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# Review of Grid Stability Concerns in the 2024 Xcel IRP

For Clean Grid Alliance, Fresh Energy, Minnesota Center for Environmental Advocacy, and the Sierra Club (Intervening as "Clean Energy Organizations")

TELOS ENERGY

August 9, 2024

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# 1 Executive Summary

In its February 1, 2024 Integrated Resource Plan (IRP), Xcel performed analysis to evaluate how the grid would perform in the absence of baseload generation. This analysis, captured in Appendix D1: Inertial Floor Study Report, considers the retirement of four units: Sherco #1 (Coal), Sherco #2 (Coal), Sherco #3 (Coal), and King (Coal). In this report, Xcel identified dynamic stability as a critical issue to address. Telos Energy has reviewed the report and agrees that system stability is an important aspect of the overall goal of maintaining system reliability. Further, Telos identifies many highly effective approaches for managing stability and achieving a reliable system, including not only conventional technologies with rotating machinery, but also inverter technologies with the latest functionality.

Telos strongly encourages that all technologies, including more recent grid forming (GFM) inverter-based resources (IBRs), be given equal consideration when determining the most cost-effective portfolio for meeting system needs for stability and reliability. This report describes in detail the comparison between synchronous machines and GFM IBR, including performance in real world examples. GFM IBRs can provide similar, and in some cases better grid services, including inertia response, damping, and voltage support, as compared to synchronous machines. There are some circumstances where synchronous machines still outperform GFM technology, however the Xcel documents evaluated by Telos[1] do not demonstrate that these conditions are present in Xcel's Minnesota system.

In addition to providing valuable comparisons of performance of synchronous machines and GFM IBR, Telos provides a review of Xcel's Appendix D1: Inertial Floor Study Report. Telos finds that no inertial floor was established and that unsupported conclusions have been drawn from the simulation results performed by Xcel. Most notably, the dynamic simulations performed by Xcel did not show a risk of system collapse, though Xcel described the results as evidence of "system collapse," which would be an extremely severe risk to the grid. Therefore, the report does not substantiate a need for retaining synchronous machine technology.

Given the importance of system reliability and the gravity of statements regarding risk of "system collapse," Telos offers this evaluation of Xcel's Inertial Floor Study to provide needed transparency into Xcel's analysis, clarify for the Commission and stakeholders that such risks are not demonstrated by Xcel's analysis, and describe the role GFM IBRs can provide to ensure grid reliability.

[1] Appendix D1 2023 Inertial Floor Study Report; Appendix M1_NSP Nuclear Leave Behind Study Report_TRADE SECRET

## 2 Understanding Challenges of Dynamic Stability

In its recent IRP filing, Xcel has performed analysis captured in Appendix D1: Inertial Floor Study Report to evaluate how the grid would perform in the absence of baseload generation including retirement of Sherco #1 (Coal), Sherco #2 (Coal), Sherco #3 (Coal), and King (Coal). Xcel identified dynamic stability as a critical issue to address for future cases involving substantial retirements of conventional resources. At the same time, Xcel has proposed the interconnection of new combustion turbines in the currently ongoing firm dispatchable procurement: two 210 MW combustion turbines at the Bison generating station[2] and two 210 MW combustion turbines at the Lyon generating station.[3] One of these proposed combustion turbines is intended to be located along a "generation tie-line" connecting to the Sherco facility, to enable re-use of interconnection rights, and Xcel has alleged such a resource is needed to maintain stability on the line.[4] Telos agrees that stability is a paramount concern in modern power systems, particularly with the integration of many generation sources on long lengths of transmission lines. Telos acknowledges the significant challenges faced in maintaining dynamic stability for any resource type, especially as the steady-state power transfer limit is approached. While challenging, maintaining stable operation of the proposed tie-line with renewables is considered within the state of the art for the industry.

Understanding the stability of power systems, particularly in the context of long transmission lines, can be facilitated by using the analogy of a spring and mass system. The stability of the power grid involves dynamic interactions between generation sources (analogous to the mass) and the transmission network (analogous to the spring). The analogy applies in many ways including by looking at the stiffness of the spring, the mass applied to the end of a spring, and damping in the system:

1. Stiffness of the Spring (Transmission Line Impedance): Like a spring's stiffness resisting deformation, a transmission line's impedance resists electrical flow. Shorter lines (stiffer springs) are more stable, while longer lines (weaker springs) can cause instability.

2. Mass (Generation Sources): Generation sources are the mass. Larger units have more inertia, slowing power flow changes, while smaller, distributed sources change power flows faster. Both can be stable or unstable.

3. Damping (System Controls and Stabilizers): Damping in power systems comes from grid elements and connected resources. Transmission lines and transformers provide moderate damping, with additional damping from power system stabilizers in conventional plants and stabilizing controls in inverter-based resources (IBRs) like wind, solar, and batteries.

[2] Xcel Energy, Proposals for Competitive Resource Acquisition Process for up to 800 Megawatts of Firm Dispatchable Generation, January 22, 2024, Docket No. E002/CN-23-212, at 1.
[3] Ibid.
[4] Reply Comments 2020-2034 Upper Midwest Integrated Resource Plan, Xcel Energy, Section 2J, Page 52, Docket No. E002/RP-19-368: https://www.xcelenergy.com/staticfiles/xe-responsive/Company/Rates%20&%20Regulations/Resource%20Plans/Upper%20Midwest%20Energy%20Plan%20-%20Reply%20Comments.pdf

Dynamic stability means the system can withstand and recover from disturbances. For a spring and mass system, this means the mass returns to equilibrium. In power systems, it ensures voltage and power flows return to their nominal values after a disturbance, such as a fault or a sudden change in load.

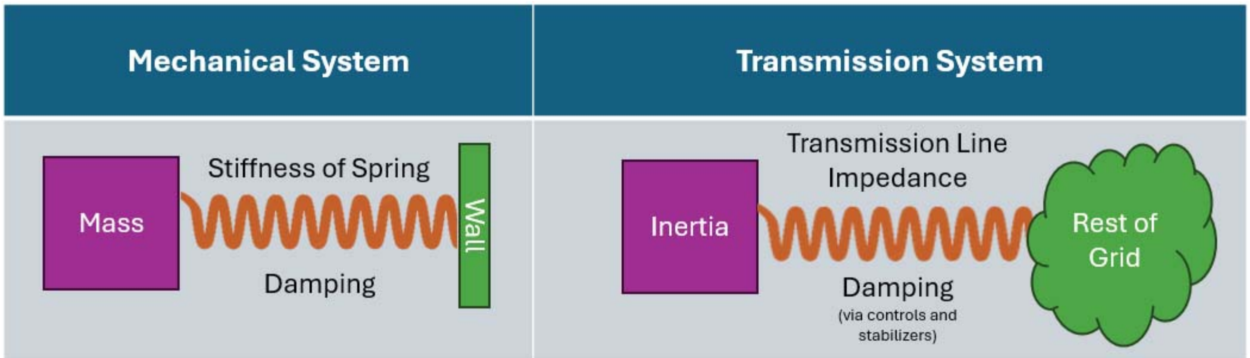


**Figure 2-1: Spring Mass Power System Analogy**

The spring analogy can help to illustrate potential concerns with increased transmission line length, including the need for damping, managing deviations, and avoiding system collapse. Just as a spring system needs damping to prevent continuous oscillations, a power system requires effective damping to stabilize voltage and power flows after disturbances. Without sufficient damping, the system can experience sustained oscillations, leading to instability. The spring in the analogy should not move excessively, and similarly, deviations in power, voltage, and angle should remain within reasonable limits. Large changes can stress the system, potentially leading to failures. In the spring analogy, a spring breaking is akin to a grid separation in the power system, which would be a severe and unacceptable failure.

Long transmission lines introduce complexities due to their higher impedance, leading to increased voltage drops and potential oscillations. These lines and high power transfer levels amplify instability risks, making it crucial to maintain precise control over voltage and frequency. Advanced technologies and robust control strategies are necessary to mitigate these risks, ensuring a resilient and reliable power grid. Fortunately, the industry has made tremendous strides in recent years with technologies and control strategies maturing to the point of commercial deployment already occurring around the world.

# 3 Classes of Technology Available to Address Challenges of Proposed Interconnections

There are multiple classes of technologies available to mitigate dynamic stability concerns, including grid forming (GFM) inverter-based resources (IBR), which could include wind, solar, and battery projects. This section of the report discusses both synchronous machine resources, such as the synchronous machines proposed by Xcel, and GFM IBR culminating in a comparison of relevant performance highlights.

## 3.1 Synchronous Machines

Synchronous machines, including the Bison and Lyon combustion turbines proposed by Xcel, are technology options which provide performance characteristics important to grid stability. Synchronous machines exhibit significant inertia because of their rotating mass, which helps to slow changes in the grid by resisting rapid changes in power flow and frequency. This large signal stability is crucial during fault events or other substantial disturbances, where coordinated protective relays and auxiliary equipment ensure that the machines trip only when necessary and ride through expected disturbances. Additionally, synchronous machines contribute to small signal stability due to the persistence of the magnetic field within the machine that resists sudden changes and through automatic voltage control systems (AVRs). It is also noted that AVRs may require supplementary devices like power system stabilizers to mitigate potential instability arising from interactions between the excitation system and machine dynamics. The combination of hardware, characterized by the physical inertia of the rotor and the “magnetic inertia” in the steel core of the machine, enables synchronous machines to effectively reduce oscillations and maintain both large and small signal stability. For this reason, grid operators have relied on synchronous machines including coal and gas fired plants to provide system stability for over a century.

## 3.2 Grid Forming Inverter-Based Resources (GFM IBRs)

GFM IBRs represent a significant technological advancement in enhancing dynamic stability of grids through the behavior of the resources that interconnect to the grid. Field experience and studies have proven that in the absence of supplemental synchronous machine-based solutions, GFM will be necessary and able to maintain stable operation.[5] Unlike traditional grid-following (GFL) inverters, which make up nearly all of the installed base of IBR around the world today, GFM IBRs are able to incorporate the best services of synchronous machine technology along with the flexibility of GFL technology. The characteristics of GFM enable these inverters to provide immediate and robust responses to changes in the external system, effectively supporting large signal stability during fault ride-through events and other significant disturbances. Additionally, GFM IBRs enhance small signal stability through finely tuned control software that can dynamically adjust to minor grid fluctuations, ensuring smooth and stable operation. By mimicking the stabilizing effects of synchronous machines without the associated damping issues, GFM IBRs offer a flexible and resilient solution for integrating renewable energy sources while maintaining grid stability. Their ability to synchronize with other grid devices and regulate both active

[5] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_Grid_Forming_Technology.pdf

and reactive power further underscores their critical role in supporting the dynamic stability and reliability of increasingly complex power systems.

## 3.3 Relative Comparison of Performance – Synchronous Machines v. GFM IBRs

This section of the report considers the advantages and disadvantages of synchronous machines compared to GFM IBRs for relevant performance indicators. The performance comparison is summarized in Figure 3-1, where a green dot represents advantage of one machine type over the other for each performance metric considered.

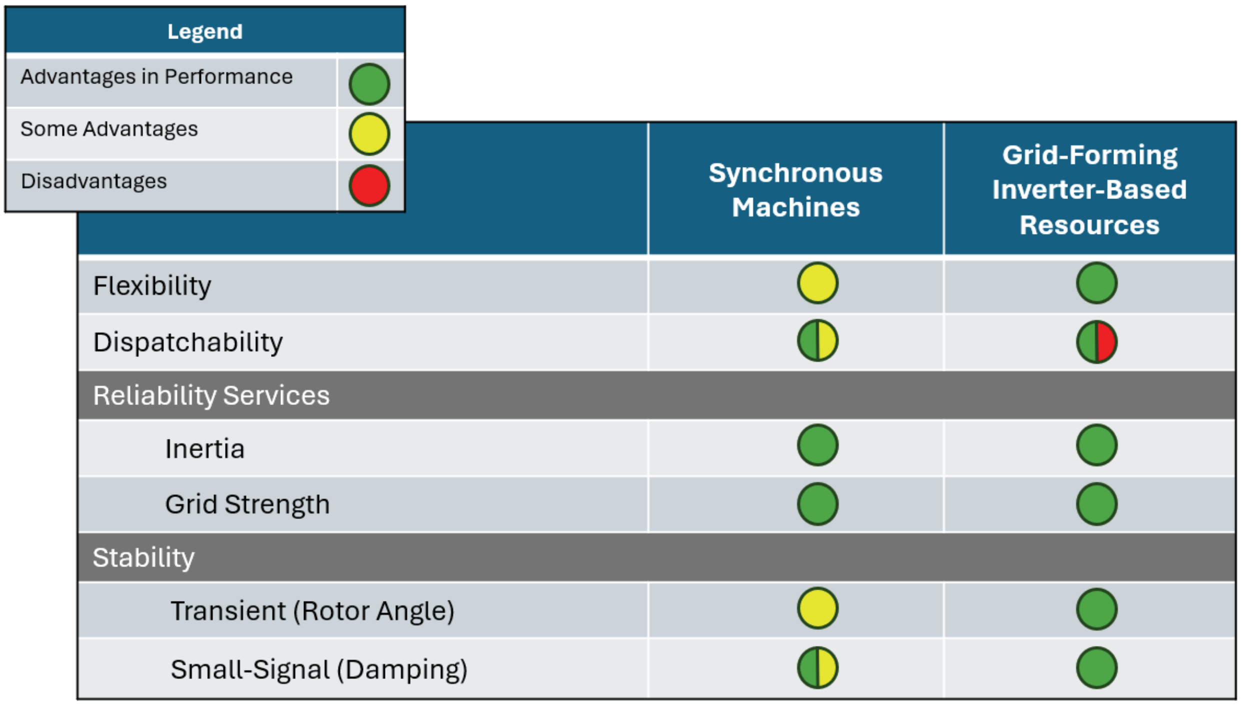


**Figure 3-1: Summary of Comparison of Performance - Synchronous Machines v. GFM IBRs**

### 3.3.1 Flexibility

GFM IBRs offer more flexibility in start-up and ramping compared to synchronous machines due to their software-defined controls and power electronics. While synchronous machines are constrained by their physical construction and inherent mechanical properties, IBRs can be precisely tuned to achieve desired functionalities. This allows GFM IBRs to respond to changes in system conditions much more rapidly and effectively than traditional synchronous machines, which are not able to ramp power up or down quickly or start quickly, relative to battery-based IBR technology. With the broad flexibility of GFM IBRs, these resources will likely be able to provide services more efficiently than synchronous generators have historically.[6]

[6] https://www.esig.energy/wp-content/uploads/2022/03/ESIG-GFM-report-2022.pdf

### 3.3.2 Dispatchability

Synchronous machines, particularly gas turbines, offer advantages in dispatchability by being able to follow power references from system operators at any time fuel is available, unlike inverter-based resources that depend on weather conditions and state of charge. However, despite their dispatchability, synchronous machines are not infallible and have experienced failures during storms, as reported by MISO among other grid operators. During winter storm Elliot in 2022, the unavailability of gas supply contributed to increased unplanned outages which pushed MISO into emergency procedures.[7] MISO analysis finds that although fuel issues during winter storm Elliott contributed significantly to unplanned gas generation outages, wind output was significantly above average during the storm.[8] Although synchronous machines are historically considered to have advantages over GFM IBR in dispatchability, they cannot be considered perfect or always available for dispatch as exhibited during recent storm examples.

Planning and operating practices, with integrated forecasting, enable system operators to effectively manage the variability of wind and solar resources and battery state-of-charge. The grid (and load) has always been variable and thus relies on forecasting to operate effectively as a matter of course.[9] Adding wind and solar resources into the mix does have an impact however is not a new concept to grid operators and planning, both in day-ahead and real-time.

### 3.3.3 Reliability Services

**Inertia**

Both synchronous machines and GFM IBRs provide inertia support, with synchronous machines relying on the kinetic energy of rotating masses and GFM IBRs relying on rapid power controls to maintain stability. Although GFM IBRs do not have traditional mechanical inertia, their response time is fast enough to stabilize power swings. As long as sufficient headroom exists through pairing with energy storage devices or pre-curtailing[10], GFM can simulate the dynamics of synchronous machine inertia; it has been shown that GFM IBRs can respond more quickly than inertia-based synchronous machines.[11]

**Grid Strength**

Both synchronous machines and GFM IBRs contribute to grid strength, with synchronous machines offering immediate corrective responses to voltage deviations, while GFM IBRs stabilize voltage magnitude and provide rapid responses to changes in terminal voltage.

[7] https://cdn.misoenergy.org/20230117%20RSC%20Item%2005%20Winter%20Storm%20Elliott%20Preliminary%20Report627535.pdf

[8] https://cdn.misoenergy.org/20230321%20Markets%20Committee%20of%20the%20BOD%20Item%2005%20MISO%20Operations%20Report628273.pdf

[9] https://www.energy.gov/sites/default/files/2023-08/Balancing%20Authority%20Backgrounder_2022-Formatted_041723_508.pdf

[10] https://www.nerc.com/comm/PC/InverterBased%20Resource%20Performance%20Task%20Force%20IRPT/Fast_Frequency_Response_Concepts_and_BPS_Reliability_Needs_White_Paper.pdf

[11] https://www.nrel.gov/docs/fy21osti/73476.pdf

**Blackstart**
Telos evaluated and provided a detailed discussion of the potential for GFM IBR to provide blackstart capabilities during Xcel's last IRP (Docket 19-368).[12] In part, that report states, "battery technology, when equipped with grid-forming (GFM) controls, can absorb reactive power and can also supply the reactive power needed to energize lines and transformers, and start motors and other power plants….There is no question that battery technology – if designed appropriately and operated with a sufficient state of charge – can perform blackstart functions." [13]

### 3.3.4 Stability

**Angular (Synchronism)**
GFM IBRs have an advantage over synchronous machines in angular stability because of their fast response time and flexibility to respond to changes in grid conditions. Their power electronics allow for quick adjustments in output, helping to stabilize rotor angles and prevent large deviations during transient events. Unlike synchronous machines which rely on the mechanical inertia of rotating masses for stability, IBRs do not have the same mechanical constraints. This allows IBRs to adjust their output and provide stabilizing responses more dynamically, without working through physical inertia, which can become an impediment to stability in certain circumstances.

**Small Signal (Damping)**
Both GFM IBRs and synchronous machines with power system stabilizers can provide a damping response and mitigation to improve small signal stability. In the spring-mass analogy discussed in Section 2 above, damping comes from both grid elements and connected resources through system controls and stabilizers. Just as a spring system needs damping to prevent continuous oscillations, a power system requires effective damping to stabilize voltage and power flows after disturbances. Damping corresponds to the system's inherent resistance to oscillations, dissipating energy to stabilize the system after a disturbance.

It is well understood in the industry that synchronous machines tend to have poor damping unless they are equipped with a special device called a power system stabilizer, which can improve the damping of synchronous machines to moderate levels. Conversely, GFM IBRs have stabilizing controls that allow for these resources to quickly adjust output and counteract fluctuations.

[12] Telos Energy "Review of Xcel's Reply Comments," filed October 15, 2021 as Attachment 2 to the Clean Energy Organizations Supplemental Comments, MPUC Docket E002/RP-19-369: https://minnesotapuc.legistar.com/View.ashx?M=F&ID=10396496&GUID=4B2CAEB7-EEAA-4DA8-BE03-2489370EFC56
[13] *Id*, p. 11

# 4 Industry Calls for More GFM Technology Deployment

GFM has been an important topic in research and development as it's recognized as an effective technology for enabling IBRs to provide the critical stability services that were previously only available from synchronous machinery. Studies and now industry experience both showcase how GFM allows grids dominated by IBRs to maintain stable operation.

In a 2023 white paper, NERC recommended that all new bulk power system (BPS) connected battery energy storage systems (BESS) have GFM controls.[14] NERC continues through the white paper to show how GFM BESS in particular presents a unique opportunity to support system stability (transient, oscillatory, voltage) with a relatively low incremental cost. GFM IBR technology is commercially available and known for improving grid conditions including in the example experiences referenced in Section 5, either deployed or under construction.

On the topic of defining specifications for GFM IBRs and providing requirements from both a power-system level as well as functional requirement, the industry understands the importance of unity and delivering clear specifications to OEMs. The Universal Interoperability for Grid-Forming Inverters (UNIFI) Consortium, funded by the Department of Energy, published a second version of GFM specifications in March 2024, aiming to provide guidelines to inverter manufacturers regarding an approach to designing and implementing new products.[15] These UNIFI specifications provide guidance on topics including autonomously supporting the grid, dispatchability, providing positive damping of voltage & frequency oscillations, and operation in grids with low system strength, among others.

MISO published a white paper in June 2024, calling for specific GFM BESS capabilities and performance.[16] This white paper, anticipated to be finalized in November 2024, is in concert with NERC's on-going efforts. In addition to the UNIFI Consortium specifications, it begins to outline requirements for GFM IBR requirements for stand-alone energy storage systems connecting to the MISO system. These requirements center around voltage regulation, frequency regulation, and angular stability (synchronism). The MISO framework proposes both functional capability and performance requirements, in addition to required simulation tests to demonstrate GFM characteristics and stable control responses. The requirements proposed by MISO target capabilities available through inverter software changes, and state that these will be applied on a "go-forward basis." As of the time of the white paper publication, MISO contacted seven OEMs to share information and request GFM IBR models. MISO references a need to test the proposed requirements on as many OEM models as practical, while also aligning general model validation and IBR data with FERC Order 901 and the NERC workplan to address FERC Order 901.[17] While FERC Order 901 does not directly address GFM IBR technology, it does address aspects of modeling and model validation; it is clear that the process by

[14] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_GFM_Functional_Specification.pdf
[15] https://www.nrel.gov/docs/fy24osti/89269.pdf
[16] https://cdn.misoenergy.org/20240604%20IPWG%20Item%2004b%20Draft%20GFM%20BESS%20Performance%20Requirements%20Whitepaper%20(PAC-2024-2)633112.pdf
[17] https://www.nerc.com/FilingsOrders/us/NERC%20Filings%20to%20FERC%20DL/NERC%20Compliance%20Filing%20Order%20No%20901%20Work%20Plan_packaged%20-%20public%20label.pdf

which MISO addresses GFM IBR modeling will be impacted by the NERC workplan to address FERC Order 901.

# 5 Field Experiences with GFM Technology

GFM IBRs are actively being deployed around the world to improve system stability in a variety of challenging grids. Today, many of the installed GFM controls are associated with BESS resources, however GFM functionality for wind generators is becoming more commercially available from several leading wind turbine manufacturers. The remainder of this section details a few of the field experiences where GFM IBR has been successfully deployed in various sizes and grid conditions.

**Table 1: GFM BESS Projects Deployed or Under Construction** [18]

| Project Name | Location | Size (MW) | Time |
|---|---|---|---|
| Project #1 | Kauai, USA | 13 | 2018 |
| Kauai PMRF | Kauai, USA | 14 | 2022 |
| Kapolei Energy Storage | Hawaii, USA | 185 | 2023 |
| Hornsdale Power Reserve | Australia | 150 | 2022 |
| Wallgrove | Australia | 50 | 2022 |
| Broken Hill BESS | Australia | 50 | 2023 |
| Riverina and Darlington Point | Australia | 150 | 2023 |
| New England BESS | Australia | 50 | 2023 |
| Dalrymple | Australia | 30 | 2018 |
| Blackhillock[19] | Great Britain | 300 | 2024 |
| Bordesholm[20] | Germany | 15 | 2019 |

## 5.1 Australia GFM Field Experiences

Australian Energy Market Operator (AEMO) has much experience with GFM BESS, including the following projects.

**Dalrymple BESS in GFM Mode**

AEMO outlined in a 2021 report multiple projects using GFM technology which have successfully been modeled, connected, and/or operated in challenging grid conditions.[19] These sites are considered state of the art, using GFM technology that is readily commercially available.

In 2018, a GFM BESS was connected in South Australia near the end of a long 132 kV single-circuit radial feeder.[20] The Dalrymple BESS project includes capabilities such as island operation, inertia, and system

[18] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_GFM_Functional_Specification.pdf
[19] https://aemo.com.au/-/media/files/initiatives/engineering-framework/2021/application-of-advanced-grid-scale-inverters-in-the-nem.pdf
[20] *Id*, p. 36

restart (blackstart)– connecting IBR in very "weak grid" regions, which are regions of the grid with so few synchronous machines that stable operation of IBR was historically not considered achievable.

**Hornsdale BESS**

The Hornsdale Power Reserve consists of a 100MW battery storage project installed in 2017 with an additional 50MW expansion installed in 2020. During the expansion, all 150MW of BESS have been upgraded to be able to provide inertia support services to the grid via Tesla's Virtual Machine Mode, which is a form of GFM technology.[21]

## 5.2 Scotland GFM Field Experiences

The 69 MW Dersalloch wind farm in Scotland was operated in GFM mode for 6 weeks to trial response and performance. Throughout its trial period, the wind turbines demonstrated responses similar to those expected of a similar synchronous generator for all but the largest disturbances.[22] Equipped with GFM capabilities, the wind turbines at Dersalloch were able to contribute to provide rate of change of frequency (ROCOF) support, blackstart, and islanded operation capability. Additionally, by integrating with additional energy storage systems, these wind turbines can offer a wider range of grid support functions and response capabilities.

## 5.3 Hawaii GFM Field Experiences

The Kapolei Energy Storage Battery is a 185MW battery storage project, connecting on a ~1000MW peak load system on the island of Oahu.[23] The project was commissioned in 2023 and as the largest single resource on Oahu (by rating), is a linchpin in the stability and security of the Oahu grid. The project helped to replace the AES coal-fired plant that closed on September 1, 2022, further supporting the ability of GFM to enhance grid reliability during the retirement of significant synchronous machinery. The battery plant has the capability of providing fast frequency response, virtual inertia, and blackstart capabilities.[24]

Kauai Island Utility Cooperative (KIUC) has multiple instances of BESS plants operating in GFM mode, one since 2018 and a second solar PV + BESS converted to GFM mode in 2022. No adverse interactions have been observed in the field to date. Both GFM plants operate stably at all hours of the day, both at times when the system is dominated by synchronous generation and when dominated by inverter-based generation.[25] Other inverter-based equipment on the island includes GFL solar PV + BESS, solar PV, and behind-the-meter solar PV.

[21] https://hornsdalepowerreserve.com.au/
[22] https://doi.org/10.1049/iet-rpg.2020.0638
[23] https://www.kapoleienergystorage.com/
[24] https://www.prnewswire.com/news-releases/worlds-most-advanced-battery-energy-storage-system-comes-online-speeding-hawaiis-transition-to-100-renewable-energy-302032803.html
[25] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_GFM_Functional_Specification.pdf

# 6 Review of Appendix D1 2023 Inertial Floor Study Report

Telos reviewed the report issued by Xcel titled "NSP Power System Inertial Floor Study Report"[26] and has found several of the statements and conclusions drawn in the report to be unsupported or misstated. The specific findings are described in this section.

## 6.1 No Inertial Floor was Established

This report does not attempt to establish a minimum level of inertia (or "floor") required in the system to maintain stability. An inertial floor would ensure that there is sufficient inertia in the system to resist rapid changes in frequency and maintain stability during disturbances or sudden changes in power demand. The concept of inertial floor provides a point at which there is so little inertia that a disturbance, such as a sudden loss of generation, causes the grid frequency to move very quickly. In such a circumstance, the grid protection systems in place to keep the system functioning (UFLS) are unable to work in time and the grid suffers severe outages, separation, or collapse. For systems with extremely high levels of inverter-based resources or weak grid conditions, establishing a minimum level of inertia can be critical to understanding grid conditions and methods for integrating additional renewable energy resources. The report did not identify the amount of inertia required for stability of the system, nor did it identify the amount of inertia lost in the retirement of baseload generators, Sherco #1, Sherco #2, Sherco#3, and King -- all coal plants.

In Xcel's report, the Company removed the four baseload synchronous machines as mentioned above from the model and did not replace them explicitly. Renewable generation (wind and solar) is added and selected based on the Tier 1 and Tier 2 order and IRP filing, per Xcel report. In addition, Xcel notes which of the natural gas Combined Cycles (CC) and Combustion Turbines (CT) are turned on. By removing large synchronous machinery and failing to add wind/solar resources with GFM IBR technology, the Xcel report implies that inertia is only available from synchronous machinery. However, as previously discussed, GFM IBRs are able to contribute productively to inertia when configured properly, particularly by providing inertia as well as other useful frequency response services like fast frequency response and primary frequency response as observed in field experiences outlined in Section 5 of this report.

## 6.2 Unsupported Conclusions Drawn from Simulations Performed

### 6.2.1 "System Collapse"

The report claims to show evidence of "system collapse" after a simulated grid event and references Plot E-4 - angle change greater than 300 degrees. Plot E-4 shows machine angles of large plants in the Twin Cities, Eastern Dakotas, and northern Minnesota regions.

[26] Appendix D1 2023 Inertial Floor Study Report

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Figure 6-1: Plot E-4 Generator Angular Stability from Appendix D1

The plot of angles alone is not conclusive in showing system collapse, and on the contrary, the fact that the machine angles do not deviate from each other indicates that there is no collapse occurring in the region. Further, the plot either does not show the condition of the system prior to the disturbance or shows that the generator angles were not stable prior to simulating the disturbance. In either case, the results do not show that the machine angles have diverged from each other and therefore do not show system separation. The stable (non-oscillatory) angular movement suggests either an issue with the initialization of the simulation, or an issue with the contingency definition. The exact issue cannot be determined from the provided plots alone.

Further examination of additional plots of voltage and frequency (for the same disturbance as simulated in Plot E-4), received through CEO IR 071 confirm that the regional system remains stable following the disturbance.

The additional voltage plots received through CEO IR 071 show that **[PROTECTED DATA BEGINS]**

**[PROTECTED DATA ENDS]** This happens at all locations that were monitored in the simulation and therefore captures the response across the system from the Dakotas to northern Minnesota.

The additional frequency plots received through CEO IR 071 show that **[PROTECTED DATA BEGINS]**

**[PROTECTED DATA ENDS]** The excursions are considered typical for a severe disturbance like the one simulated and are certainly not indicative of system collapse as they settle quickly after the event. This does not show separation nor instability of the system.

**[PROTECTED DATA BEGINS]**

**[PROTECTED DATA ENDS]**

Figure 6-2: Voltage and Frequency Response Obtained Through CEO IR 071

Examining the voltage and frequency at other locations throughout the region, the results confirm that the system is stable and has in fact recovered normally from the disturbance applied. Voltage and frequency were requested through CEO IR 071 for a Sherco 345kV bus, the Alexandria 345kV bus, and a Prairie Island 345kV bus. **[PROTECTED DATA BEGINS]**

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Figure 6-3: Voltage and Frequency Response Obtained Through CEO IR 071

### 6.2.2 Commentary on System Damping

The report notes system voltage damping issues are observed in Plot E-1. **[PROTECTED DATA BEGINS]** **[PROTECTED DATA ENDS]** which is recognized by industry as on the edge of the capability of these models and this software to represent dynamics accurately.[27] Telos believes that this is most likely a numerical issue with the model rather than reflective of actual system dynamics.

[27] P. Kundur, Power System Stability and Control, McGraw Hill, 1994.

**[PROTECTED DATA BEGINS]**

**[PROTECTED DATA ENDS]**

**Figure 6-4: Plot E-1 Voltage Damping in MISO Footprint from Appendix D1**

Inertia plays a role in stabilizing the system during sudden changes, however it does not "help oscillations dampen out," as stated in the Xcel report. Considering the spring-mass analogy described in Section 3 of this report, increasing the mass (inertia) does not help to dampen the swings, it only slows the period of response. The classic Tacoma Narrows Bridge collapse provides an illustrative example.[28] Adding more mass to the bridge would not have prevented the oscillations that ultimately led to its instability and failure, only reducing the force of the wind or increasing the damping of the bridge would stop the oscillations. Stated differently, a heavy pendulum will take more force to start swinging than a light pendulum will (the inertia will prevent rapid changes). However, if both pendulums are already oscillating, only the damping provided by air resistance or friction in the pendulum string will slow the swinging.

Only damping helps damp out the oscillations faster. Damping can be provided by mechanical systems, such as the aerodynamic losses in the compressor section of a gas turbine or friction on the rotor bearings. For that reason, there is a real-world correlation between high inertia and high damping characteristics of synchronous machines (these machines typically have both high mass AND high friction sources). However, synchronous machines do not have high damping *because* they have high inertia, but rather that these machines typically have high damping and high inertia by the fact that they are large mechanical moving objects.   Damping can also come from electrical systems, either passive

[28] https://wsdot.wa.gov/tnbhistory/bridges-failure.htm#3

like the resistive component of transmission lines, or from active sources like from power system stabilizers on synchronous machinery or from IBRs that are configured to increase damping.

This distinction is important because if Xcel does identify a need for an increased damping response to maintain the stability of their system, the tools to bring that damping response (whether through mechanical friction or electrical power system controls like those available in GFM IBRs) need to be considered equally and synchronous machines should not be favored simply because they have mechanical inertia.

# 7 Conclusion

Telos Energy has reviewed Xcel's Appendix D1: 2023 Inertial Floor Study Report and agrees with the Company that stability is a critical, challenging aspect of maintaining system reliability.

Telos strongly encourages that all technologies, including the more recent GFM IBRs, be given equal consideration when determining the most cost-effective portfolio for meeting system needs for stability and reliability. GFM IBRs are effective, and have been demonstrated in challenging, real grid applications. GFM IBR requirements are being adopted by leaders in the industry and by organizations including NERC and MISO.

The 2023 Inertial Floor Study should not preclude consideration of IBR technologies on Xcel's Minnesota system. The Inertial Floor Study does not substantiate a need for retaining synchronous machine technology and GFM IBR solutions should be considered for maintaining or enhancing system reliability. As described through this report, GFM IBRs are a commercially available option with proven field results of providing grid stabilizing services similar to synchronous machine technologies when configured properly. To ensure Xcel is using the most effective technologies, both technically and economically, Telos recommends that Xcel consider GFM IBR on a level playing field in new generation procurements.