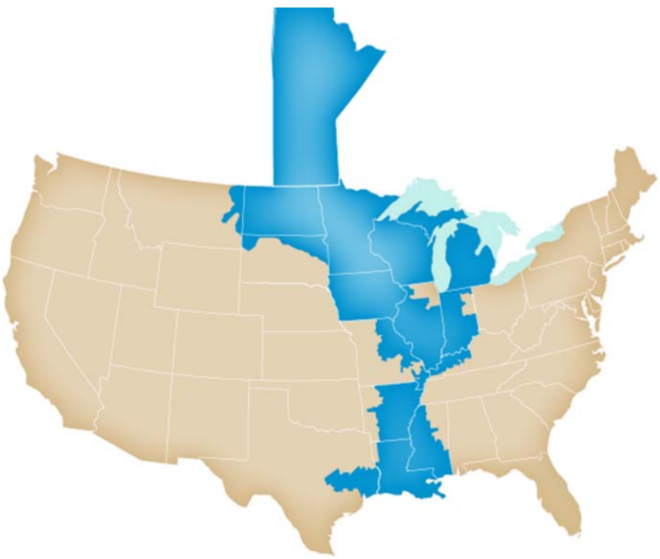


Figure 1: MISO reliability footprint as of July 2018.

Renewable energy, namely wind and solar resources, is currently the fastest growing and most prominent class of resource in MISO. Under current practices, MISO facilitates the integration of renewable resources in the energy market as dispatchable intermittent resources. Between 2014 and 2017, energy output from wind farms increased from 38 million MWh to over 50 million MWh, and accounted for 9% of MISO's energy needs in 2017. There is also 42GW of wind and 36GW of solar capacity currently in MISO's generation interconnection queue.[1] As renewable generation resources continue penetrate into the bulk electric grid, MISO expects their contribution to grid reliability services to increase. These reliability services are a fundamental component of the power industry. Hence, MISO deems additional analyses are necessary to gain better understanding of requisite resource performance on a regional scale as renewable penetrations reach higher levels.

Given the current characteristics of the electric system in MISO and its neighboring regions, including but not limited to physical infrastructure, operational practices, and regulations, there may be limits to how much renewable energy can be easily integrated into the bulk electric system. The complexity of overcoming these limitations is dependent on the types and distribution of renewable resources, the current operational characteristics and locations of existing assets, and the actions of neighboring regions. Because the exact points of these limitations are unknown, MISO developed an analytical framework, i.e., the Renewable Integration Impact Assessment (RIIA), to examine renewable integration over a wide range of penetration levels. Starting with the current system and examining penetration levels up to very high percentages of annual energy, RIIA aims to find inflection points of system integration (Figure 2). Industry studies have shown that the complexity of integrating renewables escalates non-linearly with increasing penetrations of renewables. Over

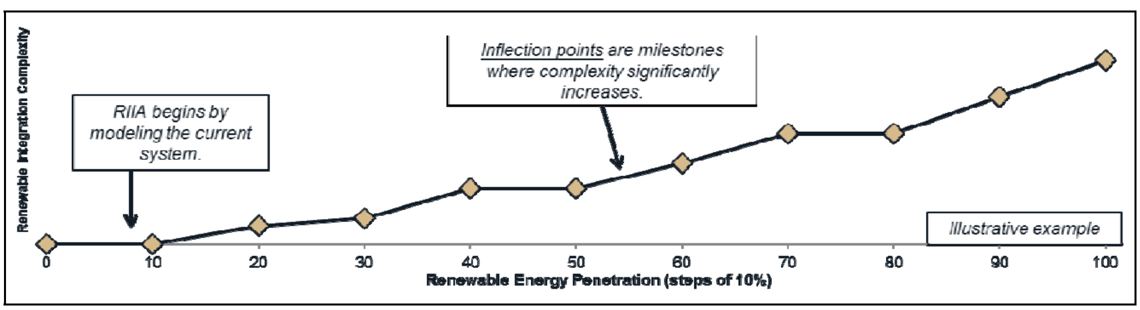


Figure 2: RIIA

certain ranges of renewable penetration, complexity is constant when there is adequate transmission and generation capacity in place. However, at specific renewable penetration levels when existing transmission and generation capacity are exhausted, complexity rises dramatically. These are system inflection points, where the underlying infrastructure and/or system operations require significant enhancement to achieve the next tranche of renewable deployment while keeping adequate levels of grid reliability.

To find system inflection points and to examine potential solutions for mitigating potential reliability risks, RIIA comprises three focus areas: Resource Adequacy, Energy Adequacy, and Operating Reliability. These three focus areas include three separate models that use mostly common assumptions.

Resource Adequacy

A key component of MISO's planning process is the Resource Adequacy analysis, pursuant to standards established by the North American Electric Reliability Corporation (NERC). The metric used to calculate the planning reserve margin (PRM) for a system is the "one day in 10 years" criterion for Loss of Load Expectation (LOLE). In other words, the system must have enough generation capacity above the gross peak load to cover load forecast errors, unexpected generation outages and planned maintenance of generation units.[2]

The integration of higher levels of renewable resources into the MISO market has driven the need to quantify the effect of wind resources on the LOLE target. MISO has adopted the effective load carrying capability (ELCC) to quantify the capacity value of wind during MISO's peak hours. In RIIA, the ELCC is quantified for each 10 percent renewable penetration milestone; each renewable technology being studied (wind, utility-scale solar distributed solar PV); the isolated collective solar technologies; and for each of the six different profile years studied (2007-2012) using load data from the real-time market and renewable generation data from the National Renewable Energy Laboratory (NREL). Figure 3 illustrates the effects of high levels of renewables penetration on the average net load shape in MISO footprint, i.e., total load minus renewable energy output (pre-curtailment).

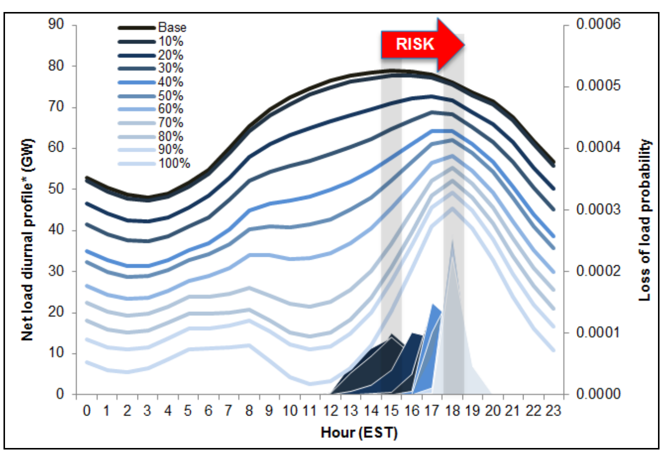


Figure 3: Risk of Losing Load

Figure 3 provides several key observations in the context of Resource Adequacy. First, as renewable penetration increases, the risk of losing load compresses into a small number of hours and shifts to later in the day. Second, at higher levels of renewables, this new period with the highest LOLE occurs when the performance of wind and solar drives a rapid increase in the net-load ramp. With this change in net load shape, the ELCC values for wind and solar are shown to decrease as penetration increases as illustrated in Figure 4. The ELCC for wind only decreases slightly along with increasing installed capacity. However, the ELCC for solar sees a steeper drop-off. Note that these approximated ELCC curves are specific to the assumed capacity mix and the siting of new renewable units. The

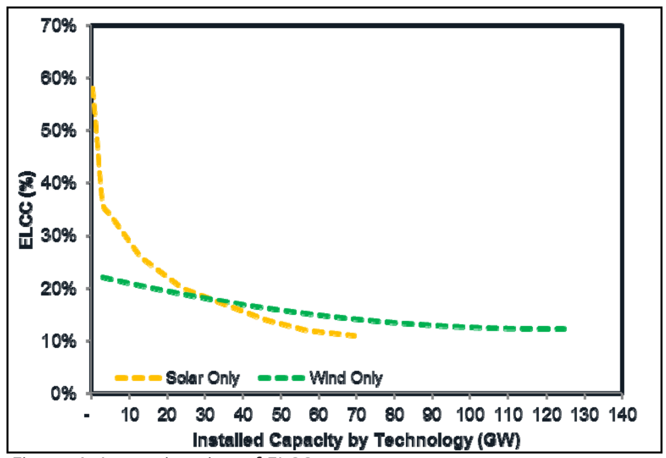


Figure 4: Approximation of ELCC

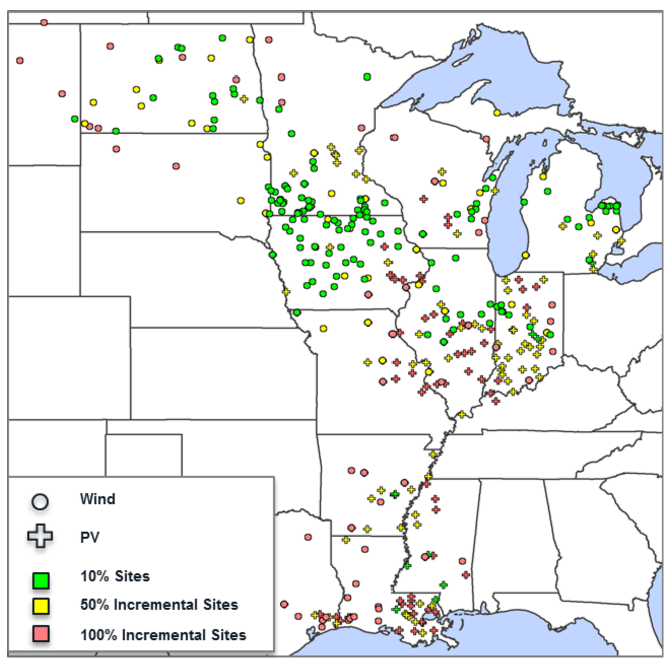
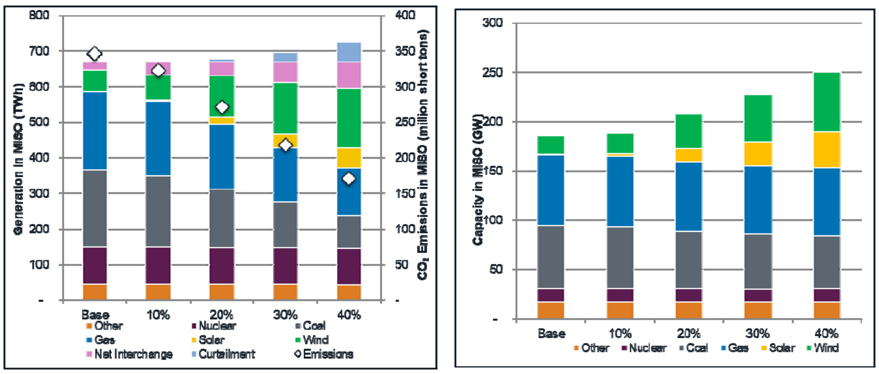


Figure 5: Geographic diversity of renewables citing

diversity of technologies and geography, as shown in Figure 5, would improve the ability of renewables to meet load (Heath and Figueroa-Acevedo, 2018).[3]

Energy Adequacy

The main goal of the Energy Adequacy assessment, defined as the ability of a bulk electric system to operate continuously, is to examine if and how the high levels of renewable penetration may affect hour-by-hour system operating conditions. MISO RIIA team develops resource generation and capacity scenarios for each milestone of renewable penetration (Figure 6 (a) and (b)), by incorporating the declining ELCC assumed for wind and solar from the previous Resource Adequacy analyses. Since Energy Adequacy assumes the planning reserve margin (PRM) holds constant, conventional generation is retired in each milestone to account for the added renewable capacity. Increasing renewable penetration along with its declining ELCC leads to an increase in total installed capacity in MISO (Figure 6 (b)).



(a) Generation (b) Capacity

Figure 6: Generation and capacity in the MISO region

RIIA team then utilizes an hourly production cost model to take a closer examination of hourly generation mix, operating reserves, system ramps, renewable curtailments, and transmission congestion. The annual generation mix can be seen in Figure 6 (a). By comparing the capacity mix to the generation mix, it is clear that despite the retirement of some generation, conventional generation remaining online still sees a decrease in its average capacity factor as energy fulfilled by renewable sources increases.

RIIA team also finds that renewable curtailment increases across each milestone. If the curtailment of renewables is too high to prevent meeting the milestone percentage of renewable penetration, the RIIA team looks at ways to mitigate the curtailment (Figure 7). For example, in the 40% RIIA case, only 32% of MISO's load is served by renewable energy. This curtailment will be addressed as RIIA progresses.

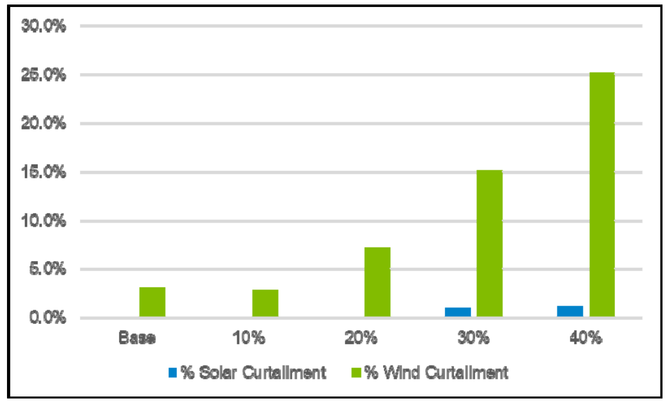


Figure 7: Wind and Solar curtailment under RIIA scenarios

System ramping behavior is another key metric examined as part of the Energy Adequacy assessment. Figure 8 represents gas and coal ramping behaviors on days with the highest amount of renewable generation. As renewable penetration levels increase, both gas and coal units see two significant ramps at the beginning and end of the day. The two ramps occur due the same behavior that reshaped the net load curve as previously discussed in the Resource Adequacy section.

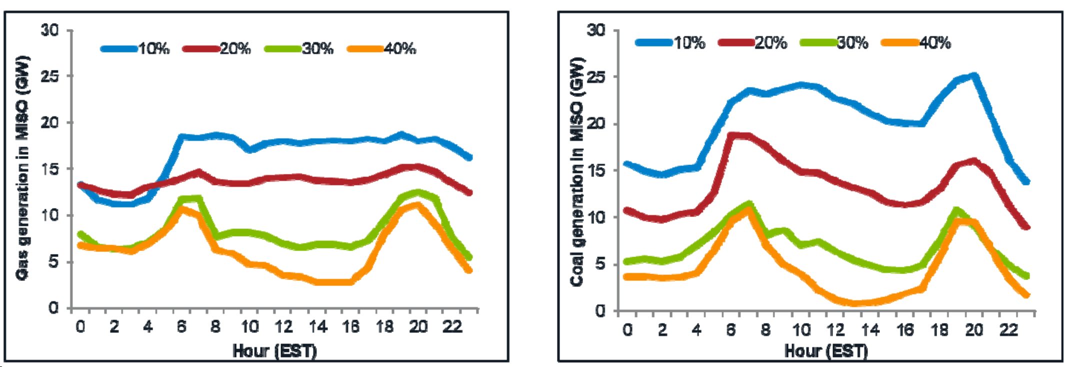


Figure 8: Hourly gas and coal generation for the peak renewable day

Operating Reliability

The RIIA Operating Reliability focus area investigates the steady-state thermal and voltage performance of the MISO system. This focus area also looks at the impact of high levels of renewable penetration on transient stability and MISO's obligations towards maintaining adequate frequency response. The RIIA team developed study models based on the generation dispatch and demand levels obtained from the Energy Adequacy yearly production cost simulations, which project system-operating patterns under different renewable penetration levels. Based on results of hourly dispatch modeling from Energy Adequacy for the entire year, the RIIA team selected three snapshot points for AC contingency analysis, as a sample representative of system's most stressful operating points: (1) peak renewable output in MISO's footprint, (2) off peak load with highest renewable penetration, and (3) peak load with highest renewable penetration. (Figure 9).

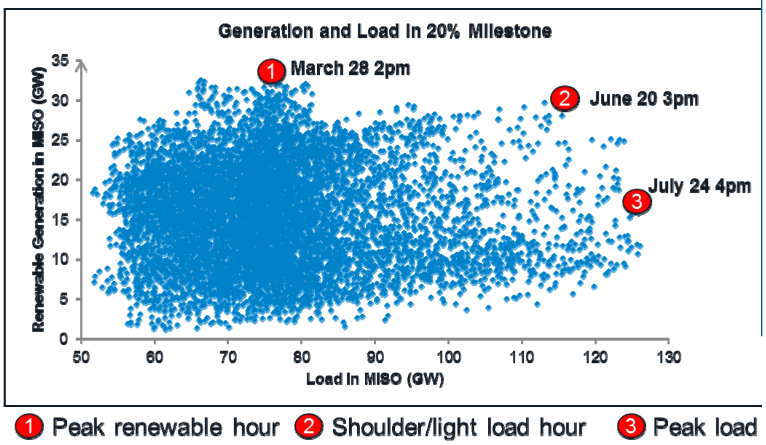
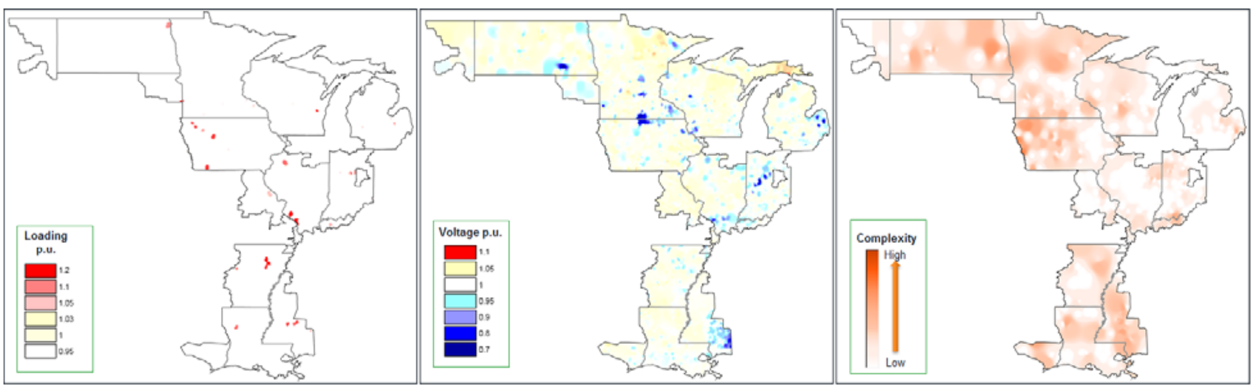


Figure 9: Stressful System Conditions

The RIIA team evaluates transmission system performance by selecting a subset of contingency categories pursuant to NERC reliability standards, to focus on high-likelihood events that tend to cause severe reliability violations on the MISO system. Once the RIIA team identifies steady-state thermal and voltage issues from these snapshots, the team then utilizes a local transmission upgrade methodology to alleviate reliability issues (Figure 10), which reflects the traditional practice in industry to mitigate local area violations. The magnitude of transmission fixes needed to address those identified issues serves as a proxy for integration complexity. Steady-state assessment suggests that integration complexity for 20% renewable milestone is in general relatively mild for MISO footprint. (Figure 10).



(a) Thermal loading *(b) Voltage issues* *(c) Integration complexity*

Figure 10: Thermal loading and voltage issues with integration complexity

The RIIA team also studies the impact of renewable penetration on frequency response by evaluating MISO's performance per NERC standards during a 60-second dynamic model simulation. MISO incorporates model updates such as asymmetrical dead-bands in existing governor models with generic values, removal of governor models for any unit that remains non-responsive to frequency events, and withdrawal of frequency support by certain units. MISO then validates the base dynamic model against actual system disturbances and responses. Figure 11 presents the simulation

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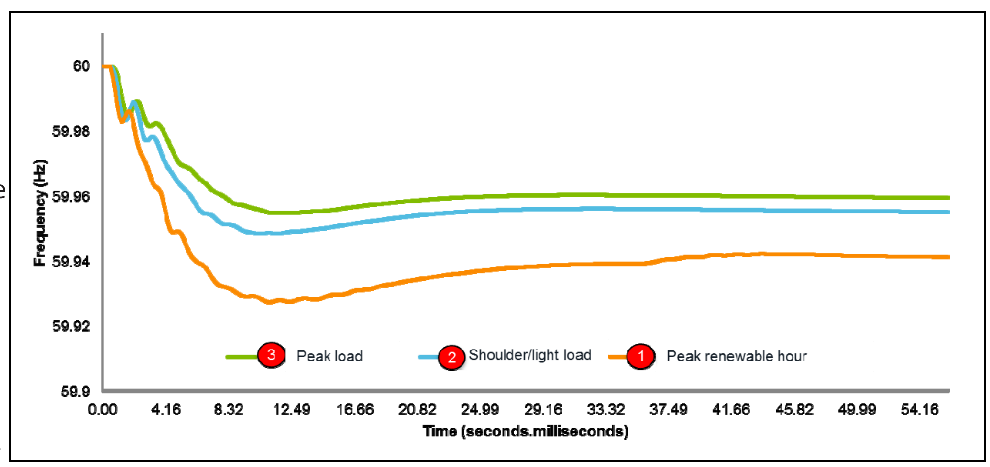

Figure 11: Base model frequency response simulation results