U.S. DEPARTMENT OF ENERGY

unifi consortium — universal interoperability for grid-forming inverters

UNIFI Consortium Grid Forming Performance Requirements and Specifications

ESIG Spring 2023 Workshop

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What is UNIFI ?

The **UNIFI Consortium** is a forum to address fundamental challenges in the seamless integration of grid-forming (GFM) inverter-based resources (IBR) into power systems of the future.

Bringing the industry together to <u>unify</u> the integration and operation of inverter-based resources and synchronous machines

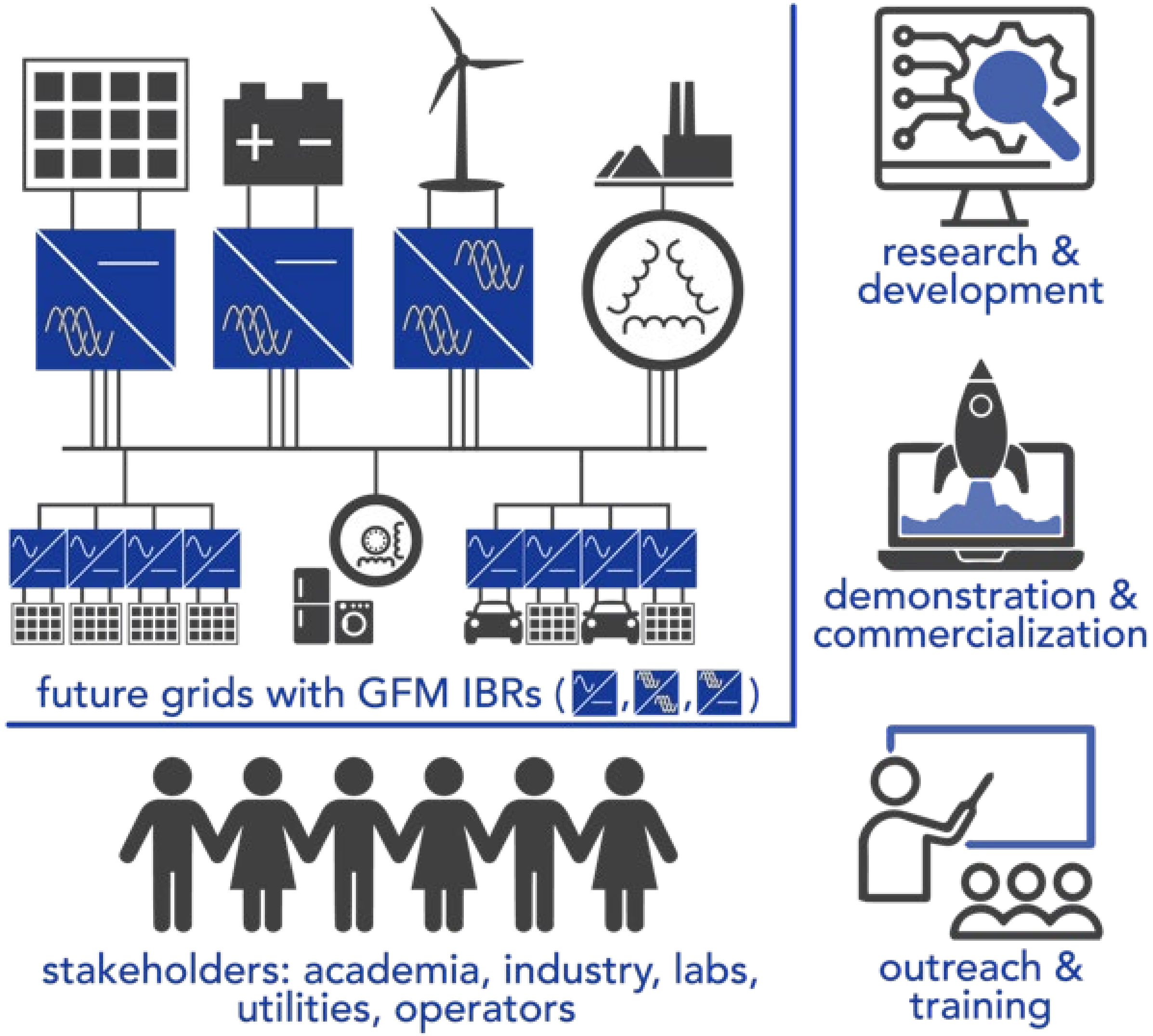
Three major focuses:

- Research & Development
- Demonstration & Commercialization
- Outreach & Training

Started in January 2022 with DOE Funding

UNIFI has:

- 22 Industry Participants (Manufacturers, utilities, system operators, system integrators,)
- 5 Research Institutions
- 12 Universities



UNIFI Members - Project Team

National Labs & Research Institutes

NREL Transforming ENERGY

EPRI

Sandia National Laboratories

PNNL

Berkeley Lab

Universities

The University of Texas at Austin

NC State University

ASU

GT

Cal

Purdue

UAF

VT

Industry

GE

Typhoon HIL

Danfoss

Hitachi Energy

OPAL-RT Technologies

SIEMENS

ANALOG DEVICES

MEPPI

EATON

Ørsted

SMA

Utilities & System Operators

Southern California Edison

Hawaiian Electric

PGE

PG&E

Southern Company

MISO

New York Power Authority

ComEd

ISO new england

CAISO

PacifiCorp

TVA

Xcel Energy

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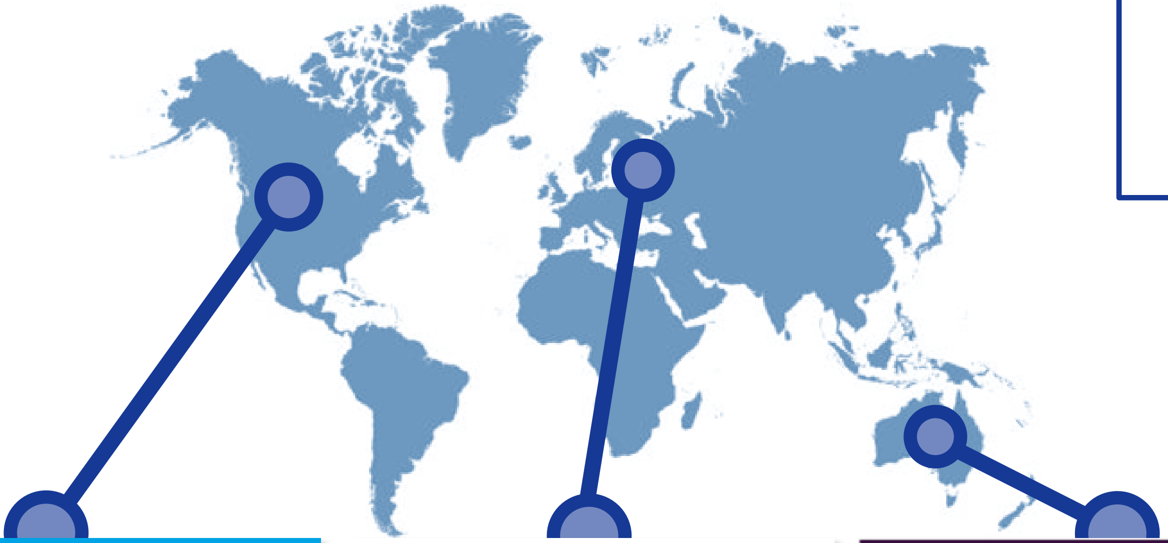
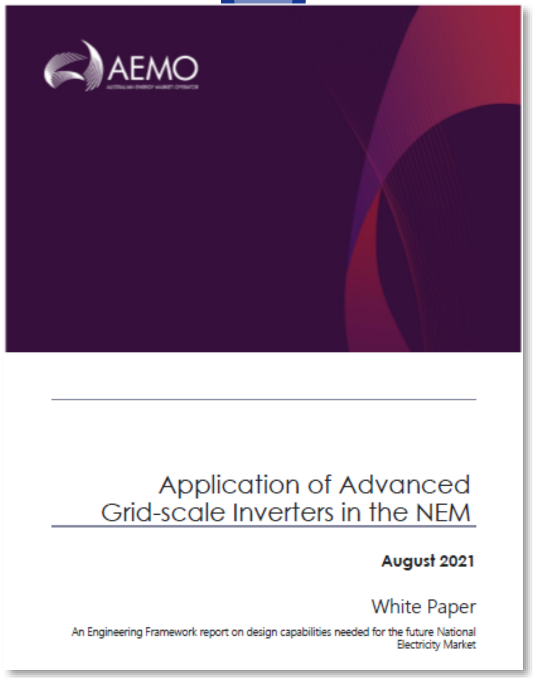
Global Landscape





Grid codes and roadmaps around the world recognize the role for (and of) grid-forming (GFM) inverter-based resources (IBRs)

Challenges

- Poor definitions of capability and functionality across technologies; lack of standardization
- Limited-to-no consensus on expected performance from unit and system levels
- Vendors/Manufacturers and Utilities/Operators appear to be locked in circular death spirals

Solution (@ a snapshot)

- Interoperability drove interconnections in the past
- Interoperability will drive innovation into the future

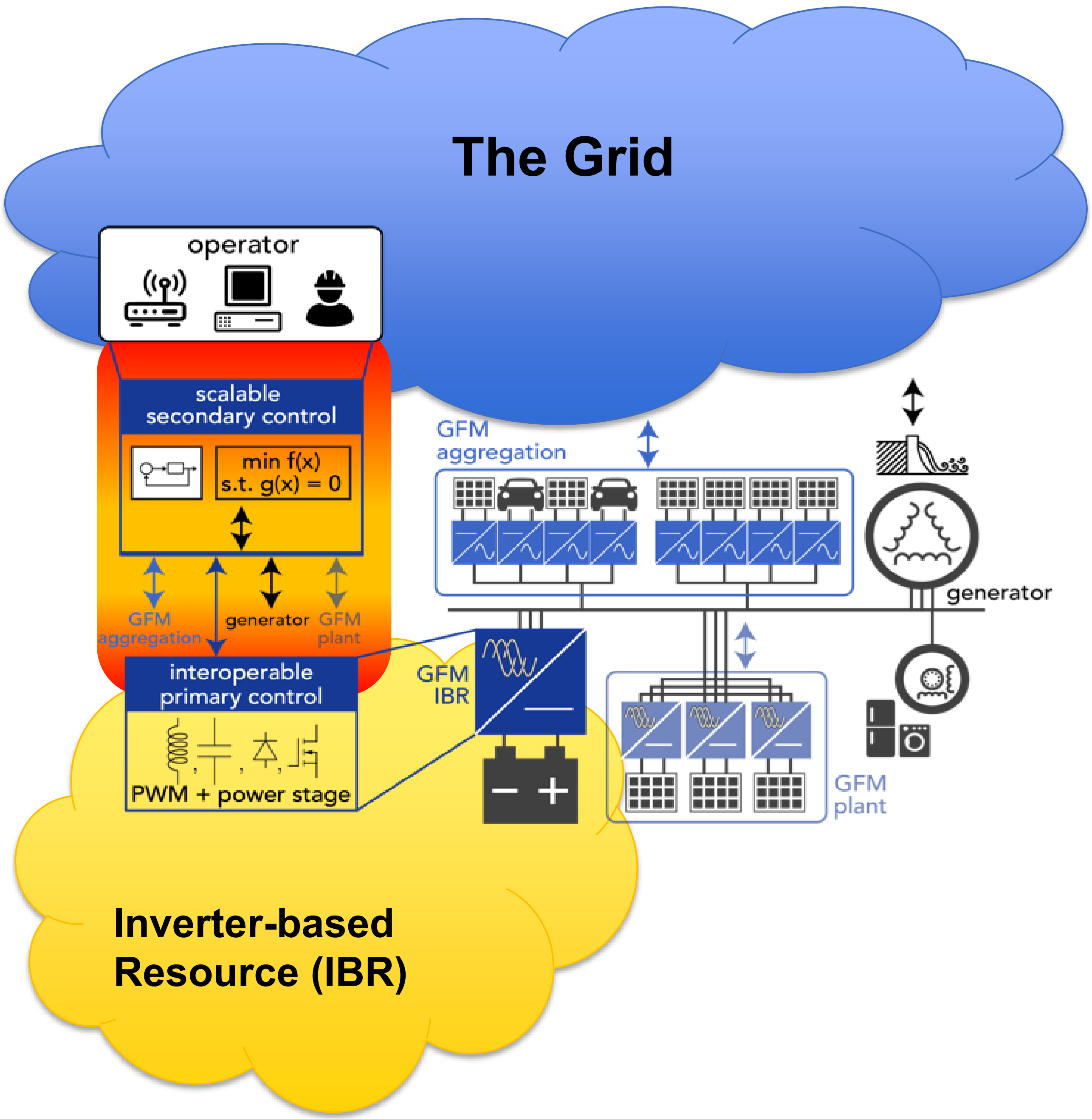
UNIFI Goals

Curate vendor- and technology-agnostic ***"UNIFI Specifications for GFM"*** that standardize performance and benchmark capabilities of GFM technologies across scales

- ***System Level - Guidelines*** *- that promote the coordinated and seamless operation of GFM technologies from multiple vendors while ensuring stable and reliable power grids*
- ***Inverter Level - Requirements*** *– that define GFM-IBR capabilities which are specified in a vendor-agnostic fashion to satisfy all system-level interoperability guidelines*

Convene continuous collaboration between inverter manufacturers (on one end) and system operators and utilities (on the other) to bridge gaps between power-systems and power-electronics industries

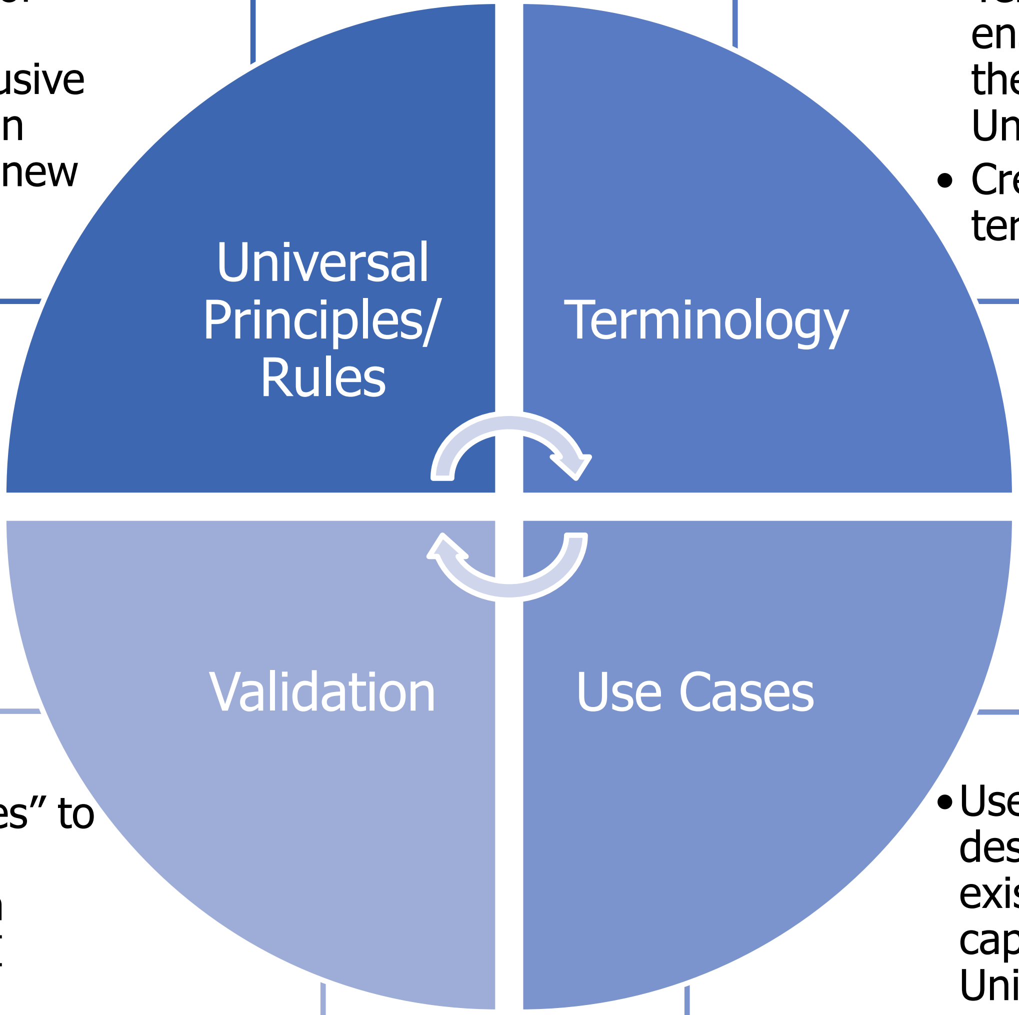
Cultivate inclusive culture and leverage member cooperation for sustained innovation



UNIFI Universal Principles/Rules Importance & Challenges

- Forward-looking description of the desired functionality of a future grid (needs to be inclusive of existing principles unless in direct conflict with what the new principles require)

- Terminology and definitions to ensure everyone understands the terms used in the Universal Principles
- Create a bridge to existing terminology and definitions



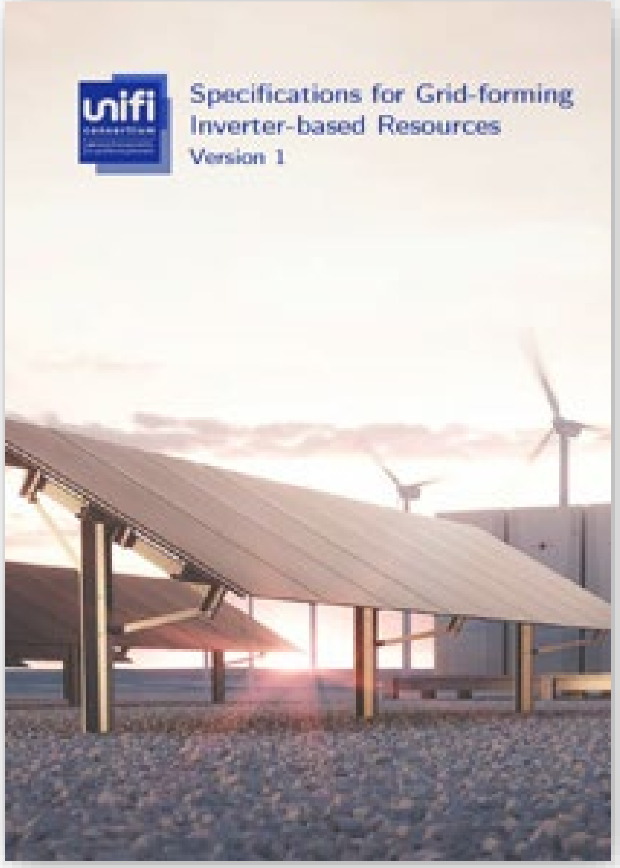
- Convert “Universal Principles/Rules” to metrics that are measurable from outside the inverter to verify if an inverter is compliant to the UNIFI principles/rules

- Use cases demonstrate desired functionality, including existing capabilities and new capabilities, resulting from the Universal Principles

UNIFI Specifications for GFM Technologies

Quick Link to UNIFI Specs

- The UNIFI Specifications for Grid-forming Technologies establish functional requirements and performance criteria for integrating GFM IBRs in electric power systems at any scale.
- Provide uniform technical requirements for the interconnection, integration, and interoperability of GFM IBR units and plants



Contents

Mapping of Universal Objectives to Specifications

Universal Objectives	UNIFI Specification Section
Seamless Transition between Grid-connected and Islanded/Microgrid Mode	Section 2.2.5
Universal Power Sharing Parameter	Section 2.1.4
Dynamic Exchange of Energy with the System to realize appropriate "Inertia" & "Damping":	Section 2.1.3 and Section 2.2.4
Passivity, damping, and interactions with other devices, even after severe transient/faults	Section 2.1.3
System Balancing, Stability & Strength	Section 2.1.5
Ability to Connect/Disconnect on Command	Section 2.2.5, Section 3.3
System Support & IBR Trip	Section 2.1.1
Cyber-secure Communications & Real-time Must-run Grid	Section 3.3
Black Starting Capabilities	Section 3.1
Dispatch-mode & Droop on Average Frequency/Voltage	Section 2.1.2 and Section 2.1.4
Support Grid Interconnection Codes and Fault Current Injection	Section 2.2.1 and Section 2.2.2
Power Quality	Section 3.2

UNIFI Specifications for GFM IBR – Version 1

Operation under Normal Grid Conditions

UNIFI Specifications for GFM IBR – Version 1

Operations under Normal Conditions

2.1.1 Autonomously Support the Grid

Both GFL and GFM IBRs are expected to autonomously respond to changes (both transient and steady state) in their locally measured signals (e.g., terminals of IBR or point of interconnection (POI) voltage, current, and frequency) to support the local power system.

2.1.12 Dispatchability of Power Output

When operating as part of an interconnected grid, a GFM IBR plant's steady state power output, within the normal range of voltage magnitude and frequency, should be dispatchable either through a grid operator command or by a locally determined goal, based upon a market clearing solution, like a GFL IBR.

UNIFI Specifications for GFM IBR – Version 1

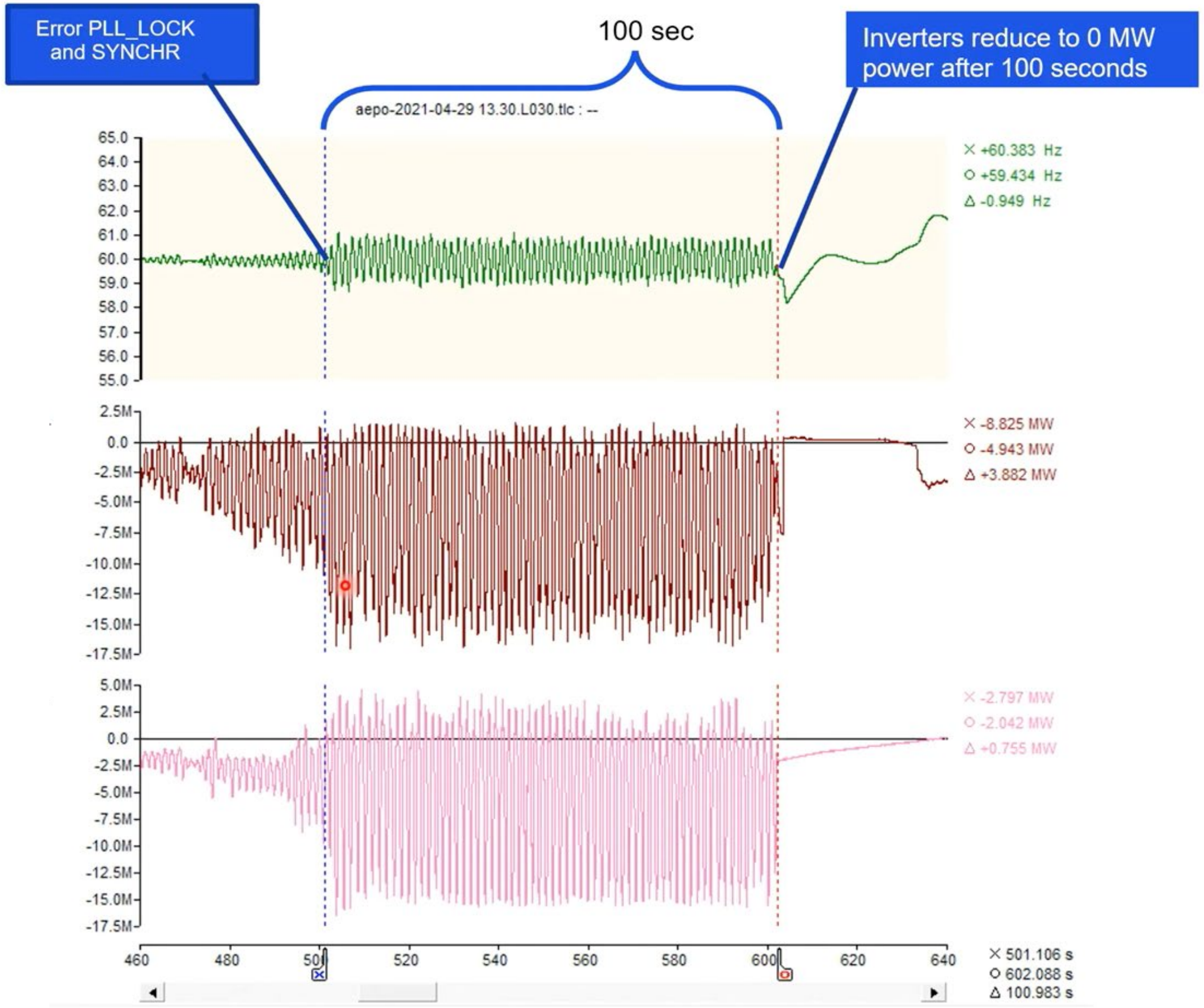
Operations under Normal Conditions

2.1.3 Provide Positive Damping of Voltage and Frequency Oscillations

It is expected that a GFM IBR will present a non-negative resistance or damping to the grid within a frequency range of common grid electrical resonances to prevent the initiation of any adverse interactions or oscillations.

2.1.4 Active and Reactive Power Sharing across Generation Resources

A GFM IBR is expected to share (e.g. incrementally increase power burden) with other generation resources using the principles of droop akin to the operation of conventional synchronous generators or GFL IBRs.



Source: Lessons Learned from Inverter-Based Grid Forming Operations, C. Krause KIUC and A. Dcosta AES Clean Energy – UNIFI Seminar Fall 2022

Operations under Normal Conditions

2.1.5 Robust Operation in Grids with Low System Strength

A GFM IBR is expected to operate stably when connected to a power system with low system strength and to improve the strength of the network in the region of connection during normal operations via a reduction in the sensitivity of voltage to current injection and a reduction in the rate of change of frequency during an event.

2.1.6 Voltage Balancing

A GFM IBR should not actively oppose or prevent the flow of negative sequence current for small levels of voltage unbalance.

Characteristics of low system strength
A power system with low system strength will exhibit one or more of the following:

- Wider area undamped voltage and power oscillations. Generator fault ride-through degradation.
- Mal-operation or failure of protection equipment to operate.
- Prolonged voltage recovery after a disturbance.
- Larger voltage step changes after switching capacitor or reactor banks.
- Instability of generator / dynamic plant voltage control systems.
- Increased harmonic distortion (a by-product of low system strength and higher system impedances).
- Deeper voltage dips and higher over-voltages (e.g. transients).

"System Strength" – AEMO March 2020

Operation outside Normal Grid Conditions

UNIFI Specifications for GFM IBR – Version 1

Operation Outside Normal Conditions

2.2.1 Ride-through Behavior

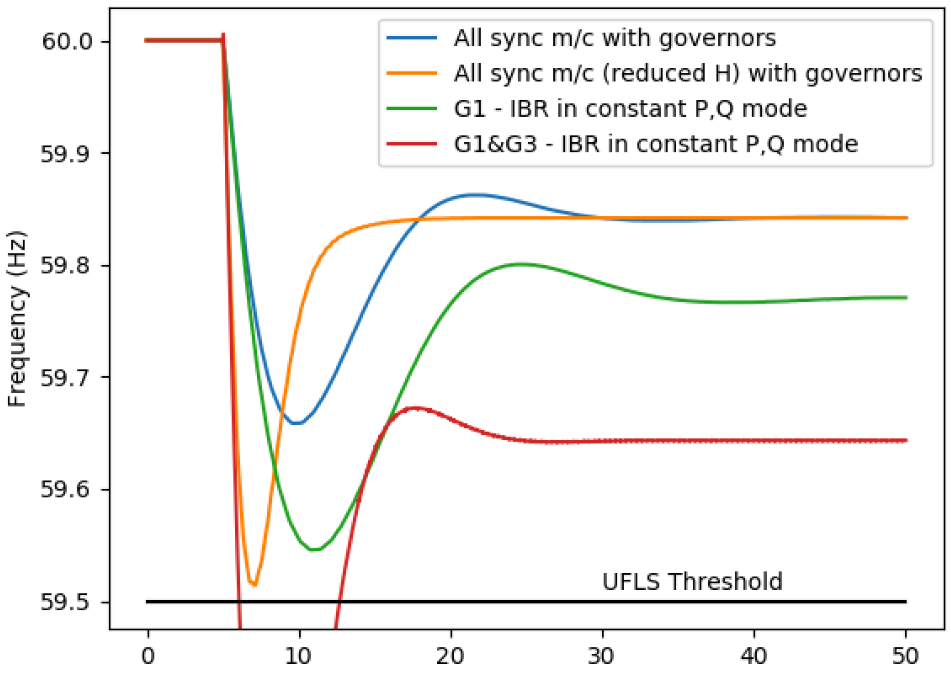
A GFM IBR is expected to inject current during and after a voltage sag to aid in voltage recovery.

2.2.2 Response to Asymmetrical Faults

During asymmetrical faults, a GFM IBR is expected to maintain a balanced internal voltage to the extent possible within its physical limits.

2.2.3 Response to Abnormal Frequency

A GFM IBR is expected to modulate active power as required during and after a frequency excursion event to aid in frequency recovery and stability.



EPRI Grid Forming Inverter Tutorial
https://www.epri.com/research/products/000000003002025483

UNIFI Specifications for GFM IBR – Version 1

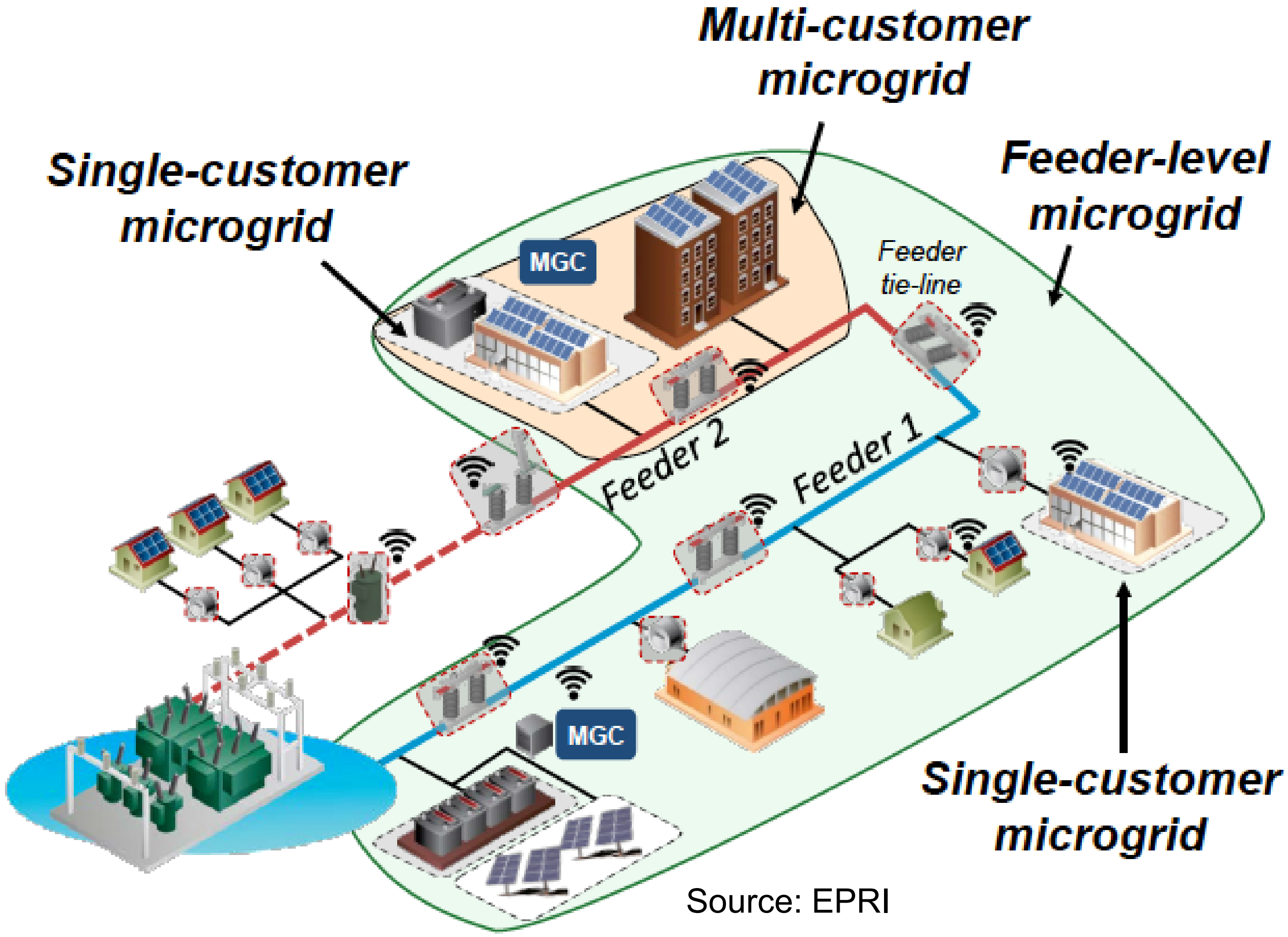
Operation Outside Normal Conditions

2.2.4 Response to Phase Jumps and Voltage Steps

A GFM IBR is expected to absorb or inject active and/or reactive power to resist changes in positive sequence voltage phase angle and is expected to do so without exceeding equipment limits.

2.2.5 Intentional Islanding

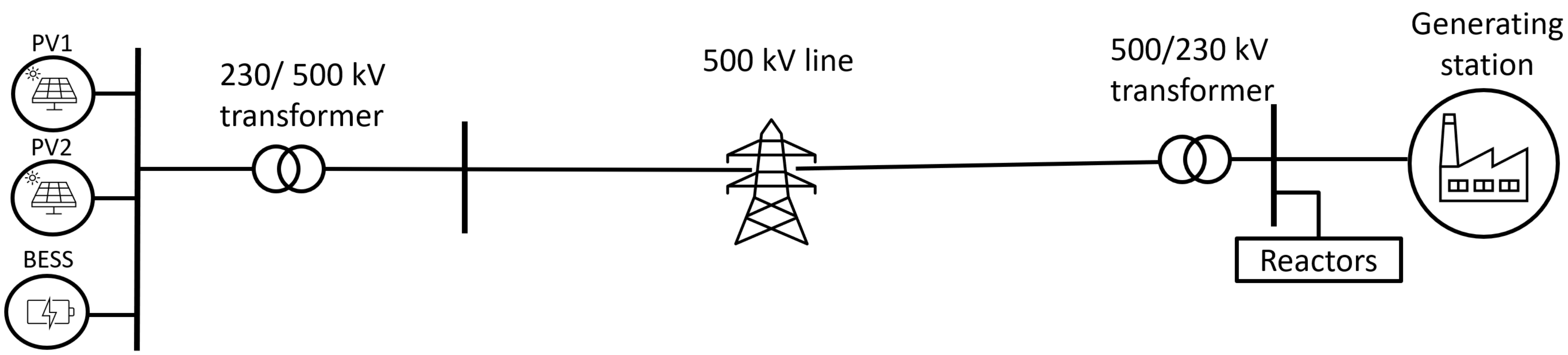
A GFM IBR (designed to maintain an intentional island) is expected to be capable of continuing to support the evolution of a stable voltage and frequency of the island/microgrid.



Source: EPRI

UNIFI Specifications for GFM IBR – Version 1

Blackstart – a GFM+ Service



IBR
Rating:
PV1 300 MVA
PV2 250 MVA
BESS 400 MVA

- ✓ Grid forming inverters (PV/BESS)

Transformers
Rating: 400- 1100 MVA

- ✓ Saturation/Hysteresis model included (Typical saturation data was assumed)

Transmission lines
(20- 60 miles)

- ✓ Frequency dependent line model used
- ✓ Parameters obtained from real data

Generator station auxilary load

- ✓ Load composition details obtained from real data
- ✓ Three phase induction motor models (NEMA type B)

Capability of Inverter technologies to meet future needs for system Blackstart
https://www.nerc.com/comm/RSTC/IRPS/IRPS_Meeting_Presentation_EPRI_SCE_blackstart_study.pdf

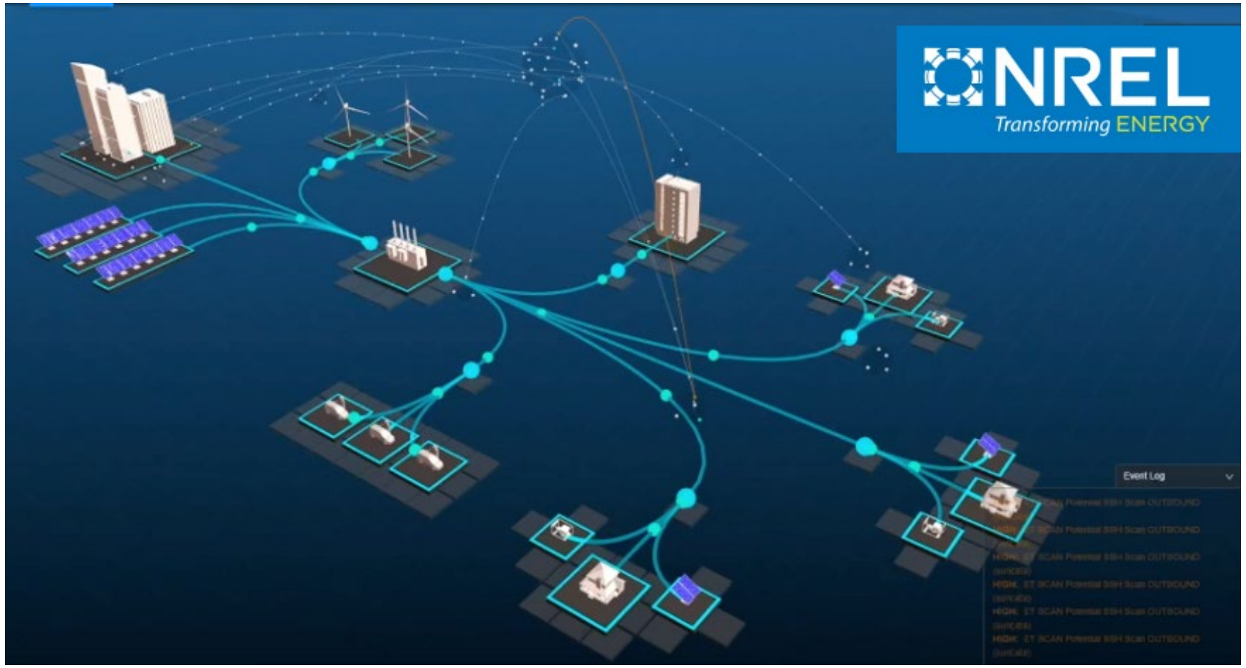
UNIFI Specifications for GFM IBR – Version 1

Communications and Secondary Response

- When communications are required between the GFM IBR units or plant and the system operator, a cyber-secure communications method should be used.

- The power system and the GFM IBR should continue to operate when communications are delayed or interrupted.

- It is expected that signals from the power system operator or an aggregator would have an update rate on the order of seconds and represent a **secondary control signal** (primary control being autonomous controls inside the IBR unit) for providing power flow set points or other commands.



UNIFI Specifications for GFM IBR – Version 1

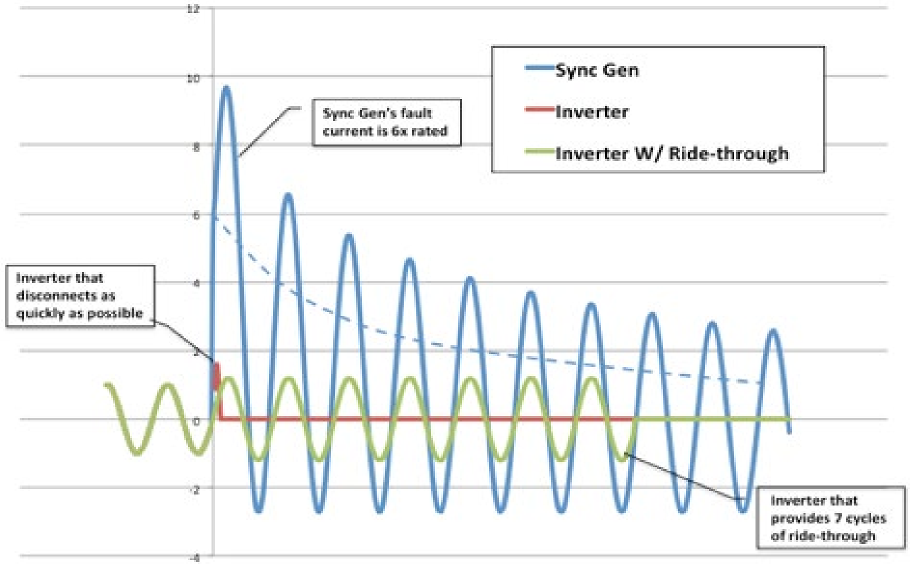
IBR Short-term Rated Current

- The IBR short-term rated current (ISRC) is the output of current in excess of the continuous rated current for a time-limited period, but without exceeding the IBR's absolute maximum current capability, so that the IBR remains able to regulate voltage and frequency.

- The GFM IBR data sheet should provide a magnitude and duration for ISRC that enables the GFM inverter to support protection operations or events like transformer inrush and motor starting. This capability might also impact the response of unbalanced faults wherein the current on one phase exceeds that of the others.

- An example IRSC specification would be "1.5 times full-rated current for 2 seconds".

- If the ISRC capability is not provided by the GFM IBR and it is used to support transformer inrush and motor starting, then the inverter should be sized properly such that its continuous current capability is sufficient in supplying the inrush current.



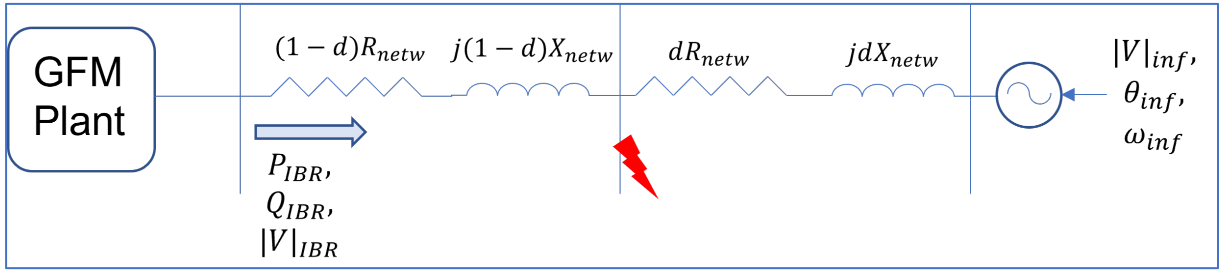
UNIFI Specifications for GFM IBR – Version 1

Constraints due to Input Source

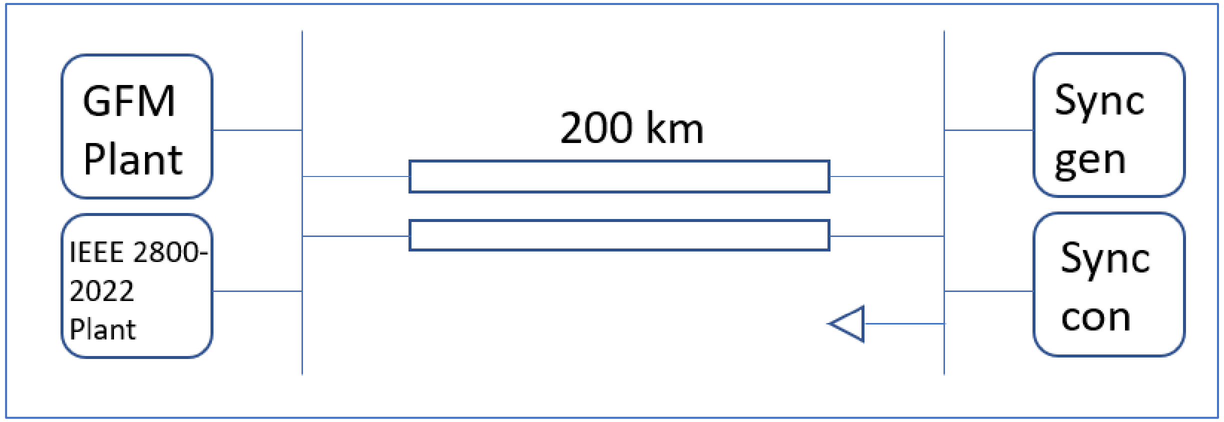
The speed of response may be constrained by the basic limitations of the DC source behind the GFM inverter.

Developing Models for GFM to Verify Specifications

UNIFI Modeling and Simulation Area Working Group is evaluating how simulation can verify various specifications



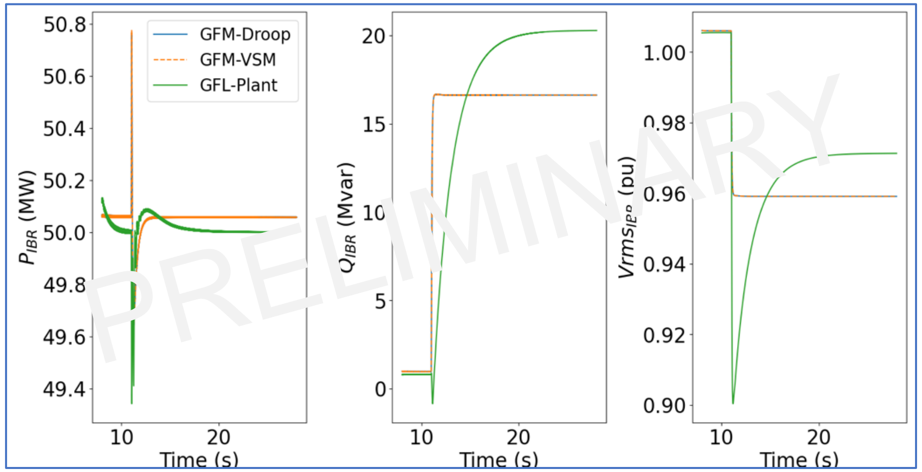
Test network A



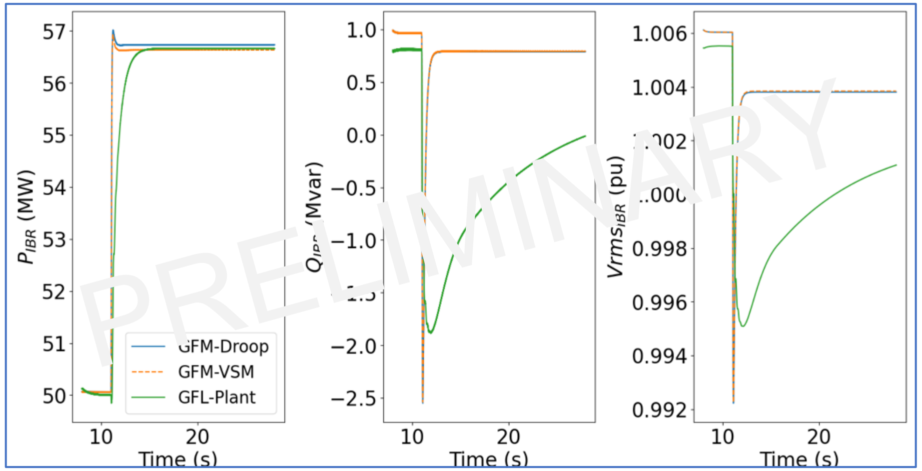
Test network B

Test	Test network	Specifications sections that can be verified
$\lvert V_{inf} \rvert$ step change	A	2.1.1, 2.1.4, 2.1.5, 2.2.4
ω_{inf} step change	A	2.1.1, 2.1.4
θ_{inf} step change	A	2.2.4
Double line to ground fault	A or B	2.2.1, 2.2.2, 3.5
Trip of synchronous sources	B	2.1.1, 2.1.4, 2.1.5, 2.2.5

Preliminary time domain results from UNIFI Modeling and Simulation Area Working Group



Step change in Voltage



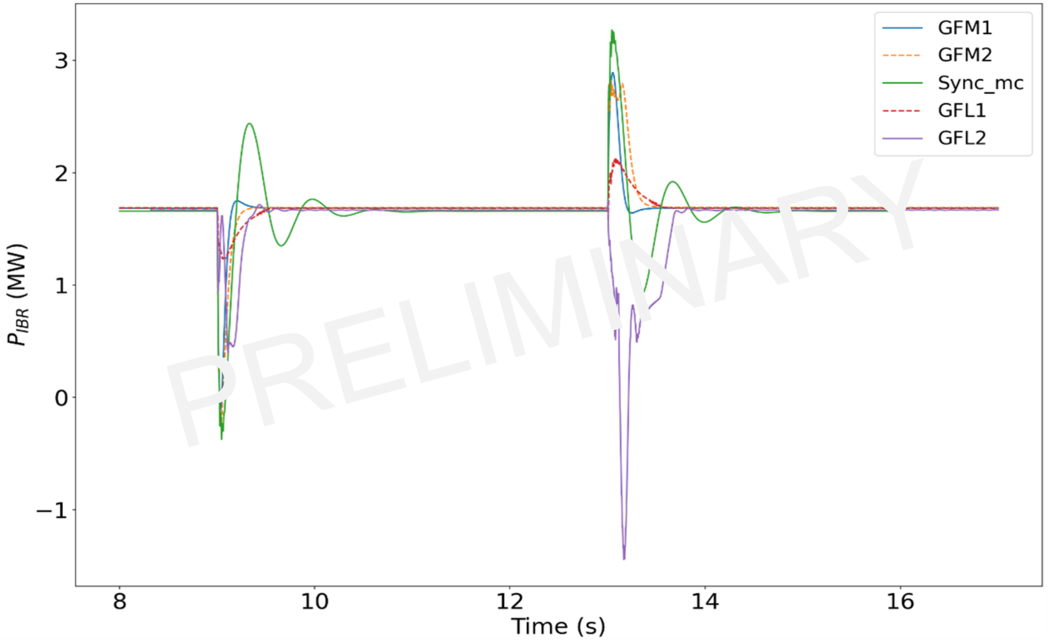
Step change in Frequency

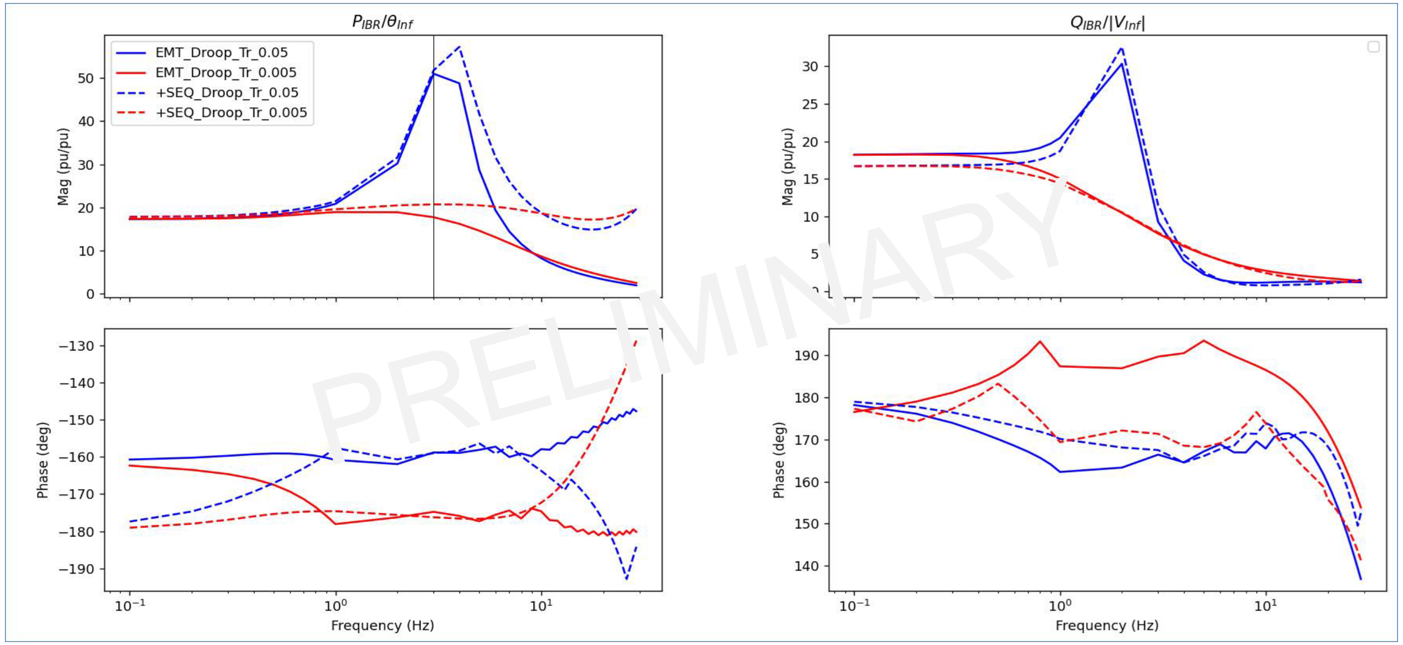
Preliminary results showcase the speed and robustness of GFM response when compared to GFL devices.

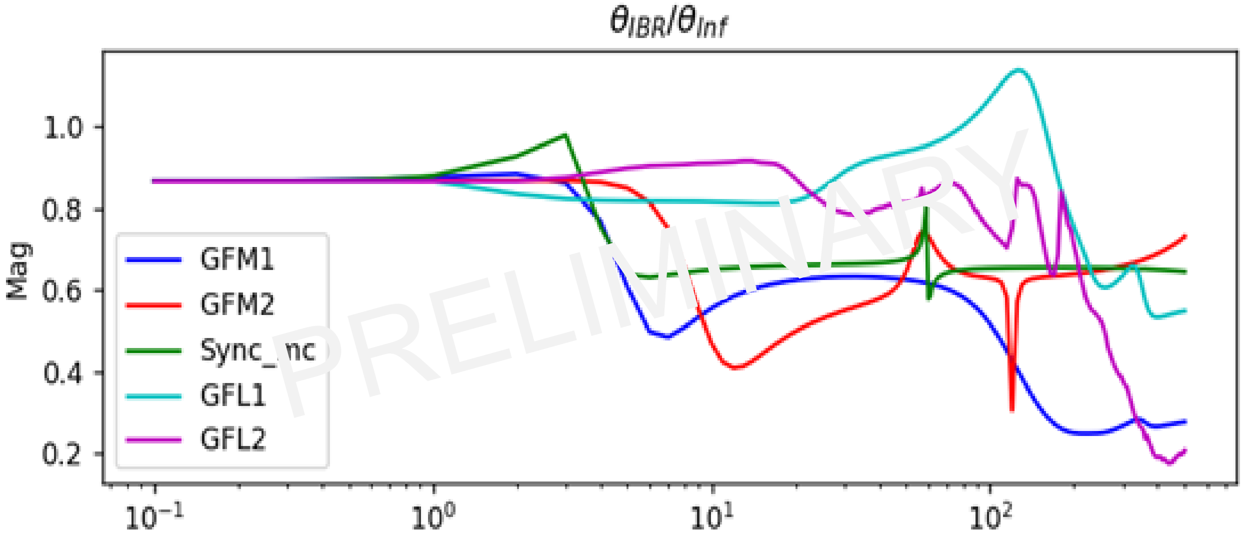
They also provide an expectation that it is possible to meet UNIFI Specifications

Frequency domain characterization to identify GFM vs GFL and carry out model validation

- Time domain characteristics are not sufficient







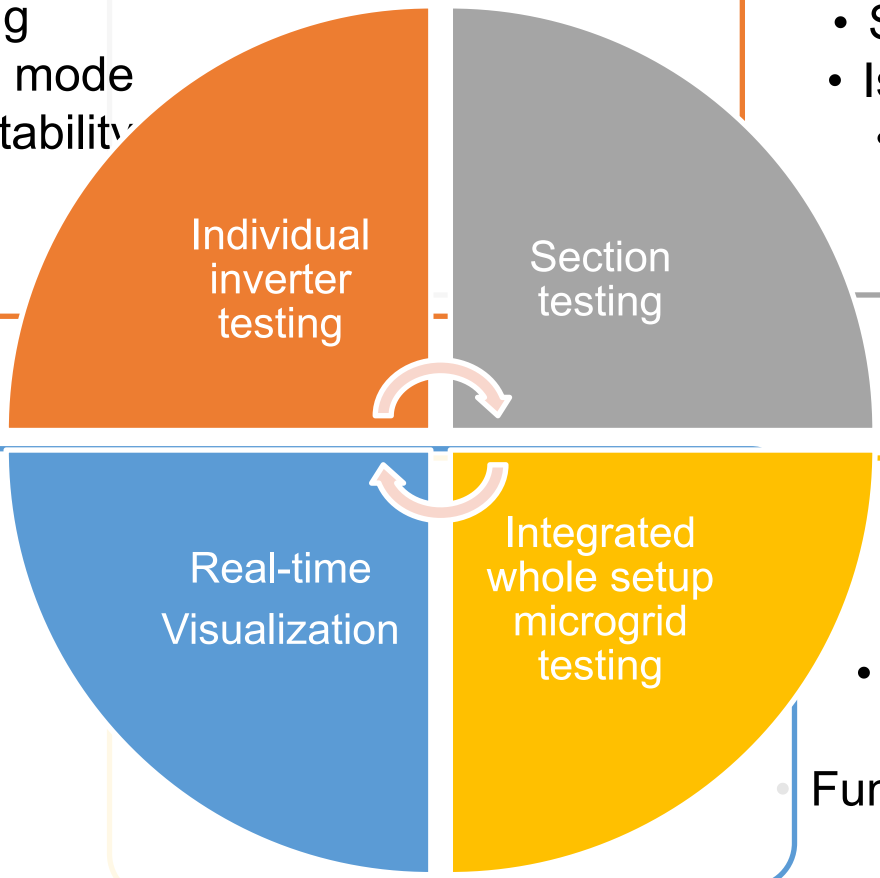
Certain frequency domain characterization can be used to identify characteristics and behavior of GFM and GFL. EMT and +SEQ model behavior can also be verified

UNIFI 1MW Multi-Vendor Experiment – Integration & Validation Working Group

Will help evaluate UNIFI Specifications

- Black-box testing
- Programmable inverter testing
- Grid-connected and islanded mode
- Evaluate individual inverter stability performance

- Mix of GFM, GFL and SG
- Single-phase residential homes
- Islanding and resynchronization
- Preliminary interactions study
- Evaluate nano-grid system



- RMS values (V, I, P, Q, f)
- Sinusoidal waveforms
- Coordination signals
- Operation modes and settings

- Multi-vendor GFM inverters
- Various GFM penetration level
- Emulate a realistic microgrid
- Functionalities and interoperability

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universal interoperability for grid-forming inverters

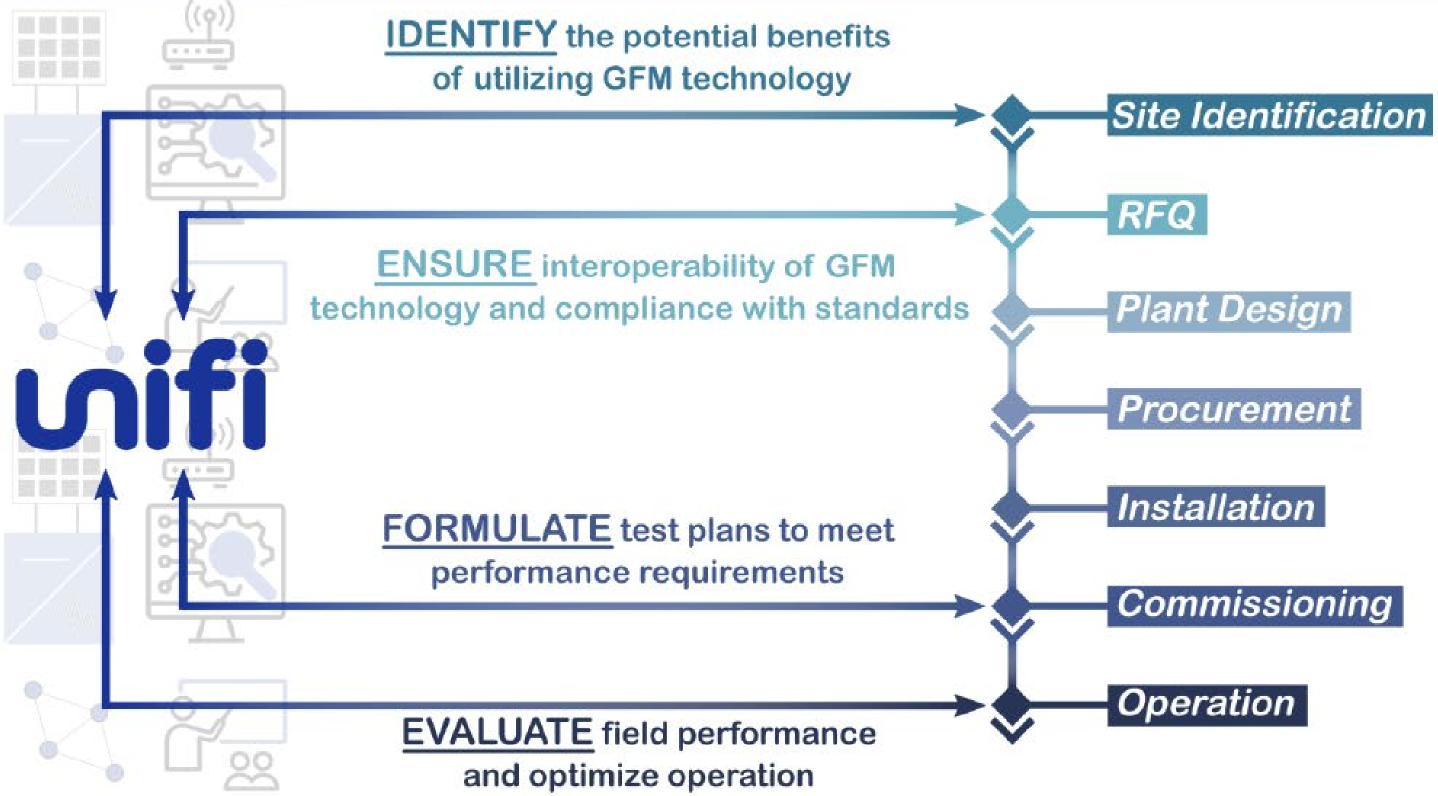
Grid-forming Inverter Capability Demonstration

are you planning a 20+ MW plant with inverter-based resources and considering grid-forming technology?

...we have you covered from site identification to operation...

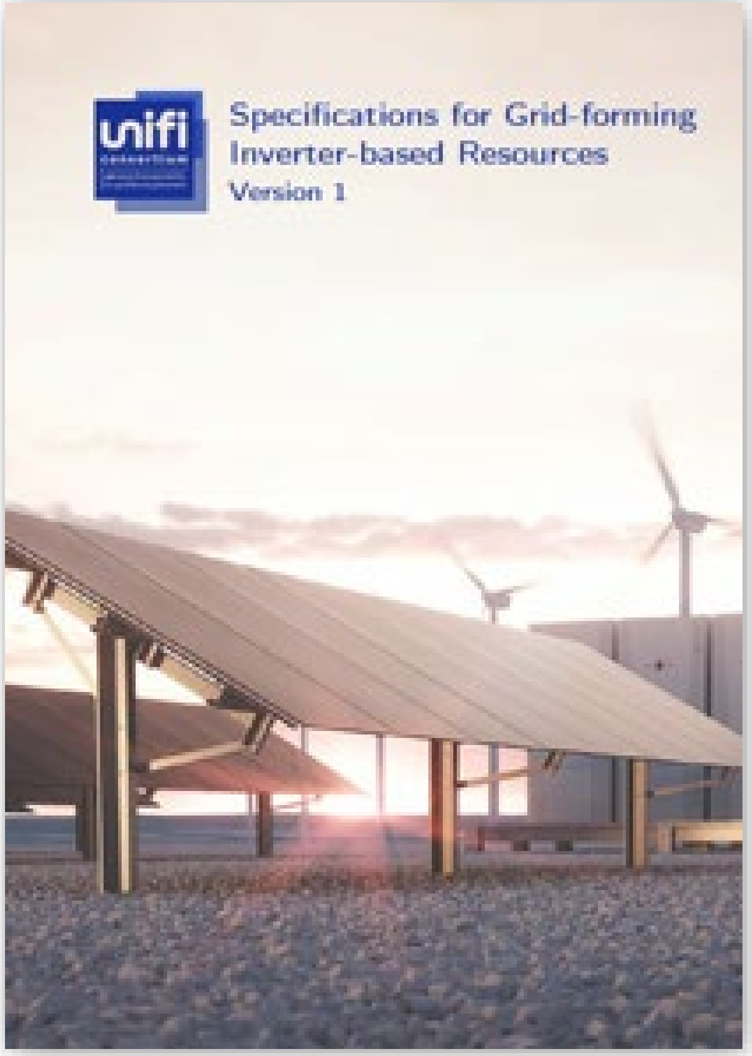
why grid forming?

- **Dispatchable active/reactive power**
  in response to system-operator needs
- **Frequency and voltage droop**
  to comply with grid codes
- **Power sharing in proportion to capacity**
  with no external communication
- **Black-start functionality**
  to maximize system resilience
- **Improved stability**
  even in low system-strength conditions



Summary

- Wind, Solar PV, and Batteries have favorable economics and are being deployed at a high rate
- Wind, Solar PV, Batteries are all inverter-based resources
- IBRs will soon be a dominant part of the power grid during many hours of the day
- IBR and synchronous generator operation needs to be unified to ensure stable and reliable operation of the grid
- GFM IBR are needed to provide grid support and stable operations above 60-70% instantaneous levels
- GFM specifications, models, testing procedures, and integration processes are needed
- UNIFI Consortium is actively working on these items (and more!)



Google: **UNIFI Consortium** or go to
https://sites.google.com/view/unifi-consortium

Thank you

Special Thanks to the UNIFI Consortium Area Leads:

- Wei Du, PNNL
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