GRID RELIABILITY IN NORTH DAKOTA

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GRID RELIABILITY IN NORTH DAKOTA

AT A GLANCE

- The North Dakota electric grid is reliable and has systems in place as described below to ensure future reliability. North Dakota is well positioned for a strong, reliable future because of the long-range planning described in this report. P.4
- North Dakota's electric grid is managed by MISO and SPP. Both have processes in place that examine and evaluate potential reliability concerns before they present themselves, which have successfully provided power to North Dakota without significant interruption. P.4
- Study results show that when the MISO-wide renewables are approaching 30 percent, more study is required to be able to confidently move to higher levels of renewable generation. At the time of the study, MISO's renewable portfolio was 8.6% in 2019. PP.4-5
- MISO and SPP have rigorous, pro-active committees, stakeholder feedback, working groups, and staff members who continuously evaluate the impact of future renewable development with the objective of maintaining system reliability. P.5
- Electric system reliability involves a number of entities, each with its own capabilities and scope of responsibility. The entities involved with reliability are the following:
    - Load Serving Electric Utilities (LSE)
    - North Dakota Public Service Commission (PSC)
    - Regional Transmission Organizations (RTO)
    - North American Electric Reliability Corporation (NERC)
    - Federal Energy Regulatory Commission (FERC) P.9
- California and North Dakota are quite different in grid reliability. California is normally an electricity importer while North Dakota is normally an electricity exporter. During the summer of 2020, California had a shortage of thermal generation to serve load at night during extremely hot weather, but the responsible parties in California had failed to do enough about it. (See report for details). P. 12
- Renewables can be dispatched up or down (run higher or lower) under some circumstances.
- Pre-curtailment means the renewable plant's output has been reduced below its maximum, given the wind speed or solar insolation to allow headroom for increasing its output. P. 19
- For North Dakota, the key is the coordination between MISO and SPP during times of system stress. Reserve-sharing agreements between them can help support reliability. RTOs were created to operate the transmission system reliably and to promote reliability by sharing power among the members of the RTO. There is also power sharing between different RTOs, which helps to maintain reliability as well. P. 20
- Existing processes are in place at utilities and RTOs to ensure the grid will operate reliably. P. 25

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Executive Summary

With the growth of natural gas and wind generation, and the reduction in coal-fired power, concerns have been raised about the reliability of North Dakota's electricity supply—the grid. This report describes grid reliability including long-term planning and investment in grid resources, daily operations, the short time periods during which grid contingency events occur, and the recovery response. Using this framework for grid reliability, we discuss recent and ongoing studies of the future power system that includes North Dakota. The mechanisms described below highlight potential future concerns and are designed to help plan for the future and changes in the grid. As a result, the North Dakota electric grid is reliable and has systems described below to ensure future reliability and to see that North Dakota is well positioned for a strong future because of the long range planning described in this report. Our reference materials include documents from the National Renewable Energy Laboratory (NREL), the North American Electric Reliability Corporation (NERC), the Midcontinent Independent System Operator (MISO), the Southwest Power Pool (SPP) and others. Two appendices provide more details for the interested reader.

This report focuses on reliability. It does not evaluate the economic viability of wind and solar compared to other energy sources such as coal or natural gas and does not address the economic benefits of coal-based or wind-based power.

North Dakota's electric grid is managed by two regional transmission organizations (RTOs): the Midcontinent Independent System Operator (MISO) and the Southwest Power Pool (SPP). MISO operates in 15 states and 1 Canadian province, while SPP operates in 14 states. North Dakota's transmission grid is divided between the two RTOs. Both have processes in place that examine and evaluate potential reliability concerns before they present themselves which have successfully provided power to North Dakota without significant interruption. With the recent and anticipated increase in renewable energy resources, both RTOs have studied the potential impact of future high levels of renewables on power system operations and reliability. These studies are based upon rigorous modeling of the power system, taking into account future renewable energy, and based upon realistic data representing how these renewable plants will perform in the future and are designed to ensure reliability of the grid.

MISO has several processes that are devoted to assessing future reliability of the grid. MISO recently conducted a Renewable Integration Impact Assessment (RIIA) that shows the impacts of increasing the current levels of renewable generation. This assessment is a wide-focus, long-term look at the effect of increasing wind and solar in MISO. The study looks at the impacts of higher levels of renewable generation in increments of 10 percent from 10 to 50 percent on an annual basis. Study results show that when the MISO-wide renewables are approaching 30 percent, more study is required to be able to confidently move to higher levels of renewable generation.

Currently, wind energy in North Dakota produces 27% of the electricity generated. North Dakota's grid is split between the two large RTOs, so more study is needed to evaluate if higher levels of renewables in North Dakota will cause reliability to decrease, based on detailed modeling and analysis. (The concern identified by MISO at 30% across the entire MISO footprint does not translate the same concern for the 27% threshold reached in North Dakota. In the RIIA, when all of MISO is at 30% renewable, MISO North--which includes North Dakota-- would be at 56% renewable. MISO's renewable portfolio was 8.6% in 2019.)

The RIIA identifies issues that are being addressed in other MISO study work and stakeholder discussions, including the Resource Availability and Need (RAN), Resource Adequacy Subcommitte (RASC), and Market Subcommitte (MSC). The RIIA highlights the need for coordinated planning to identify potential problems and solutions, and it demonstrates that MISO is taking a pro-active role to identify these potential issues long before they occur. Resource accreditation is being discussed in these MISO stakeholder groups, and the groups are also addressing concerns regarding how the system can be reliably dispatched with higher levels of renewable resources. For example, the MISO Independent Market Monitor presented findings in a December 8, 2020, report showing sudden decreases in wind generation on October 16, 2020. This is being included in the resource accreditation discussions in the MISO stakeholder groups[1].

In any event, the RTO will redispatch generation (increase or decrease) – renewable or not - if needed to maintain reliability even with higher levels of renewables. Likewise, the interconnection and planning models of the RTOs will identify issues before they become a reliability problem.

MISO and SPP have rigorous, pro-active committees, working groups, and staff members who continuously evaluate the impact of future renewable development so that steps can be taken to ensure reliability before issues can arise. Processes that are in place at utilities and RTOs ensure that the grid will operate reliably. Beginning with the planning process, significant effort is placed upon reliability assessments of each possible future resource mix. Resource portfolios that are shown to be unreliable are not adopted.

For example, SPP's 2015 wind integration study recommended improved real-time operations tools to help monitor voltage stability limits, add renewable generation to the economic dispatch process,

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1) https://cdn.misoenergy.org/20201208%20Markets%20Committee%20of%20the%20BOD%20Item%2008%20IMM%20Quarterly%20Report499524.pdf

evaluate transmission expansion projects and their interaction with both wind and solar generation, and further evaluate the use of phasor measurement units (PMUs[2]) to help with situational awareness for the power system operators. SPP has successfully managed very high wind penetrations in actual operations. SPP set a record wind output level of 18,442 MW at 6:20 p.m., November 14, 2020. This represents more than 64% of the average hourly demand. Also on November 14, 2020, SPP obtained 60.2% of the day's total energy from wind, and holds the record for highest one-hour wind penetration of 72%.[3]

MISO has undertaken a rigorous analysis that evaluates several renewable energy penetrations up to 50% of annual energy. At renewable penetrations above 30% for the MISO footprint, additional challenges have been identified, especially during periods of high renewable generation and low demand. On these occasions the RTOs will curtail renewable generation to maintain system stability. In MISO, this curtailment process has been incorporated into normal system operations.

Additional analysis is performed by both MISO and SPP in order to ensure long-term reliability of the power system:

- Both MISO and SPP have carried out both operational analyses and long-term reliability studies. The latter utilizes probabilistic methods to calculate the reliability of the resource portfolio.
- Both RTOs have calculated the capacity contribution of wind energy, generally in the range of 10-20% of nameplate capacity, which is dependent on a number of factors.
- MISO and SPP have carried out analyses of the future stability of the power system with high levels of renewables. The findings from these studies are being used in the planning process so that reliability can be ensured in the future.

The core of RTO operations practice includes security-constrained commitment and dispatch. This means that the generators that are scheduled to run in the future can withstand any credible outage. The security-constrained nature of the dispatch process ensures that the dispatch position (level of output) of each unit is such that the dispatched resources can also withstand any credible outage, and therefore maintain reliability. System operators utilize state of the art forecasting for wind and solar resources, and incorporate those forecasts into routine operational practice. Sufficient contingency reserves, flexibility reserves, and other operating reserves can ensure reliable operations across multiple credible contingencies or operational challenges.

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2) PMUs provide time-synchronized measurements of electrical characteristics such as voltage, current, and frequency.

3) S&P Global. https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/111620-spp-sets-new-wind-record-of-184-gw-tops-60-of-the-days-output

Finally, grid services such as supporting voltage and frequency can be provided by renewable resources, and can potentially provide better disturbance response than large conventional generators. As the grid evolves, it is important that the need for grid services is accurately assessed, and that the ability of all resources to provide grid services, to the extent they can, is accounted for.

MISO and SPP (RTOs) have used processes thus far to ensure grid reliability, as demonstrated in current operations, and have systems and processes in place to ensure the future reliability of the grid that includes North Dakota. Regulatory oversight and the RTOs are working toward ensuring reliability thoughout the operating and planning cycles of the electric grid.

Background

North Dakota is ranked 6th in the US, for energy production (US EIA). It exports approximately 50% of the electricity it produces. The state is rich in natural resources, including one of the largest deposits of lignite coal in the world, and it has seven mine-mouth, coal-fired power plants that provide 67% of the electricity generated in the state and 4% of the nation's coal production. North Dakota is the second-largest oil-producing state in the US. It flared 19% of the one trillion cubic feet of gas produced in 2019. Most of the oil and gas is sold out of state; some is converted to electricity and sold into regional electric markets. Wind power has been developed in 29 of the 53 counties in North Dakota, represents about half of the rated capacity of generation in the state, and produces 27% of the electricity generated.[4]

Development of wind challenges the coal industry, and has raised questions regarding the reliability of the electric grid. The state's coal industry has been a significant part of the economy and culture in central North Dakota for decades. Two coal-fired power plants have recently been closed (Stanton Station) or converted to natural gas (Heskett Station). A third, Coal Creek Station - the state's largest coal-fired powerplant - is scheduled to close in 2022. The coal industry nationwide has been struggling, losing market share to natural gas and wind in recent years. Natural gas replaced coal as the #1 electricity producer in the US in 2016 (US DOE, 2017). At the same time, wind development has continued to advance in the state, nearly equaling the rated capacity of coal.

In 2017, at the request of Secretary Rick Perry, the US Department of Energy studied the changes in the nation's electric supply and found at a high level that the growth in renewable energy did not threaten the reliability of the nation's electric grid. This report describes the current status of North Dakota's electric grid, potential reliability concerns, and ways that these reliability concerns can be addressed. We note that there are many detailed studies of the power system, using high-fidelity modeling, that explore potential future levels of renewable penetration on the power system. In many cases, if a potential future reliability issue is identified, the planning processes currently in place will allow for solutions to be implemented prior to experiencing reliability shortfalls on the power system. These solutions may include any combination of changing the target resource mix or location, enhancing transmission to facilitate greater flexibility, adopting potential new or enhanced technologies such as battery storage or hydrogen conversion.[5]

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4) Wind does not blow all the time, but coal is available all the time, so a wind power plant that has the same capacity as a coal power plant typically will produce less energy over the course of a year, subject to the way in which the coal plant is operated.

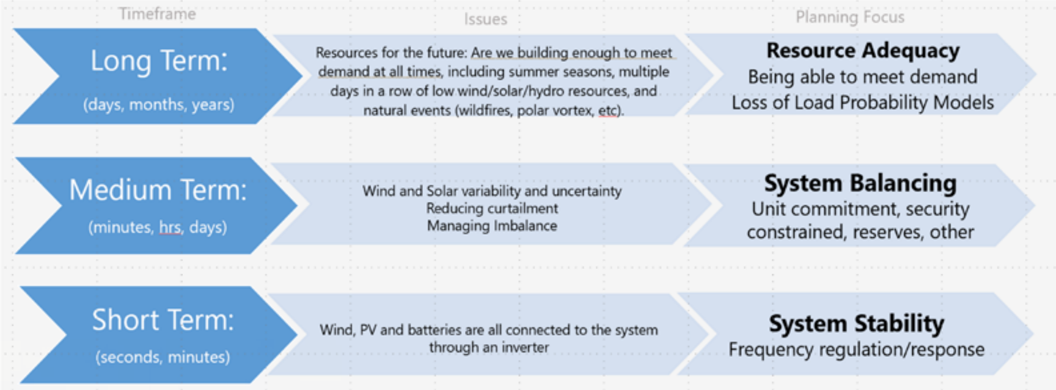
5) Recent studies that have examined high levels of renewable energy on the United States grid include the "2035 Report," available at https://www.2035report.com and "Consumer, Employment, and Environmental Benefits of Electricity Transmission Expansion in the Eastern U.S." Available at https://www.vibrantcleanenergy.com/wp-content/uploads/2020/10/EIC-Transmission-Decarb.pdf

This report describes grid reliability in time periods that range from fractions of a second, through daily operations, and to long-term planning and investment that occur over periods of years. We also discuss recent and ongoing studies of the future power system that include North Dakota.

Introduction to Reliability

Electricity has the unique characteristic of being produced, delivered, and consumed in virtually the same instant of time over thousands of square miles. There are no other energy delivery systems with this unique characteristic. Protection systems on the electric grid constantly monitor system frequency. If there is not enough generation to meet the load, system frequency drops, and electric load is automatically removed from the system in discrete steps. It is extremely rare for this to occur, and it is designed to avoid large scale system blackouts. The continuum of effort from the system planning to the system operations must take this real-time delivery of electricity into account in order to maintain the same level of reliability.

Operating a power system requires making multiple decisions at various time periods, from milliseconds to several years ahead of real-time dispatch. For our discussion we simplify all of these aspects of reliability and put them into two basic categories: (1) planning/investment, and (2) operations. In turn, we can divide the operations time frame into medium-term operations, which includes planning for days, weeks, or even months, and short-term operations, which covers events occurring in minutes, seconds, and even less than a second. Figure 1 shows the time periods of grid reliability: long-term (resource adequacy), medium-term (system balancing), and short-term (system stability).



Timeframe	Issues	Planning Focus
Long Term: (days, months, years)	Resources for the future: Are we building enough to meet demand at all times, including summer seasons, multiple days in a row of low wind/solar/hydro resources, and natural events (wildfires, polar vortex, etc).	**Resource Adequacy** Being able to meet demand Loss of Load Probability Models
Medium Term: (minutes, hrs, days)	Wind and Solar variability and uncertainty Reducing curtailment Managing Imbalance	**System Balancing** Unit commitment, security constrained, reserves, other
Short Term: (seconds, minutes)	Wind, PV and batteries are all connected to the system through an inverter	**System Stability** Frequency regulation/response

Figure 1. Grid Reliability Time Periods[6]

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[6] Adapted from Lew, D. (April 2020). Webinar #1: Long Term Reliability- Resource Adequacy. Western Interconnection Regional Advisory Body. https://www.westernenergyboard.org/wirab-webinar-series-webinar-1-long-term-reliability-resource-adequacy/

Operational reliability requires that the planning and investment processes deliver a grid that can be operated reliably and economically. Failure to design a grid that can deliver electricity reliably will make it difficult or impossible for the operators to accomplish this goal. In this report, we will cover short-term reliability first, but the reader should understand that excellent long-term planning is an essential pre-requisite to excellent short-term operation. A grid that is not planned with excellence will be difficult to operate with excellence.

The system operator, whether an RTO or an electric utility, "inherits" the physical grid from planners and investors. In the short-term it cannot change the fleet of generators, the transmission network, or long-term contracts or agreements with others. The operator must make informed decisions about which resources to commit day-ahead, the implication of wind or solar forecasts, and many other decisions. Operational decisions include ensuring sufficient reserves that can be called upon if things go wrong, and many things can go wrong – generating units can fail, transmission links can fail, and weather may differ markedly from the forecast, causing the actual combination of demand and generation to deviate from anticipated levels.

In the short term, there are multiple automated processes that ensure balance. These include automatic generation control (AGC), which is generally a 4-second balancing system, and frequency response.[7] These are discussed later in this report.

This report describes each of the three main timeframes of reliability. We begin with a short discussion of Regional Transmission Organizations, because that provides some of the contexts for North Dakota. We then describe short-term reliability, medium-term reliability, and long-term reliability.

Roles for Reliability

Electric system reliability involves a number of entities, each with its own capabilities and scope of responsibility. The entities involved with reliability are the following:

- Load Serving Electric Utilities (LSE)
- North Dakota Public Service Commission (PSC)
- Regional Transmission Organizations (RTO)
- North American Electric Reliability Corporation (NERC)
- Federal Energy Regulatory Commission (FERC)

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7) "Frequency response" refers to the ability of an alternating-current system to maintain its frequency of 60 cycles per second, also known as 60 hertz (Hz).

LSEs have the responsibility for serving the ultimate customer. Some LSEs such as Basin Electric Power Cooperative have generation resources used to serve members (customers), while others such as Central Power Electric Cooperative have an all-requirements purchase contract with Basin, which moves the electric resource procurement and considerations of reliability to the entitiy that is providing the all-requirements power. LSEs that have electric generation resource planning responsibilities determine the mix of owned generation resources versus purchased wholesale power and the mix of conventional versus renewable resources. LSEs take into consideration the expected reliability of the resource mix but each one is only responsible for its share of the system.

The North Dakota PSC has authority over the siting of electric generation facilities. The PSC also conducts a resource planning process that examines each LSE's plans for assuring resource adequacy and the reliability of its system.[8] The PSC is also involved with the RTOs, providing input as a key stakeholder in the arena of evaluating electric system reliability.

FERC has delegated reliability authority to NERC and requires RTOs to comply with NERC standards. FERC takes into account input from all interested stakeholders in a wide range of regulatory matters, including electric system reliability.

The responsibility for ensuring reliability throughout the United States, including North Dakota, resides with NERC whose mission is to ensure the reliability and security of the bulk electric system. There are many other NERC standards that describe the requirements for grid operators to maintain balance. This will be covered in more detail below. NERC requires that frequency be held in a nominal range, that imbalance be non-zero for only a short period of time (subject to limits), that various disturbance control performance requirements be adhered to, and many other requirements.[9] Some of these standards, if violated, carry large financial penalties, providing strong incentives to ensure reliable system operation.

The RTOs (MISO and SPP) have the responsibility of demonstrating compliance with the NERC reliability standard, MOD-004-1, that requires the use of a loss of load expectation study, a loss of load probability study, or other risk-analysis study to determine a capacity benefit margin.[10] The application of the standard varies slightly for each RTO on how an event is defined, but the main point of this aspect of reliability is that the RTO has the abilty to analyze all LSEs with generation resources within its footprint and demonstrate that there are adequate resources to meet the

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8) Investor-owned utilities are required to provide resource planning information to the PSC. Electric cooperatives voluntarily provide resource planning information to the PSC.

9) A complete list of NERC standards can be found at https://www.nerc.com/pa/Stand/Pages/AllReliabilityStandards.aspx

10) NERC Standard MOD-004-1 – Capacity Benefit Margin. https://www.nerc.com/files/MOD-004-1.pdf.

MOD-004-1 standard. New transmission-connected generation resources, and retirement of existing generation resources, must be approved by the RTO. (See Appendix 2.)

Regional Transmission Organizations (RTOs) Assure Reliability

North Dakota's electric grid is managed by two regional transmission organizations (RTOs): MISO and SPP. (See Figure 2.) North Dakota's transmission grid is divided between the two RTOs. Most of the power in the eastern part of the state flows through MISO, whereas most of the power in the western portion of the state flows through SPP. However, the state is a checkboard pattern of jurisdiction between the two RTOs.

The two RTOs are responsible for ensuring electric grid reliability - the system's ability to match aggregate demand with aggregate supply at all times.[11] They perform regional planning and determine where additional power lines and generators are required, although they lack the authority to require member companies to make these investments. However, RTOs can require transmission upgrades in conjunction with approving new generation resources. The RTOs do have the authority to prevent member companies from closing power plants that are required to maintain reliability. Although state regulatory agencies (PSCs) have the statutory authority to evaluate generating resource additions and retirements being considered by utilities through certificate of public convenience and necessity and resource planning proceedings, the RTOs actually operate the electric grid. Using tools that model the entire RTO interconnection, and the interfaces to other RTOs, the RTOs have the means to evaluate the impacts of resource additions and retirements.

The North Dakota grid is not an island. Resource additions and retirements both inside and outside of North Dakota impact the market-clearing price of electricity and generation resource dispatch in North Dakota. Wholesale electricity prices in each RTO are affected by load and generation throughout each of the two regions, as well as by transmission constraints and the efficiency or inefficiency of transmitting electricity over short or long distances.

RTOs have a significant role in determining the transmission additions required for new generation additions in the interconnection process. Appendix 2 describes the interconnection process and how the process works for both SPP and MISO.

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11) Milligan, M. (November 2018). Sources of grid reliability services. The Electricity Journal. Volume 31, Issue 9. Pages 1-7. https://www.sciencedirect.com/science/article/pii/S104061901830215X?openDownloadIssueModal=true

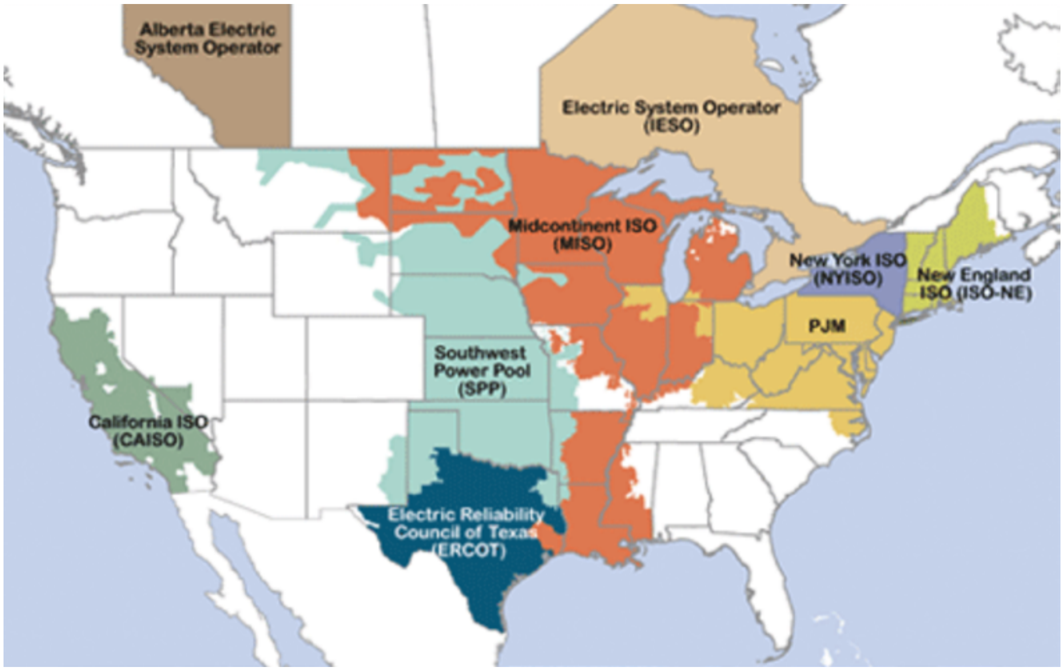

Figure 2. RTOs in the United States. Source: FERC[12]

Not all RTOs Are the Same

RTOs all have some differences. These have arisen because of the different rates of industry restructuring that began in the 1990s. In some regions, utilities were required to sell off most or all of their generation resources. The restructuring in California is an example, and to date, very little, if any, generation is owned by the investor-owned load-serving entities in that state. In both the MISO and SPP regions utilities largely kept their generation. In those regions, utilities (load serving entities, LSEs) go before public utility commissions to obtain approval to develop new resources, and recover those capital costs through the retail rate base.

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12) FERC. Electric Power Markets. National Overview. https://www.ferc.gov/industries-data/market-assessments/overview/electric-power-markets

However, all RTOs conduct event analysis within their footprints.[13] For example, the recent outages in California on August 14 and August 15 were extensively analyzed by the California Independent System Operator (CAISO), which concluded that the key factors contributing to the outages were:[14]

- An extreme heat storm across the West that extended well beyond California. "The existing resource planning processes are not designed to fully address an extreme heat storm like the one experienced in mid-August." (This prevented CAISO from importing needed electricity from neighboring markets that also experienced extraordinary energy demands).
- "Resource planning targets have not kept pace to lead to sufficient resources that can be relied upon to meet demand in the early evening hours."
- Technical market issues in the day-ahead energy market that "exacerbated the supply challenges under highly stressed conditions."

California and North Dakota are quite different. Among other things, California is normally an electricity importer while North Dakota is normally an electricity exporter. During a regional shortage of generation, California is generally worse off than some of its neighbors. During a regional shortage of generation, North Dakota would be generally better off than some of its neighbors. This past summer California had a shortage of thermal generation to serve load at night during extremely hot weather but the responsible parties in California had failed to do enough about it.[15]

Several recommendations have emerged from this analysis, most of which address shortcomings in the planning processes that are currently in place. These shortcomings may be exacerbated by the complications posed by the divestiture of generation from the LSEs, coupled with California's transition to a resource mix with more renewables. The unusual weather is an example of how future years in the planning process may diverge significantly from historical patterns.

Unusual weather events should be considered as part of the planning process. In 2014 there was a winter "polar vortex" that caused significant disruption in the electricity supply in much of the U.S., ranging from the upper Midwest to large parts of the East/Northeast. NERC created a systematic review of the circumstances that contributed to the electricity supply disruptions.[16] A number of recommendations emerged from that assessment, including various measures to improve winterization of power plants, review natural gas supply and transportation issues, and to ensure

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13) https://www.nerc.com/pa/rrm/ea/Pages/default.aspx

14) CAISO, "Preliminary Root Cause Analysis, Mid-August 2020 Heat Storm. October 6, 2020. http://www.caiso.com/Documents/Preliminary-Root-Cause-Analysis-Rotating-Outages-August-2020.pdf

15) Ibid.

16) NERC, "Polar Vortex Review," September 2014. https://www.nerc.com/pa/rrm/January%202014%20Polar%20Vortex%20Review/Polar_Vortex_Review_29_Sept_2014_Final.pdf.

reasonable losses of gas-fired generation in planning. Notably absent from the key recommendations is that utilities must utilize more robust load forecasts that account for unusual weather impacts on both supply and demand.

In MISO and SPP, utility ownership of generation predominates, and utilities go through state commissions to ensure resource adequacy. Typically, each LSE must demonstrate its own resource adequacy, and this often doesn't account for assistance from neighboring utilities. If accounted for, the potential assistance of neighbors, whether through non-firm external support or other mechanisms that may include reserve-sharing groups, would result in less needed capacity. Because external support is often not accounted for, there is likely an "excess" reserve margin for utilities in large markets such as MISO and SPP.[17]

Short-term Reliability: Grid Services that Occur in Seconds or Minutes

Power system operators and operational practice ensure that the grid remains in balance at all times, subject to NERC reliability rules. Although there are some regional differences in the way some of these services are defined, there is broad agreement regarding the need for grid services and a recognition that inverter-based resources (IBR), such as wind, solar, and storage, can provide many of these services.

Description of Grid Services

There is no universal definition of grid services, but there is broad agreement on what they are. Grid services refers to requirements on the grid that support capacity and energy delivery. These include:

- Disturbance ride-through: The ability of the resource to stay online during grid events that can potentially de-stabilize the system. These include unexpected voltage drops and/or reactive power that is outside nominal range. Ride-through is effective within limits.
- Arresting frequency drops: When a generating resource or transmission line fails, the grid frequency can fall. Fast frequency response will slow, and eventually stop, this decline of frequency.

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17) Ibanez, E.; Milligan, M. (2012). Probabilistic Approach to Quantifying the Contribution of Variable Generation and Transmission to System Reliability: Preprint.Prepared for the 11th Annual International Workshop on Large-Scale Integration of Wind Power into Power Systems as Well as on Transmission Networks for Offshore Wind Power Plants Conference, November 13-15, Lisbon, Portugal; 7 pp.; NREL Report No. CP-5500-56219.

- Stablizing frequency: After a frequency decline is arrested, primary frequency response helps stabilize frequency.
- Frequency restoration: after frequency is stabilized, it must be returned to its nominal 60 Hz level. This is typically accomplished with a combination of primary frequency response, automatic generation control, and dispatchability.
- Automatic generation control (AGC): Every 4 seconds a computer sends a signal to a subset of resources, telling them to increase or decrease output so that balance between supply and demand is maintained.
- Dispatchability: The ability for an online resource to increase or decrease its output. Thermal resources cannot be dispatched unless they have been committed, turned on, and synchronized to the grid. Many resources have minimum generation levels, and can not be dispatched below those levels. No resource can be dispatched upwards (increase output) if it is already at its maximum output level. Renewable resources can be dispatched up and down, but instead of being subject to commitment, are subject to the availability of the wind or the sun.

Role of Inverters

Wind and solar energy, along with batteries, are non-synchronous with the grid. This is because the grid is operated with alternating current (AC), and these energy sources produce direct current (DC). To convert this DC power to AC power requires a device called an inverter. Inverters are composed of power electronics devices that are configured by computer software. The configuration of the AC power signal can be manipulated in such a way that the inverter can respond to grid events in many cases.

Voltage and frequency must be maintained within nominal limits at all times to avoid potential reliability events and damage to equipment. During normal operations, various devices provide voltage support. If the voltage deviates from nominal limits, modern inverters are set so that the device can “ride through” voltage excursions (within limits) and remain online. This helps reliability by ensuring there is not a massive loss of generation that results from voltages that are too low or too high.

Frequency on the AC grid must be maintained at 60 Hz, but it can vary slightly from this nominal value.[18] If frequency begins to increase from 60 Hz, the software and controls of the inverter can respond by reducing its frequency, helping to restore the overall system frequency to 60 Hz. Likewise, if grid frequency begins to drift downward, the inverter can increase the frequency of its output, helping to bring the system frequency up to its nominal value.

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18) Hz is an abbreviation for hertz, or cycles per second.

In recent years there has been a recognition that grid services can be provided by renewable energy sources via the inverter, but these controls must be activated to be effective. Simulations carried out at the National Renewable Energy Laboratory[19] on the Western Interconnection confirm the benefit of fast frequency response (FFR) from renewables. Figure 3 shows the results of simulations for transient disturbances carried out during "light spring" (relatively low demand) using a base case with little renewable generation compared to alternative cases with renewables. The left panel shows the no-renewable base case and the high renewables case, which contains a mix of wind and solar. In the left panel, no frequency controls on the wind/solar were enabled. In comparing the two responses in the left part of the graph, the renewables case shows a slightly worse frequency response for the first 20 seconds. The right panel shows the renewables case with and without frequency controls. The slope of the decline is more gradual, the nadir—the minimum frequency level after the contingency event—is higher (better), and the overall performance of the response exceeds even that of the no renewables case.

This example illustrates how the grid of the future might respond to disturbances. Many large coal units have been recently retired, and this trend may continue. Large, rotating masses (the large turbine-generators) provide mechanical and electrical inertia to the system, which is helpful in the first seconds of a disturbance. As shown in Figure 3, immediately after a disturbance, the system frequency falls. The slope of that decline is largely a function of the level of inertia on the system at the time of the disturbance. The gradual retirement of coal plants will reduce the inertia on the grid, which would tend to make the slope of the frequency decline sharper, resulting in a faster frequency drop than if coal-based generation remained on the system. However, as shown in the right-hand panel of the Figure 3 (and discussed more fully in the Appendix), when controls are enabled on the inverters of renewable installations, there is a faster "turn-around" of frequency, resulting in a faster rebound and recovery to nominal frequency. These effects are complex; however, the extremely fast frequency response on renewable inverters can mitigate, or perhaps even eliminate, the concern arising from the loss of inertia from coal plants.

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[19] Milligan et al. (2015) Alternatives No More: Wind and Solar Power are Mainstays of a Clean, Reliable, Affordable Grid. IEEE Power and Energy Magazine (Volume: 13, Issue: 6, Nov.-Dec. 2015)

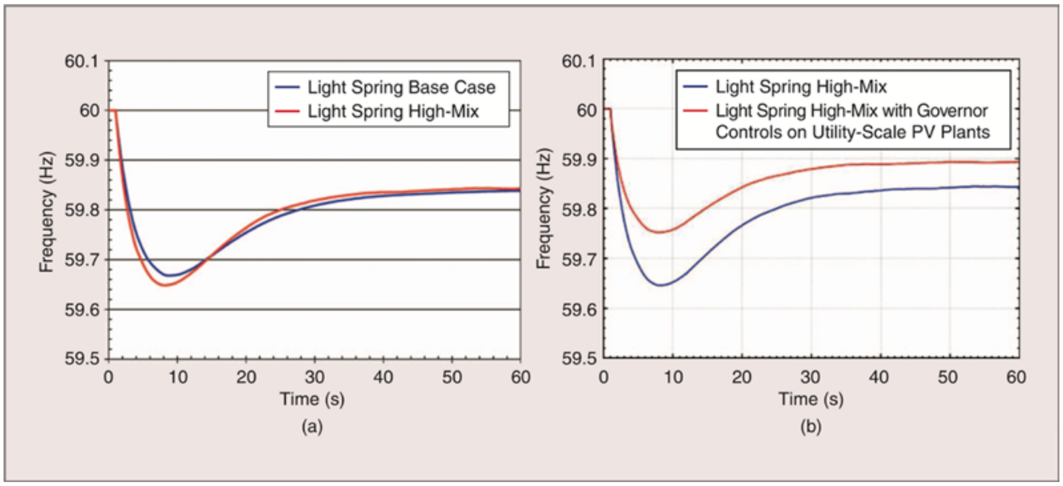

Figure 3. Western Interconnection frequency response to the loss of two Palo Verde units for Light Spring conditions. (a) The base case is compared to a high mix of wind and solar. (b) High mix with and without frequency controls.

Sources of Grid Services

The bulk power system (BPS) is undergoing a digital revolution. With the recent and continuing growth of inverter-based generation, mainly from wind and solar energy, the power system industry has begun exploring the implication of high levels of wind and solar energy on power system reliability and resilience.

Not all resources are capable of providing all grid services. Milligan[20] describes each grid service in more detail, and provides a summary table that shows typical technological capabilities to provide these services.

The speed of provision, depth of provision, and machine type and state will all play a role in determining the physical capability of each resource type. Market and reliability rules may limit response in some cases; however, rules should be revised if that is the case.

Grid Services Summary

Renewable energy technology can provide grid services to a large degree. Power system simulations have shown that enabling frequency controls can reduce the impact of contingency events. This fast frequency response can largely replace the inertia that is expected to be withdrawn from the grid as

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20) Milligan, M. (2018). Sources of grid reliability services. The Electricity Journal, 31(9), pp. 1-7.

large coal units retire. Grid operators must recognize and account for the grid services that can be supplied by renewable resources so the appropriate level of each service is obtained.

Medium-term Reliability: System Operations and Balancing in Five-Minute and Daily Intervals

Grid operators are tasked with supplying electricity in the most cost-effective manner, subject to reliability constraints. During most time periods, there are no large unanticipated events that may compromise reliability. During those times, changes in demand are accurately anticipated and factored into operational plans and execution. Similarly, wind and solar energy are reasonably well-forecasted.

Various types of operating reserves are maintained—extra capacity that that can be called upon if needed, possibly at very short notice. There is no universal definition of "operating reserves" but the term generally refers to a combination of reserves that are "set aside" so that extra capacity is available if needed.

One type of reserve is "contingency reserve," which helps maintain balance and reliability immediately following large, unanticipated events such as an electrical or mechanical failure in a generating unit.[21] Ensuring sufficient reserves is part of the process of balancing demand and supply. When demand and supply are in balance, the supply side includes reserves to provide supply during unexpected contingencies.

Other types of reserves, such as flexibility reserves, can be utilized if wind or solar energy generate more or less than anticipated, or if demand is higher than forecasted. Regulating reserve anticipates the need for automatic generation control (AGC), and it ensures that sufficient AGC is available when needed. Details can be found in Ela et al.[22]

To balance demand and supply, grid operators plan and control the generation-load balance from the day ahead to real-time dispatch.

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21) Operating reliability means "the ability of the bulk power system to withstand sudden disturbances, such as electric short circuits or unanticipated loss of system elements from credible contingencies, while avoiding uncontrolled cascading blackouts or damage [to] equipment."NERC. (August 2013). Understanding the Grid, p. 2. https://www.nerc.com/AboutNERC/Documents/Understanding%20the%20Grid%20AUG13.pdf

22) Ela, E.; Milligan, M.; Kirby, B. (2011). Operating Reserves and Variable Generation. A comprehensive review of current strategies, studies, and fundamental research on the impact that increased penetration of variable renewable generation has on power system operating reserves. 103 pp.; NREL Report No. TP-5500-51978.

- **Day Ahead.** In the day ahead of dispatch, grid operators forecast their load on a per hour basis. After running an optimization model that minimizes costs subject to physical constraints, operators determine which generators need to be committed (operated) during the following day. To respond to contingencies, the flexibility of individual generation resources and the system as a whole is also part of the consideration.
- **Real Time.** Real-time economic dispatch is carried out in 5-minute intervals in MISO and SPP. This economic dispatch function chooses among the units that have been committed and instructs resources to generate a given level of output, based on an economic optimization model. Operating reserves provide extra capacity if needed for credible contingencies.

Since demand and generation fluctuate between the dispatch intervals, a computer system monitors the grid frequency and balance and sends signals at much shorter intervals (every 4 seconds) to AGC resources so they can automatically increase or decrease their output. This process is called frequency regulation, and it serves to compensate for the small variations in supply and demand and to restore balance. Dispatch and regulation services are key to preserving system balance.

Balancing Standards

The North American Electric Reliability Corporation (NERC) is the federally-recognized reliability organization of the United States. Over the years, NERC has developed various reliability rules that transmission operators must follow. Some of these reliability rules focus on balancing requirements that must be met by each Balancing Area Operator (BAA). SPP and MISO are both considered as BAAs and are subject to these balancing rules.[23] “Balancing” refers to equalizing electricity supply and demand in a given area. NERC has the ability to levy fines if rules are violated. The reliability rules include balancing standards.

As the penetration of renewable energy increases on power systems around the world, there is an increasing body of knowledge that can help inform grid operators to ensure reliable operation. Some of these include:

- Greater system flexibility with faster ramping capability, lower turn-down levels on thermal units, and shorter minimum up-times and down-times,
- Advances in the forecasting of renewables, and
- Utilizing grid services from inverter-based resources (discussed above). [24]

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23) NERC also has other types of rules, including rules that govern disturbance recovery.

24) ESIG Brief: Maintaining Reliability in Power Grids with High Levels of Wind and Solar. Available at https://www.esig.energy/wp-content/uploads/2020/06/Maintaining-Reliability-in-Power-Grids-with-High-Levels-of-Wind-and-Solar-2.pdf.

Beginning one or more days prior to the operating period, grid operators determine the hourly schedules for all their generators for the following day, sometimes considering several days at a time. During the day, the economic dispatch process selects from the committed resources, and then units are dispatched every 5 minutes to meet demand. In systems with wind or solar energy, the hydro-thermal fleet is generally dispatched to meet demand net of wind and solar generation. This dispatch is sometimes called "load following." Generators move every five minutes to a dispatch point, or setpoint, subject to the result of the real-time economic optimization. At the smallest timeframe is regulation reserve, which adjusts generator output every 4 seconds to manage variability within the interval of dispatch.

Dispatchability of Renewables

Renewables can be dispatched up or down under some circumstances. "Economc dispatch" refers to either starting a generating unit or moving a unit's output up or down in response to market prices. In recent years there have been multiple demonstrations that show renewable energy sources are capable of economic dispatch and frequency regulation. Because the level of renewable generation depends on the level of wind speed or solar insolation, renewables can't increase their output unless they have been "pre-curtailed." Pre-curtailment means that the renewable plant's output has been reduced below its maximum, given the wind speed or solar insolation to allow headroom for increasing its output.[25] This would be done only if economic, or if needed for system reliability.

A more common approach is that renewable output can be reduced to help achieve system balance during periods where there is not adequate transmission capacity to deliver renewable generation. Wind and solar generation can be "turned down" so that some thermal plants can be run at a high enough level to maintain their required minimum generation level. This method of dispatch keeps the system in balance and allows for thermal units to remain on line if they are anticipated to be needed in the next hours or days. Appendix 1 provides more detail.

Summary of Medium-term Reliability

Medium-term reliability is primarily a function of the day-ahead unit commitment and real-time economic dispatch processes, combined with the reliability rules that are set by NERC. Utilities and RTOs work together so that the grid can be operated reliably and at least cost. The commitment and dispatch activities which are fundamental for reliable system operation are carried out by RTOs such

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25) Note that thermal resources cannot increase output if they are already at maximum. In that sense, they must be generating below maximum output to be dispatched upward. This is similar to renewable resources, as described in the section "Description of Grid Services" above.

as MISO and SPP. These processes are carried out so that NERC balancing standards can be met in real-time operations and so the grid can be reliably operated at all times.

Long-term Reliability: Resource Adequacy over a Period of Years

Resource adequacy is a planning process to assure that generation resources are adequate to serve load over multiple time frames. Changes to the grid, whether involving generation or transmission, must be planned in advance. Part of this planning process is to ensure that the future grid is capable of being operated in a reliable, cost-effective manner. Shortfalls in design and planning could potentially result in a system that will not operate reliably. Power system planners in RTOs and utilities collaborate with multiple stakeholders and utility commissions to ensure that the planning process results in a grid that meets the objective of attaining system adequacy - a combination of generation and transmission capable of operating reliably. The planning processes are robust and critical because they result in plans that will result in the power system's future design and characteristics.

Resource adequacy is most often assessed with a risk model that evaluates the likelihood (probability) that generation will be able to meet demand in future time periods. Long-term reliability models calculate a metric called "loss of load expectation" (LOLE) along with related metrics that characterize the level of reliability of the future grid. LOLE is a probabilistic measure of the likelihood that the level of supply will be inadequate to meet demand and is the "flip side" of measuring reliability.

Because reliability is expensive, a tradeoff exists between reliability and cost. RTOs typically set a reliability target for resource adequacy evaluations that account for this tradeoff. A common target is a loss of load expectation of 1 day in 10 years, a statistical expectation that resources will be insufficient only 1 day per 10 years. Long-term reliability assessments that are central to resource adequacy are undergoing changes, incorporating more advanced and comprehensive reliability measures that are more appropriate for grids with high levels of renewable resources.

The capacity contribution of any resource, including renewables, is calculated with the same long-term reliability model, and is typically measured as the effective load-carrying capability of the resource. The capacity contribution of wind and solar energy is typically a percentage of its rated capacity, generally less than conventional resources because of the variability of the resource, and because wind and solar generation may not always occur during high-risk periods. High-risk periods include peak and near-peak demand, but other factors can drive risk during non-peak periods.

The specific capacity contribution of a given resource will vary based upon the quality of the renewable resource, the timing of resource availabity relative to peak demand, and whether other renewable sources have already been added to the power system. In general, the capacity contribution of renewable energy declines as its penetration increases; however, this also depends upon the technology and specific resource characteristics.

Resource adequacy also depends upon the relationship between the host utility or RTO and neighboring utilities or RTOs. Transmission, along with operational coordination, has been shown to increase the grid's carrying capacity. For North Dakota, the key element in this regard is the coordination between MISO and SPP during times of system stress. Reserve-sharing agreements between them can help support reliability. RTOs were created not just to operate the transmission system reliably but also to further promote reliability by sharing power among the members of the RTO. There is also power sharing between different RTOs, which helps to maintain reliability as well.

Long-term Reliability: Renewable Energy Impact Analysis

RTOs perform multiple types of analysis and modeling on potential future grid conditions. With the rapid rise of wind and solar generation in recent years, significant attention has been placed upon evaluating the impact of these renewable resources on power system operations. To carry out these studies, electricity production simulation models are employed, along with high-quality, detailed data sets that include grid configuration, resource characteristics, and estimated future fuel costs and technology costs. The objective of these studies is to provide insight into how the system might best be operated with high levels of renewable resources, and inform transmission expansion planning.

MISO Renewable Integration Impact Assessment[26]

MISO has conducted a Renewable Integration Impact Assessment (RIIA)[27] that assesses the impacts of increasing the current levels of renewable generation. The study looks at the impacts of higher levels of renewable generation in increments of 10 percent from 10 to 50 percent with location-specific information. Study results are showing that when the MISO-wide renewable penetration approaches 30 percent, further study is required before moving to higher levels of renewable generation. The 2019 level of renewable energy generation in all of MISO was 8.6 percent.

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26) SPP conducted a similar assessment in 2017. https://www.spp.org/documents/45106/2017%20variable%20generation%20intergration%20study%20(vis)%20-%20170221.pdf

27) See https://www.misoenergy.org/planning/policy-studies/Renewable-integration-impact-assessment/#t=10&p=0&s=&sd=

The study begins the process of identifying changes to the grid that could be made to accommodate higher percentages of renewables. Grid modifications to accommodate more renewables will be carried out through MISO's Long-Range Transmission Planning process and its process of aligning Resource Availability and Need (RAN). The development of battery storage, either at utility scale or incorporated into renewable power plants, also has the potential to solve problems. The RIIA study is an example of proactive, forward-looking analysis that may need to be repeated as the grid continues to evolve.

The following are important MISO RIIA study results:

- **Figure 4** shows the MISO regions. The percentage of expected renewable resources for each of the three regions is significant, while the renewable percentage in MISO North is much higher due to favorable locations for siting wind generation. When the MISO-wide percentage of renewable is 10%, the MISO North percentage is 33%. The MISO-wide case for 30% implies a MISO North renewable percentage of 56%. Thus the MISO assessment that 30% renewables in all of MISO triggers a need for further study corresponds to 56% renewables for MISO North, which includes North Dakota. The MISO study is showing an additional 20,000 MW of wind generation for the 30% renewable case, and the siting map for the generation additions indicates that a significant percentage is expected to be sited in North Dakota. MISO's study is not a prediction or a forecast, it is a set of possible future scenarios.

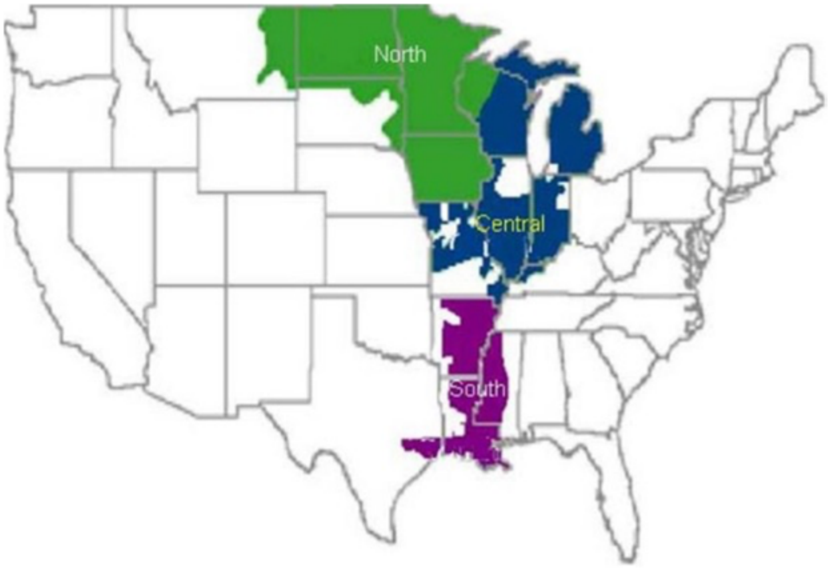
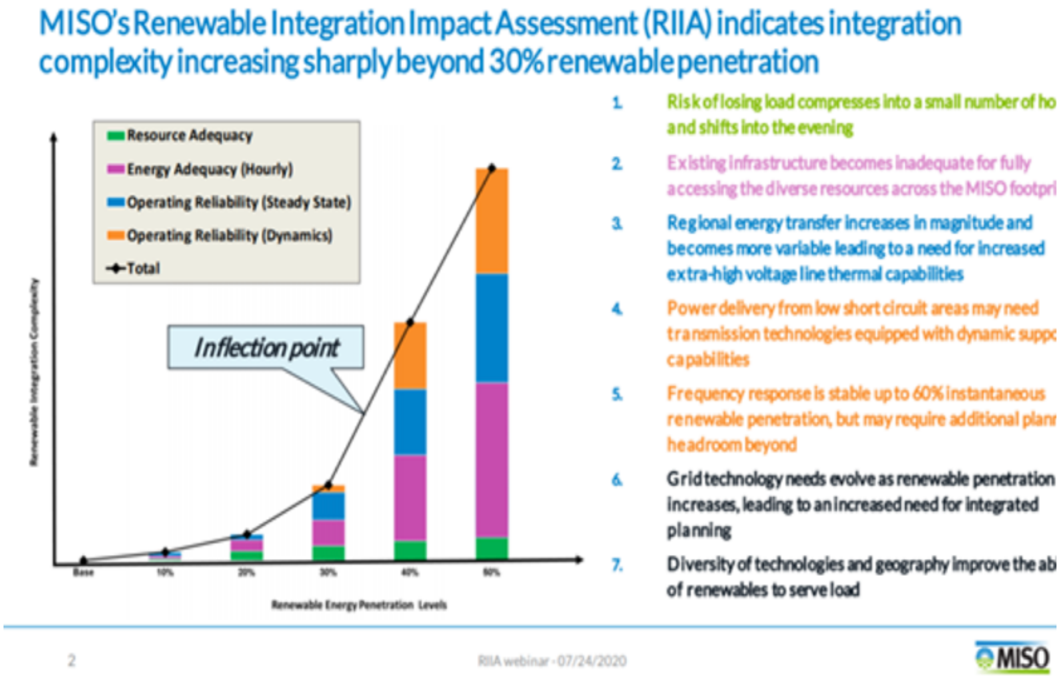


Figure 4. MISO's footprint

- The renewable integration complexity beyond 30 percent has increasing levels of uncertainty in the realm of seven identified areas that were evaluated in the study. **Figure 5**, taken from a MISO presentation[28], shows the summary of the seven criteria showing the impacts on Resource Adequacy, Energy Adequacy, Operating Reliability (steady-state), and Operating Reliability (transient state). This list of issues and concerns needs to be properly addressed before higher levels of renewable energy percentages can be implemented in the MISO footprint.



MISO's Renewable Integration Impact Assessment (RIIA) indicates integration complexity increasing sharply beyond 30% renewable penetration

1. Risk of losing load compresses into a small number of ho and shifts into the evening
2. Existing infrastructure becomes inadequate for fully accessing the diverse resources across the MISO footpri
3. Regional energy transfer increases in magnitude and becomes more variable leading to a need for increased extra-high voltage line thermal capabilities
4. Power delivery from low short circuit areas may need transmission technologies equipped with dynamic suppo capabilities
5. Frequency response is stable up to 60% instantaneous renewable penetration, but may require additional plan headroom beyond
6. Grid technology needs evolve as renewable penetration increases, leading to an increased need for integrated planning
7. Diversity of technologies and geography improve the ab of renewables to serve load

2 RIIA webinar - 07/24/2020 MISO

Figure 5. Key results from MISO's RIIA

Impact of Increasing Renewable Penetration

Electric utilities have typically described renewable implementation in terms of a percent of their total load that is being served by renewable resources on an annual basis. As an example, a utility that has 3,000,000 MWh of load with a 30% renewable portfolio has 900,000 MWh of renewable energy. The balance of 2,100,000 MWh comes from other, non-renewable resources.

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28) MISO RIIA Presentation 7/24/2020 Slide #2
https://www.misoenergy.org/events/renewable-integration-impact-assessment-riia---july-24-2020/

If the resource portfolio objective for this example load-serving entity was increased to a 70% goal, where the annual amount of resources used to serve load is now increased to a total of 2,100,000 MWh (70% * 3,000,000), the shape of the resource mix changes dramatically, and renewable generation could exceed load on some lightly loaded days. Unless there is an opportunity to export energy to another region, the renewable generation must be curtailed to match load during hours when it would otherwise exceed load. In addition, some thermal generation resources will need to be on line at minimum load, ready to ramp up if the wind stops blowing or the sunny day becomes cloudy. The amount of thermal generation online at mimimum load will result in further curtailment of renewable resources.

If this entity was a small part of the overall system (in this example, it is only 0.44% of the MISO load), the rest of the MISO system would easily adapt and continue to maintain the system energy balance. The challenge that MISO faces is that if all its members would desire to have this same objective, the MISO system would be requiring the rest of the electric grid to supply energy during the hours when the wind was not enough to serve the load and to back down its generation portfolio when the wind generation was higher than the MISO load. The amount of variance would be extremely challenging to fit into the real-time requirements of system dispatch. If this situation begins to develop, the resource mix may need to evolve to accommodate the higher level of renewables.

In summary, the objective of having a higher percentage renewable portfolio for part of the system is feasible with the rest of the system absorbing the dispatch, but requiring all load-serving entities to have a high renewable objective at the same time may be challenging. The MISO RIIA results show increasing challenges in this realm for overall renewable percentages greater than 30%. However, it is important to note that potential changes in the resource mix, and cost reductions in storage that lead to significant storage on the grid will have a favorable impact.

There are a number of occurrences in the RIIA analysis where the hourly percent of renewable resources are in the range of 80-90% of the hourly load level. These hours have been identified as being potentially unstable, which would require curtailment of renewables. One of the key concerns here is the impact of a contingency event—loss of a large resource or transmission line—and the ability of the renewable resources to maintain frequency. This is an ongoing area of research because the fast frequency response of inverter-based resources may be able to provide sufficient stability in the future. Also, as described above, renewables can be dispatched up or down in some circumstances, and this could be an example where renewable redispatch would be necessary. This phenomenon is essential to properly model in order to understand the viable solutions to this complex interaction of real-time delivery on the electric grid when considering high levels of renewable energy implementation.

Electric generation resources can be characterized as either being grid-forming or grid following. Grid forming resources are in sync with the 60 hertz design of the AC grid, and are used to establish the synchronous connection of grid following resources. The high percentage of renewable energy that is grid-following was identified in RIIA analysis stakeholder discussions as needing to be resolved in order to maintain system reliability. This issue has been recognized and there is currently research underway to better understand the conditions under which grid-forming resources are needed, and how smart inverters can be utilized to provide this service.

Studies such as the MISO RIIA allow grid planners and operators to assess potential future problems and develop solutions, therefore avoiding reliability problems.

MISO's Long-term Reliability Analysis and Modeling

MISO has a large number of processes that involve technical committees of MISO staff and stakeholders from utilities within its footprint[29]. These committees address issues that affect the market design and practice at MISO and focus on reliability issues. Committees that address long-term reliability include

- Loss of Load Expectation Working Group (LOLEWG)[30]
- Resource Adequacy Subcommittee (RASC)[31]

The LOLEWG focuses on developing and enhancing MISO's modeling capability, which provides the input to its resource adequacy analysis. RASC uses this analysis to provide direction to MISO regarding the impact of changes in the grid to long-term reliability and resource adequacy. The LOLEWG and the RASC are currently exploring the impact of alternative renewable energy mixes on resource adequacy, and evaluating the use of new, enhanced reliability metrics that can help inform the planning process and ensure a reliable mix of future resources (subject to state regulatory guidance). The results from this work also help to inform MISO's Transmission Expansion Planning (MTEP) process.[32]

MISO's Reliability Subcommittee (RSC) focuses more on short-term reliability, providing "...a forum to discuss issues within the context of the MISO tariff, Transmission Owner Agreement,

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29) A list of MISO committees can be found at https://www.misoenergy.org/stakeholder-engagement/committees/

30) https://www.misoenergy.org/stakeholder-engagement/committees/loss-of-load-expectation-working-group/

31) https://www.misoenergy.org/stakeholder-engagement/committees/resource-adequacy-subcommittee/

32) MTEP's home page is https://www.misoenergy.org/planning/planning/

Amended Balancing Authority Agreement, MISO seams agreements, NERC Reliability Standards, applicable Regional Standards, and other applicable documents for direction on implementation and maintenance of reliability and tariff administration functions at MISO within the MISO footprint and between MISO and adjacent areas."[33]

Long-term Reliability: Summary

Long-term reliability models are used to assess whether a resource portfolio is likely to be sufficient over some future period. These models calculate the level of resource adequacy that can be expected from a portfolio of resources, and can then be used to help ensure that a reliable power system is designed and built. These same models can be used to assess the contribution of renewable resources. Other models are also used so that the future operation of the power system can be simulated and evaluated. These operational studies typically inform the transmission expansion planning process. A robust planning process is required, involving a broad group of stakeholders, so that the future grid can attain its reliability objectives.

Summary

Existing processes that are in place at utilities and RTOs ensure that the grid will operate reliably. Short-term reliability, or grid services, can be provided by renewable resources. Renewables can potentially provide better disturbance response than large conventional generators. As the grid evolves, it is vital that the need for grid services is accurately assessed, and that the ability of all resources to provide grid services, to the extent they can, is accounted for.

Medium-term reliability includes day-ahead and real-time dispatch. The generators scheduled to run in the forward commitment period can withstand any credible outage. System operators utilize state-of-the-art forecasting for wind and solar resources, and they incorporate those forecasts into routine operational practice. Sufficient contingency reserves, flexibility reserves, and other operating reserves ensure reliable operations across multiple credible contingencies or operational challenges.

Long-term reliability, which is developed from a robust planning process, involves reliability assessments of each possible future resource mix. Portfolios that are shown to be unreliable are not adopted. A necessary condition of a prospective resource mix is that it must be able to be operated reliably and cost-effectively. Planning and operational models are utilized to ensure operational feasibility. A robust planning process is required to fulfill these objectives, and participation by utilities, RTOs, and other stakeholders is part of the process.

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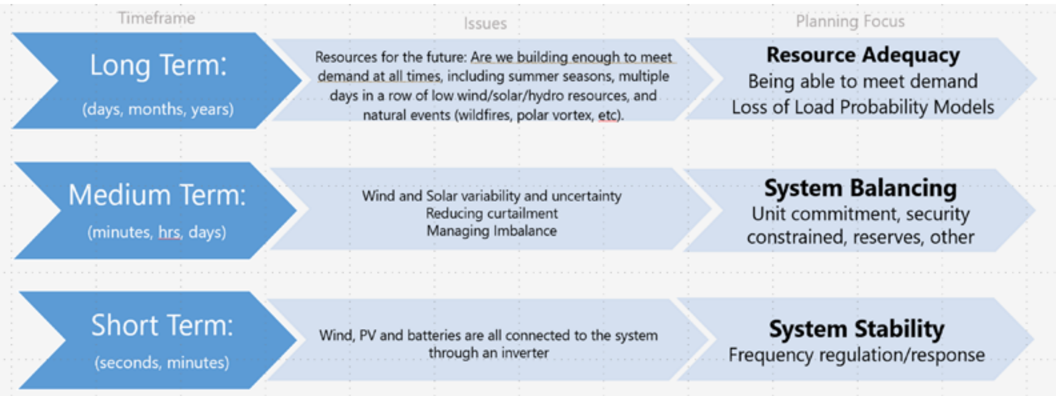
33) https://www.misoenergy.org/stakeholder-engagement/committees/reliability-subcommittee/

Appendix 1: What is Grid Reliability?

Appendix 1.1: Introduction to Reliability

Operating a power system requires making multiple decisions at various time scales, from milliseconds to several years ahead of real-time dispatch. For our discussion we simplify all of these aspects of reliability and put them into two basic categories: (1) planning/investment, and (2) operations. We can in turn divide the operations time frame into medium-term operations, which includes planning for days, weeks, or even months, and short-term operations, which covers events occurring in minutes, seconds, and even less than a second. Figure 6 shows the timescales of grid reliability: long-term (resource adequacy), medium-term (system balancing), and short-term (system stability).



Timeframe	Issues	Planning Focus
Long Term: (days, months, years)	Resources for the future: Are we building enough to meet demand at all times, including summer seasons, multiple days in a row of low wind/solar/hydro resources, and natural events (wildfires, polar vortex, etc).	**Resource Adequacy** Being able to meet demand Loss of Load Probability Models
Medium Term: (minutes, hrs, days)	Wind and Solar variability and uncertainty Reducing curtailment Managing Imbalance	**System Balancing** Unit commitment, security constrained, reserves, other
Short Term: (seconds, minutes)	Wind, PV and batteries are all connected to the system through an inverter	**System Stability** Frequency regulation/response

Figure 6. Grid Reliability Timescales[34]

Operational reliability requires that the planning and investment processes deliver a grid that can be operated reliably and economically. Failure to design a grid that can deliver electricity reliably will make it difficult or impossible for the operators to do their job. In this report, we will cover short-term reliability first, but the reader should understand that excellent long-term planning is an essential pre-requisite to excellent short-term operation. A grid that is not well planned will be difficult to operate well.

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34) Adapted from Lew, D. (April 2020). Webinar #1: Long Term Reliability- Resource Adequacy. Western Interconnection Regional Advisory Body. https://www.westernenergyboard.org/wirab-webinar-series-webinar-1-long-term-reliability-resource-adequacy/

The system operator, whether an RTO or an electric utility, "inherits" the physical grid from planners and investors, and in the short-term cannot change the fleet of generators, the transmission network, or long-term contracts or agreements with others. The operator must make informed decisions about which resources to commit day-ahead, the implication of wind or solar forecasts, and many other decisions. Operational decisions include ensuring sufficient reserves that can be called upon if things go wrong, and many things can go wrong – generating units can fail, transmission links can fail, and weather may differ markedly from forecast, causing the actual combination of demand and generation to deviate from anticipated levels.

In the very short term, there are multiple automated processes that ensure balance. These include automatic generation control (AGC), which is generally a 4-second balancing service, and frequency response. These will be discussed later in this document.

This document describes each of the three main timeframes of reliability. We begin with a short discussion of Regional Transmission Organizations, because that provides some of the context for North Dakota. We then describe short-term reliability, medium-term reliability, and long-term reliability.

The next section of this report shows how general reliability is applied to North Dakota.

Appendix 1.2: RTOs Assure Reliability

Regional Transmission Organizations (RTOs) are electric power system operators that control and monitor electric grids spanning multiple states. RTOs are responsible for ensuring power grid reliability (the ability of the system to match aggregate demand with aggregate supply at all times[35]). They perform regional planning and determine where additional power lines and generators are required, although they lack the authority to require member companies to make these investments. The RTOs do have the authority to prevent member companies from closing power plants that are required for reliability.

RTOs are voluntarily created and fall under the regulatory umbrella of the Federal Energy Regulatory Commission (FERC). Their role[36] is to

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35) Milligan, M. (November 2018). Sources of grid reliability services. The Electricity Journal. Volume 31, Issue 9. Pages 1-7. https://www.sciencedirect.com/science/article/pii/S104061901830215X?openDownloadIssueModal=true

36) Blumsack, S. (February 2019). Department of Energy and Mineral Engineering. The Pennsylvania State University. https://www.e-education.psu.edu/eme801/node/535

- Manage the transmission system
- Ensure non-discriminatory access to the transmission grid
- Dispatch generation assets to keep supply and demand in balance
- Plan for generation and transmission at the regional level

Membership in an RTO includes multiple utilities, which can be investor-owned utilities, cooperatives, municipal utilities, or Federal Power Marketing Administrations. Utilities typically own assets that include transmission, and in some states they also own generation facilities. In addition to owned generation, utilities often enter into long-term contracts to secure energy either on short-term or long-term bases. Some key elements of RTOs are

- RTOs purchase power from generators and resell it to utilities, who re-sell it to retail customers. RTOs do not sell electricity to retail customers
- RTOs are non-profits
- RTOs do not own any physical assets

There are two RTOs serving North Dakota, the Midcontinent Independent System Operator (MISO) and the Southwest Power Pool (SPP). As can be seen on the map in Figure 7, North Dakota falls within both MISO and SPP, but the geography of the split between the RTOs is not straightforward. At the intersection point of two or more RTOs, the electrical "seam" must be managed so that imports and exports can be balanced according to schedule, and the RTOs must develop rules that govern how the seam will be operated. In general, these seams introduce some operational inefficiency as compared to a single RTO operating the entire region.

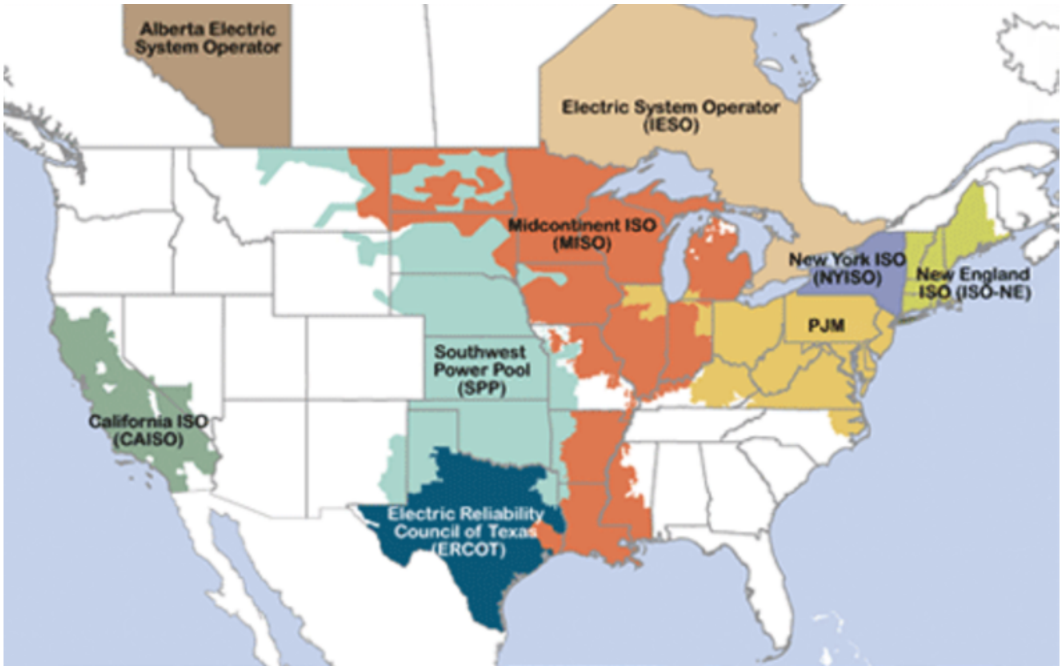

Figure 7. RTOs in the United States. Source: FERC[37]

Appendix 1.3: Short-term Reliability: Grid Services

Power system operators and operational practice ensure that the grid remains in balance at all times, subject to NERC reliability rules. Although there are some regional differences in the way some of these services are defined, there is broad agreement regarding the need for grid services, and a recognition that inverter-based resources (IBR, such as wind, solar, storage) can provide many of these services.

Appendix 1.3.1: Role of Inverters

Wind and solar energy, along with batteries, are non-synchronous with the grid. This is because the grid is operated with alternating current (AC) and these energy sources produce direct current (DC), as shown in Figure 8. To convert this DC power to AC power requires a device called an inverter. Inverters are composed of power electronics devices, which can be configured by computer software.

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37) FERC. Electric Power Markets. National Overview. https://www.ferc.gov/industries-data/market-assessments/overview/electric-power-markets

The configuration of the AC power signal can be manipulated in such a way that the inverter can respond to grid events in many cases.

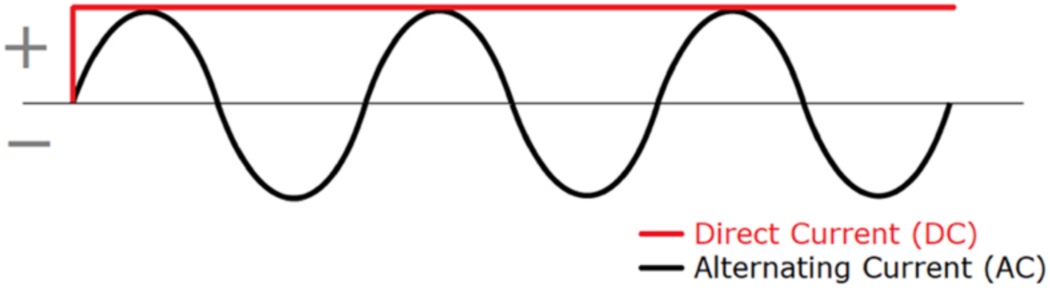

Figure 8. AC and DC power

Voltage and frequency must be maintained within nominal limits at all times to avoid potential reliability events and damage to equipment. During normal operations, various devices provide voltage support. If the voltage should deviate from nominal limits, modern inverters are set so that the device can "ride through" voltage excursions (within limits) and remain online. This helps reliability by ensuring there is not a large loss of generation that results from voltages that are too low or too high.

Frequency on the AC grid must be maintained at 60 Hz, but it can vary slightly from this nominal value. If frequency begins to increase from 60 Hz, the software and controls of the inverter can respond by reducing its frequency, helping to restore the overall system frequency to 60 Hz. Likewise, if grid frequency begins to drift downward, the inverter response can increase the frequency of its output, helping to bring the frequency back up to its nominal value.

Appendix 1.3.2: Grid Disturbance Characteristics

From time to time there can be system disturbances that could, if uncontrolled, could cause either severe voltage or frequency fluctuations, both of which could potentially damage electrical equipment, or in the extreme cause a blackout. A disturbance is often the result of the sudden failure of a generator or transmission line. In the seconds and minutes following a disturbance, the response of the remaining generators on the grid is critical to maintain system balance.

Figure 9[38] provides an example of how grid services will help restore the system after the disturbance.

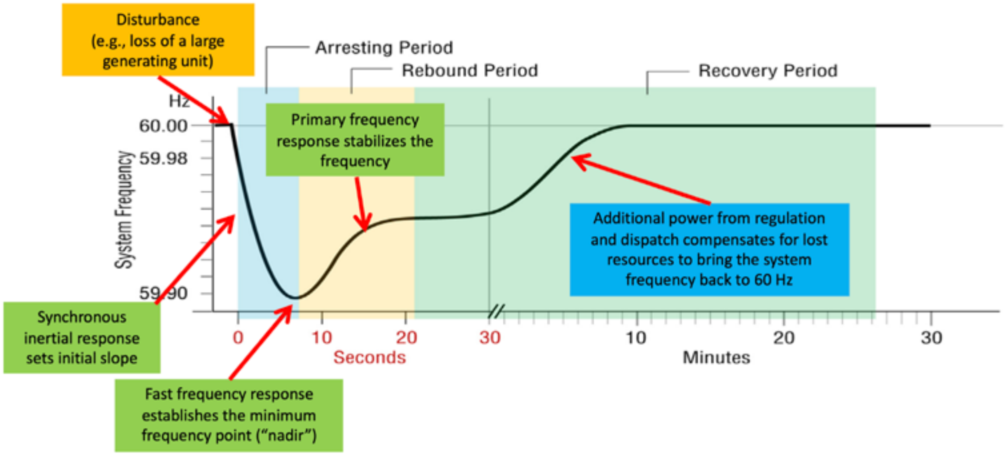

Figure 9. A generic system disturbance and response

Figure 9 shows the system frequency on the y-axis and shows time on the x-axis (note the change in scale between seconds and minutes). The orange box shows the point at which the disturbance occurs, and the beginning of the frequency drop that results. The frequency drop is a function of the synchronous inertial response of large rotating generators, which sets the slope of the response. Resources that can provide fast frequency response (FFR) will slow, and then reverse, the frequency decline. This minimum point is called the "nadir" and establishing this nadir so as to limit the decline in frequency can make a difference between an event that is easily recovered from, and an event that results in a blackout. Other resources respond more slowly, and provide primary frequency response (PFR) through droop controls during the next tens of seconds.

These actions are supplemented by automatic generation control (AGC) which is an automated process that signals a subset of the generation fleet to increase or decrease output every 4 seconds to help maintain system balance. In regions with RTO markets, such as MISO and SPP, economic dispatch is done every five minutes. This process determines the best mix of resources to turn up or down so that demand and supply are kept in balance. AGC and economic dispatch processes are shown in the blue box in the diagram.

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38) Figure from J. Eto, LBNL, https://www.ferc.gov/industries/electric/indus-act/reliability/frequencyresponsemetrics-report.pdf and modified with credit to Mark Ahlstrom, FPL Energy.

Appendix 1.3.3: The Sources of Response to Disturbances Are Changing

Historically, large coal, nuclear, and some large gas units have provided inertial response to a frequency decline, and resources such as gas or hydro have provided fast frequency response (FFR). The large units generally also have provided primary frequency response (PFR), and little if any FFR. As more coal units are retired and more renewables are added to the grid, this frequency recovery will change somewhat.

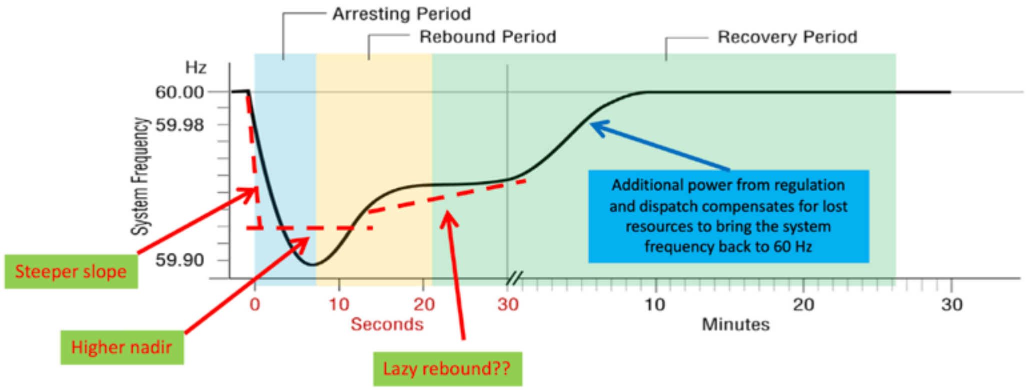

Figure 10. Response to a grid disturbance with high levels of IBR

In recent years there has been a recognition that grid services can be provided by renewable energy sources, via the inverter, but these controls must be activated to be effective. Simulations carried out at the National Renewable Energy Laboratory[39] on the Western Interconnection confirm the benefit of FFR from renewables. Figure 11 shows the results of simulations carried out during “light spring” (relatively low demand) using a base-case with little renewable generation compared to alternative cases with renewables. The left panel shows the no-renewable base case and the high renewables case, which contains a mix of wind and solar. In the left panel, no frequency controls on the wind/solar were enabled. In comparing the two responses in the left part of the graph, the renewables case shows a slightly worse frequency response for the first 20 seconds. The right panel shows the renewables case with and without frequency controls. The slope of the decline is more gradual, the nadir—the minimum frequency level after the contingency event—is higher (better), and the overall performance of the response exceeds even that of the no renewables case.

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39) Milligan et al. (2015) Alternatives No More: Wind and Solar Power are Mainstays of a Clean, Reliable, Affordable Grid. IEEE Power and Energy Magazine (Volume: 13, Issue: 6, Nov.-Dec. 2015)

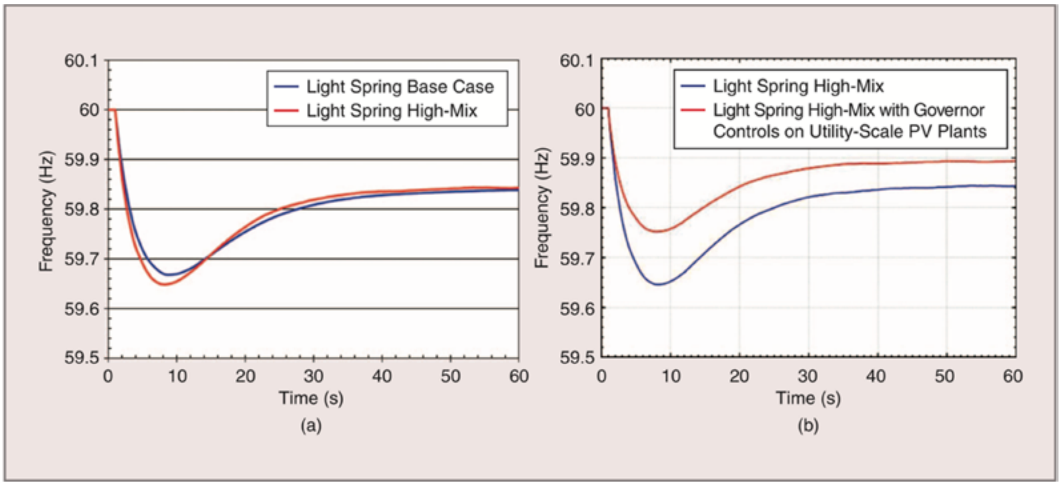

Figure 11. Western Interconnection frequency response to the loss of two Palo Verde units for Light Spring conditions. (a) The base case compared to a high mix of wind and solar. (b)High mix with and without frequency controls.

Appendix 1.3.4: Other Grid Services from Renewable Energy

Wind plants have demonstrated the ability to provide other grid services. Currently, MISO requires new renewable resources to be part of its "Dispatchable Intermittent Resource" program. Under this program, renewables bid into the market with a price for downward dispatch. This is incorporated into MISO's economic dispatch so that the downward dispatch—which is a partial curtailment—is optimized. Currently, MISO does not allow renewables to provide regulation services; however, MISO is now working to allow it.[40] Renewable resources can provide upward regulation and dispatch if they are generating less than full capacity, based upon the supply of wind or sunshine. Although the provision of upward services is generally not economic, it is available if needed to support reliability.

The following is an example of a wind power plant that provides both AGC and dispatch services.[41] The example is from Xcel Colorado. Figure 12 shows a time period of approximately 4 hours, during which the wind plant provided a combination of dispatch services and AGC. The following discussion explains the various traces in the figure and their significance.

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40) https://www.misoenergy.org/stakeholder-engagement/issue-tracking/allow-dispatchable-intermittent-resources-dirs-to-provide-regulation-service/

41) Michael Milligan, et al., Alternatives No More: Wind and Solar Power are Mainstays of a Clean, Reliable, Affordable Grid, IEEE Power and Energy Magazine, Nov./Dec. 2015.

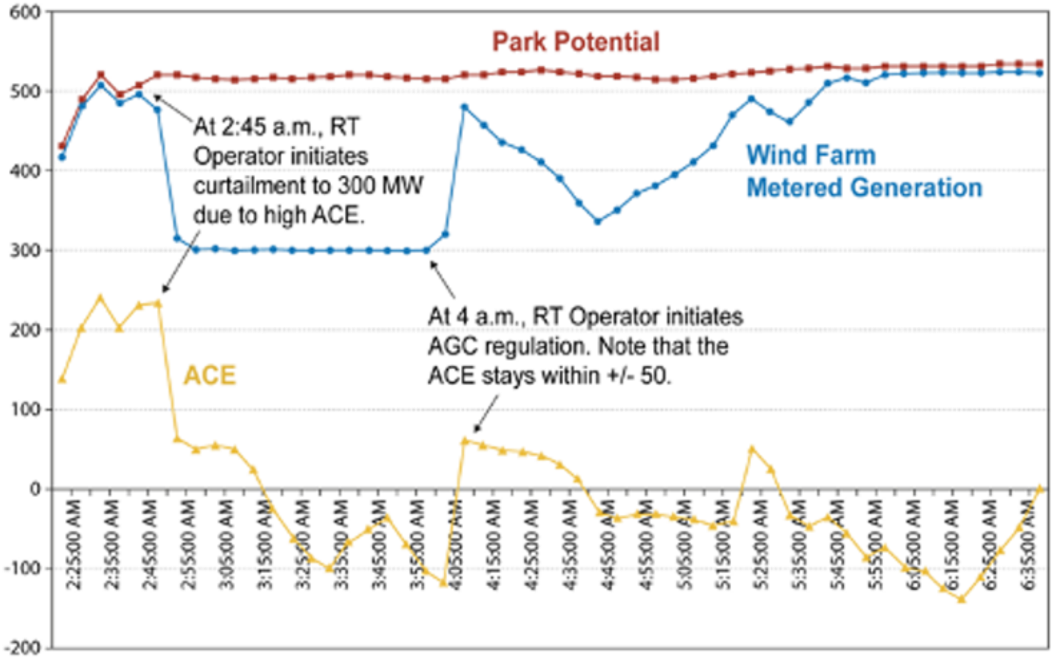

Figure 12. Example of wind plant providing AGC and dispatch services

Area Control Error

The yellow trace, area control error (ACE), is a measure of system imbalance. An ACE value of 0 indicates the system is perfectly balanced; the sum of demand and exports is equal to the sum of generation and imports. There is an additional frequency term that is not important for this discussion.[42] A large absolute value of ACE indicates that the system is out of balance; the system either has too much generation and not enough demand, or it has too much demand and not enough generation. A positive ACE indicates that the system is experiencing over-generation relative to demand and should reduce generation (or increase demand, such as charging a storage device if possible), whereas a negative ACE indicates insufficient generation within the balancing area, indicating that the system should increase generation to maintain system balance.

Wind Plant Response to Area Control Error: Dispatch

In Figure 12, starting at about 2:30 AM, the system operator observes that ACE is too high—about 200-250 MW. That means generation should be decreased to maintain system balance. In this case, the utility had already turned down all its thermal resources to minimum generation

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42) See Balancing and Frequency Control, North American Elec. Reliability Corp. (2011), https://www.nerc.com/docs/oc/rs/NERC%20Balancing%20and%20Frequency%20Control%20040520111.pdf (showing full equation for ACE).

levels. Reducing them further would have required at least one unit to be shut down; however, all the online units would have been unavailable for the next day because of minimum down-time constraints. Therefore, the operator knew that none of the thermal plants could be turned down or turned off. Instead, at 2:45 AM, the operator gave the wind plant a dispatch setpoint that instructed the plant to reduce its output from about 500 MW to about 300 MW. Wind plants (and solar plants, both of which are connected to the grid via power electronics controls) can respond quickly to such commands, as can be seen in Figure 12. ACE falls to less than 100 MW from more than 200 MW very quickly, and it continues to decline until falling below zero. At around 4:00 AM, the operator determined that ACE was too low, and generation should be increased. Instead of instituting a series of manual dispatch commands, the operator changed the control paradigm of the wind plant, putting it on AGC.

Wind Plant Response to Area Control Error: AGC
At about 4:00 AM, the wind plant was put on AGC. This means that, every 4 seconds, the wind plant would receive a control signal from the AGC that would instruct the plant to increase or decrease output to maintain ACE within limits. At the time of this event, the acceptable limit for ACE was approximately 50 MW. Starting at 4:00 AM, the wind plant output changed so that ACE generally stayed within limits until the morning load pickup began around 6:00 AM. When considering whether to place wind plants on AGC, the following questions arise:

- Is the resource in an operational position to provide the service?
- Are there compensation methods that align the objectives of the grid operator, consumer, and resource providing the service?

Appendix 1.3.5: Sources of Grid Services

The bulk power system (BPS) is undergoing a digital revolution. With the recent and continuing growth of inverter-based generation, largely from wind and solar energy, the power system industry has begun exploring the implication of high levels of wind and solar energy on power system reliability and resilience.

Not all resources are capable of providing all grid services. Milligan[43] describes each grid service in more detail, and he provides a summary table that shows typical technological capabilities to provide these services.

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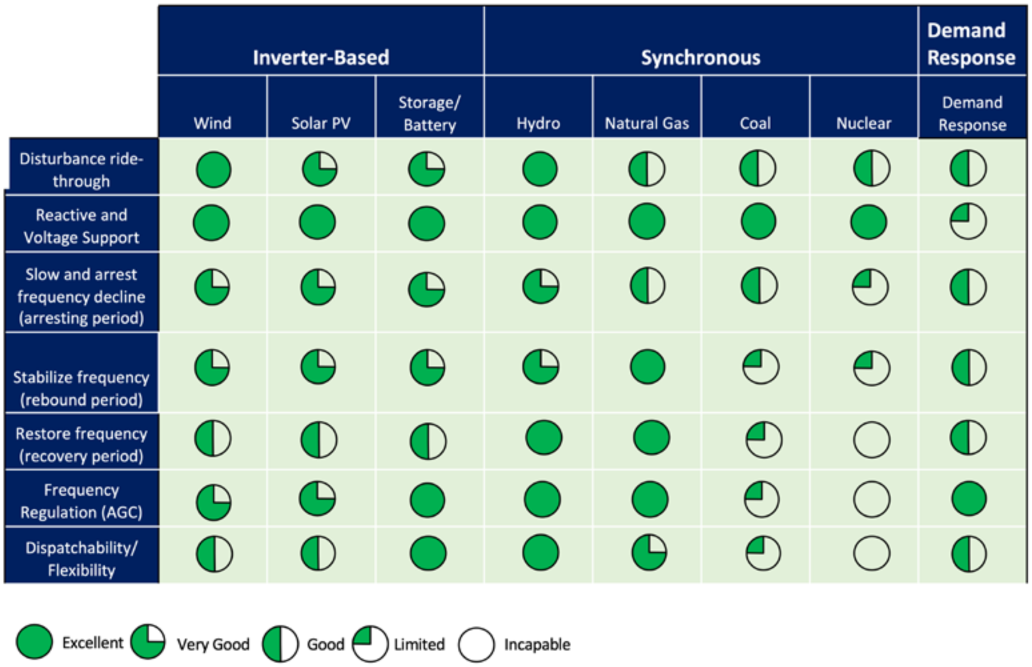
[43] Milligan, M. (2018). Sources of grid reliability services. The Electricity Journal, 31(9), pp. 1-7.

The speed of provision, depth of provision, and machine type and state will all play a role in determining the physical capability of each resource type. Market and reliability rules may limit response in some cases; however, rules should be revised if that is the case. Table 1 summarizes the discussion of the reliability service capabilities from different resources.



	Inverter-Based			Synchronous				Demand Response
	Wind	Solar PV	Storage/ Battery	Hydro	Natural Gas	Coal	Nuclear	Demand Response
Disturbance ride-through	●	◕	◕	●	◑	◑	◑	◑
Reactive and Voltage Support	●	●	●	●	●	●	●	◔
Slow and arrest frequency decline (arresting period)	◕	◕	◕	◕	◑	◑	◔	◑
Stabilize frequency (rebound period)	◕	◕	◕	◕	●	◔	◔	◑
Restore frequency (recovery period)	◑	◑	◑	●	●	◔	○	◑
Frequency Regulation (AGC)	◕	◕	●	●	●	◔	○	●
Dispatchability/ Flexibility	◑	◑	●	●	◕	◔	○	◑

● Excellent ◕ Very Good ◑ Good ◔ Limited ○ Incapable

Table 1. Grid Services Summary

Appendix 1.3.6: Grid Services Summary

Renewable energy technology can provide all grid services to a large degree. Power system simulations have shown that enabling frequency controls can reduce the impact of contingency events. This fast frequency response can, to a large degree, replace the inertia that is expected to be withdrawn from the grid as large coal units retire. It is important that grid operators recognize and account for the grid services that can be supplied by renewable resources so that the appropriate level of each service is secured.

Appendix 1.4: Medium-term Reliability: System Operations and Balancing

Grid operators are tasked with supplying electricity in the most cost-effective manner, subject to reliability constraints. During most time periods, there are no large unanticipated events that may compromise reliability. During those times, changes in demand are accurately anticipated and factored into operational plans and execution. Similarly, wind and solar energy are reasonably well-forecasted.

Various types of operating reserves are maintained—extra capacity that may not be needed, but that can be called upon if needed, possibly at very short notice. Contingency reserves help maintain balance and reliability immediately following large, unanticipated events such as an electrical or mechanical failure in a generating unit. Operating reliability means "the ability of the bulk power system to withstand sudden disturbances, such as electric short circuits or unanticipated loss of system elements from credible contingencies, while avoiding uncontrolled cascading blackouts or damage [to] equipment." (NERC, 2013, page 2).[44]

Other types of reserves, such as flexibility reserves, can be utilized if wind or solar energy generate more or less than anticipated, or if demand is higher than forecast. Regulating reserve is a type of reserve that anticipates the need for AGC, and it ensures that sufficient AGC is available when needed. Details can be found in Ela et. al.[45]

To balance demand and supply, grid operators plan and control the generation-load balance from the day ahead to real time dispatch, carrying out a security-constrained unit commitment and security-constrained economic dispatch function:

- **Security-constrained unit commitment (SCUC)**. In the day ahead of dispatch, grid operators forecast their load on a per hour basis. After running an optimization model that minimizes costs subject to physical constraints, operators determine which generators need to be committed (operated) during the following day (or other commitment period). A security-constrained commitment is a commitment schedule that is robust enough to account for credible contingencies, such as the failure of a large generator or a transmission outage.

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44) NERC. (August 2013). Understanding the Grid. https://www.nerc.com/AboutNERC/Documents/Understanding%20the%20Grid%20AUG13.pdf

45) Ela, E.; Milligan, M.; Kirby, B. (2011). Operating Reserves and Variable Generation. A comprehensive review of current strategies, studies, and fundamental research on the impact that increased penetration of variable renewable generation has on power system operating reserves. 103 pp.; NREL Report No. TP-5500-51978

To respond to contingencies, the flexibility of resources/system is now being considered in commitment by some system operators.

- **Security-constrained economic dispatch (SCED)**. This form of dispatch is carried out in 5-minute intervals in MISO and SPP. This economic dispatch function chooses among the units that have been committed to instruct these resources to generate a given level of output, based on an economic optimization model. The security-constrained element of the dispatch accounts for operating reserves to provide extra capacity if needed for credible contingencies, similarly to the SCUC.

Since demand fluctuates between the dispatch intervals, a computer system monitors the grid frequency and balance, and sends signals at much shorter intervals (every 4 seconds) to AGC resources, so that they can automatically increase or decrease their output. This process is called frequency regulation, and it serves to compensate for the small variations in supply and demand, and to restore balance. Dispatch and regulation services are key to preserving system balance.

Figure 13 is a graphical representation the discussion above. Beginning one or more days prior to the operating period, grid operators determine the hourly schedules for all their generators for the following day, sometimes considering several days at a time (circled in green). During the day, the economic dispatch process selects from the committed resources, and units are dispatched every 5 minutes to meet demand. In systems with wind or solar energy, the hydro-thermal fleet is generally dispatched to meet demand net of wind and solar generation. This dispatch is sometimes called “load following” (circled in red). Generators move every five minutes to a dispatch point, or setpoint, subject to the result of the economic optimization described above. At the smallest timeframe is regulation reserve (circled in blue), which adjusts generator output every 4 seconds to manage variability within the interval of dispatch.

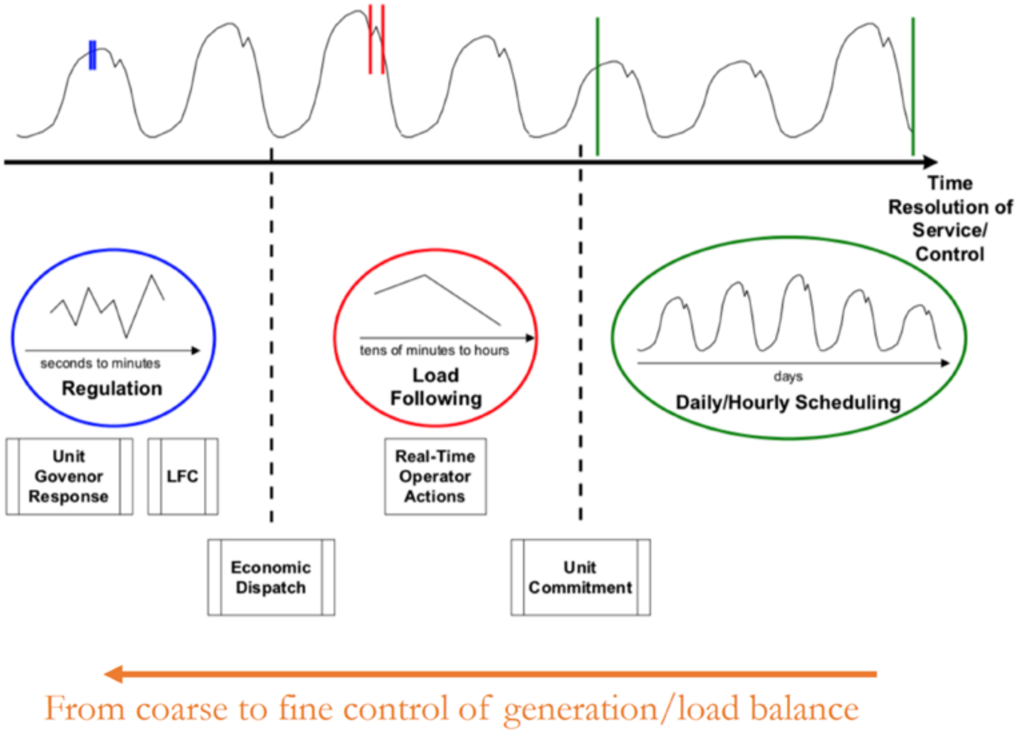

Figure 13. Illustration of system balancing and operations[46]

There are many physical constraints that must be accounted for in the economic dispatch process. These include:

- Generator startup times – how quickly the unit can be brought online and synchronized to the grid
- Ramp rates – how quickly can the resource change output, up or down
- P_{min}, the minimum generation level that thermal generators can achieve while maintaining stability.
- Minimum downtime – how long the unit must remain off before re-starting
- Minimum runtime – the minimum length of time the unit must run after starting
- Accounting for "headroom" (ability to increase power) to maintain operating reserves
- Power flows must respect transmission limits

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46) Lew, D. (April 2020). Webinar #2: Medium Term Reliability- System Balancing. Western Interconnection Regional Advisory Body

Appendix 1.4.1: Balancing Standards

The North American Electric Reliability Corporation (NERC) is the federally-recognized reliability organization of the United States. Over the years NERC has developed various reliability rules that transmission operators must follow. NERC has the ability to levy fines if rules are violated.

Grid operators are allowed some limited levels of imbalance between generation and demand, subject to various reliability rules. This imbalance is called area control error (ACE). Currently, the NERC balancing standard BAL-001-2 specifies the allowable deviation of ACE based upon system frequency in real time.[47] Balancing Area Authorities (BAAs) have some latitude to run relatively small ACE, but this depends on whether the BAA in question is helping move frequency back to its nominal 60 Hz, or whether the BAA's frequency deviation is in the same direction as the interconnection frequency. In the former case, the BAA has more latitude, and in the latter, the BAA has less latitude. NERC requires each BAA to submit performance logs, and if a given BAA is found to be in violation, it can be subject to a significant fine.

As the penetration of renewable energy increases on power systems around the world, there is an increasing body of knowledge that can help inform grid operators to ensure reliable operation. Some of these include

- Greater system flexibility with faster ramping capability, lower turn-down levels on thermal units, and shorter minimum up-times and down-times
- Advances in forecasting of renewables
- Utilizing grid services from inverter-based resources (discussed above)[48]

Appendix 1.4.2: Summary of Medium-term Reliability

Medium-term reliability is primarily a function of the security-constrained unit commitment and security-constrained economic dispatch processes, combined with the reliability rules that are set by NERC. Utilities and RTOs work together so that the grid can be operated reliably and at least cost. The commitment (SCUC) and dispatch (SCED) activities are carried out by RTOs such as MISO and SPP, and although some of the specifics may vary, the fundamental approach to achieving a secure commitment and dispatch is a pre-requisite for reliable system operation. These processes are

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47) A good explanation can be found in BAL-001-2 – Real Power Balancing Control Performance Standard Background Document. Feb 2013. https://www.nerc.com/pa/Stand/Project%202010141%20%20Phase%201%20of%20Balancing%20Authority%20Re/BAL-001-2_Background_Document_Clean-20130301.pdf

48) ESIG Brief: Maintaining Reliability in Power Grids with High Levels of Wind and Solar. Available at https://www.esig.energy/wp-content/uploads/2020/06/Maintaining-Reliability-in-Power-Grids-with-High-Levels-of-Wind-and-Solar-2.pdf.

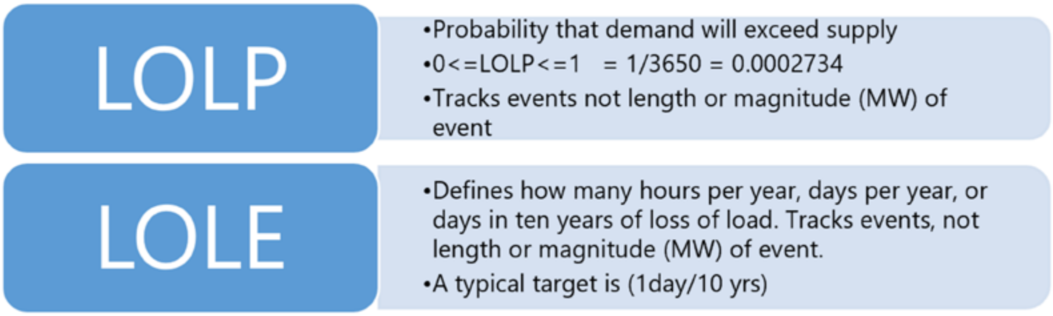
carried out so that NERC balancing standards can be met in real-time operations, and so the grid can be reliably operated at all times.

Appendix 1.5: Long-term Reliability - Resource Adequacy

Resource adequacy is a planning process to assure that generation resources are adequate to serve load over multiple time frames. Changes to the grid, whether involving generation or transmission, must be planned in advance. Part of this planning process is to ensure that the future grid is capable of being operated in a reliable, cost-effective manner. Shortfalls in design and planning could potentially result in a system that will not operate reliably. Power system planners in RTOs and utilities collaborate with multiple stakeholders and utility commissions to ensure that the planning process results in a grid that meets the objective of attaining system adequacy—a combination of generation and transmission capable of operating reliably. These planning processes are critical because they result in plans that will result in the future design and characteristics of the power system. This requires a robust planning process.

The process of assessing resource adequacy focuses on ensuring sufficient resources to meet future demand. This resource adequacy process may not explicitly consider transmission, although deliverability must be assessed to ensure operability. It is not possible to cleanly separate these; however, planning processes and modeling are complex, so there may be some separate consideration of generation and transmission. Moving into the future, the planning process will become more complex with the significant additions of wind and solar energy, battery storage, and demand response (dispatchable demand such as interruptible electric water heaters and cycled air conditioners).

Resource adequacy is typically measured with a probabilistic metric called loss of load expectation (LOLE). LOLE is calculated using reliability data from all power plants in the system being studied, along with hourly data for demand, and wind and solar generation. A common target value for LOLE is a loss of load of 1 day in 10 years. This means that there is sufficient generation (and demand response) to ensure a reliable supply of electricity for 10 years, less one day. This target is a policy decision, and there are common variations, such as 0.1 day/year. The specific loss-of-load events that are covered by this analysis are only those that result from building insufficient resources. LOLE is based in part on a related metric called loss of load probability (LOLP). Figure 14 shows the key properties of LOLE and LOLP.



LOLP

- Probability that demand will exceed supply
- 0<=LOLP<=1 = 1/3650 = 0.0002734
- Tracks events not length or magnitude (MW) of event

LOLE

- Defines how many hours per year, days per year, or days in ten years of loss of load. Tracks events, not length or magnitude (MW) of event.
- A typical target is (1day/10 yrs)

Figure 14. Relationship between LOLP and LOLE

There is a tradeoff between reliability and cost. Since there are diminishing returns of trying to build a system that is 100% reliable, and electricity must be affordable, then building a 'perfect' system becomes unattainable.[49] This is why the LOLE target is subject to a policy decision – more reliability has a higher cost; perfect reliability is likely unattainable; thus policy must decide what the best level of long-term reliability will be.

As more renewable energy is added to the grid, along with more demand response and storage, there is a need for more comprehensive and more reliable measures to provide a better picture of the reliability. One such measure is the Expected Unserved Energy (EUE), which measures the magnitude in MWh of energy shortfall during a loss of load event. Other measures include daily LOLE, which counts the number of days of shortfalls, and the hourly LOL (LOLH), which counts the number of hours of shortfall, among others. Additional metrics may also be useful, and power system operators such as MISO are evaluating some of these metrics. **Figure 15** illustrates some of these metrics.

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49) North American Electric Reliability Corporation. Integrating Variable Generation Task Force on Probabilistic Methods Team. M. Milligan and M. O'Malley, leads. (2011). Methods to Model and Calculate Capacity Contributions of Variable Generation for Resource Adequacy Planning. Available at https://www.nerc.com/comm/PC/Integration%20of%20Variable%20Generation%20Task%20Force%20IVGT/Sub%20Teams/Probabilistic%20Techniques/IVGTF1-2.pdf

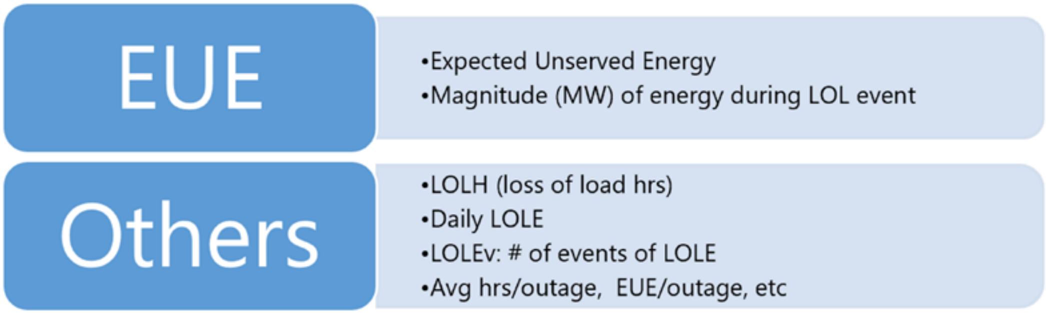

Figure 15. Additional metrics for measuring long-term reliability

Appendix 1.5.1: Determining Contribution to Resource Adequacy

The increased penetration of variable energy resources (VER) has created the need to better quantify the capacity value of wind and solar to improve systems planning. The preferred method to calculate the contribution of an individual resource to meeting resource adequacy is the Effective Load Carrying Capacity (ELCC), although there are similar metrics that are also based upon LOLE models.

For a given power system, the system ELCC is the maximum load that could be served while meeting the reliability target (often 0.1 day/year). For a given generation unit, the ELCC is the increase in demand that can be served after this unit is added to the system, maintaining the same risk level that would be achieved without the new generator at the lower level of demand.

To calculate ELCC, hourly load data and generator characteristics are required. For variable resources like wind and solar, at least one year of time-synchronized, hourly power output is required, but longer periods of data are preferred.[50] Wind and solar contribution to resource adequacy depends on their hourly output profile for over the course of multiple years.

Figure 16 shows a graphical representation of ELCC. For a given system (in blue), as load increases, the LOLE (probability that the system does not have enough resources to meet demand) increases. Given a reliability target (red line) of 0.10d/year, the system needs a little over 10GW to meet the target. This is represented by circle #1 in the figure. If, for example a wind plant is added to the system, this new generation would provide higher levels of reliability, therefore the LOLE would

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50) Milligan, M. and Porter, K. (June 2008). Determining the Capacity Value of Wind: An Updated Survey of Methods and Implementation. Conference Paper. NREL/CP 500-43433. National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy08osti/43433.pdf

decrease to about .09d/yr (represented by circle #2). To achieve the same reliability target level as before, the reliability curve shifts right from the blue line to the dotted line. At the 0.10 reliability target, the system can now meet a demand of about 10.4 GW (circle #4). Thus, the amount of additional load that can be supplied at the target reliability level by this wind resource would be 400MW. This is the ELCC for the wind generation unit. ELCC is often expressed as a percentage of rated capacity. If this wind plant were 1,200 MW, then the ELCC as percent of rated capacity would be 33.3%.

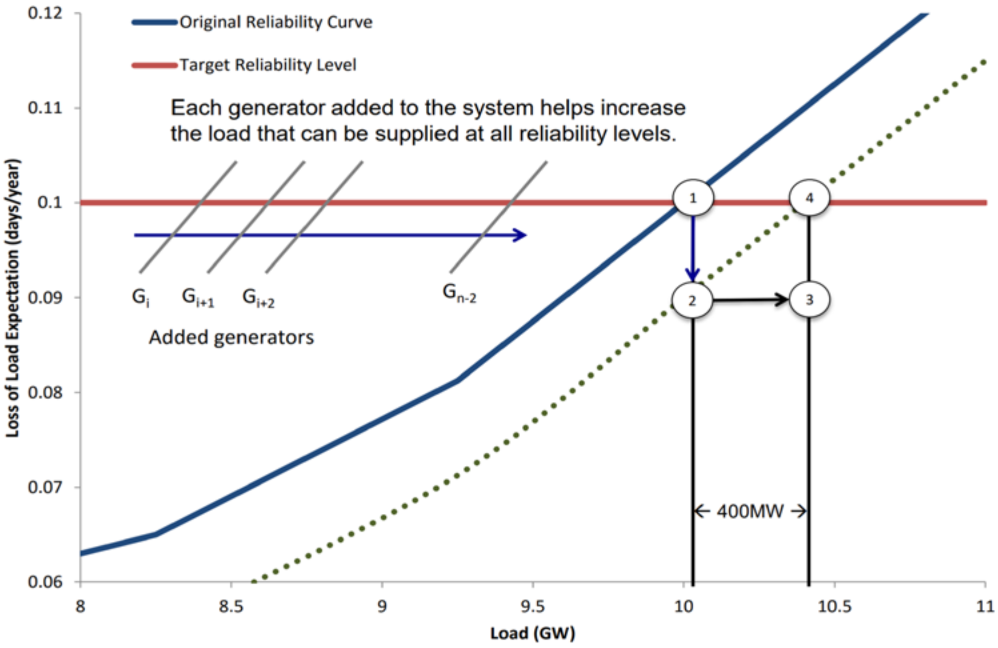

Figure 16. ELCC measure the contribution of a given resource (or type of resource) to resource adequacy[51]

Wind and solar resourcess' capacity contribution, ELCC, is typically a fraction of rated capacity, and is less than that of more conventional resources. As **Figure 17** demonstrates, for the same nameplate capacity (100MW), fossil, wind and solar generation provide less MWs of perfect capacity. But wind

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51) Milligan, M (March 2017). Introduction to Capacity Adequacy and Reliability. UVIG. National Renewable Energy Laboratory

and solar capacity credit is lower than that of fossil generation, with values that can range from 10-40% for wind, and 30-82% for solar.[52]

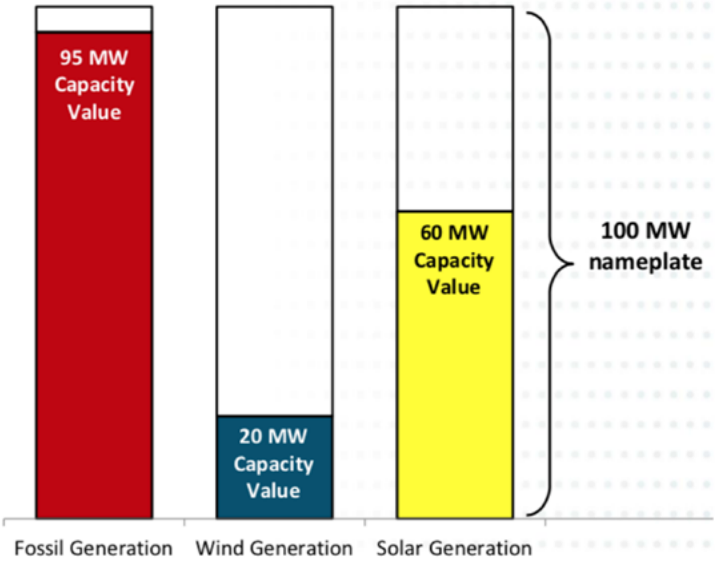

Figure 17. Illustrative capacity values for hypothetical 100 MW resources[53]

Appendix 1.5.2: Capacity contribution of wind and solar decreases with increased penetration

With increases in penetration of any resource, capacity credit declines. But when additional renewable energy is added, capacity credit declines faster. Figure 18 presents a graphical representation of the rate of change in capacity value for wind and solar. As wind penetration increases, its capacity value declines, albeit not as rapidly as photovoltaics (PV), which starts with a much higher capacity value (approximately 30%).

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52) Milligan, Michael; Bethany Frew; Ibanez, Eduardo; Kiviluoma, Juha; Holttinen, Hannele; Söder, Lennart, Capacity Value Assessments for Wind Power: An IEA Task 25 Collaboration. Wiley Wires. 2016. For solar see Mills, Andrew; Wiser, Ryan, An Evaluation of Solar Valuation Methods Used in Utility Planning and Procurement Processes. Presentation Available at http://oregonpuc.granicus.com/MetaViewer.php?view_id=1&clip_id=23&meta_id=895

53) A.Olsen, E3, CREPC Spring Meeting 2017. Taken from Lew, D. (April 2020). Webinar #1: Long Term Reliability- Resource Adequacy. Western Interconnection Regional Advisory Body.

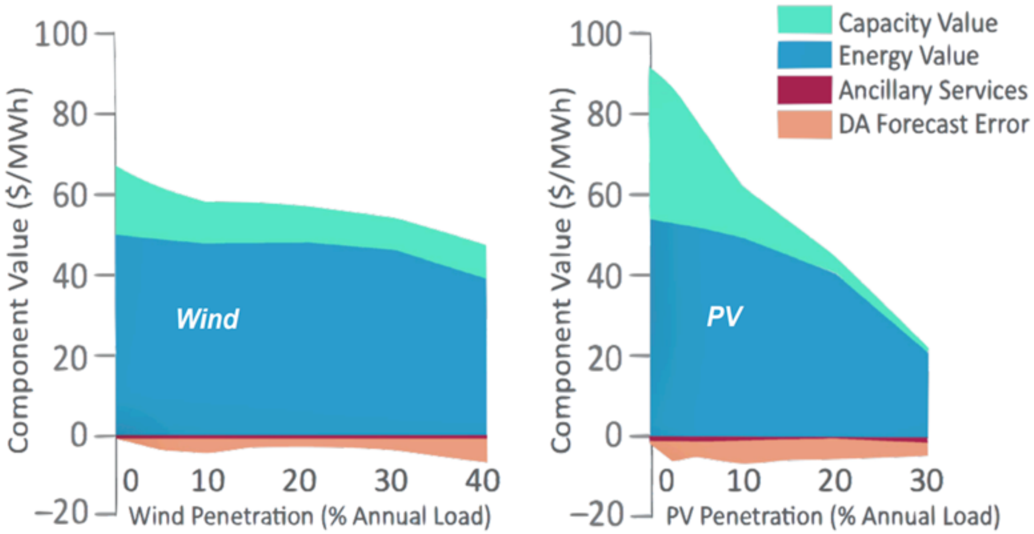

Figure 18. Example decreases in capacity and energy value for wind and solar PV[54]

Appendix 1.5.3: Inter-annual variability can be significant

Another factor affecting capacity credit for wind and solar is the year-to-year resource variability. Years with unexpected weather events could greatly impact the capacity credit of a resource. Figure 19 presents the ELCC of PV in Colorado Springs from 2011-2016. For most of these years, the capacity value of PV was relatively similar (within 15 percentage points of each other), but in year 2012, the capacity value increased significantly due to wildfires outside of Colorado Springs, which caused increased demand for air conditioning during the day.

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54) A. Mills. (March 2014). Strategies for Mitigating the Reduction in Economic Value of Variable Generation with Increasing Penetration Levels. Lawrence Berkeley National Laboratory

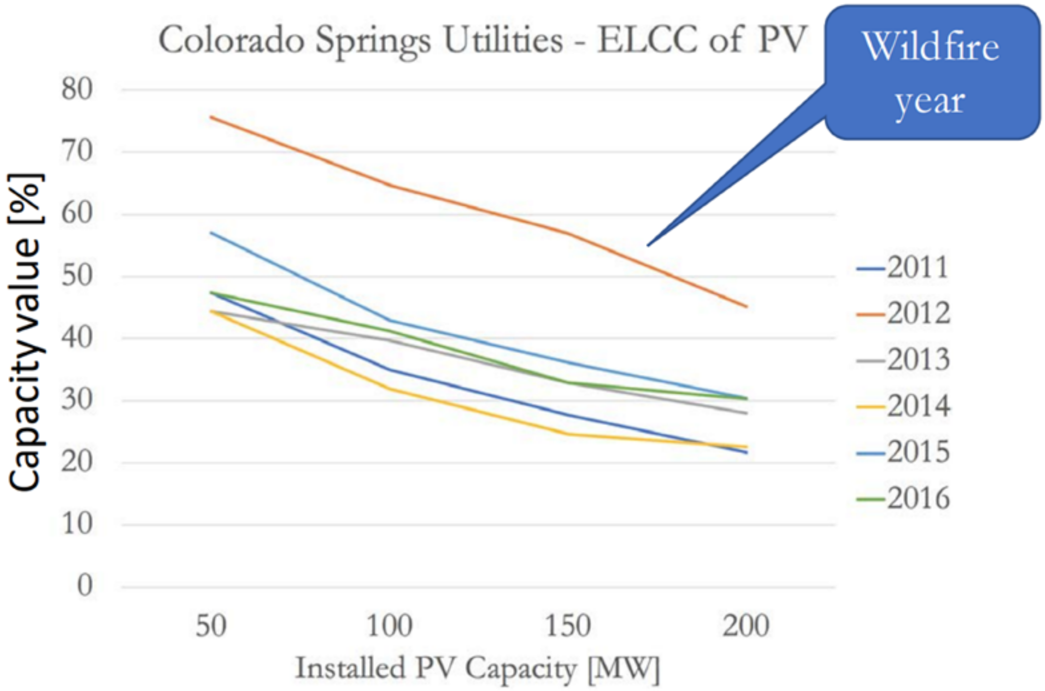

Figure 19. ELCC of PV from 2011-2016 [55]

Appendix 1.5.3: Interconnecting with neighboring systems can reduce capacity needs

Adding transmission that strengthens existing links or adding new links to neighboring systems can reduce the need for installed capacity if operational coordination can also be utilized. This operational coordination is already part of RTO operations.

NREL's Eastern Wind Integration and Transmission Study (EWITS)[56] evaluated several scenarios and found that existing transmission provided 50GW of capacity benefits and the new transmission evaluated in the study provided 8.5GW of capacity benefits. Since "it is highly unlikely that the

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55) Lew, et al. (2017). Solar Program Design Study. GE Energy Consulting. Taken from Lew, D. (April 2020). Webinar #1: Long Term Reliability- Resource Adequacy. Western Interconnection Regional Advisory Body.

56) NREL's Eastern Wind Integration and Transmission Study. Available at https://www.nrel.gov/docs/fy11osti/47078.pdf

balance of resources and load is evenly distributed along the entire footprint, the transmission system can facilitate the transfer of extra generation capacity to the most problematic areas."[57]

Figure 20 compares the ELCC of wind in four different scenarios and for three years (2014-2016), with and without transmission overlay, taken from the EWITS study. The capacity of value of wind fluctuates between 15-35% of nameplate (black bars). The transmission overlay significantly contributes to the capacity value of wind generation, increasing it between 1.3 to 8.5GW in all years and all scenarios. This is possible due to generator diversity, load diversity, and the fact that some surpluses in one location can be used to meet demand in a neighboring region, thus translating into capacity savings.

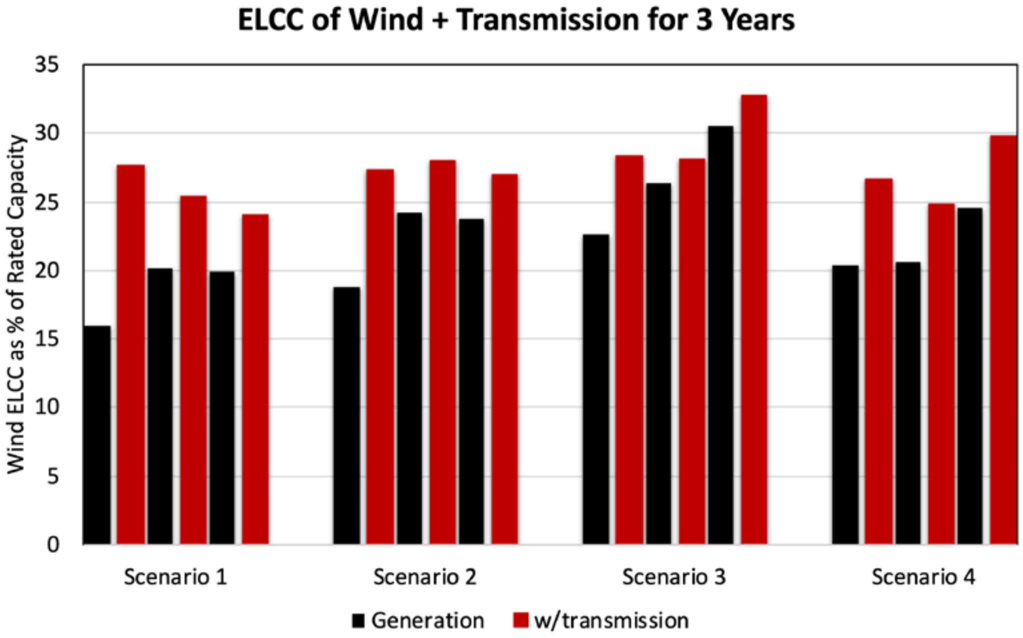

Figure 20. ELCC for high wind penetration scenarios, with and without transmission (2014-2016). Adapted from Eastern Wind and Transmission Integration Study[58]

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57) Ibanez, E.; Milligan, M. (2012). Probabilistic Approach to Quantifying the Contribution of Variable Generation and Transmission to System Reliability: Preprint.Prepared for the 11th Annual International Workshop on Large-Scale Integration of Wind Power into Power Systems as Well as on Transmission Networks for Offshore Wind Power Plants Conference, November 13-15, Lisbon, Portugal; 7 pp.; NREL Report No. CP-5500-56219.

58) Enernex Corporation. (February 2011). Eastern Wind Integration and Transmission Study. NREL/SR-5500- 47078. National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy11osti/47078.pdf

Appendix 1.5.4: Storage and demand response

Storage contributes to resources adequacy, but it is subject to limitations based on its storage capacity. As with all resources, storage capacity value decreases as more batteries are added to the system. In addition, multiple days-in-a-row events (such as low solar) can be problematic if storage is not long-duration. Further, forecast errors can decrease the capacity value of storage.

Demand Response can also contribute to capacity requirements by reducing electricity consumption during peak periods. This could potentially prevent expensive new combustion turbine capacity from being built.

Appendix 1.5.5: Resource adequacy summary

Long-term reliability models are used to assess whether a resource portfolio is likely to be sufficient over some future period. These models calculate the level of resource adequacy that can be expected from a portfolio of resources, and they can therefore be used to help ensure that a reliable power system is designed and built. These same models can be used to assess the contribution of renewable resources. A robust planning process is required, involving a broad group of stakeholders, so that the future grid can attain its reliability objectives.

Appendix 1.6: Long-term Reliability - Renewable Energy Impact Analysis

RTOs perform multiple types of analysis and modeling on potential future grid conditions. With the rapid rise of wind and solar generation in recent years, significant attention has been placed upon evaluating the impact of these renewable resources on power system operations. To carry out these studies, electricity production simulations models are employed, along with high-quality, detailed data sets that include grid configuration, resource characteristics, and estimated future fuel costs and technology costs. The objective of these studies is to provide insight into how the system might best be operated with high levels of renewable resources, and inform transmission expansion planning.

Appendix 1.6.1: MISO Renewable Integration Impact Assessment[59]

MISO has conducted a Renewable Integration Impact Assessment (RIIA)[60] that assesses the impacts of increasing the current levels of renewable generation. The study looks at the impacts of higher levels of renewable generation in increments of 10 percent from 10 to 50 percent with location-specific information. Study results are showing that when the MISO-wide renewable penetration approaches 30 percent, further study is required before moving to higher levels of renewable generation. The 2019 level of renewable energy generation in all of MISO was 8.6 percent.

The study begins the process of identifying changes to the grid that could be made to accommodate higher percentages of renewables. Grid modifications to accommodate more renewables will be carried out through MISO's Long-Range Transmission Planning process and its process of aligning Resource Availability and Need (RAN). The development of battery storage, either at utility scale or incorporated into renewable power plants, also has the potential to solve problems. The RIIA study is an example of proactive, forward-looking analysis that may need to be repeated as the grid continues to evolve.
The following are important MISO RIIA study results:

- **Figure 21** shows the MISO regions. The percentage of expected renewable resources for each of the three regions is significant, while the renewable percentage in MISO North is much higher due to favorable locations for siting wind generation. When the MISO-wide percentage of renewable is 10%, the MISO North percentage is 33%. The MISO-wide case for 30% implies a MISO North renewable percentage of 56%. The MISO study is showing an additional 20,000 MW of wind generation for the 30% renewable case, and the siting map for the generation additions indicates that a significant percentage is expected to be sited in North Dakota.

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59) SPP conducted a similar assessment in 2017. https://www.spp.org/documents/45106/2017%20variable%20generation%20intergration%20study%20(vis)%20-%20170221.pdf

60) See https://www.misoenergy.org/planning/policy-studies/Renewable-integration-impact-assessment/#t=10&p=0&s=&sd=

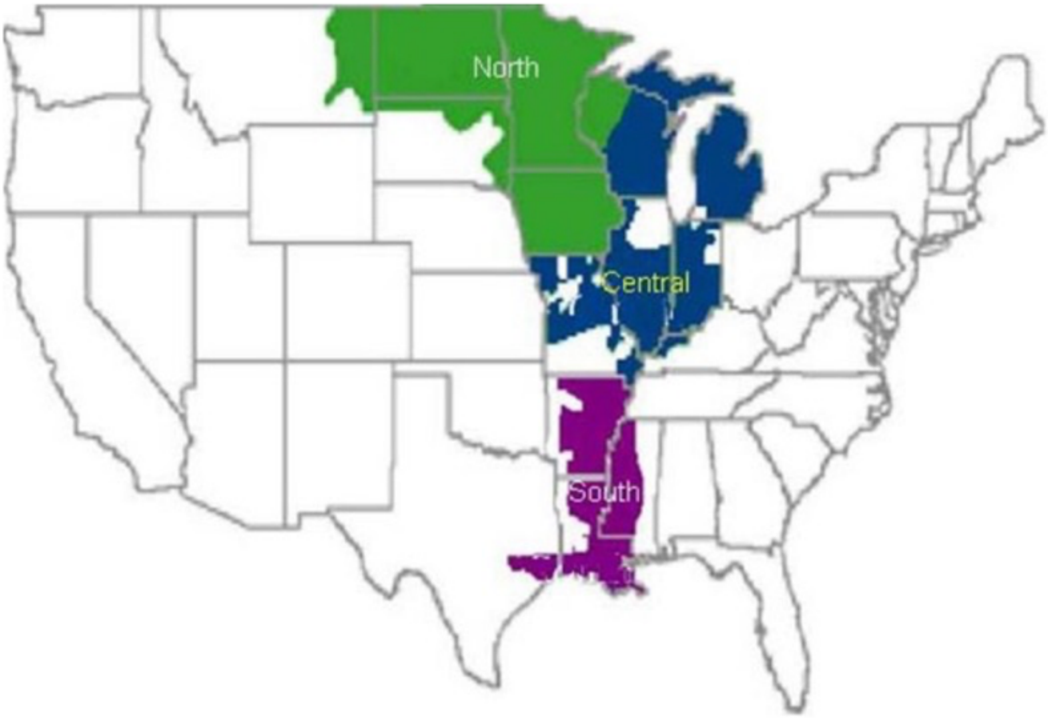

Figure 21. MISO's footprint

- The renewable integration complexity beyond 20 percent has increasing levels of uncertainty in the realm of seven identified areas that were evaluated in the study. **Figure 22**, taken from a MISO presentation[61], shows the summary of the seven criteria showing the impacts on Resource Adequacy, Energy Adequacy, Operating Reliability (steady-state), and Operating Reliability (transient state). This list of issues and concerns needs to be properly addressed before higher levels of renewable energy percentages can be implemented.

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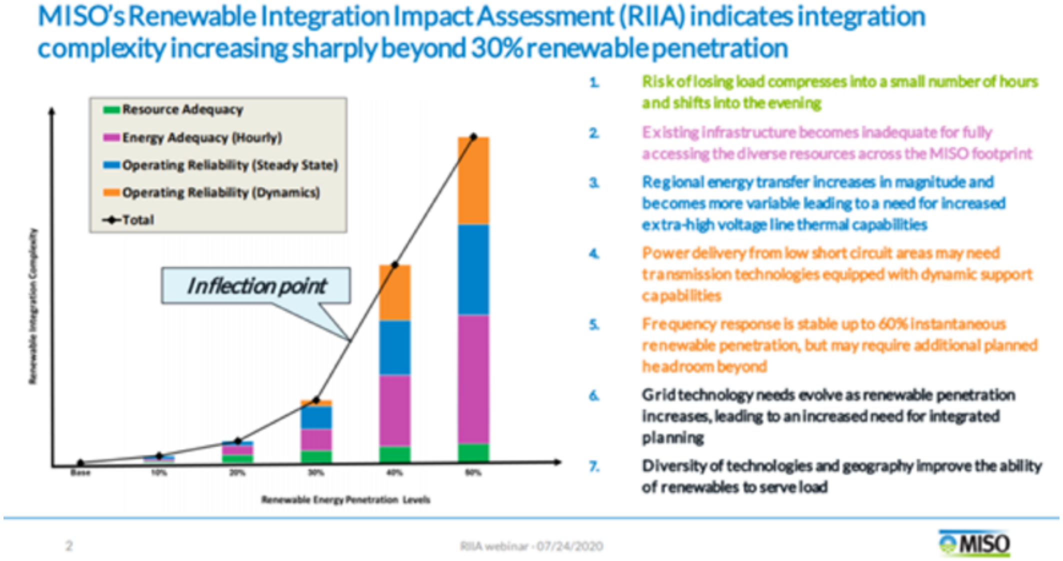
61) MISO RIIA Presentation 7/24/2020 Slide #2. https://www.misoenergy.org/events/renewable-integration-impact-assessment-riia---july-24-2020/



MISO's Renewable Integration Impact Assessment (RIIA) indicates integration complexity increasing sharply beyond 30% renewable penetration

1. Risk of losing load compresses into a small number of hours and shifts into the evening
2. Existing infrastructure becomes inadequate for fully accessing the diverse resources across the MISO footprint
3. Regional energy transfer increases in magnitude and becomes more variable leading to a need for increased extra-high voltage line thermal capabilities
4. Power delivery from low short circuit areas may need transmission technologies equipped with dynamic support capabilities
5. Frequency response is stable up to 60% instantaneous renewable penetration, but may require additional planned headroom beyond
6. Grid technology needs evolve as renewable penetration increases, leading to an increased need for integrated planning
7. Diversity of technologies and geography improve the ability of renewables to serve load

2

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MISO

Figure 22. Key results from MISO's RIIA

Appendix 1.6.2: Impact of Increasing Renewable Penetration

Electric utilities have typically described renewable implementation in terms of a percent of their total load that is being served by renewable resources on an annual basis. As an example, a utility that has 3,000,000 MWh of load with a 30% renewable portfolio has 900,000 MWh of renewable energy. The balance of 2,100,000 MWh comes from other, non-renewable resources. Figure 23 shows the hourly load shape and wind shape for a representative dataset based on the MISO hourly load and wind generation data from 2018. The wind shape fits within the resource need for the load shape, and the balance of resources used to serve the load is met from other generation resources.

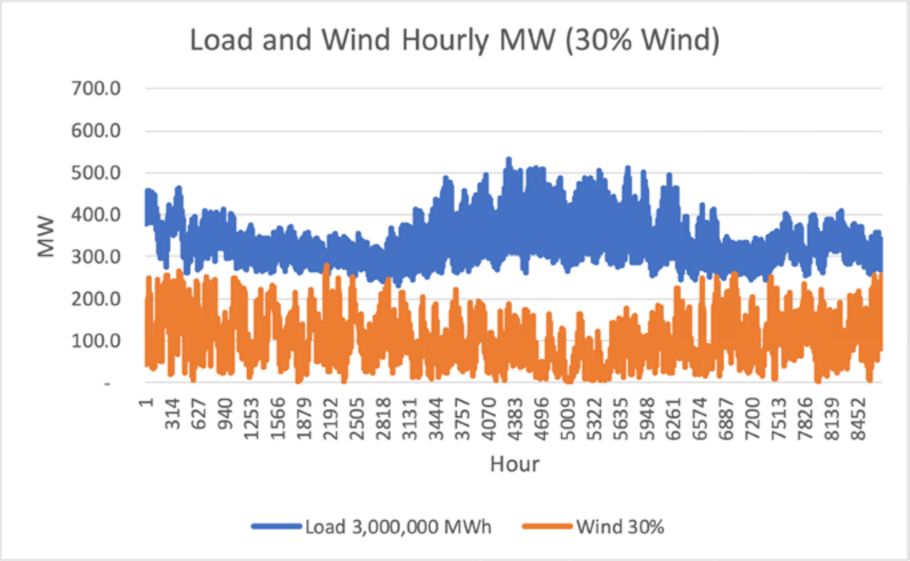


Figure 23. Example wind and load shape from MISO, 30% wind

If the resource portfolio objective for this example load-serving entity was increased to a 70% goal, where the annual amount of resources used to serve load is now increased to a total of 2,100,000 MWh (70% * 3,000,000), the shape of the resource mix changes dramatically, as shown in **Figure 24**.

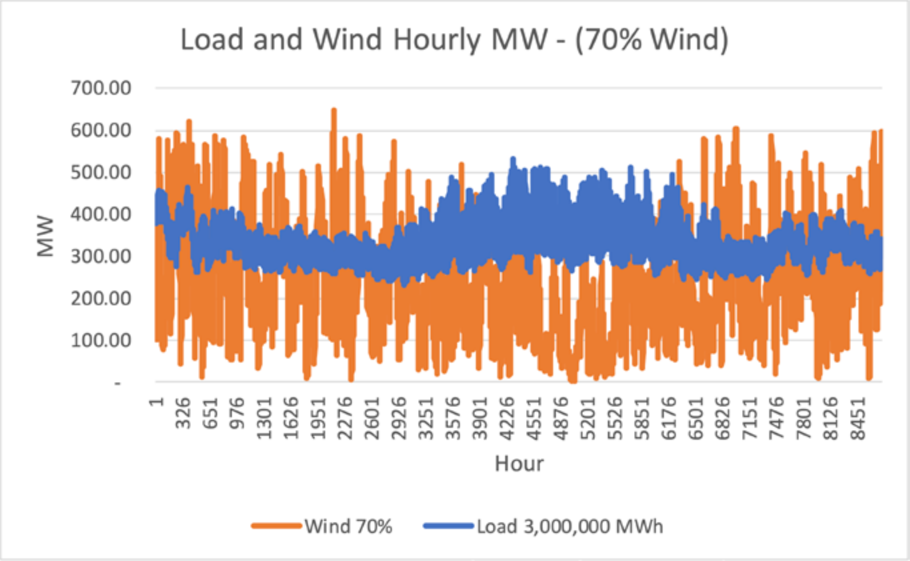
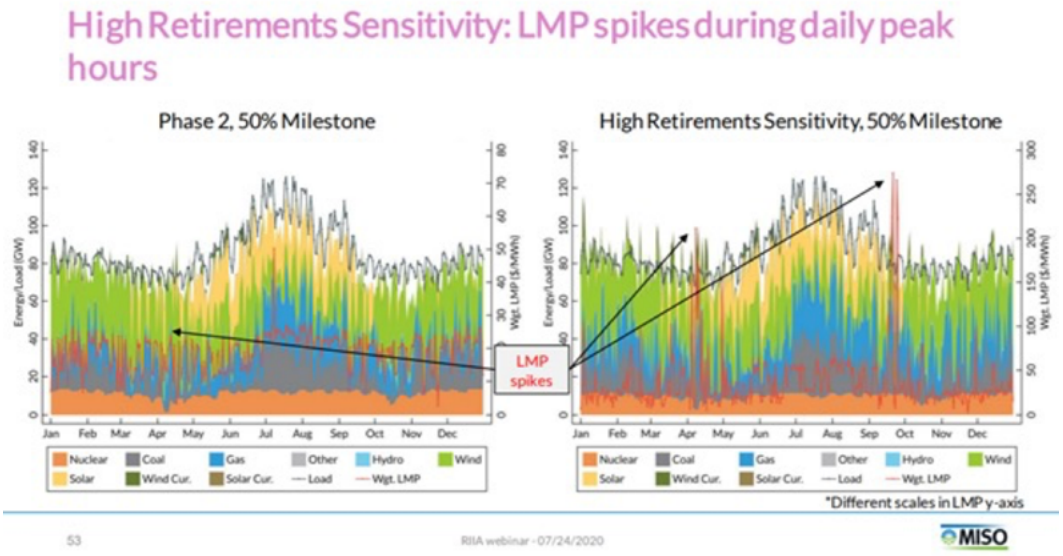


Figure 24. Example wind and load shape from MISO, 70% wind

The first observation is that there are a number of hours when the wind is much lower than the load, so the dependency on other resources is significant. There are also many hours when the wind generation is greater than the load. This causes the power to be exported to serve other loads or decreases the dispatch of other resources in the absence of significant levels of storage. If this entity was a small part of the overall system (in this example, it is only 0.44% of the MISO load), the rest of the MISO system would easily adapt and continue to maintain the system energy balance. The challenge that MISO faces is that if the all its members would desire to have this same objective, the MISO system would be requiring the rest of the electric grid to supply energy during the hours when the wind was not enough to serve the load and to back down its generation portfolio when the wind generation was higher than the MISO load. The amount of variance would be extremely challenging to fit into the real-time requirements of system dispatch. If this situation begins to develop, the resource mix may need to evolve to accommodate the higher level of renewables.

In summary, the objective of having a higher percentage renewable portfolio for part of the system is feasible with the rest of the system absorbing the dispatch, but requiring all load-serving entities to have a high renewable objective at the same time is extremely challenging. The MISO RIIA results show increasing challenges in this realm for overall renewable percentages greater than 30%. However, it is important to note that potential cost reductions in storage that lead to significant storage on the grid will have a favorable impact.

Figure 25 shows a MISO RIIA chart with a high level of renewable resources and high retirements. The periods of not having adequate resources in early April and mid-September are shown having a high market price spike. In February when the resources were higher than the load, it resulted in very low market prices and in higher exports of energy from MISO.



High Retirements Sensitivity: LMP spikes during daily peak hours

*Different scales in LMP y-axis

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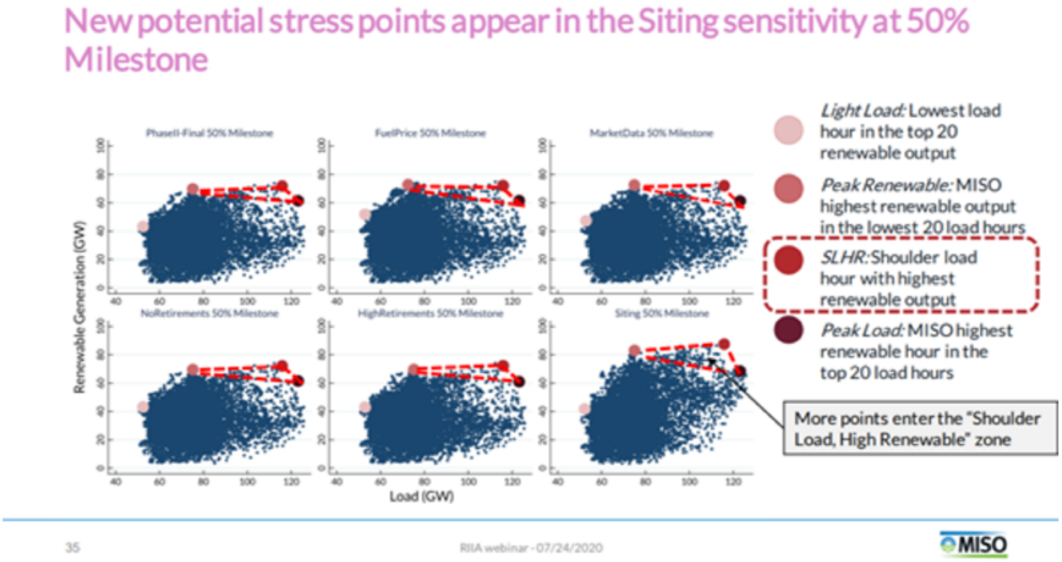
Figure 25. High retirements and LMPs from MISO's RIIA

There are a number of occurrences in the RIIA analysis where the hourly percent of renewable resources are in the range of 80-90% of the hourly load level, as shown in **Figure 26**. These hours have been identified as being potentially unstable, which would require curtailment of renewables unless the fast frequency response capability of the renewables can be shown to provide sufficient stability. The high percentage of renewable energy that is grid-following creates a situation where small variances in the generation and load could cause the generation to get out of sync with the load. Grid operators at the RTO would need to be prepared to curtail renewable generation and increase fossil generation in this situation. This phenomenon is essential to properly model in order to understand the viable solutions to this complex interaction of real-time delivery on the electric grid when considering high levels of renewable energy implementation and is currently an ongoing topic of significant research and analysis.



New potential stress points appear in the Siting sensitivity at 50% Milestone

● *Light Load:* Lowest load hour in the top 20 renewable output

● *Peak Renewable:* MISO highest renewable output in the lowest 20 load hours

● *SLHR:* Shoulder load hour with highest renewable output

● *Peak Load:* MISO highest renewable hour in the top 20 load hours

More points enter the "Shoulder Load, High Renewable" zone

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Figure 26. MISO's analysis of potential stress points from RIIA

Studies such as this allow grid planners and operators to assess potential future problems and develop solutions, therefore avoiding reliability problems.

Appendix 1.6.3: Summary: Renewable Energy Impact Analysis

Wind and solar energy can provide capacity value, and this can be calculated with a long-term reliability model. There are many factors that influence the capacity contribution calculations, including the penetration level of renewables, inter-annual variability, and transmission connections to other electrical regions.

Appendix 1.7: General Reliability Summary

Existing processes that are in place at utilities and RTOs ensure that the grid will operate reliably. Short-term reliability, or grid services, can be provided by renewable resources. Renewables can potentially provide better disturbance response than large conventional generators. As the grid evolves, it is vital that the need for grid services is accurately assessed, and that the ability of all resources to provide grid services, to the extent they can, is accounted for.

Medium-term reliability includes day-ahead and real-time dispatch. The generators scheduled to run in the forward commitment period can withstand any credible outage. System operators utilize state-of-the-art forecasting for wind and solar resources, and they incorporate those forecasts into routine operational practice. Sufficient contingency reserves, flexibility reserves, and other operating reserves ensure reliable operations across multiple credible contingencies or operational challenges.

Long-term reliability, a planning process, involves reliability assessments of each possible future resource mix, and portfolios that are shown to be unreliable are not adopted. A necessary condition of a prospective resource mix is that it must be able to be operated reliably and cost-effectively. Planning and operational models are utilized to ensure operational feasibility. A robust planning process is required to fulfill these objectives, and participation by utilities, RTOs, and other stakeholders is part of the process.

Appendix 2: MISO and SPP Interconnection Processes

Appendix 2.1: MISO Generator Interconnection Process

MISO has a 3-phase Definitive Planning Phase (DPP) generator interconnection process that is 505 days long. After the annual Generator Interconnection Request (GIR) application deadline has passed, valid interconnection requests proceed through the structured DPP phases which all generally have the following steps: model build/verification, group System Impact Study (SIS), and Interconnection Customer (IC) Decision Point. Throughout the process, ICs must make milestone payments to continue into the next phase and have some limited opportunities to reduce their project size or downgrade their request from Network Resource Interconnection Service (NRIS) to Energy Resource Interconnection Service (ERIS). ICs can withdraw their requests at any point in the process with amount of refundable milestone payments reducing the further along the request proceeds. After DPP3, the remaining IC requests proceed to the Generator Interconnection Agreement (GIA) phase.

During the various study phases, MISO coordinates with neighboring RTOs and they perform Affected Systems Studies to determine if the MISO generator interconnection (GI) request has an adverse impact on their systems that requires mitigation.

Appendix 2.2: SPP Generator Interconnection Process

SPP has a new 3-phase Definitive Interconnection System Impact Study (DISIS) generator interconnection process that is 485 days long. After the annual GIR application deadline has passed, valid interconnection requests proceed through the structured DISIS phases. Phase 1 includes a study deposit and financial security 1, steady-state analysis, and decision point 1. Phase 2 includes financial security 2, stability and short-circuit analysis, and decision point 2. Phase 3 includes financial security 3, facilities study, and decision point 3.

Throughout the process, ICs have some limited opportunities to reduce their project size, downgrade their request from NRIS to ERIS, or make a turbine/inverter change. ICs can withdraw their requests at any point in the process with the amount of refundable milestone payments reducing the farther along the request proceeds. After decision point 3, the remaining IC requests proceed to the GIA phase.

During the various study phases, SPP coordinates with neighboring RTOs and they perform Affected Systems Studies to determine if the SPP GI request has an adverse impact on their systems that require mitigation.

Appendix 2.3: MISO-SPP Seams Coordination

Both MISO and SPP have members in North Dakota, among other states, and therefore a shared boundary or seam exists where coordination takes place between the parties. With respect to GIR coordination, MISO and SPP participate in each other’s GIR as Affected Systems. This coordination must respect the queue priority of the interconnection requests along with the processes of the other party. Through the Affected System Studies, MISO evaluates the impact of SPP GIRs on MISO transmission facilities; similarly, SPP evaluates MISO GIR impacts on its transmission facilities.

Appendix 2.4: Generator Interconnection Queues

Currently, there are 46 projects totaling 8,352.2 MW located in the state of North Dakota that are in the Generation Interconnection study processes within MISO (22 projects, 4,213.8 MW), SPP (18 projects, 2,787.2 MW), and Minnkota Power Cooperative (MPC) (6 projects, 1,351.2 MW). These include 31 wind projects totaling 6,001.1 MW (MISO 15 projects, 2,953.8 MW; SPP 12 projects, 2,046.1 MW; and MPC 4 projects, 1,001.2 MW); 13 solar projects totaling 2,232 MW (MISO 7 projects, 1,260 MW; SPP 4 projects, 622 MW; and MPC 2 projects, 350 MW); one battery project (74.1 MW); and one gas project (45 MW).

Appendix 2.5: Models

MISO and SPP both start from Eastern Interconnection Reliabiity Assessment Group (ERAG) Multiregional Modeling Working Group (MMWG) reliability base models from which they develop their own independent generator interconnection study models. While the purpose of these models is to study the impacts of the new interconnection requests on the respective MISO or SPP facilities, the Eastern Interconnection is one large interconnected system and a more coordinated GIP model development process would make for more consistent results for generator requesting interconnection along the MISO-SPP seam.

Appendix 2.6: Generation Dispatch

Generation dispatch of interconnection request projects is another area where MISO and SPP differ in their methodologies. For example, MISO dispatches active cycle wind projects at 15.6% in the summer peak models and 100% in the shoulder peak models. SPP dispatches active cycle wind projects at 20% in low-variable energy resource models for In Group Summer and Winter peak models and 100% in high-variable energy resource models for all In Group seasonal models and 20%

for all Out Group HVER models except the Light Load model where the dispatch is 10%. With the differences in generation dispatch on either side of the seam, it may be more advantageous to request interconnection with either MISO or SPP if a project is near the seam.

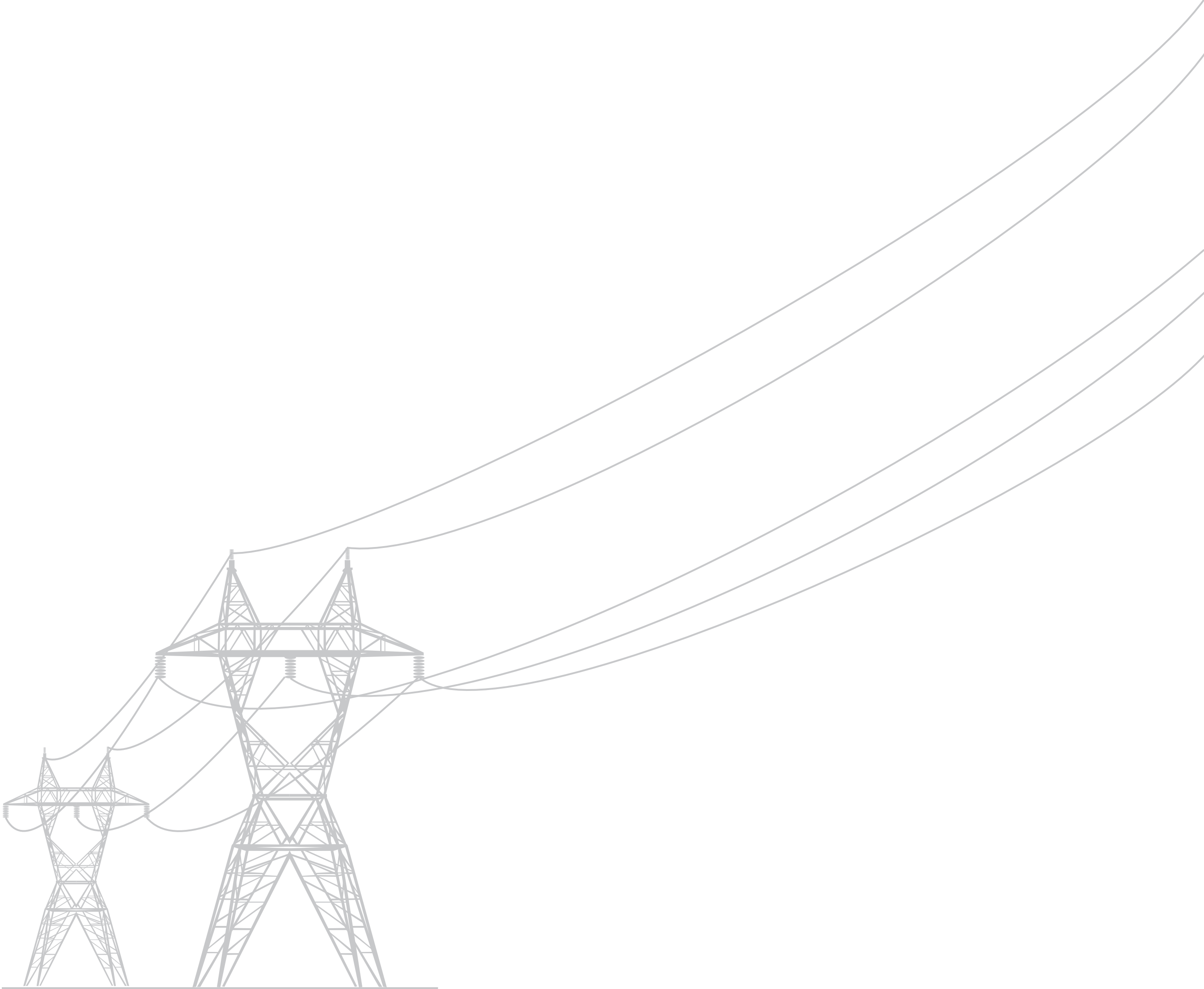
Appendix 2.7: Network Upgrades

Network upgrades are identified in the System Impact Studies performed by MISO and SPP on their facilities for their own GI studies and as Affected Systems for neighboring region GI studies. This approach is appropriate but can lead to Network Upgrades being assigned as mitigation that do not get modeled for subsequent analysis due to the timing of the Affected Systems studies sometimes being delayed beyond the next decision point for the IC. This can lead to ICs having to make decisions without knowing all the required network upgrades and in some cases taking on financial risks or forfeiting the opportunity to receive a refund of some of their milestone payments.

Appendix 2.8: Study Delays

Finally, with the very large generator interconnection queues, the MISO and SPP studies have been experiencing delays adding additional pressure to the ICs seeking to secure production tax credits (PTCs) and execute power purchase agreements (PPAs). This has created a backlog of interconnection requests waiting to be studied, resulting in significant delays in providing study results. For example, as of October 9, 2020, SPP estimates that an interconnection request that was submitted by April 30, 2020 into the DISIS-2020-01 study cycle will receive its final study results by March 20, 2025. Similarly, as of October 1, MISO estimates that a project which applied for interconnection by June 25, 2020 for inclusion in the DPP-2020-Cycle 1 study cycle will complete the study process by May 27, 2022. Studies in MISO West, including North Dakota, are coordinated between MISO and SPP; study delays in either RTO may delay studies in the other.

Many factors have contributed to these study delays, including timing issues between the overlapping 3-phase study approaches, the need to perform restudies when ICs reduce or withdraw their interconnection requests for various reasons, the inability to make up time for portions of the generator interconnection process that have prescribed time allocated in the FERC-approved tariffs, the need to coordinate studies between MISO and SPP, and a variety of other reasons. MISO and SPP have been working with stakeholders to minimize study delays, but under the current procedures, some delays seem inevitable.



GRID RELIABILITY IN NORTH DAKOTA