Comparison of Grid Forming Specifications

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10/26/2022

Grid Forming

- **Grid-Forming:** The primary objective of grid-forming controls for IBRs is to maintain an internal voltage phasor. When grid-forming controls are applied in bulk power system (BPS) connected IBRs, the voltage phasor is held constant in the sub-transient to transient time frames. This allows the IBR to immediately respond to changes in the external system and provide stability in the controls during challenging network conditions. This phasor must be controlled to maintain synchronism with other devices and control active and reactive currents to support the grid. When grid-forming controls are applied in non-BPS connected IBRs (for example black-start or microgrids), this synchronization functionality is removed or limited, and the voltage phasor may be held relatively constant over time. This allows the plant to operate in an electrical island and define the grid frequency.
- There are many variations of both grid-forming and grid-following converter controls. Both are subject to physical equipment constraints including voltage, current and energy limits, mechanical equipment constraints (on WTGs) as well as external power system limits.
- Further, performance requirements for GFL plants, will also apply to GFM inverters unless explicitly identified as inapplicable.

Source: Grid Forming Technology in Energy Systems Integration

Grid Following

- A GFL IBR maintains active and reactive components of its output current at a constant value during the transient time frame. To do this, the GFL IBR relies on a fast-acting synchronizing function typically using a phase-locked loop (PLL) that determines the angle of the grid voltage at the IBR's point of connection. The inverter uses this measured angle to tightly control the active and reactive components of the current it supplies. In other words, the controls "follow" the measured grid voltage. If the controller cannot accurately and quickly track the external voltage, a GFL IBR cannot maintain controlled, stable output. In the transient time frame, GFL IBRs appear to the grid as constant current sources. Most IBRs in service today are GFL

Source: [Grid Forming Technology in Energy Systems Integration]

Grid Forming Specifications Landscape

- **EU- funded MIGRATE project** – proposed high level GFM functions – 2019
- **ENSTO-E, High Penetration of Power Electronic Interfaced Power Sources** (HPOPEIPS) – identified seven properties of GFM plant – 2020
- **VDE/FNN Guideline**: Grid forming behavior of HVDC systems and Power Plant Modules – performance verification procedure for grid forming – 2020
- **Hawaiian Electric Company requested GFM functionality** from all proposed projects that include battery storage – high level functional requirements in combination with required model tests – 2019, 2021
- **National Grid Electricity System Operator finalized GC0137** – non-mandatory GFM specification – 2022
- **EU-funded OSMOSE project** – defined grid forming capability and new services – 2022
- **DOE-funded project UNIFI**, Specifications for Grid-forming Technologies – functional requirements and performance criteria for integrating GFM IBRs in electric power systems – ongoing
- **NERC Inverter-Based Resource Performance Subcommittee (IRPS) Defining Grid Forming Capability in Interconnection Requirements for BPS-Connected Battery Energy Storage Systems**: Functional Specifications, Verification, and Modeling – ongoing
- **Australian Energy Market Operator** – working on a draft of voluntary GFM specifications – ongoing

National Grid ESO, GC0137 Grid Forming Requirements

On January 31th 2022 the Great Britain's Office of Gas and Electricity Markets (OFGEM) approved the GC0137 grid code change, defining a non-mandatory technical specification for GFM plants. At a high level GFM IBR shall:

- Comprise an internal voltage source (IVS) and physical reactance
- Remain synchronized with the system and maintain a load angle between 0 and 90 degrees,
- Be capable of supplying:
  - Phase Jump Active Power (inherent, < 5 ms, response to phase change between IVS and POI)
  - Real Inertia Power (inherent, < 5 ms, response to changes in phase and frequency)
  - RoCoF Response Power (incl. Real Inertia Power and Control Based Real Droop Power when subject to RoCoF)
  - Damping Active Power (inherent, < 5 ms, response to oscillations)
  - Voltage Jump Reactive Power (inherent, <5 ms, reactive power response to a step or ramp change in the difference between IVS and POI voltage magnitudes.
  - Fast Fault Current Injection (reactive current that starts to rise in <5 ms when the voltage falls <0.9 pu; deployment up to 1 pu shall be achieved in < 30 ms)
  - Control Based Real Droop Power (response to frequency changes with Maximum Capacity within <1 s, FFR)
  - Control Based Real Power (incl. Control Based Real Droop Power),
  - Control Based Reactive Power,

National Grid ESO, GC0137 Grid Forming Requirements

- Control Based changes have a bandwidth limited to 5 Hz (to avoid AC System resonance problems)
- Phase Jump Active Power and Real Inertia Power can have frequency components to over 1000 Hz.
- If a unit is designed with black start capability, then it is required to have grid forming capability
- A minimum Phase Jump Angle Limit, for the unit to remain in linear control (without hitting current limits), of 5 degrees is recommended and
- A 60 degrees Phase Jump Angle Withstand capability is specified.
- The RoCoF response power is assessed for 1Hz/s, while RoCoF withstand capability is requested up to 2 Hz/s
- The cumulative energy delivered is defined for a 1Hz/s System Frequency fall from 52 Hz to 47 Hz in MWs, but also an inertia constant value (H) must be declared by the service provider.

Source: https://www.nationalgrideso.com/industry-information/codes/grid-code-old/modifications/gc0137-minimum-specification-required
https://www.nationalgrideso.com/document/207571/download
https://www.osmose-h2020.eu/wp-content/uploads/2022/03/OSMOSE-D3.3-Analysis-of-the-synchronisation-capabilities-of-BESS-power-converters.pdf

Hawaii GFM IBR Requirements

- Hawai’i has a number of small, islanded systems. By 2023 they may be seeing near 100% renewable penetration with very high DER (50-70% penetration is expected)
- Scenarios for 2023 for Oahu and Maui unstable in steady state if all IBRs are GFL
- They will need to be relying on GFM IBRs to maintain grid frequency and prevent blackouts.
- Very high-level performance requirement for GFM capability was included in the recent project’s power purchase agreement (for battery storage):

  IBRs shall be capable of operating in GFM mode supporting system operation under normal and emergency conditions without relying on the synchronous machines. This includes operation as an AC voltage source during normal and transient conditions (within the inverter limits) and the ability to synchronize to other voltage sources or operate autonomously if a grid reference is unavailable

- In addition to this high-level requirement, a detailed set of tests was applied to prospective generator models.

Source: Andrew Isaacs, Hawaiian Electric GFM Requirements, ESIG Grid-Forming Workshop

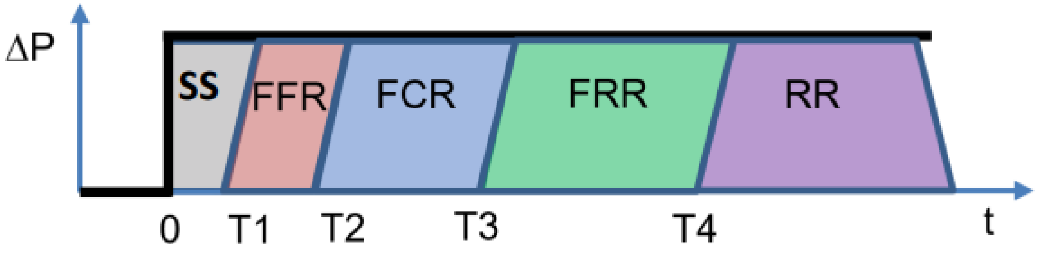
Hawaii GFM IBR Requirements

Based on the follow-up EMT study, the following details were added to the GFM requirements for the next round of resource procurement including additional sets of tests. Within equipment limits, GFM IBR shall:

- Operate in a stable manner on low system strength grids (low SCR, low or zero inertia).
- Set an internal voltage waveform reference and be able to either synchronize with the grid or operate independently of other generation.
- Respond to changes in system frequency and voltage, contributing toward the system recovery
- Have a damping control function that damps oscillations within the interconnection and other adverse interactions among power electronic devices.
- Upon the loss of the last synch. gen, operate autonomously if a grid reference is unavailable and share the active and reactive power burden with other voltage sources without impacts on system stability.
- Be able to transition from an electrical island to a grid-connected state without impacts on system stability.
- Provide active low-order harmonics cancellation.
- Provide black-start capability (if applicable).

EU-funded Project OSMOSE

- H2020 EU funded project lead by RTE Jan 2018-Apr 2022
- Large scale demonstrators led by TSOs to foster participation of new flexibility providers, incl. grid forming storage (two demos: 720 kVA battery and 1000 kVA battery with supercapacitors
- Recommendations for specifying grid forming capability in EU grid codes, definition of synchronization services, validation of GFM capability from an off-the-shelf MVA-scale battery, multi-service optimization framework, metrics to evaluate performance.



Fast Frequency Response FFR
Frequency Containment Reserve FCR
Frequency Restoration reserve FRR
Replacement Reserve RR

T1= ~250ms-2s
T2=10-30s
T3= 5-15min
T4= 15-60 min

New Services:

- Synchronizing Active Power – immediate active power injection following a phase jump
- Inertia response – immediate active power injection following a frequency ramp
- System strength – immediate reactive power injection following grid voltage variation
- Faut Current – an immediate current injection (within rating) following voltage dips

Source: Osmose, Analysis of the synchronization capabilities of BESS power converters, www.osmose-h2020.eu/wp-content/uploads/2022/03/OSMOSE-D3.3-Analysis-of-the-synchronisation-capabilities-of-BESS-power-converters.pdf

OSMOSE: Types of grid forming units

- **Type 4:**
  - Services provided: Type 3 + **high fault current** (> 2 pu)
  - Criticality: if protection fail to detect faults
  - Cost: high for converters (oversizing), null for synchronous machines
- **Type 3:**
  - Services provided: Type 2 + **inertial response**
  - Criticality: when system inertia decreases system-wide
  - Cost: limited due to the need of an energy buffer from a few seconds to 1 minute
- **Type 2:**
  - Services provided: Type 1 + **synchronizing power**
  - Criticality: when system inertia decreases locally
  - Cost: very limited due to the need of an energy buffer < 1 s (other FFR resources can then take over)
- **Type 1**
  - Services provided: Stand alone + System Strength+ fault current (within ratings), wide range of SCR operation
  - Criticality: when system strength decreases locally
  - Cost: null, only software changes

Synchronous Machine

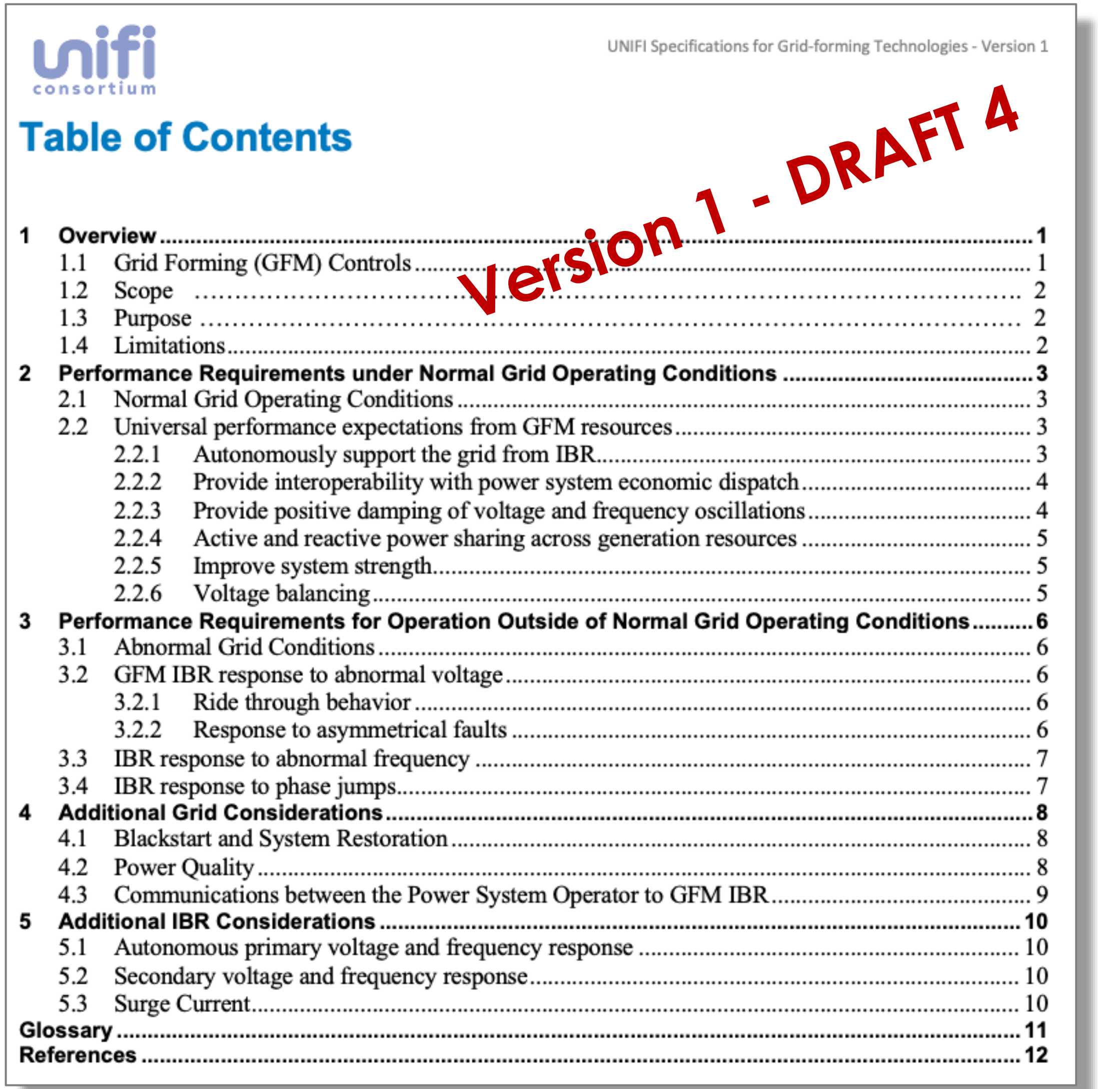
GFM Battery

Source: Carmen Cardozo, OSMOSE presentation at ESIG GFM Workshop
https://www.esig.energy/event/2022-special-topic-workshop-grid-forming-ibrs/

U.S. DOE-funded UNIFI

- Universal Interoperability for Grid-Forming Inverters (UNIFI) Consortium
- Brings together leading researchers, industry stakeholders, utilities, and system operators
- Forum to address fundamental challenges in seamless integration of grid-forming (GFM) technologies into power systems of the future
- Includes R&D, Commercialization and Demonstration, Outreach and Training
- 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

https://sites.google.com/view/unifi-consortium/home
UNIFI Channel


unifi consortium

UNIFI Specifications for Grid-forming Technologies - Version 1

Version 1 - DRAFT 4

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Comparison at Glance

Specs	GC0137	OSMOSE	VDE/FNN	UNIFI (draft)	HECO
Response to phase-jump	Yes, defines response time (< 5ms) and size of phase-jump angle (5 deg)	Yes, similar to GC0137	Yes, Provides a time-dependent profile with a minimum sustain time	Yes	Yes, high level
Inertial Response / Immediate Active Power	Yes, defines response time (< 5ms)	Yes, defines response time (< 5 ms) and proposes to set min sustain time	Yes (implicit), frequency change test	Yes	Yes, high level
System Strength/ Immediate Reactive Power / Response to voltage Step	Yes, defines response time (< 5 ms)	Yes, defines response time (< 5 ms)	Yes, verified through voltage step tests	Yes (improve system strength)	Yes, high level
Fast Fault Current (balanced and unbalanced)	Yes, defines response time (<5 ms) and time to full response (<30 ms)	Yes, defines response time (< 5 ms) , discusses active/reactive current share and pos/negative sequence prioritization	TBC	Yes, at high level and by definition	Yes, high level

This specification generally apply within equipment limits and all requirements applicable to GFL IBRs also apply (unless conflicts with GFM requirements above)

Comparison at Glance

Specs	GC0137	OSMOSE	VDE/FNN	UNIFI (draft)	HECO
Low SCR operation	Yes	Yes, by definition	Yes	Yes	Yes, high level
Active/Reactive power sharing	Yes (implicit in other req.)	Yes (implicit in islanded test)	Yes (implicit in islanded test)	Yes	Yes, high level
Damping of voltage and frequency oscillations	Yes, defines response time (<5 ms)	May be	Yes	Yes	Yes, high level
Islanded operation	Yes	Yes	Yes	Yes	Yes, high level
Counter Harmonics	No (existing requirements for GFL apply, additional requirements may be agreed bilaterally)	No (requirement not to contribute to harmonics as applied to GFL is already challenging)	Yes	Yes	Yes, high level
Black start	Yes, if applicable	Yes, if applicable	Yes, if applicable	Yes, if applicable	Yes, if applicable

These specifications generally apply within equipment limits and all requirements applicable to GFL IBRs also apply (unless conflicts with GFM requirements above)

Common Functionalities

- Response to voltage phase angle step
- Response to voltage magnitude step
- Active/Reactive Power Sharing
- Provide Damping
- Counter Harmonics
- Response to RoCoF event (MW loss)
- Response to Faults (balanced and unbalanced)
- Low SCR Operation
- Island Operation
- Black Start

Conclusions

- GFM specifications is still a new topic and is developing together with GFM controls
- All specifications are similar in terms of functionalities, with main differences being around level of specificity and if a requirement is explicit or implicit in a certain specified behavior
- Some of the requirements are more specific while others are high level, in some cases accompanied with performance expectations during testing
- Balance is needed between incentivizing desired behavior (as synchronous machines are being displaced) and allowing freedom in control implementation by OEMs
- High level requirements accompanied with more detailed performance guidelines seems to be a preferred approach today
- Some functionalities can be implemented in grid following inverters as well; these shouldn’t be included as a part of GFM specifications.

High Share of IBR TF

- Benefits of Grid-Forming Energy Storage Resources: A Unique Window of Opportunity, white paper by the end of December 2022
- Grid Forming Landscape – update paper including latest initiatives around grid forming technology, end of December 2022
- What do GFM specifications mean? Performance expected from GFM – end of 2023
- New Services with high shares of IBR including ERCOT case study – end of 2023
- Stability Assessment Methods with High Shares of IBR – January 2023

THANK YOU

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