unifi consortium

universal interoperability for grid-forming inverters

# Annual Newsletter 2022

A look back at key developments in the **Un**iversal **I**nteroperability of Grid-**f**orming **I**nverters (UNIFI) Consortium in 2022

## What's Inside?

- Foreword
- Updates on: GFM Specifications, Standards development, Hardware, Integration & Validation, 20+MW Demonstration, Modeling & Simulation, Controls, and Education

## Points of Pride

- Raja Ayyanar & Alejandro Domínguez-García elevated to IEEE Fellow
- Aidan Tuohy named in the Public Utilities Fortnightly under Forties list
- IEEE Transactions on Power Systems paper on Power-system Stability definitions and classifications co-authored by Vijay Vittal receives IEEE PES Prize Paper Award
- Deepak Divan delivers closing plenary talk at APEC 2022 on Inverters for the Future Grid
- Dominic Groß and Brian Johnson received the National Science Foundation (NSF) CAREER award

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**• UNIFI consortium members gathered at NREL in July 2022 for our first in-person meeting •**

# Foreword

The Universal Interoperability for Grid-forming Inverters (UNIFI) Consortium is a US DOE sponsored collaboration of researchers, industry stakeholders, utilities, and system operators pursuing advances in grid-forming (GFM) inverter technologies. The goal of the consortium is to facilitate the planning, design, and operation of grids with high levels of Inverter-based Resources (IBRs). Large-scale integration of renewable energy resources into the existing power grid brings with it a unique set of challenges spanning stability, security, and seamless operation. Current research has identified the adoption of GFM IBRs as a solution to address a variety of such issues. To ensure seamless operation of GFM IBRs, interoperability will be key. UNIFI is pursuing a broad range of strategies to target the interoperability of GFM technology. Once standards and methods have been established, they will need to be proven effective through demonstration at increasing scales.

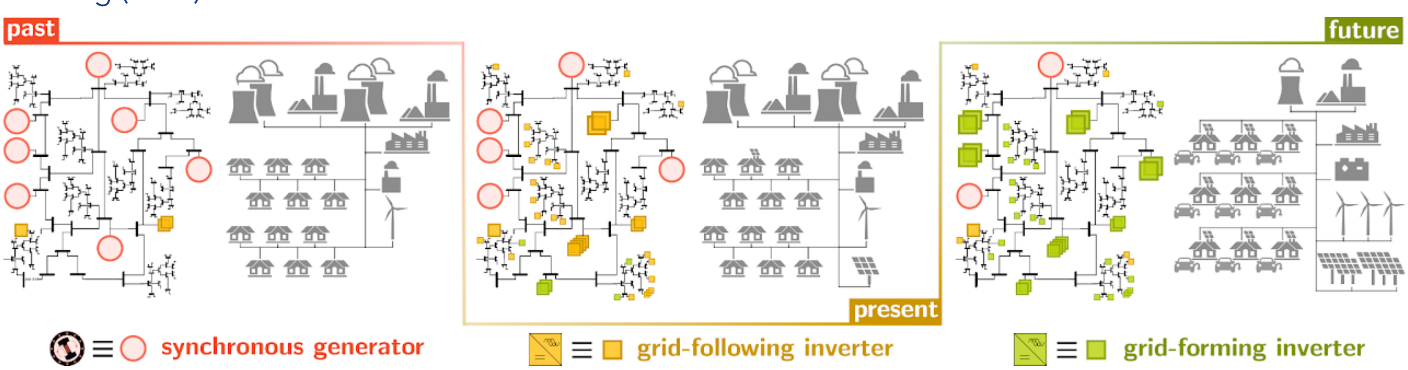
The objective of UNIFI is to create a forum to address these fundamental challenges in the seamless integration of GFM technologies into power systems. Key to UNIFI's success will be the development of vendor-agnostic guidelines and specifications for seamless integration of GFM technologies with large electric power grids. UNIFI is organized around three thrusts: Research and Development (R&D) that is set up to identify methods, standards, and best practices to share with industry, including the development of vendor-agnostic guidelines and specifications for integration at GFM system and IBR unit levels; Demonstration and Commercialization (D&C) to organize and realize mid- to large-scale demonstrations that prove out standards and methods developed in R&D, providing real world proof of the success or failure of the solutions we have developed; and finally, Outreach and Training (O&T) to create education and workforce training materials that will enable the next generation of researchers and operators to participate in the integration of IBRs and companion technology.

This report highlights key accomplishments in six research areas in 2022, the first year of the UNIFI consortium operation. In particular, we focus on: GFM Specifications, Standards development, Hardware, Integration & Validation, 20+ MW Demonstration, Modeling & Simulation, Controls, and Education. •

# GFM Specifications

UNIFI released Version 1 of the Specifications for Grid-forming Inverter-based Resources. This document establishes functional requirements and performance criteria for integrating GFM IBRs in electric power systems at any scale. This may include devices used at the local customer, microgrid, distribution, and transmission scale. The GFM specifications focuses on the AC side performance requirements as they relate to interoperability between GFM IBRs and the power system. The document covers operations under normal and abnormal conditions as well as advanced GFM capabilities such as black start. See here for the full document and an option for providing us with feedback based on your expertise and experience with GFM technology. •

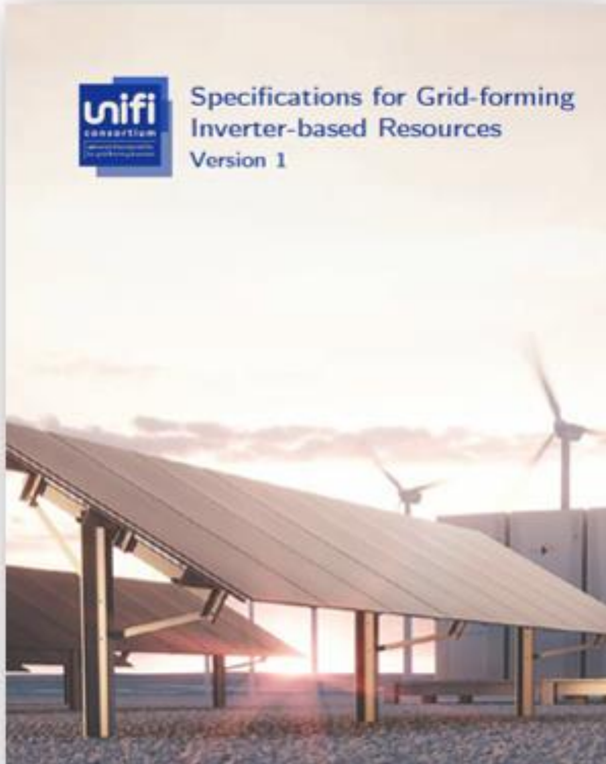
**• UNIFI anticipates the rapid changes in the power grid as it transitions from being dominated by synchronous generators (past) to grid-following inverters (today) to grid-forming inverters (in the very near future) •**



# Standards

Through the UNIFI Standards area, we have been identifying inadvertent barriers to GFM technology in the existing Institute of Electrical and Electronics Engineers (IEEE) 1547 and IEEE 2800 series of standards. Further, we are also working towards an assessment of the existing standards to identify gaps that may limit their application in identifying pathways for adoption of GFM technology. Over the last year, our primary tasks were the appointment of liaisons from the UNIFI Consortium to the IEEE 1547 and 2800 standard working groups. By common consensus, Dr. Aminul Huque and Dr. Jens Boemer were confirmed as the liaisons to the IEEE 1547 and 2800 standard working groups.

Subsequently, we started working on a barrier and gap assessment of relevant standards with respect to performance expected from GFM IBRs and associated technology. This was accompanied by simulation studies using generic models built through the Modeling and Simulation Area tasks. We are also working on identifying gaps that may exist between the respective standards and version 1 of the UNIFI Specifications that can be found here. •




**• Version 1 of the UNIFI GFM Specifications document is now available here •**

# Hardware

The Hardware Area is focused on engineering practical, and yet, high-performance state-of-the-art implementations of GFM controllers on power electronics circuitry. Since our emphasis is on hardware implementation and deployment, we channeled our efforts towards: i) the creation of Digital Code Development Platforms which yield digitized sets of usable GFM control code, and ii) an analysis of various power electronics circuit topologies used throughout industry and their ability to be controlled by the aforementioned GFM code. These objectives were guided by the overarching UNIFI vision of creating a technology that offers superior interoperability across all grid-connected inverters while carrying out key functions necessary for grid stabilization and GFM operation. Our end goal is to make Digital Code Development Platforms publicly available while producing a set of experiments, publications, and reference designs that guide practitioners in all aspects of their hardware implementations.

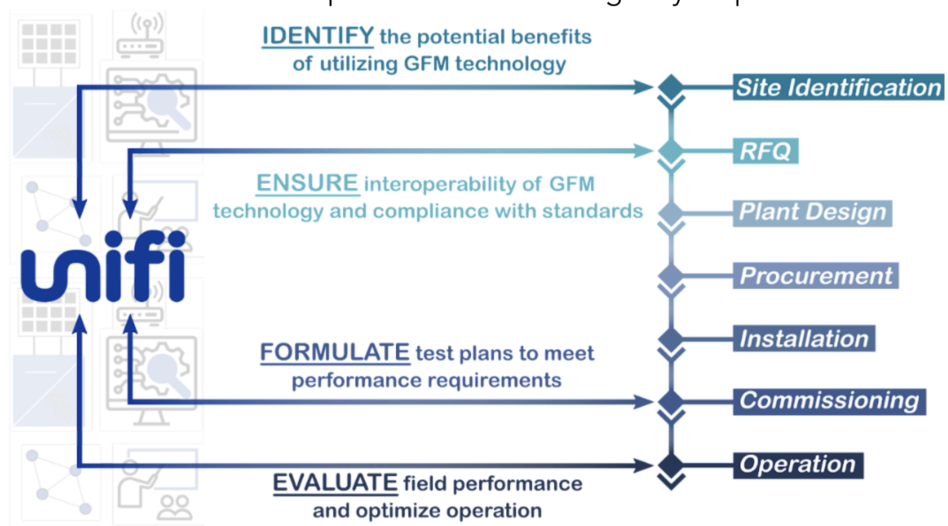
To realize this ambitious goal, our code was strategically segmented into modular libraries that each carry out a particular set of functions. These code modules were then organized into a hierarchy, where low-level functions, which closely interact with the power electronics hardware circuitry itself, carry out hardware-specific routines. On the other hand, segments of code higher up the stack execute core control responses as well as provide a signal input/output interface to facilitate communication with system operators. This allows for a large majority of the code to be recycled across a broad swath of converters across power levels (Watts to Megawatts), voltages (low and medium), applications (single-phase residential to three-phase commercial & utility scale), and topologies with minimal modification. Only the lowest-level code modules that are hardware specific require special attention whereas the rest of the code segments can be universally applied. The group also completed a survey of existing converter topologies across our labs and are gearing up to run experiments next year. •

# Integration & Validation

The Integration and Validation Area in UNIFI is focused on development of the validation and verification of infrastructure that will be utilized to inform other R&D areas regarding the impact of baseline GFM operation. We evaluate GFM models, hardware, and controls produced by the other R&D Areas in complex interoperable systems using controller hardware-in-loop (C-HIL), power hardware-in-loop (P-HIL), and pure power-hardware testbeds available at UNIFI partner facilities.

Over the last year, we established common use cases, scenarios, and reference systems for GFM integration into power systems that can be standardized across the multiple R&D areas dispersed across research organizations throughout UNIFI. Establishing use cases allows us to define operational benchmarks. These benchmarks are used to evaluate baseline (current state-of-the-art) GFM operation as well as future technological work products, to understand and compare unit-level and system-level performance for the differing technologies.

Additionally, we are building a 1+MW multi-vendor demonstration at NREL to validate the UNIFI Specifications for GFM IBRs. The 1+MW hardware experiment includes products from multiple vendors of GFM IBRs, grid-following IBRs, and rotating machines, enabling experiments with GFM IBR penetration levels ranging from 0% to 100%. As part of this testbed, we developed evaluation and testing protocols for single inverter units, groups of inverters, and full systems that can be used as the basis for future standards. •




**• UNIFI can assist in all aspects of identifying, designing, commissioning, and operating GFM plants across scales •**

# 20+MW Demonstration

The 20+MW demonstration Area is tasked to demonstrate the deployment of GFM technologies from multiple vendors that provide a range of grid services at impactful unit/plant sizing. The 20+MW demo will evaluate the GFM Specifications by engaging utilities, manufacturers, and system operators with mixed assets, functionalities, and usage scenarios. The demonstration will examine the impact of a wide variety of normal and contingency operation modes and illustrate possible impacts on system resilience and stability that can come about by the integration of GFM IBRs and their associated technologies.

Over this first year of UNIFI, we worked on developing a set of evaluation criteria for proposed demonstration sites that can be used to quantify a site's controllability and heterogeneity. These evaluation criteria can be used, if needed, to prioritize the flexibility of the host site to include the broadest range of GFM technologies. We are currently evaluating multiple possible locations for a 20+MW demonstration. Evaluations involve collaborating with developers to identify utility-scale merchant plants that can be augmented with additional GFM technologies from various manufacturers a well as partnering with utilities to identify appropriate load-serving, distribution, or transmission-scale demonstrations. As the purpose of the 20+MW demonstration is to demonstrate both the interoperability and controllability of GFM implementations, the ideal site would have both a heterogenous mixture of assets, DC-side sources, control modes, loads types, manufacturers, and the ability to apply a wide variety of normal and contingency operating conditions to the system. •

# Modeling & Simulation

The Modeling & Simulation Area has developed a set of generic positive-sequence and electromagnetic transient (EMT) models of GFMs that represent typical controls reported in literature, including droop-based GFM, virtual-synchronous-machine-based GFM, and virtual-oscillator-controller-based GFM. The model development work has received wide support and encouraging feedback from the utility industry. Specifically, a model specification of a droop-based GFM positive-sequence model was adopted by the Western Electricity and Coordinating Council Modeling and Validation Subcommittee and is expected to be included in the model libraries of commercial simulation tools for industry use. In addition, model specifications for droop, virtual synchronous machine, and dispatchable virtual oscillator based GFM have been adopted by a few EMT simulation software tools. Beta versions of these models are expected to be included in future releases. These models can be used by system operators and utilities to examine GFM behavior and carry out preliminary evaluations on system impact. To better understand the difference between the positive-sequence models and EMT models of power systems with a high penetration of GFMs and provide guidelines on selecting appropriate models for different study purposes, we also began developing positive-sequence and EMT software testbeds with different penetration levels. These software testbeds included transmission systems, distribution systems, and microgrids. We completed an initial comparison between EMT and positive-sequence simulations. Further, we used the developed generic GFM models to conduct studies on actual future scenarios of high inverter percentage island power system networks and larger power networks with local area high percentage of inverter-based resources. These studies highlight the value that could potentially be obtained from the use of GFM technology. •

# Controls

The UNIFI Controls Area has been working on ways to make it easier for IBRs from different vendors to work together seamlessly. To this end, we developed technology- and vendor-agnostic methods for characterizing and coordinating GFM IBRs. The results will help us categorize and standardize different classes of GFM devices based on their level of functionality. We identified three main types: i) GFM Core: Devices with basic GFM capabilities that can be realized with low energy-storage capacity; ii) GFM: Devices with more advanced GFM capabilities and requiring storage and/or curtailed generation; iii) GFM+: Devices with even more advanced GFM capabilities such as cold start.

To standardize GFM control functionalities, we identified the salient features and degrees of freedom of a wide range of GFM controls and the conditions on the system and control parameters under which existing GFM controls provide identical functionalities. We initiated work on systematically translating high-level interoperability guidelines and functional requirements into precise technology- and vendor-agnostic specifications for GFM


**• UNIFI partners have unique capabilities to evaluate GFM technologies across all scales •**

technologies that can be verified without knowledge of the device internals. Moreover, we completed initial steps towards defining a vendor- and technology agnostic middle layer for grid-forming control. The middle layer serves as an abstraction that translates signals between proprietary controls and devices, monitors their response to ensure compliance with interoperability specifications, and seamlessly integrates into the prevailing system hierarchy. •

# Education

UNIFI's education activities primarily dealt with three areas of activities related to GFM inverters: i) educational material for undergraduate students in electrical engineering; ii) educational material for high school students; iii) education material for elementary school students.

For undergraduate students, we identified a set of self-learning video tutorials which include textual material, PLECS simulation, and a simulation exercise covering a wide range of topics in power electronics. This material was originally developed under a PSERC Future Grid Initiative project funded by DOE and available at the PSERC website linked here.


**• The UNIFI meeting at Georgia Tech saw unprecedented industry interest from vendors and operators in GFM tech •**

For high school students, we identified several different websites. We consolidated URLs for these websites and will post them on the UNIFI website.

For students in elementary schools, we identified several excellent sites and consolidated those URLs, which will be posted on the UNIFI website. •

# Stay in the loop

The UNIFI consortium seminar series on GFM technology is held every Monday in the Fall and Spring academic semesters at 5 PM ET. The series typically features presentations on the latest and greatest in GFM from experts in academia, industry, and research labs. You must register for each series. Details on registration are available on our website. Prior seminar recordings are available on the UNIFI consortium YouTube channel. •

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