Large Scale Field Demonstration Evaluation Plan

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List of Acronyms

UNIFI	Universal Interoperability for Grid-forming Inverters
GFM	Grid Forming
DERMS	Distributed Energy Resource Management System
DMS	Distribution Management System
RMS	Root mean squared
DC	Direct Current
AC	Alternating Current
EERE	Energy Efficiency and Renewable Energy
PCC	Point of Common Coupling
PF	Power Factor
THD	Total Harmonic Distortion
PU	Per Unit
IBR	Inverter Based Resource
RFP	Request for Proposal

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1 Field Demonstration Purpose

The purpose of the Field Demonstration in the UNIFI (Universal Interoperability for Grid-forming Inverters) Consortium is to demonstrate, in fielded operation, the deployment of Grid Forming (GFM) technologies from multiple vendors that provide a range of grid services at impactful unit/plant sizing. The Field Demonstration will evaluate the UNIFI "Specifications for Grid-forming Inverter-based Resources"[1] produced by the Consortium in a relevant fielded implementation through engaging utilities, manufacturers, and system operators to identify and implement a GFM field demonstration with mixed assets, functionalities, and usage scenarios.

The demonstration will be set up to examine the impact of a wide variety of normal and contingency operation modes to demonstrate possible impacts on system resilience and stability through the incorporation of GFM technologies. The focus on a multi-vendor demonstration will be critical to illustrate the UNIFI "Specifications for Grid-forming Inverter-based Resources" at work in the field. The demonstration will also target complete integration into system control and utility operations (e.g., SCADA, AGC, DERMS, DMS, EMS) and protection systems. This will allow the demonstration system to evaluate a wide variety of functionalities in the field including (but not limited to): interoperable and primary and secondary control, frequency and voltage control, power sharing, black-start, and operations to achieve up to 100% power contribution from Inverter Based Resources (IBRs) during medium- and high-demand periods through a mixture of simulation, experimental evaluation, and long-term data monitoring.

This document is meant to define commissioning tests for GFM inverters/plants as part of the Field Demonstration activity. These commissioning tests can be used by plant owner/operators to exercise GFM control and operation without significant cost in testing architecture for evaluation equipment (e.g., load banks, grid simulators).

2 Evaluation Process

2.1 Complete GFM Evaluation

If there were no constraints on time and budget, it would be possible to carry out a complete evaluation of GFM operation in all operational conditions in its actual fielded environment. Unfortunately due to cost constraints, as power levels of assets and installations increase, the ability to fully characterize GFM IBRs under normal and contingency conditions is limited. For large unit and plant installations, only a small subset of tests to verify operations are tractable. To ensure applicability for GFM technologies in all situations, it is necessary to carry out testing throughout the entire process of asset incorporation into the power system, from preliminary simulation through laboratory acceptance testing through fielded evaluation and long-term

[1] Ramasubramanian D, Kroposki B, Dhople S, Groß D, Hoke A, Wang W, Shah S, Hart P, Seo GS, Ropp M, Du W. Performance Specifications for Grid-forming Technologies. In2023 IEEE Power & Energy Society General Meeting (PESGM) 2023 Jul 16 (pp. 1-5). IEEE. Updated Speifications can be found at the UNIFI website: https://unificonsortium.org/activities-products/work-products

monitoring and evaluation. An example of this process, utilizing documents throughout the UNIFI Consortium, is shown in Figure 1.

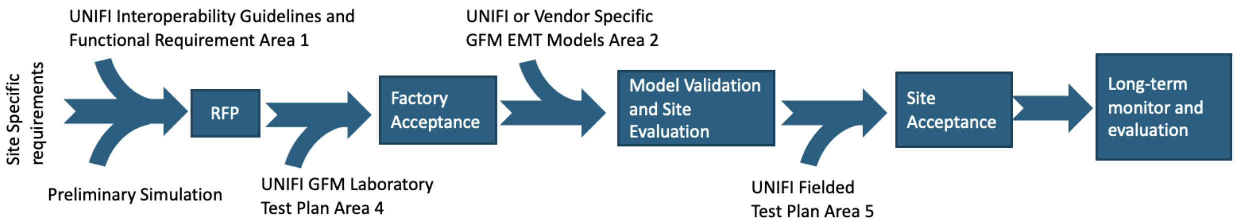

Figure 1: Field Demonstration Evaluation Process

For basic evaluation and quantification of the benefits for GFM incorporation at a specific site, preliminary simulation utilizing generic GFM models[2] compatible with the UNIFI "Specifications for Grid-forming Inverter-based Resources",should be utilized, such as REGFM_A1. This preliminary simulation along with site-specific requirements can be used to define basic operational requirements of the GFM asset for a variety of different normal and contingency conditions for both current as well as projected future grid states. These operational requirements can be used to derive a Request for Proposal (RFP) from manufacturers.

Factory acceptance testing of GFM is typically in a controlled laboratory environment and thus has greater freedom for applying a variety of operational conditions to the GFM. The laboratory testing plan drafted by the UNIFI consortium details the types of tests factory acceptance testing could utilize to evaluate GFM operations[3].

The results from these laboratory acceptance tests can be utilized to validate vendor-specific electromagnetic transient (EMT) models that can be used in a detailed design evaluation. This is especially important for contingency operations that may be impossible to implement in the field. For example, creating a fault in the bulk power system to evaluate GFM contingency operation is not tractable in most instances.

This document is meant to lay out fielded GFM inverter or plant testing protocols that could be utilized for site-acceptance testing and to evaluate and validate the extensive simulations carried out in EMT modeling. Finally, once commissioned, long-term monitoring and evaluation should be carried out in order to evaluate GFM inverter/plant operation over a wide variety of scenarios. This can help to quantify the benefits of GFM incorporation for that system or identify issues with stability and interoperability that would require tuning of control schemes by the manufacturer.

2.2 Fielded GFM Inverter/Plant Testing

Fielded GFM inverter/plant testing evaluates the autonomous response of a single inverter or a collection of inverters in a plant under a variety of scenarios when operating stand-alone or connected to a larger grid. For the purposes of these tests, *stand-alone islanded operation* is

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[2] Du, Wei. *Model Specification of Droop-Controlled, Grid-Forming Inverters (REGFM_A1)*. No. PNNL-35110. Pacific Northwest National Laboratory (PNNL), Richland, WA (United States), 2023.
[3] Wang, J; Thiagarajan, R; Shirazi, M; Flicker, J; Wang, W; Pant, S; Gong, M. "UNIFI 1MW Demonstration Layout and GFM Testing Protocols"*UNIFI Consortium Deliverable,* December, 2022 (In Draft).

islanded operation where the inverter/plant is the sole (GFM) power source energizing a local-area power system (or microgrid). *Heterogenous islanded operation* is islanded operation where the inverter/plant is operating in parallel with at least oneother GFM source. *Grid-connected operation* is where the inverter/plant is operating in parallel with a larger grid including many GFM sources.

In the grid-connected case, synchronization has two flavors: one is the inverter/plant powering up from off-state and connecting to either an already energized local-area power system, and the other is the inverter/plant already operating stand-alone energizing a local-area power system (or microgrid) and then synchronizing to a larger grid. The latter test is optional as not all plants have stand-alone capability. For these optional synchronization tests, a separate controllable switch, typically a circuit breaker, will be required to connect the energized local-area power system (or microgrid) to a larger grid. Requirements for the circuit breaker, any associated protective relaying, and voltage sensing signals will vary depending on the synchronizing approach adopted by the inverter.

Signals to be monitored during these tests are indicated in the bulleted list below, if available. Many plants will not have all signal streams available to be monitored due to the topology of the plant. For example, some delta-connected plants may not have easy access to phase-to-ground measurements. Additionally, some data streams may not be fully instrumented as described here. For example, many plants have either phase-to-ground *or* phase-to-phase measurements, but not both. Addiontally, some plants may not have high resolution data acquisition and instead rely on lower resolution data needed for plant controls (e.g. 1-second data). This signal list should be thought of as an idealized list of the data streams with the understanding that many plants will have different configurations, numbers of channels, and data resolution due to a number of factors. This evaluation plan is designed to be able to be implemented within cost, topology, and effort restrictions on a plant-to-plant basis and utilizing whatever monitoring infrastructure that is available.

In this list, it is assumed that if the inverter/plant requires a transformer to connect to an external power system, then the synchronizing switch is on the grid side of the transformer. If the synchronization switch is on the inverter side of the transformer, then additional voltage and current measurements should be made at the output of the transformer.

- Inverter/plant AC-terminal voltage, on plant side of synchronizing switch. If the inverter natively generates a neutral or includes a delta-wye transformer, voltage should be measured on each phase to neutral and neutral to ground. If there is no neutral, voltage should be measured on each phase-phase as well as at least two phase-ground.
- Inverter/plant AC-terminal voltage, on grid side of synchronizing switch. If the inverter natively generates a neutral or includes a delta-wye transformer, voltage should be measured each phase to neutral and neutral to ground. If there is no neutral, voltage should be measured each phase-phase as well as at least two phase-ground.
- Inverter/plant AC-terminal current, on grid side of synchronizing switch. If there is a neutral, current should be measured out of each phase and ideally (but not required if

sufficiently high bandwidth simultaneously sampled measurements) out of the neutral as well. If there is no neutral, current should be measured out of each phase.

For the steady-state tests, a high-quality power analyzer capable of measuring both DC-side and AC-side quantities is desired. For the transient tests, a high-quality oscilloscope capable of measuring both DC side and AC side quantities is desired. Frequency, whether computed directly via the power analyzer / oscilloscope or after the fact when processing raw waveform data, should have as high a resolution as possible. The frequency measurement is important not only as a metric itself, but also for use in RMS and real/reactive power computations, which, whether computed directly by the instrument or computed after the fact when processing raw waveform data, should be computed over a window corresponding to the actual measured power frequency, not a fixed window assuming a nominal frequency (e.g., 60 Hz).

2.2.1 Islanded Operation where Inverter/Plant is Sole Source

During these tests, the inverter/plant is operating stand-alone as the sole GFM source supplying power to an islanded power system. These tests assume the ability to isolate the inverter/plant from the bulk grid point of interconnection with or without a local load.

2.2.1.1 Steady state

Steady-state tests during inverter/plant stand-alone islanded operation are primarily intended to demonstrate ability of the inverter/plant to maintain high power quality and achieve/maintain desired operational points under a variety of steady-state loading conditions. Steady state performance should be evaluated based on metrics which include frequency regulation, voltage regulation, and harmonic specifications. Metrics are meant to determine if the GFM behavior meets plant design criteria and thus no quantitative values of metrics are given in this document, as different plants may have different criteria based on interconnection environment[4].

2.2.1.1.1 Balanced Load

The frequency and voltage regulation should be measured about the expected steady-state values. Steady-state operating points and power quality should be evaluated for power factors of 1, 0.8 lagging, and 0.8 leading (or the plant's corner capability region) Ideally, the inverter/plant should be supplying some local load. If this load is controllable, then power quality should be evaluated for 5%, 10%, 25%, 50%, 75%, and 100% of kVA inverter/plant rating or in as granular a manner as possible.

2.2.1.2 Transient

Transient tests during inverter/plant stand-alone islanded operation are intended to demonstrate ability of the inverter/plant to maintain voltage and current waveforms within acceptable plant design criteria limits (subject to hardware limitations such as current rating of IBR, energy storage

[4] For example, GFM plants may inject harmonic current to correct any existing system voltage harmonics within its control bandwidth. This should be permitted and not considered a violation of harmonic requirements as it is within the GFM plant design criteria.

state of charge, etc.) during dynamic events. The metrics are based on both instantaneous waveform as well as RMS/frequency responses.

2.2.1.2.1 Black start

Some GFM inverters/plants may have the ability to blackstart their local area power system. If the inverter/plant has this capability, then the inverter/plant should be evaluated for its ability to black start its local area power system. Two tests are to be performed. In one test, starting from OFF, the inverter/plant energizes its local area power system with no load and then load (if possible) applied. In the second test, starting from OFF, the inverter/plant must energize a transformer of kVA rating similar to its own. This transformer is in addition to any transformer provided with the inverter. For both tests, relevant metrics are instantaneous and RMS current deviations and time from initial energization to full voltage on the local area power system. This test is optional in that not all GFM units have black start capabilities. If GFM is capable of black start, then this functionality should be exercised.

2.2.1.2.2 Secondary control capability

The inverter/plant should be tested for its ability to respond to secondary control setpoints, for example the setpoints could represent the 60 Hz active- power intercept and nominal voltage (e.g., 480 V) reactive power intercept on P/f and Q/V droop curves, or they could represent the zero-kW frequency intercept and zero-kVAR voltage intercept on the same curves. During stand-alone operation, these setpoints have the effect of changing steady-state frequency and voltage. The test setup must include a way to measure time from the moment the setpoint is sent from an external controller. Ideally there would also be a way to indicate/record the time at which the primary inverter/plant controller receives the setpoint, but this may not be possible. Relevant metrics include total time from when the new setpoint is sent until the relevant parameter (frequency or RMS voltage) moves 90% of the way to the new steady-state operating point, rise/fall times measured from when the relevant parameter is first observed to begin changing until it moves 90% of the way to the new steady-state operating point. Other metrics may include transient deviations of instantaneous and RMS voltage/current (both magnitude and duration of the deviations) as well as frequency deviations (both magnitude and duration of deviations) outside of the expected setpoint envelope during the transitions.

2.2.1.2.3 Inductive inrush

The inverter/plant should be evaluated for its ability to energize an inductive load while operating stand-alone as the only power source on the local-area power system. This will be similar to an inductive motor start or a cold-load pickup condition. This test is different than the black start test above as the local-area power system is already energized by the inverter/plant and voltage must remain within acceptable limits during the inrush event. Inductive inrush should be provided by energizing a transformer or the largest motor the GFM under test would need to energize in practice (ideally up to the rating of the GFM). Relevant metrics are instantaneous and RMS voltage and current deviations (both magnitude and duration of deviations) as well as frequency deviations (both magnitude and duration of deviations).

2.2.2 Grid Connected Operation

During these tests, the GFM inverter/plant is operating in parallel with a much larger interconnected grid.

2.2.2.1 Steady state

Steady-state tests during grid-connected operation of the inverter are intended to demonstrate ability of the inverter to stably source or sink power from the grid without significantly distorting the grid voltage at the point of common coupling (PCC) beyond acceptable limits. However, in most connection cases (especially in weak-grid connections), the inverter may still affect frequency and voltage at the PCC. Thus, steady state operational points and power quality should be evaluated based not only ona ctive- and reactive-power regulation, but also on frequency regulation, voltage regulation, and harmonic voltage specifications, and will include quantification of any oscillations in power flows, voltage, and frequency. The frequency and voltage regulation will be measured about the expected steady-state values associated with the active- and reactive-power output.

2.2.2.1.1 Sourcing power

With the inverter/plant set to near zero reactive power output (or equivalent command to achieve 0 reactive-power flow such as the alteration of voltage droop curve intercept or other voltage regulation function), the inverter/plant active power setpoint (or frequency droop curve intercept) should be adjusted to cause the inverter/plant to source 5%, 10%, 25%, 50%, 75%, and 100% rated kW. With inverter/plant power set to zero (or frequency droop curve intercept set to achieve 0 active- power flow), the voltage or reactive power setpoint (e.g., droop curve intercept) should be adjusted to cause the inverter/plant to source 5%, 10%, 25%, 50%, 75%, and 100% rated kVAR. An additional test should be used to test the plant's corner capability region (or operating window). In this test P and Q output are equivalent (on a nameplate p.u. basis). The voltage or reactive power setpoint *and* the active power setpoint should then be adjusted to source 5%, 10%, 25%, 50%, 75%, and 100% of rated apparent power in kVA.

2.2.2.1.2 Sinking power

With the inverter/plant set to near zero reactive power output (or equivalent comments to achieve 0 reactive-power flow such as the alteration of voltage droop curve intercept or other voltage regulation function), the inverter/plant active power setpoint (or frequency droop curve intercept) should be adjusted to cause inverter/plant to sink 5%, 10%, 25%, 50%, 75%, and 100% rated kW. With inverter/plant power set to zero (or frequency droop curve intercept set to achieve 0 active-power flow), the voltage or reactive power setpoint ((e.g., droop curve intercept) should be adjusted to cause the inverter/plant to sink 5%, 10%, 25%, 50%, 75%, and 100% rated kVAR. An additional test should be used to test the plant's corner capability region. In this test P and Q output are equivalent (on a nameplate p.u. basis). The voltage or reactive power setpoint *and* the active power setpoint should then be adjusted to sink 5%, 10%, 25%, 50%, 75%, and 100% of rated apparent power in kVA.

2.2.2.2 Transient

2.2.2.2.1 Loss of Grid

With the inverter/plant voltage droop curve intercept set to achieve 0 active-power flow, the inverter/plant should be isolated from the bulk grid through disconnection of the PCC. The inverter/plant should maintain stability, energizing its local area without tripping. This test should be repeated for the inverter/plant at 50% and 100% sourcing and sinking states before disconnection of the PCC. Relevant metrics include instantaneous and RMS voltage and current deviations (magnitude and duration of deviation), frequency deviations (magnitude and duration of deviation), and power quality (distortion) during the transitions. Deviations from nominal are expected during this test, but must return to nominal levels. The allowable magnitude and durations of these deviations should be determined by the applicable plant design criteria.

2.2.3 Synchronization

Synchronization has two flavors. The first is the inverter/plant powering up from off-state and connecting to either an already energized local-area power system (microgrid) or to the bulk grid, and the other is the inverter already operating stand-alone energizing a local-area power system (microgrid) and then synchronizing to a larger grid. The difference between these two tests is whether the GFM IBR in interconnected into the larger power system either before or after the GFM is online.

Either test may be optional as not all inverters/plants will have both capabilities, but all plants must have at least one of the two capabilities. For the latter synchronization test, a separate controllable switch, typically a circuit breaker, will be required to connect the energized local-area power system (or microgrid) to a larger grid. Requirements for the circuit breaker, any associated protective relaying and voltage sensing signals will vary depending on the synchronization approach adopted by the inverter.

2.2.3.1 Transient

2.2.3.1.1 From OFF to grid-connected

During this test, the inverter/plant is initially off and must synchronize to the larger utility grid. Relevant metrics include instantaneous and RMS voltage and current deviations (magnitude and duration of deviation), frequency deviations (magnitude and duration of deviation), and power quality (distortion) on the power system side of the inverter synchronizing switch, as well as the time to synchronize as measured from the time of the voltage first being applied on the inverter side of the synchronizing switch until the switch closes.

2.2.3.1.2 From stand-alone islanded operation to grid-connected

During this test, the inverter/plant is initially operating as a single source energizing a local-area power system. The local-area power system can connect to a larger grid across an external synchronizing switch, typically a circuit breaker. Requirements for the circuit breaker, any associated protective relaying, and voltage sensing signals will vary depending on the synchronization approach adopted by the inverter/plant. In many cases, the circuit breaker may be required to have a sync-check relay, in which case a breaker open / close request will be received (e.g., from a grid operator or plant control). The breaker may also need to sense the grid-side voltage(s), although the sensing need not be high speed and could be via digital communications to the relay. It is less likely but also possible that the plant may need high-speed sensing of both inverter-side and grid-side voltages.

The test setup should include a method to measure time from the moment the synchronization command is issued. Relevant metrics include instantaneous and RMS voltage and current deviations (magnitude and duration of deviation), frequency deviations (magnitude and duration of deviation), and power quality (distortion) on the grid side of the external synchronizing switch, as well as the time to synchronize as indicated by moment the synchronizing command is issued until the synchronizing switch closes.

2.2.4 Islanded Operation in Heterogeneous System

In many systems, GFM are utilized in microgrid-type implementations, where multiple sources (GFM, GFL, and/or synchronous machine) is co-located with load and can be isolated from the larger power system. During these tests, the grid-forming inverter/plant is operated in parallel with a similar-sized source (for example, another GFM inverter/plant or a diesel generator) providing power to an islanded power system. For these tests, the other sources should be operated with voltage and frequency droop to enable power sharing with the inverter. For consistency, the inverter/plant and any other sources should proportional voltage and frequency droop slopes to allow for equal (on a p.u. basis) power sharing during frequency events.

2.2.4.1 Steady state

Steady-state tests during operation of the inverter/plant in parallel with a voltage source are primarily intended to demonstrate stable active- and reactive-power sharing between the inverter/plant and the alternative voltage source (e.g., another GFM inverter/plant or a diesel generator). Power quality and achievement/maintenance of desired operational points should be evaluated based on metrics which include frequency regulation, voltage regulation, and harmonic specifications. Parallel operation includes quantification of any oscillations in power flows, voltage, and frequency. The frequency and voltage regulation should be measured about the expected steady-state values associated with the load. Metrics are meant to determine if the GFM behavior meets plant design criteria and thus no quantitative values of metrics are given in this document, as different plants may have different criteria based on interconnection environment.

2.2.4.1.1 Balanced load

Steady-state tests during inverter/plant stand-alone islanded operation are primarily intended to demonstrate ability of inverter/plant to maintain high power quality under a variety of steady-state loading conditions. Power quality should be evaluated based on metrics which include frequency regulation, voltage regulation, and harmonic specifications. Frequency and voltage regulation should be measured about the expected steady-state values. Power quality should be evaluated for power factors of 1, 0.8 lagging, and 0.8 leading. Ideally, the inverter/plant should be supplying some local load. If this load is controllable, then power quality should be evaluated for 5%, 10%, 25%, 50%, 75%, and 100% of kVA inverter/plant rating or in as granular a manner as possible.

Tests should be run with the inverter/plant and diesel generator having equal voltage and frequency droop intercepts (which should result in equal power sharing on a per-unit basis). In addition, tests should be run at loads equal to the smaller of inverter/plant vs the combined rating of the remaining voltage sources (e.g., for example, another GFM inverter/plant or a diesel generator). This should ideally be relatively close to the 50% loads discussed above. For these tests, the inverter/plant voltage and frequency droop intercepts should be adjusted to force the inverter/plant to take 0% and 90% of the active- and reactive-power loads.

2.2.4.1.2 Sinking power

With no load applied, inverter/plant voltage and frequency droop intercepts should be individually adjusted so that the inverter/plant is sinking the smaller of the inverter vs the combined rating of the remaing voltage source (e.g., another GFM inverter/plant or a diesel generator) kVA and kVAR ratings.

2.2.4.2 Transient

Transient tests during operation of the inverter/plant in parallel with another voltage source (e.g., another GFM inverter/plant or a a diesel generator) are intended to demonstrate stable transitions to new power sharing allocations due to changes in system state. The metrics include ones based on instantaneous waveform as well as RMS/frequency responses.

2.2.4.2.1 Secondary control capability

The inverter/plant should be tested for its ability to respond to secondary control setpoints, for example the setpoints could represent the 60 Hz real power intercept and nominal voltage (e.g., 480 V) reactive power intercept on P/f and Q/V droop curves, or they could represent the zero-kW frequency intercept and zero kVAR voltage intercept on the same curves. During islanded operation in parallel with another voltage source (e.g., diesel generator), these setpoints have the effect of changing steady-state real and reactive power flows. The test setup must include a way to measure time from the moment the setpoint is sent from an outside controller. Ideally there would also be a way to indicate the time at which the primary inverter controller receives the setpoint, but this may not be possible.

Relevant metrics include total time from when new setpoint is sent until relevant parameter (real or reactive power) reaches 90% of the way to the new steady-state operating point, rise/fall times measured from when the relevant parameter is first observed to begin changing until reaching 90% of the way to the new steady-state operating point. Other metrics include instantaneous and RMS voltage and current deviations (magnitude and duraction of deviation), frequency deviations (magnitude and duraction of deviation), and power quality (distortion) during the transitions.

2.2.4.2.2 Loss of generation.

These tests should be performed with balanced three-phase PF=1 load representing 100% of the inverter kVA rating (ideally). The other voltage source(s) (e.g., another GFM inverter/plant or a diesel generator) will be tripped offline. Relevant metrics include instantaneous and RMS voltage and current deviations (magnitude and duraction of deviation), power quality (distortion) during the transient, frequency deviations (magnitude and duraction of deviation) and rise/fall times of RMS voltage and current, frequency, and active and reactive power.

2.3 Summary of Fielded Inverter/Plant Testing

The testing described here is meant to evaluate operation of fielded GFM inverters/plants with a minimum of external infrastructure required. Additional testing may be possible with the use of load banks, other generation resources, and grid simulators to evaluate the operation of the GFM inverters more comprehensively. However, this is highly dependent on the ability to source and install appropriately sized hardware and may be financially intractable to implement. In the case where additional testing is possible, fielded inverter testing approaches the testing laid out for inverters in a laboratory setting. More details of these tests are discussed in UNIFI document A5.1.2.2: “UNIFI 1MW Demonstration Layout and GFM Testing Protocols”. A subset of tests are utilized for fielded units.

The test plan described here goes through testing of inverters/plants in stand-alone operation, where they are the only voltage source in the local area power system. This testing may or may not have local load that may or may not be controllable. Additional tests for grid connected operation are specified. Finally, a set of tests are described for heterogeneous system operation, where the inverter/plant is operated alongside another voltage source unit, if available. . A summary of the tests described in this document is shown in Table 1.

Table 1: Summary of inverter/plant tests

<table>
<tr><th>Configuration</th><th>Test Type</th><th>Scenario</th><th>Metrics</th></tr>
<tr><td rowspan="4">Stand-alone islanded operation</td><td>Steady state</td><td>Balanced load</td><td>V_{rms} and f regulation; V_{rms} and I_{rms} THD; % V_{rms} imbalance</td></tr>
<tr><td rowspan="3">Transient</td><td>Black start</td><td>V_{inst} and I_{inst} peak; V_{rms} and I_{rms} peak; V_{rms} and f rise time</td></tr>
<tr><td>Secondary control</td><td>V_{rms} and f over/under shoot, rise/fall time, and settling time; time from when new SP sent until reaching 90% of new operating point</td></tr>
<tr><td>Inductive inrush</td><td>V_{inst} and I_{inst} peak; V_{rms}, I_{rms} and f peak, nadir and settling time; Vinst transient distortion last than more than 2-3 cycles</td></tr>
<tr><td rowspan="3">Grid-connected</td><td rowspan="2">Steady state</td><td>Sourcing power</td><td rowspan="2">V_{rms}, f, P, and Q regulation; V_{rms} and I_{rms} THD; oscillations</td></tr>
<tr><td>Sinking power</td></tr>
<tr><td>Transient</td><td>Loss of Grid</td><td>Instantaneous and RMS voltage and current deviations (magnitude and time), power quality (distortion) during the transient, frequency deviations (magnitude and time) and rise/fall times of RMS voltage and current, frequency, and real and reactive power.</td></tr>
<tr><td>Synchronization</td><td>Transient</td><td>OFF to grid-connected</td><td>Bus-side:
V_{inst} and I_{inst} peak; V_{rms}, I_{rms}, P, Q and f peak, nadir and settling time; V_{inst} transient distortion
Time from when sync command issued until breaker closes</td></tr>
</table>

		Stand-alone islanded to grid-connected	μgrid-side (prior to sync): V_{rms} and f regulation; V_{rms} and I_{rms} THD Bus-side: V_{inst} and I_{inst} peak; V_{rms}, I_{rms}, P, Q and f peak, nadir and settling time; V_{inst} transient distortion Time from when sync command issued until breaker closes
Heterogenous islanded operation (if applicable)	Steady state	Balanced load	V_{rms} and f regulation; V_{rms} and I_{rms} THD; oscillations
		Sinking power	
	Transient	Secondary control	V_{rms}, f, P and Q over/under shoot, rise/fall time, and settling time; time from when new SP sent until reaching 90% of new operating point
		Loss of generation	V_{inst} and I_{inst} peak; V_{rms}, I_{rms} and f peak, nadir and settling time; V_{inst} transient distortion