A CALL TO ACTION FOR A STABLE ENERGY TRANSITION

Grid-Forming Battery Energy Storage Systems

Brief for Decisionmakers

By Ryan Quint (Elevate Energy Consulting), Andrew Isaacs (Electranix Corporation), Farhad Yahyaie (Elevate Energy Consulting), Lukas Unruh (Electranix Corporation), Julia Matevosyan (Energy Systems Integration Group), and Casey Baker (GridLab)

March 2025

GridLAB

ESIG
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Background

The electricity sector continues to undergo a rapid transformation toward increasing levels of renewable energy resources—wind, solar photovoltaic, and battery energy storage systems (BESS). These resources electrically connect to the grid through an inverter—power electronic devices that convert DC energy into AC energy—and are referred to as inverter-based resources (IBRs). As the generation mix changes, so do the electrical characteristics and attributes of the bulk power system that we have relied upon for over a century. The grid was fundamentally designed, engineered, planned, and operated around conventional synchronous generators (e.g., natural gas– or coal-fired generators) with large spinning masses. To date, IBRs have been designed to rely upon these conventional resources to provide a stable grid that they can connect into. However, grid stability may be challenged as increasing amounts of synchronous generators retire and are replaced with IBRs—whether system-wide, regionally, or locally. Early, proactive action can mitigate reliability challenges that could otherwise require significant transmission infrastructure investment.

Grid-forming (GFM) BESS, which use advanced inverters to connect to the grid, are a noteworthy approach to helping stabilize the grid under high levels of renewables. However, while GFM BESS are commercially available and deployed globally, U.S. deployment is lagging. This brief describes the benefits of GFM technology and lays out the results of a study undertaken to quantitatively demonstrate the benefits of GFM BESS if more widely deployed in a typical interconnected bulk power system. According to the study summarized here, the widespread adoption of GFM BESS would bring significant value to ensuring reliability, resilience, and affordability of the bulk power system.[1]

The widespread adoption of GFM BESS is likely to bring significant value to ensuring reliability, resilience, and affordability of the bulk power system.

Shared Vision of Reliability

Utilities, system operators, regulators, renewable energy developers, equipment manufacturers, and policymakers share a common goal: a reliable, resilient, and cost-effective grid. In a time of rapid grid transformation, booming energy demands driven by data centers and artificial intelligence, extreme weather events, and technological advancements, new and innovative solutions are called for. It is incumbent upon the industry to implement technologies that "do no harm" while providing significant benefits to the grid.

1 This brief is available at https://www.esig.energy/benefits-of-gfm-bess-project-team/, where you can also find links to a recording of ESIG's webinar on this topic including presentations and Q&A (https://www.esig.energy/event/webinar-benefits-of-gfm-study-discussion/).

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A Critical Gap in Grid Services Following Conventional Generator Retirements

The traditional power grid has long relied on conventional synchronous generators to provide essential services such as inertia, frequency regulation, voltage support, and short-term ramping to balance generation and demand. The inherent physical characteristics of a rotating synchronous generator resist changes in system voltage and frequency and thereby help stabilize the overall system during disturbances. As these generators retire, their stabilizing properties are also removed, leaving a critical gap. A variety of technologies have the capability to provide stabilizing grid services, some even more quickly and controllably than the conventional generators that came before them.

Diving Deeper: What's the Issue with Conventional IBR Technology?

Nearly all grid-connected IBRs—including wind, solar, batteries, and others—have been designed with controls referred to as "grid following" (GFL)—the inverter essentially measures or "follows" the grid quantities and uses that as a reference to control power and voltage. This underlying control assumes that the grid is inherently strong and stable (i.e., backed by a significant amount of synchronous generation). In more technical terms, a GFL IBR measures[2] grid phasor quantities and seeks to inject a tightly controlled amount of active and reactive current to maintain constant active and reactive power output. However, if the grid voltage phasor is not strongly defined by conventional synchronous generators, it has an increased sensitivity to changes in IBR current injection, and the IBR controls may struggle to reliably and stably control power. Put another way, just as when an organization with all followers is lost, a grid with all followers goes unstable.

In contrast, GFM control is fundamentally different. In the short time immediately after something changes in the grid, the GFM control objective is to maintain a constant voltage phasor, in a similar fashion to synchronous machines.[3] In some ways, GFM technology replicates some of the essential grid-stabilizing attributes[4] that we grew accustomed to with conventional synchronous generators. GFM inverters can help "form" grid voltages rather than "follow" them.

Synchronous generators also have inherent physical attributes like inertia, which is desirable in many ways, although these attributes also create stability challenges that have been studied for over 100 years. If thoughtfully designed, GFM controls can mimic the desirable characteristics of conventional synchronous generators while avoiding some of the undesirable attributes due to the flexibility of these inverter-based controls.

Has GFM Technology Been Proven?

Multiple recent reports have described GFM technology, ranging from technical GFM training,[5] to leveraging

GFM BESS have important advantages, including technical readiness, commercial availability, and unique economic and grid-stabilizing benefits.

2 The inverter measures the grid instantaneous voltages and currents and evaluates the corresponding phasor value – referred to here as "measure" for simplicity.

3 https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_Grid_Forming_Technology.pdf

4 These attributes are generally available when the resource has "headroom," which is to be expected under most operating conditions for the BESS. This is particularly true when considering a fleet of BESS across a larger system. If additional assurance that GFM capability is provided across *all* operating conditions, some degree of headroom may be needed in which case a market mechanism is appealing.

5 EPRI, "Grid Forming Inverters: EPRI Tutorial" (Palo Alto, CA, 2024), https://www.epri.com/research/products/000000003002030937.

GFM technology as a way to maintain system reliability as levels of renewables rise, to allowing systems to integrate higher levels of renewables.[6] Over the last few years, GFM technology has become increasingly used to solve unique stability-related issues. GFM is available in HVDC technology as well as in STATCOMs; however, this brief focuses specifically on GFM BESS because of its technical readiness, commercial availability, and unique economic and grid-stabilizing benefits.

There are numerous GFM BESS projects around the world, mostly in the UK, Australia, and Hawaii.[7] These networks have deployed GFM BESS for multiple reasons, all centered around improving system-wide stability and stabilizing the grid during normal operation and during grid disturbances. However, in the continental U.S., there is currently only one operational GFM BESS—the Provincetown BESS project on the tip of Cape Cod, Massachusetts—which helps stabilize and bring resilience to a long, radial, sub-transmission network in the Eversource system.

So Why Aren't We Seeing More GFM Installed?

Particularly in the U.S., the adoption of GFM technology has been dramatically slower than what industry experts would like to see. Unless there is a requirement for equipment oversizing, operation outside of normal equipment limits, or capacity reservation, enabling and using GFM controls in a BESS has a low incremental cost when incorporated early in the design and interconnection process. Overall, initial modeling, studies, and real-world experience internationally have shown that GFM technology brings substantial benefits to networks in need of stability support. Some parts of the world have even adopted GFM for most, if not all, new utility-scale BESS projects. A selection of industry reports, guidelines, and requirements regarding GFM technology can be seen in Figure 1.

FIGURE 1

A Selection of Industry Reports, Guidelines, and Requirements Regarding GFM Technology

These and additional GFM specifications can be found in ESIG's "GFM landscape" web resource at https://www.esig.energy/working-users-groups/reliability/grid-forming/gfm-landscape/specifications-and-requirements/.

Source: Energy Systems Integration Group.

6 Energy Systems Integration Group, *Grid-Forming Technology in Energy Systems Integration* (2002), https://www.esig.energy/grid-forming-technology-in-energy-systems-integration/.

7 Energy Systems Integration Group, "Installed and Planned Grid-Forming Projects," https://www.esig.energy/working-users-groups/reliability/grid-forming/gfm-landscape/projects/.

> **Enabling and using GFM controls in a BESS has a low incremental cost when incorporated early in the design and interconnection process, particularly when compared against alternative solution options. Some parts of the world have even adopted GFM for most, if not all, new utility-scale BESS projects.**

Herein lies the question: is GFM technology only a solution option in unique, difficult-to-solve parts of the system that require special stabilizing controls? Or could GFM be used more widely to help enhance stability during the energy transition to high IBR levels. **Why hasn't GFM been more widely adopted and at a faster pace given the potentially severe grid reliability risks posed by high IBR conditions with insufficient grid-stabilizing resources?** The answers center around a "path to production" focused on technology readiness, access to industry educational and training materials, modeling and studies, lessons learned from pilot deployments, and harmonized standards for GFM technology.

The Technology Is Ready: Here's a Path to Production

While IBR equipment manufacturers and developers have successfully deployed GFM BESS technology in various parts of the world, progress in the U.S. is much slower. Here we present a "path to production" for GFM BESS that can help explain the current situation (see Figure 2, p. 5), and describe the focused study work below. Our path to production focuses on the following six key areas, oriented toward the U.S. grid and its stakeholders but generally applicable anywhere.

Technology Readiness

The technology is widely available; multiple prominent manufacturers of BESS inverters offer GFM control in commercial products today.

Increased Access to Education and Training Materials

Industry needs a clear understanding of GFM technology, how it works, and what its key differences and similarities are to GFL technology. Substantial education and training materials are currently available on GFM technology.

Improved Modeling of GFM Controls

The models representing GFM controls in interconnection studies, long-term transmission planning studies, and operational studies must be high quality, accurate, and available from the equipment manufacturers across different simulation domains. To date, equipment manufacturers have delivered high-quality electromagnetic transient (EMT) models, can provide user-defined phasor-domain transient (PDT) models, and are working with industry to develop standard library PDT models as well as short-circuit models. However, there is room for improvement in this arena to make available more accurate and usable GFM models for grid planning and operations studies.

Studies of the Benefits of GFM BESS Resources for Typical Systems

Some exploratory studies have been conducted using generic (i.e., not manufacturer-specific) PDT and EMT models, but there have been few illustrative system studies that leverage real-world models from actual manufacturers, and these have been limited to special applications or island networks. The lack of studies that represent typical or widely representative systems—and therefore provide a clear basis for action regarding the benefits of GFM technology—may be tempering industry's confidence in this technology. ***This paper focuses on this need and summarizes a study assessing the benefits of GFM BESS for an actual transmission grid.***

Pilots

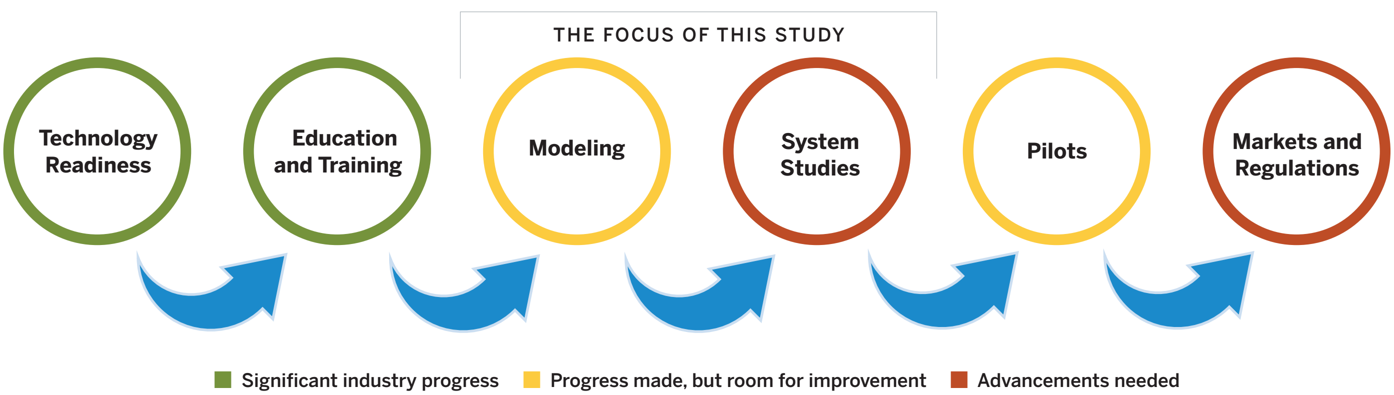
Equipment manufacturers and IBR developers have successfully deployed GFM BESS technology in various parts of the world, and this has led to useful findings over the last few years. However, beyond international experience deploying GFM technology or experience with smaller island networks, there are very few pilots of GFM BESS within U.S. utilities. Pilots are needed to help both the generator owner/operators as well as the utilities and system operators gain an increased understanding and trust of GFM technology on their systems.

Harmonized Standards for GFM Technology Across North America

Some utilities and market operators have developed GFM BESS requirements globally. Within North America, Hawaiian Electric Company has required GFM technology for several years, the Electric Reliability Council of Texas (ERCOT) and Midcontinent Independent System Operator (MISO) are in the process of implementing GFM BESS requirements currently,[8] and some utilities are actively exploring or developing requirements of their own. Similarly, some market operators such as the Australian Energy Market Operator (AEMO) and the National Energy System Operator for Great Britain (NESO) are developing GFM access standards, which may involve procuring these types of capabilities and services through a market. Equipment manufacturers welcome the certainty and efficiency that can be achieved with a harmonized and comprehensive set of improved IBR interconnection standards and requirements. Uniformity and consistency across transmission providers and ISO/RTOs can help expedite the interconnection process and support a reduction of the interconnection queue backlog. Harmonized standards across North America would help accelerate adoption.

Equipment manufacturers welcome the certainty and efficiency that can be achieved with a harmonized and comprehensive set of improved IBR interconnection standards and requirements.

FIGURE 2
Pathway to Widespread GFM Adoption



The first two steps toward widespread GFM adoption, technology readiness and availability of education and training materials, have been completed. This paper describes efforts to address the third and fourth steps of modeling and system studies demonstrating GFM technology's ability to improve system reliability and stability while not causing other issues. The fifth and sixth steps, pilots and markets and regulation, remain to be fully addressed.

Source: Energy Systems Integration Group; adapted from Elevate Energy Consulting.

8 See https://www.ercot.com/committees/ros/ibrwg and https://www.misoenergy.org/engage/committees/interconnection-process-working-group/.

ESIG and GridLab's Study of the Benefits of GFM BESS

ESIG and GridLab initiated a joint study including Elevate Energy Consulting, Electranix, American Transmission Company (ATC), and various equipment manufacturers to explore the value of and any challenges associated with GFM batteries. The study used:

- Simulation models for GFM and GFL BESS provided by five different equipment manufacturers that are representative of commercial products available on the market[9]
- GFM performance criteria and tests developed by the North American Electric Reliability Corporation (NERC)
- A real-world system of an interconnected utility in the U.S., ATC

The models provided by the manufacturers were used to test and compare the performance of GFM and GFL batteries in the ATC system in both a weak and strong part of the network. The study explored a set of core questions and yielded the outcomes in green in Table 1.

Below we provide an overview of modeling and studies and share the key findings and takeaways from our studies of GFM BESS performance in typical or widely representative systems.

Testing GFM BESS Against the NERC GFM Specification and Simulation Test Procedures

NERC published *Grid Forming Functional Specifications for BPS-Connected Battery Energy Storage Systems* in September 2023.[10] The group of industry experts that developed the paper sought to harmonize and standardize how utilities and system operators can specify GFM BESS performance requirements. The specifications include a set of simulation test procedures, conducted using EMT models, to test that the proposed GFM resource has the specific performance characteristics desired.

TABLE 1
Study Outcomes in Response to the Core Questions

Is GFM BESS a "do no harm" solution option?	Yes
Do the NERC GFM BESS functional specifications and test procedures hold up?	Yes
Is the growth of GFM BESS likely to be free of any notable reliability challenges?	Yes
Can GFM batteries provide specific grid-stabilizing benefits in weaker grids?	Yes
Can GFM batteries operate stably and reliably in strong grids?	Yes
Are GFM batteries interoperable across equipment manufacturers and with GFL IBRs?	Yes
Can GFM batteries help defer more costly solution options and serve as a bridge to long-lead-time solutions like transmission infrastructure build-out?	Yes

Source: Energy Systems Integration Group.

9 Close collaboration with the inverter manufacturers was instrumental to the success of this project.

10 https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_GFM_Functional_Specification.pdf

TABLE 2
Results from Testing OEM-Supplied GFL and GFM Models

Test #	OEM "A"		OEM "B"		OEM "C"*		OEM "D"		OEM "E"	
	GFM	GFL	GFM	GFL	GFM	GFL	GFM	GFL	GFM	GFL
Test 1	Pass	Fail	Pass	Fail	Pass	Fail	Pass	X	X	X
Test 2	Pass	Fail	Pass	Fail	Pass	Fail	Pass	X	X	X
Test 3	Pass	Fail	Pass	Fail	Pass	Fail	Pass	X	X	X

All functional GFM BESS models passed the NERC tests while all GFL BESS models failed, indicating that the NERC specification works as designed.

Notes: "X" indicates that modeling could not be addressed with OEM [original equipment manufacturer]. OEM "C" did not provide a power plant controller (PPC). A generic PPC based on REPC_A was used.

Source: Elevate Energy Consulting.

The study described here tested GFM and GFL simulation models that were supplied by five equipment manufacturers and represent the commercially available products with appropriate system service capabilities enabled. Of the functioning[11] GFM and GFL models tested, all GFM models passed the NERC tests while all GFL models failed, as expected (see Table 2). While both types of models would still need to pass other model quality or performance conformity tests, this result demonstrates that the NERC GFM Functional Specification and Test Procedures work as designed to differentiate the core GFM characteristics. Furthermore, it shows that the equipment manufacturers have developed GFM products that are able to meet the desired performance characteristics.

This study confirms that the NERC GFM simulation tests are an excellent place to start for transmission providers seeking to implement some form of GFM specification. The study team used the simulation models that performed adequately in subsequent microcosm system testing and simulations on the ATC system.

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Gaining a Deeper Understanding of GFM Batteries in a Microcosm Test System

Before deploying GFM batteries in the simulations on the ATC system, the study team explored how the GFM and GFL BESS models would operate in a set of small microcosm test systems in order to better understand the performance of GFM BESS technology compared with that of GFL batteries. Figure 3 (p. 8) shows one of the microcosm test systems used for testing.

Key findings from testing in the microcosm test system were the following.

GFM Batteries Successfully Stabilized a 100% IBR System

In a system with only GFM batteries from different manufacturers, the GFM batteries were able to successfully transition from a grid-connected system to an islanded system with 100% IBRs. In contrast, conventional GFL batteries were unable to stably operate through this transition to an islanded network.

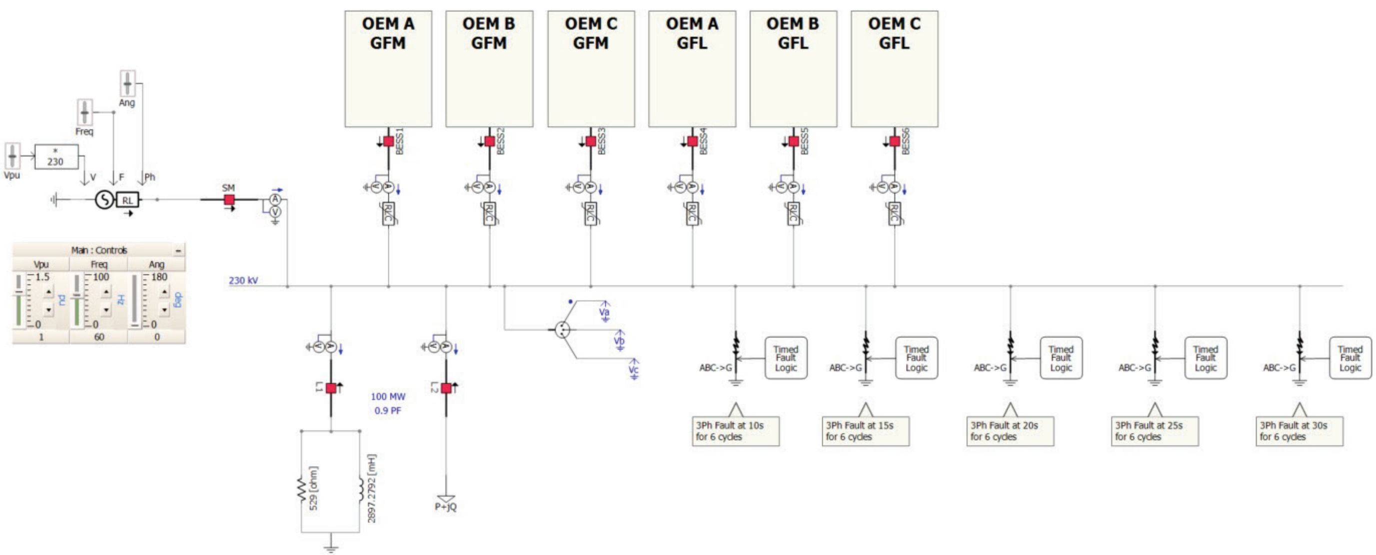
GFM Batteries Had Superior Performance to Extreme Events

GFM BESS were also able to stably handle large load step changes, riding through extended-duration faults with both a strong and weak connection between plants.

11 The team was unable to resolve modeling issues from one manufacturer due to limited engagement from the manufacturer. And a GFL model from another manufacturer was not functioning and therefore also not tested.

FIGURE 3

Exploring GFM Performance in a Microcosm Test System



Testbed for focused evaluation of manufacturer-supplied BESS models.

Source: Elevate Energy Consulting.

GFM and GFL Batteries Were Interoperable

With both GFM and GFL BESS in the system, both types of BESS operated seamlessly and reliably, either in grid-connected or islanded mode with 100% IBRs.

GFM Batteries Improved System Stability with Other GFL IBRs

The stability of the microcosm system increased as the ratio of GFM to GFL batteries increased; having more GFM BESS improved system stability.

GFM and GFL BESS Showed Resilience to RoCoF and Phase Jump

The GFM and GFL BESS simulation models provided by the equipment manufacturers passed a rather large 5 Hz/s rate of change of frequency (RoCoF) test and a ±180° phase angle jump test, illustrating robustness of inverter-based technology.

Testing GFM Batteries in the MISO Footprint: The ATC Case Study

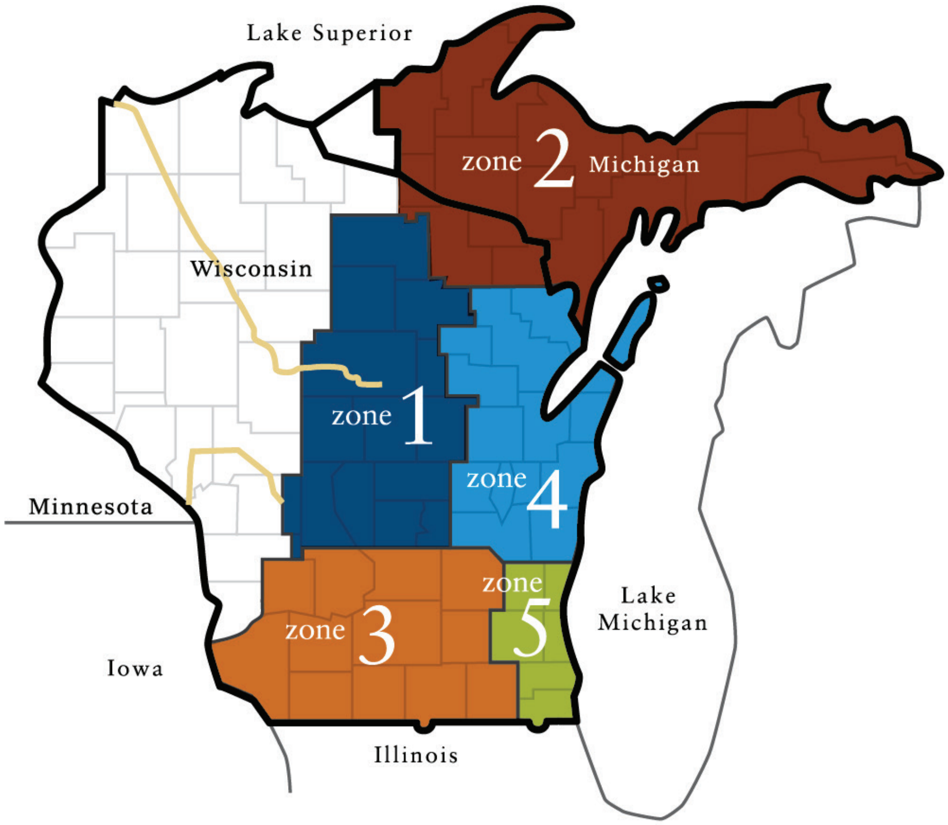
ATC served as a utility partner for these exploratory studies. ATC serves 5 million electricity customers across Wisconsin and the Upper Peninsula of Michigan, has over 10,000 miles of transmission circuits and more than 580 substations, and has a summer peak load of 13,000 MW. Its footprint is within the Eastern Interconnection and has a diversity of networks: pockets where transmission is sparse (weak grids), areas with IBR-dense interconnection requests (stability issues), and metropolitan load pockets with very strong interconnection transmission networks (strong grids) (see Figure 4, p. 9). The ATC was an excellent testbed to provide insights applicable to many other areas of the North American and global grid.[12]

ATC has also developed an extensive EMT model of its system and has focused on gathering high-quality EMT models from IBR developers for a number of years. Its

12 GFM gets a lot of attention for addressing stability issues on unique systems such as islanded networks, weak radial network connections, etc. However, the focus of this study was to illustrate benefits of GFM within a more common portion of the larger interconnected bulk power system.

FIGURE 4

ATC System and Planning Zones



Zones 1 and 5 were selected for the weak and strong grids, respectively.

Source: American Transmission Company.

library of highly detailed IBR models and transmission system elements is extensive and well tested. Thus, minimal work was needed to prepare the study cases as the groundwork was already laid.

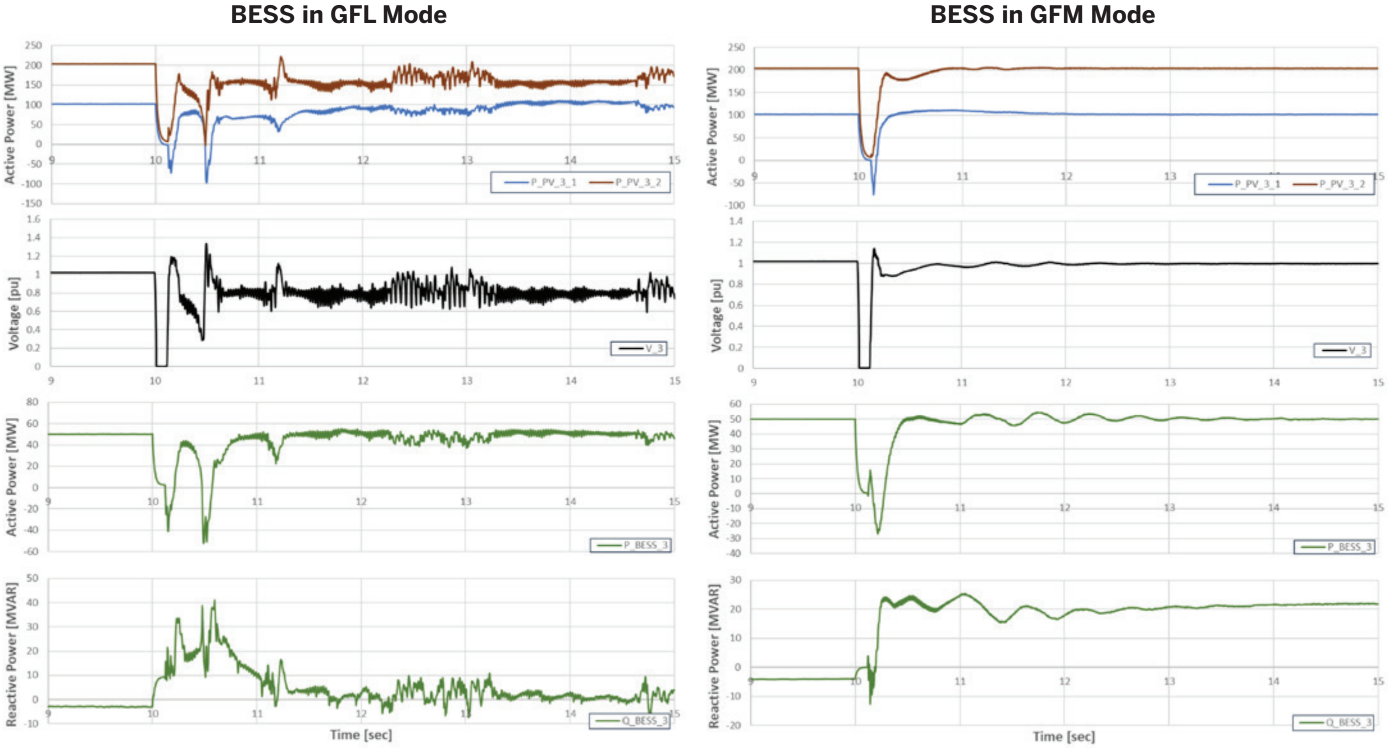
Weak Grid Study

The weak grid study focused on a portion of the ATC system that is saturated with existing IBRs and has a large number of proposed IBR interconnection requests. The surrounding transmission network is rather strong; however, this pocket of the system being studied has a fairly weak grid with limited transmission interconnections —i.e., sparse transmission and no nearby conventional synchronous resources. Under conditions involving the loss of one or multiple transmission elements (N-1 or N-1-1), short-circuit ratios (SCR) can fall very low (e.g., near 1.3). A very low SCR means that an IBR has a very large impact on the local grid voltage, which can cause GFL controls to become unstable; unstable GFL controls can lead to curtailment of the resource, as the system temporarily disconnects the resource in an effort to maintain system stability.

The study focused on the worst-case scenarios in which the network is segmented, separating the IBRs from the strong sources connecting to the rest of the system. The addition of both GFL and GFM BESS was studied in order to understand whether GFM technology improves local stability, whether it supports higher levels of IBR integration, and whether GFM batteries can help avoid operational curtailment of other IBRs in the vicinity. Figure 5 (p. 10) illustrates the stability improvements of GFM compared with GFL for an N-1 fault event in this area; GFM BESS are able to maintain network stability whereas GFL BESS are unstable. Figure 6 (p. 11) illustrates an N-1-1 contingency where a change in control from GFL to GFM in local BESS is sufficient to significantly reduce IBR curtailment.

FIGURE 5

Illustration of an Outage Involving the Loss of One Transmission Circuit in Weak Grid Conditions, with a GFL BESS Becoming Unstable and a GFM BESS Operating Stably and Reliably



Findings:

- **SCR < 1.3 under N-1**
- **GFL BESS scenario is unstable**
- **GFM BESS scenario is stable**

Comparison of the impact of GFM and GFL BESS on weak system performance. GFM controls are able to correct the weak system instability caused by GFL IBRs.

Source: Electranix.

Key findings from these studies using detailed EMT models of extensive portions of the ATC network included that:

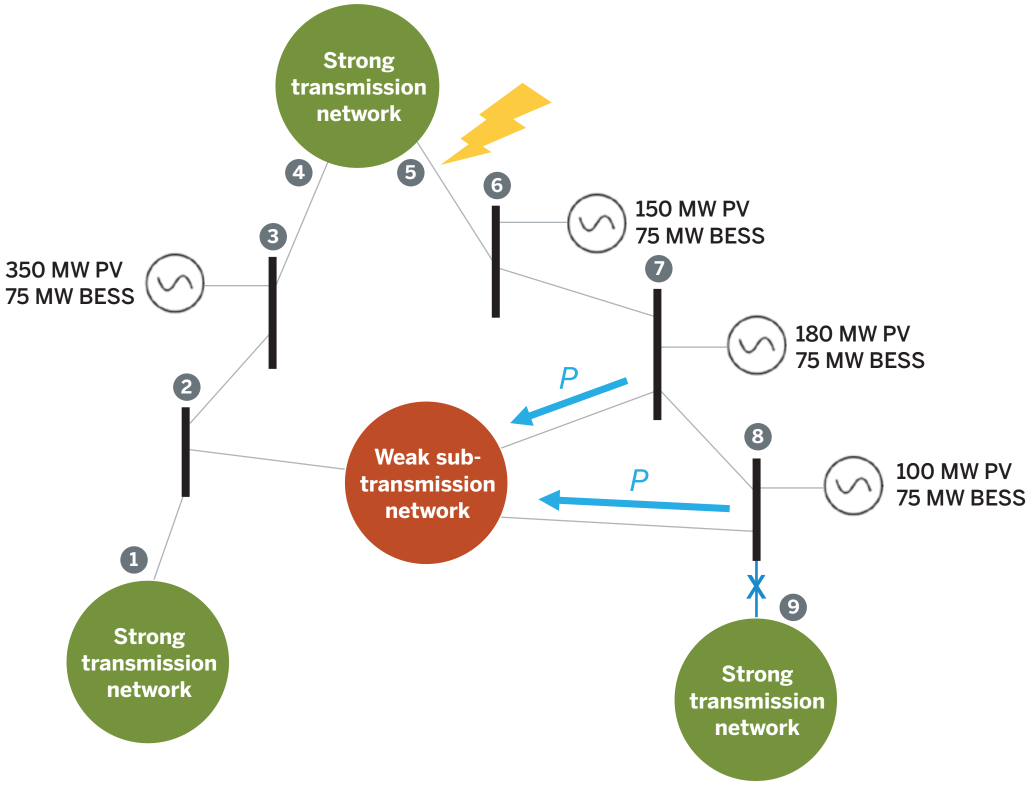
- GFM BESS provided a more stable response than GFL BESS and were able to stably respond to fault events where GFL BESS became unstable.
- The addition of GFM BESS unlocked additional IBR hosting capacity—allowing higher levels of IBRs to be integrated into a specific network or part of the system—while the addition of GFL BESS did not.
- GFM BESS from multiple equipment manufacturers in close proximity were able to operate stably and reliably, demonstrating the interoperable nature of GFM controls in weak grids.

Strong Grid Study

The strong grid study focused on a looped 345 kV network outside of Milwaukee, Wisconsin (see Figure 7, p. 12), a large load center with an SCR greater than 50 (that is, very strong electrically). IBR levels are currently

FIGURE 6

Illustration of Example of an Outage Involving the Sequential Loss of Two Transmission Elements in Weak Grid Conditions



Findings:

- **With line 8-9 out of service, the fault at line 5-6 creates significant IBR penetration connected through weak sub-transmission network.**
- **There was very low WSCR under N-1-1 conditions.**
- **IBR curtailment was required in both GFL and GFM BESS scenarios but was much less under the GFM BESS scenario.**
  - **Curtailment with GFL BESS = 250 MW**
  - **Curtailment with GFM BESS = 50 MW**

Weak region within the ATC system used to evaluate the benefits of GFM BESS. Key disturbances were simulated to stress the region to a breaking point, with line 8-9 out of service and a fault at line 5-6. "P" lines show active power flows out of the pocket of generation. The system was modeled with all BESS as GFL and all BESS as GFM, and showed significantly less curtailment with GFM BESS.

Source: Electranix.

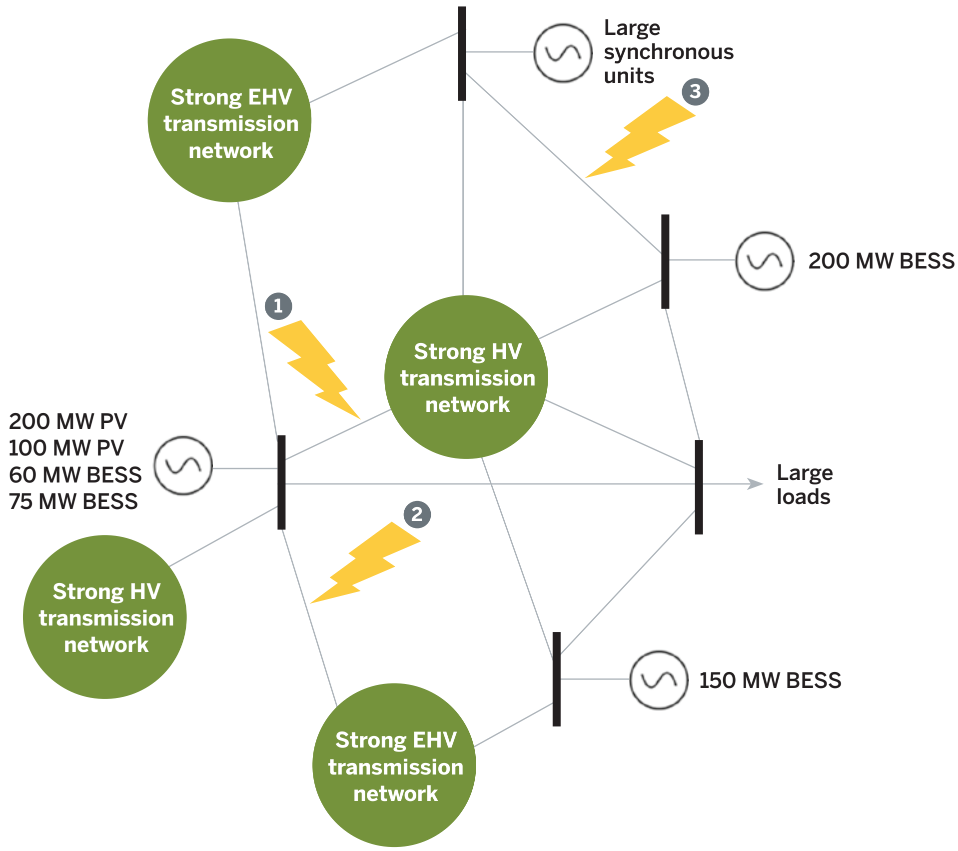
low and concentrated in a specific location, as seen on the left side of the figure. The system has GFL BESS in service today and will soon be adding more BESS to the local area. This scenario explored the addition of the same GFM BESS simulation models used in the weak grid scenario, described above, to understand any benefits or challenges of adopting GFM BESS in strong grids. Simulations focused on grid disturbances involving the loss of one transmission circuit (N-1) with BESS in charging and discharging conditions.

This study determined that:

- In this strong grid scenario, the same GFM BESS simulation models that were used in the weak grid scenario also operated stably with no control tuning needed.

FIGURE 7

Strong Grid Network in an ATC Metropolitan Area and the Scenario of Adding a Significant Number of GFM BESS in the Vicinity



A strong region within the ATC system used to test the stability of multiple GFM BESS in close proximity (left side of the figure). Key disturbances were simulated to test for stable behavior.

Source: Electranix.

- GFM BESS outperformed GFL BESS in some faults studied and the performance of the two types was similar in other faults. Some GFM BESS exhibited machine-like swings after disturbances, but these were well damped and not significant enough to indicate a problem.
- No interactions between GFM BESS, either within the same plant or across different plants, were observed, indicating that concerns over interactions between devices were unfounded in this case.

Key Benefits of GFM BESS

Figure 8 (p. 13) provides the benefits shown in these studies of GFM BESS resources in typical, widely representative systems. No downsides were observed.

A Call to Action

The widespread adoption of GFM BESS is likely to bring significant value to ensuring reliability, resilience, and affordability of the bulk power system. Digital infrastructure, national security, telecommunications, and every other critical infrastructure sector depend on stable and reliable electricity. The bulk power system is the largest machine in the world and is the foundation of modern society. Least-cost solutions that enable a more stable grid are not just an opportunity, they are a necessity. Bridging the gap between traditional services and requirements used for a grid founded on centralized conventional generators and the modern power electronic IBR-based grid offers a pathway to a resilient future grid.

FIGURE 8

Key Benefits of GFM BESS

Quantifiable grid-stabilizing benefits	GFM BESS provided quantifiable grid-stabilizing benefits in both weak- and strong-grid conditions.
Controls requiring no tuning between strong and weak grid conditions	GFM BESS controls used in this representative study required no tuning between strong and weak grid conditions, which could allow for less complex stability studies in the future. This also demonstrates the robustness of GFM controls in areas where system conditions may vary between strong and weak depending on time of day, season, etc.
Superior stability and performance	GFM BESS provided superior stability and performance compared to GFL BESS, improving (rather than degrading) system performance and stability with the addition of IBRs.
Support for increased IBR hosting capacity	GFM BESS significantly increased IBR hosting capacity in the tested areas by providing grid-stabilizing attributes that supported existing and planned new IBRs.
Reduction in stability-related curtailments for nearby GFL IBRs	GFM BESS reduced stability-related curtailments for nearby GFL IBRs.
Ability to help offset or avoid more costly network upgrades	GFM BESS could help to offset or avoid more costly network upgrades such as the addition of synchronous condensers, STATCOMs, and expanded/upgraded transmission infrastructure.
Reliable and stable operation with controls from multiple equipment manufacturers	GFM BESS operated reliably and stably with controls from multiple equipment manufacturers within the same plant or at adjacent and nearby plants, demonstrating strong interoperability of controls.
Ability to withstand more severe grid disturbances	GFM BESS stably and reliably withstood more severe grid disturbances and operating conditions than GFL BESS did.

Source: Energy Systems Integration Group.

Digital infrastructure, national security, telecommunications, and every other critical infrastructure sector depend on stable and reliable electricity. Least-cost solutions that enable a more stable grid are not just an opportunity, they are a necessity.

GFM BESS technology provides the capabilities and attributes to overcome future grid instability challenges. GFM BESS also help unlock additional IBR hosting capacity, enabling more IBRs to connect to the grid at lower cost. The incremental cost to developers and utilities of incorporating GFM technology in newly connecting BESS is notably lower than alternative solutions such as synchronous condensers, STATCOMs, must-run synchronous machines, renewables curtailment, or transmission infrastructure. By adopting GFM technology, the industry can collectively build a grid that not only meets the demands of today but is ready for tomorrow.

The positive attributes of GFM BESS observed in this study area benefit all stakeholders. **Policymakers, state regulators, and federal regulators** benefit from a more stable grid and value to ratepayers during the energy transition. **System operators and utilities** benefit from stability enhancements, increased operating limits, potentially less complexity and easier planning processes, and higher utilization of the existing grid. **Renewables developers and equipment manufacturers** benefit from unlocking IBR hosting capacity, maximizing operating limits, and reducing the likelihood of IBR curtailment in stability-limited areas. And **consumers** benefit from more affordable, reliable, and clean electricity.

Action is needed now to capture these broad benefits and make that future vision a reality. Policymakers, regulators, utilities, renewable developers, equipment manufacturers, and the rest of the ecosystem should pilot, scale, and deploy GFM battery technology as quickly as possible during the IBR interconnection boom to maximize the value that modern IBR technology can bring to the grid.

PHOTOS

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This brief for decisionmakers is available at https://www.esig.energy/benefits-of-gfm-bess-project-team/.

To learn more about the topics discussed here, please send an email to info@esig.energy.

The Energy Systems Integration Group is a nonprofit organization that marshals the expertise of the electricity industry's technical community to support grid transformation and energy systems integration and operation.

GridLab's mission is to provide expert capacity and thought leadership to address technical challenges and reliability questions in the implementation of clean energy policies.