# GFM Functional Specifications and Universal Principles

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U.S. DEPARTMENT OF ENERGY

unifi is co-led by NREL, University of Washington, and EPRI

# unifi consortium

universal interoperability for grid-forming inverters

***Bringing the industry together to unify the integration and operation of inverter-based resources and synchronous machines***

# Project Team

## National Labs and Research Institutes

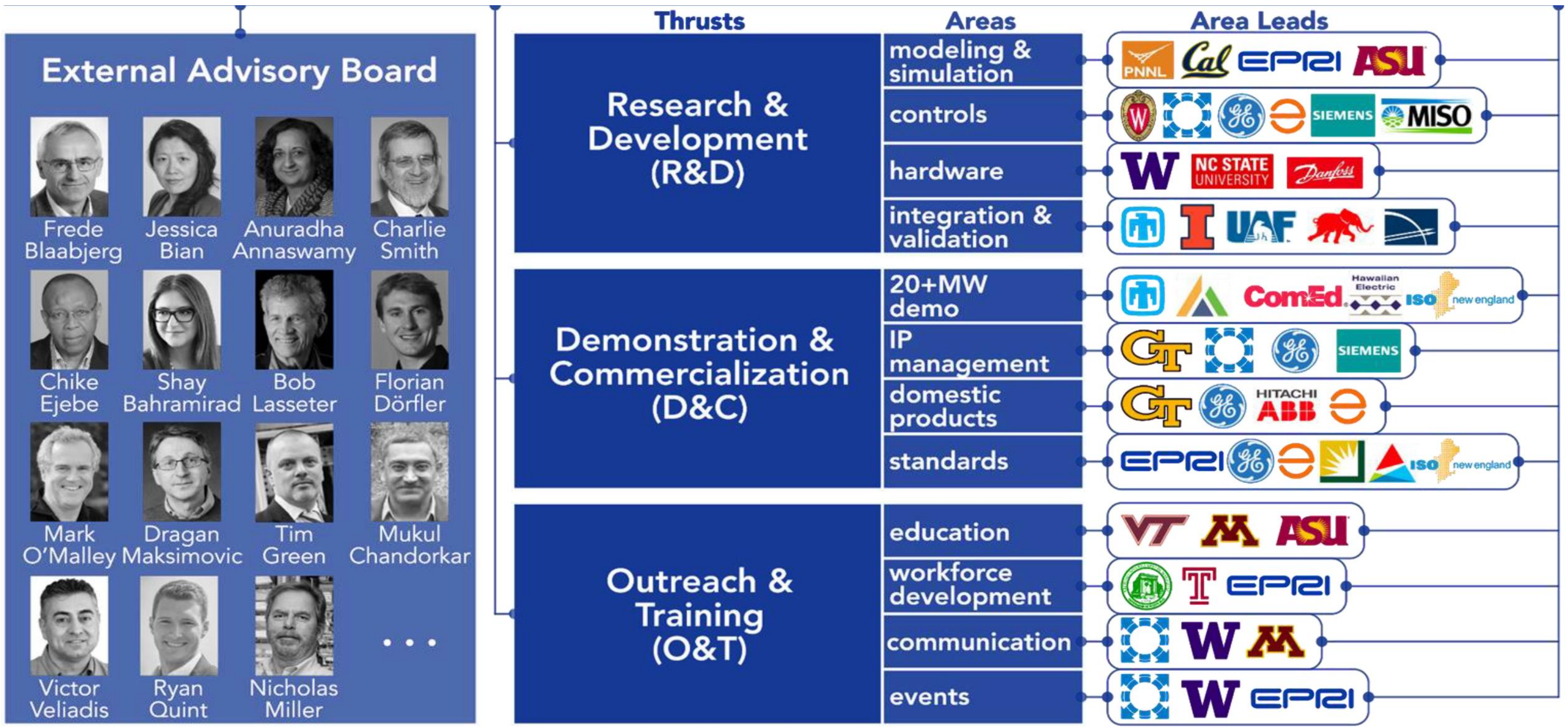
## Universities

## Industry

## Utilities and System Operators

unifi consortium

# Organization



**The points on the following slides are still in draft form and under discussion**

## Universal Principles/Rules

- ✓ Autonomously act to support or form the grid as needed (GFL or GFM mode not known), and to transition from grid-connected to microgrid mode autonomously without communications or system knowledge
- ✓ Locally measured average (not dynamic) frequency (a DC quantity) is the universal parameter across the system that governs average (transactive) power sharing between sources
- ✓ Provide the right amount of inertia and damping at a given point-in-time to support the stability of the system under steady-state and transients (disturbance rejection)
- ✓ Provide damping under all conditions, including to prevent resonances, oscillations, instabilities, even when detailed system topology and control algorithms are unknown
- ✓ Present passive characteristics to the grid and all its devices at all frequencies so as to prevent interactions with other grid elements
- ✓ Act to bring local voltage unbalances and harmonics to within specified limits, while ensuring that IBRs can operate with significant current unbalances and harmonics
- ✓ Grid-connected IBRs should not trip, except for internal faults. The IBR should not trip based on energy constraints
- ✓ IBRs should coordinate at a system level using cyber-secure communications, but should allow the system to continue to operate (perhaps sub-optimally) if communications are delayed or interrupted

### "Grid-Connected" Operation:

- ✓ Dispatch mode under grid operator command or locally determined transactive goal ⟹ (P, Q, V)
- ✓ Droop on the average frequency is the rule that governs average (transactive) power (active and reactive) sharing between sources under extreme system stress conditions ⟹ meet internal constraints (e.g., power, energy, economic)
- ✓ Meet grid interconnection and support codes (LVRT, RoCoF, FRT, fault recovery) under normal, abnormal & fault conditions

### "Microgrid" Operation:

- ✓ Grid-forming and black starting capabilities, if needed
- ✓ Connect/disconnect with the system (grid, islanded, or microgrid) at will, and be able to manage major faults and topology changes (frequency and phase jumps) without tripping, acting to rapidly stabilize the system to a new normal operating point
- ✓ Droop on the average frequency is the rule that governs average (transactive) power sharing between sources, while also meeting internal constraints
- ✓ Should act autonomously to stabilize the system under power surplus and shortage

# Universal Principles/Rules — Potential Transmission System Unique Requirements/Exceptions

- ✓ Provide negative and/or zero sequence fault current as required by existing system protection schemes
- ✓ Improve system strength (voltage support) in pockets of the transmission network even with synchronous machines being present in the grid
- ✓ Droop on voltage (point of connection voltage) especially with parallel connected IBRs and/or IBRs in a cluster
- ✓ Do not introduce any new oscillatory modes in the network
- ✓ Seamless transition between day-time and night-time operations
- ✓ Maintain and retain system stability and operation even with trip of last synchronous machine, without requiring knowledge of synchronous machine trip
- ✓ All transmission system resources today have closed loop droop control for voltage and frequency (implemented at plant level) and reactive power control at inverter level. GFM IBR plants will be expected to have these droops along with voltage control implemented at the inverter level
- ✓ Transmission system resources today are dispatchable. It is expected that GFM IBR resources are also dispatchable
- ✓ Any resource (including GFM), once it has previously disconnected (electrically isolated), cannot connect to the **transmission grid** at will. Coordination with system operator is crucial
- ✓ IBR should have the ability to seamlessly connect/disconnect instantaneously upon receiving command from the grid operator

# Mapping Test Cases with UNIFI Universal Principles

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**Microgrid Interconnection**
- Connect/disconnect with the system (grid, islanded, or microgrid) at will, and be able to manage major faults and topology changes (frequency and phase jumps) without tripping, acting to rapidly stabilize the system to a new normal operating point
- Autonomously act to support or form the grid as needed (GFL or GFM mode not known), and to transition from grid-connected to microgrid mode autonomously without communications or system knowledge
- Should act autonomously to stabilize the system under power surplus and shortage

**Load Step**
- Droop on the average frequency is the rule that governs average (transactive) power sharing between sources, while also meeting internal constraints

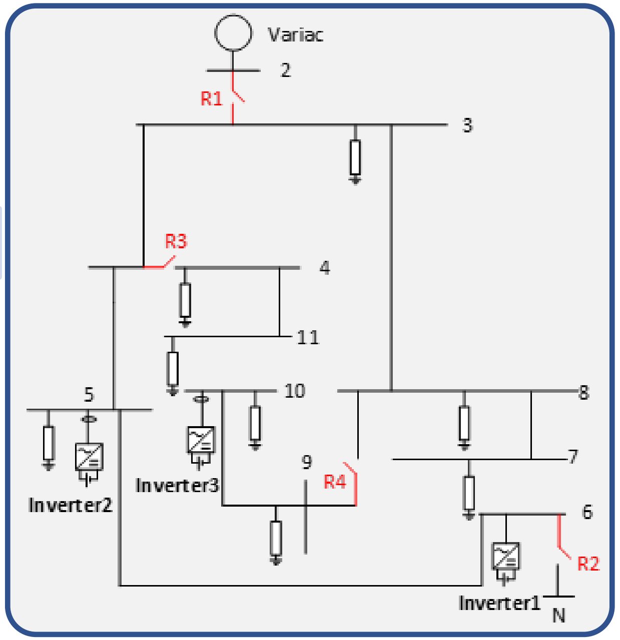
**Fault-ride through**
- Meet grid interconnection and support codes (LVRT, RoCoF, FRT, fault recovery) under normal, abnormal & fault conditions

**Grid Connection**
- Dispatch mode under grid operator command or locally determined transactive goal ⟹ (P, Q, V)
- Provide damping under all conditions, including to prevent resonances, oscillations, instabilities, even when detailed system topology and control algorithms are unknown

**Fault-Ride-through with Grid/SG**
- Meet grid interconnection and support codes (LVRT, RoCoF, FRT, fault recovery) under normal, abnormal & fault conditions

**Phase-Jump**
- Provide the right amount of inertia and damping at a given point-in-time to support the stability of the system under steady-state and transients (disturbance rejection)

## Distribution System Example




- Distribution System is the Modified 14-Bus CIGRE Feeder (data taken from CIGRE recommended system)
- Overall System rating less than 10 MVA
- Overall System rating less than 10 MVA
- 3 single/three-phase inverters
- 3 smart switches for grid and microgrid interconnection, as well as fault testing

# Mapping Test Cases with UNIFI Universal Principles

**Increase of Load in the Network**

- Droop on the average frequency is the rule that governs average (transactive) power sharing between sources, while also meeting internal constraints
- Droop on voltage (point of connection voltage) especially with parallel connected IBRs and/or IBRs in a cluster
- Autonomously act to support or form the grid as needed (GFL or GFM mode not known), and to transition from grid-connected to microgrid mode autonomously without communications or system knowledge
- Should act autonomously to stabilize the system under power surplus and shortage
- Provide the right amount of fast energy injection and damping at a given point-in-time to support the stability of the system under steady-state and transients (disturbance rejection)
- Determine 2x2 MIMO transfer function in frequency domain

**Balanced and Unbalanced Faults in the Network**

- Provide negative and/or zero sequence fault current as required by existing system protection schemes
- Do not introduce any new oscillatory modes in the network
- Meet grid interconnection and support codes (LVRT, RoCoF, FRT, fault recovery) under normal, abnormal & fault conditions
- This should also have phase jump as part of it
- If a phase-jump occurs – provide the right amount of inertia and damping at a given point-in-time to support the stability of the system under steady-state and transients (disturbance rejection)

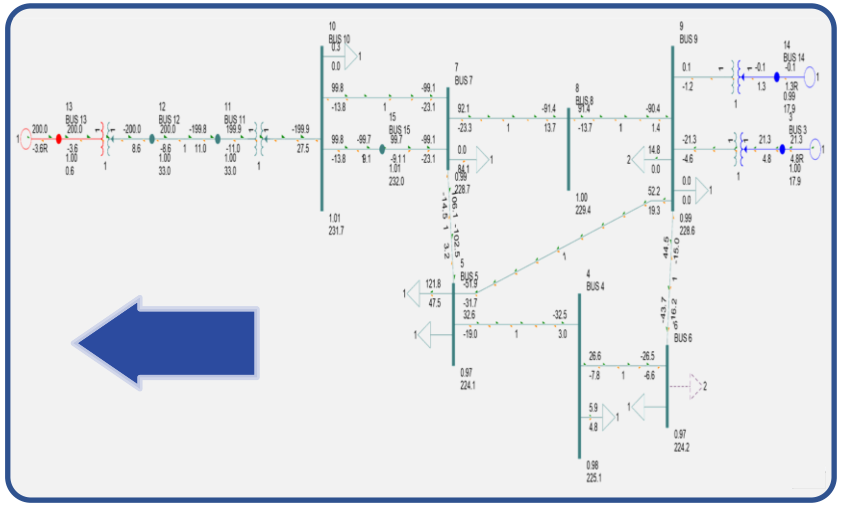
**Trip of Machine**

- Maintain and retain system stability and operation even with trip of last synchronous machine, without requiring knowledge of synchronous machine trip

**Motor Load Stalling and Recovery**

- Do not introduce any new oscillatory modes in the network
- Improve system strength (voltage support) in pockets of the transmission network even with synchronous machines being present in the grid

## Transmission System Example



- Existing GFL resource with plant level voltage and frequency control and inverter level P and Q control
  - More than one GFL resource can be connected to the same location through additional long transmission lines
- 200 km long 230kV transmission line
- Synchronous condenser with static exciter and H = 2.0s
- Synchronous generator with H = 2.0s and with static exciter and general thermal governor
- GFM resource under test can be connected to bus 10 in parallel to existing GFL resource
  - More than one GFM resource can be connected at various points in the network to test for controller interactions

## Thank you

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