unifi consortium

universal interoperability for grid-forming inverters

• UNIFI consortium members gathered at UT Austin in February 2024 [Credit: UT Austin] •

Annual Newsletter 2023

A look back at key developments in the **Un**iversal **I**nteroperability of Grid-**f**orming **I**nverters (UNIFI) Consortium in 2023

What's Inside?

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Foreword

The Universal Interoperability for Grid-forming Inverters (UNIFI) Consortium is a U. S. Department of Energy (DOE) Solar Energy Technologies Office (SETO) funded effort to advance grid-forming (GFM) inverter technology. It brings together researchers, industry stakeholders, utilities, and system operators pursuing advances in GFM inverter technologies. UNIFI's goal is to facilitate the planning, design, and operation of grids with high levels of Inverter-based Resources (IBRs). UNIFI is pursuing a broad range of strategies to target the interoperability of GFM technology, standardize their operation in a variety of applications, and demonstrate best practices.

This newsletter recaps key accomplishments in 2023, the second year of the UNIFI consortium operation. Reading on, you will learn all about our recent push towards long-term organizational sustainability, our contributions to modeling and simulation, our effort in driving consensus on specifications, the unique 1 MW muti-vendor demonstration at the Energy Systems Integration Facility (ESIF) in the National Renewable Energy Laboratory (NREL), and how we continue to push education and outreach for this technology. •

From the front page ...

UNIFI team members were hosted by Brian Johnson (Assistant Professor, University of Texas-Austin) at the University of Texas Austin on February 6-7 for our annual meeting. This latest gathering featured in-depth technical presentations from consortium members, big-picture viewpoints from invited speakers across academia and industry, and posters from our student researchers. Early results from the 1 MW multi-vendor experiment coming together at the Energy Systems Integration Facility (ESIF) in the National Renewable Energy Laboratory (NREL) drew a lot of discussion, as did UNIFI's latest endeavor to set up agile teams focusing on cross-cut topics relevant across the wide spectrum of the consortium's activities including: control under constraints, stability limitations/interactions of GFM technology with multiple devices, scalability in simulation and control architectures, and certification.

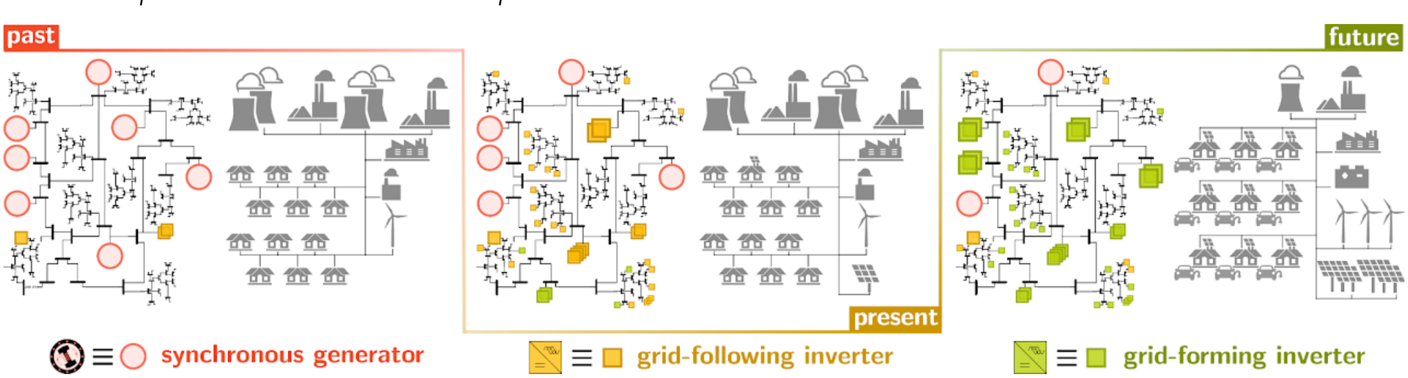
Congrats to Ashwin Venkataramanan from Virginia Tech for winning the best poster award for his work: "Black and Model-Free Transient Response Shaping for Inverter-Based Resources." He is pictured alongside his academic advisor, Ali Mehrizi-Sani (Associate Professor, Virginia Tech) and Ben Kroposki (UNIFI Organizational Director) receiving the recognition in the bottom-right picture in the collage below. ■

[Credit: NREL]

UNIFI & IEEE-ISTO

The UNIFI leadership team launched an independent membership-based UNIFI Consortium. While the UNIFI Consortium began as a U. S. Department of Energy funded effort, we always had plans to launch a self-sustaining independent organization. The purpose of the independent UNIFI Consortium is to maintain the momentum started by UNIFI and continue to bring together industry leaders to shape the future of

• 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) •



GFM inverters. To host the new consortium, we chose the IEEE Industry Standards and Technology Organization (ISTO), an international federation of member alliance programs dedicated to advancing standardized technologies for industry. ISTO has formed almost 100 alliances and consortia in various industry ecosystems since inception, allowing Program Members, including UNIFI Consortium, to operate as a legal operating not-for-profit entity, and receive membership, financial, operational, and administrative support.

As part of UNIFI Consortium's dedication to creating a secure alliance where members can collaborate effectively, governing documents were created and approved by the leadership team, providing guidelines on operations, intellectual property, anti-trust, and membership structure. Through this strong foundation, the UNIFI Consortium can focus on forwarding its mission and strategy. The UNIFI Consortium looks forward to this new chapter as an independent organization and invites prospective members to join in shaping the future of GFM inverters. •

Points of Pride in 2023

It has been a busy year for UNIFI team members! Our efforts in advancing R&D in power systems and power electronics continue to be recognized broadly across industry, professional societies, funding agencies, and regulatory bodies. Some notable points of pride from 2023 are listed below:

- Vahan Gevorgian (National Renewable Energy Laboratory) was elevated to IEEE Fellow for contributions to wind and solar photovoltaics in grids.

- Michael Ropp (Sandia National Laboratories) was elevated to IEEE Fellow for contributions to distributed energy resources integration in power systems.

- Xiaonan Lu (Purdue) and Iqbal Husain (NCSU) played key roles in the organization of the IEEE ECCE 2023 Conference.

- Vijay Vittal (ASU) was featured in the IEEE Spectrum for his career-long contributions to power systems stability and recent contributions to integration of renewables.

- Jennifer Bui (Graduate student at UW-Madison with Dominic Gross) was awarded a research fellowship from the National Science Foundation (NSF) Graduate Research Fellowship Program (GRFP).

- Deepak Divan received the 2022 IEEE Transactions on Power Electronics Prize Paper Award for work on solid-state transformers.

[Credit: IEEE PELS]

- Brian Johnson (UT-Austin) and Sairaj Dhople (U Minnesota) received the 2022 IEEE Transactions on Power Electronics Prize Paper Award (second place) for work on nonlinear GFM control.

[Credit: IEEE PELS]

- Deepak Divan received the 2023 IEEE PES Nari Hingorani Custom Power Award.

- Nick Miller (HickoryLedge LLC), member of our External Advisory Board, was elected to the U.S. National Academy of Engineering (2024) for contributions to the reliable integration of wind and solar plants into electric power systems.

GFM Specifications v2

UNIFI released Version 2 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 focus 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. The full document and an option for providing us with feedback based on your expertise and experience with GFM technology is on the UNIFI website. •

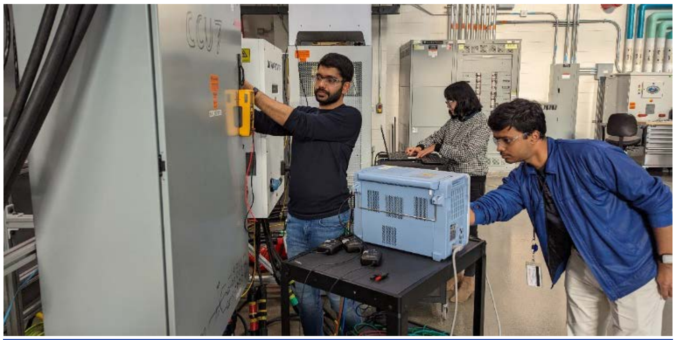
Updates on Modeling & Simulation

The Modeling and Simulation team continues to work with inverter manufacturers, software vendors, utilities, system operators, and other UNIFI members on developing generic GFM inverter models for industry and academia use. Specifically, the droop-based grid-forming inverter model named REGFM_A1 has been officially approved by the Western Electricity and Coordinating Council (WECC) Modeling and Validation Subcommittee (MVS) and released in transmission planning engineers' everyday simulation tools including PTI-PSS®E, GE-PSLF, PowerWorld Simulator, and PowerTech Labs TSAT, marking the first generic GFM inverter model that has been included in all major commercial simulation tools. Meanwhile, the team is also working on developing a synchronous-machine-based grid-forming inverter model, named REGFM_B1. The REGFM_B1 model specification was recently approved by WECC MVS, and the beta version of model has been released in PTI-PSS®E and PowerWorld Simulator. In addition, the team has also developed generic electromagnetic transient (EMT) models of GFM inverters and have them released in commercial EMT simulation tools including PSCAD and EMTP. Since these models have been developed, numerous industry stakeholders have used them to evaluate how GFM inverters will impact their power grids. Some of the study results have been published in technical reports, presentations, and papers. For example, WECC published a report on evaluating how GFM inverters impact the system frequency response. The Electric Reliability Council of Texas (ERCOT) has made a presentation on how GFM energy storage systems can better support the connection of renewable sources in weak power grids. American Electric Power (AEP) has studied the stability benefit that GFM energy storage can bring to their system. In addition, the models have also been used to evaluate the impacts of GFM inverters on Alaska, Puerto Rico, Hawaiian islands, and many other power grids.

Further, the team has also been working on methodologies and a framework that can be used to identify the extent of provision of grid forming behavior from various devices, especially black-box original equipment manufacturer (OEM) simulation models. This work allows utilities and system operators to improve their confidence in use of black-box models both in EMT and positive sequence domains. The intent here is to avoid categorizing grid forming characteristics based on type of control structure. A suite of tests and associated performance criteria have been formulated that can help a practitioner determine whether a simulation model provided by an OEM can provide performance expected from a GFM IBR. These performance criteria, when used to compare models across simulation domains, could be useful in determining the limits of a model in that simulation domain. The tests and performance criteria also help identify the impact of different hierarchies of control objective within an IBR plant. They can thus help provide insight into the framing of interconnection requirements. •

1MW Multi-vendor Demonstration

The UNIFI 1MW multi-vendor GFM inverter demo plays a pivotal role in the consortium. We have developed a testbed that includes 7 GFM inverters from 6 vendors, multiple grid-following (GFL) inverters, one diesel generator and various loads (RLC load, motor load and non-linear load). This testbed is designed to evaluate the control, functionality, and interoperability of GFM inverters in general and also to validate UNIFI specifications and identify best practices and recommendations



• NREL researchers Jing Wang, Subhankar Ganguly, and Soham Chakrabortty architecting the 1 MW multi-vendor demonstration at ESIF [Credit: NREL] •

for industry (power systems and power electronics). To this end, we have developed standardized and streamlined testing approaches and performance evaluations, from the unit level to the system level. The unit tests evaluate GFM inverters from a 360° perspective and they include standalone tests (steady state test: balanced load, unbalanced load, nonlinear load, and sinking power; transient test: black start, load steps, motor start, overload, DC dynamics, and secondary control), heterogeneous tests (steady state test: balanced load and sinking power; transient test: load steps, loss of generation, and secondary control), grid-connected tests (sourcing active and reactive power, sinking active power, voltage jump, phase jump and rate of change of frequency (ROCOF), impedance scan, and harmonic voltage regulation) and transition operation test. System-level tests investigate the interactions between GFM and GFL inverters and diesel generators.

The 1MW multi-vendor demonstration project works closely with GFM vendors to relay feedback on their products and discuss solutions to problems and challenges that can be anticipated and gleaned from the testing. This pure hardware testing gives deep understanding of commercial GFM inverters' capabilities and limitations in terms of controls, functionalities, and interoperability. It will guide how industries (particularly, GFM inverter vendors) should improve their products to offer robust performance in future grids.

Evaluations of grid technologies from different vendors is nothing new and has been useful in the past to verify interoperability in power systems. A short article dwelling into one such instance from the past with an intention to illustrate the benefits on offer to collaboration follows. •

From the pages of history …

In 1928, an engineer reported to his company's Development Committee that "if there is a discrepancy between … two controllers, there would almost certainly be tendacy [sic] for the two instruments to 'fight.'" The prior year, his company (Leeds & Northrup) had participated in a field test with a competing device from General Electric Company – the two frequency control devices were installed side-by-side on a small interconnected system, with better frequency results regardless of which device was used. The field test revealed the overall benefits of automatic frequency control, but also the need for more research because the devices interfered with scheduled load distribution. The field tests and fights continued. A major conundrum of the mid-twentieth century grid involved maintaining stable operations on interconnected power systems. In the 1920s and 1930s, in fact, utility managers lamented that there were no controls that ensured stability while simultaneously respecting the contracts between linked companies. Both well-known and lesser-known manufacturers, such as General Electric, Westinghouse, and Leeds & Northrup Company, competed fiercely to gain the business of power companies. With their proprietary inventions, and a litigious history, they were reluctant to cooperate. Yet the only way the industry came to understand how to control alternating current power on interconnected systems was through collaboration. Companies had been building interconnections since the beginning of the twentieth century. The power-sharing agreements ranged from handshakes to formal contracts, and by the end of WWI, fairly significant networks appeared across the country. Interestingly, the electricity on these networks responded more reliably to the laws of physics than the laws of the market. Regardless of which company planned to sell power to which customer, all the generators on the interconnection responded to changes in demand at the same time. In other words, when someone started up the conveyor belt at a factory, or a power line tripped off the grid, every generator "felt" the change, and responded to it. Not only did the human system operators have to make adjustments by hand on *a minute-by-minute basis, but the contractual agreements between companies for who sold how much power and when had no bearing on who actually did sell how much power and when. And, as the saying goes, the electricity followed the path of least resistance (and impedance). Inventors, manufacturers, academics, and utility engineers began producing proprietary methods and devices to automatically control the flow of electricity on these networks. To learn whether a control instrument could do the job, the inventor had no choice but to install it on the power system and give it a try, while real people were busy turning things on and off, hopefully unaware of the experiment underway. It was not uncommon for a utility to install competing devices side-by-side to compare how they worked. These tests were not always friendly. In 1931, competitors Leeds & Northrup Company and General Electric again agreed to place their devices on the same system, this time in Ohio. Participating utilities, the National Electric Light Association (fore-runner of today's Edison Electric Institute), and others observed the test. The competitors, though friendly at the start, sniped at each other. For example, a General Electric engineer stayed on site full time to monitor and help with the test. Leeds & Northrup saw this as an underhanded attempt to gain all the advantages, and decided to "play ball" and do the same. The results illustrated that centralizing control at one facility was burdensome, while fully distributing control without standardized settings on the devices was unhelpful. Though inconclusive, the results did point to what success could look like: a combination of distributed and centralized control that respected the boundaries of each operating system and adhered to the contractual agreements in place. While technologies and circumstances are substantially different, we find once again, when it comes to the electric power grid, UNIFI confronts challenges similar in framework to those faced a century earlier.* ■

This information is excerpted from a forthcoming publication by Rice University's Baker Institute for Public Policy; full text will be available at https://www.bakerinstitute.org/research-library. The views expressed therein are those of the individual author(s), and do not necessarily represent the views of Rice University's Baker Institute for Public Policy.

By: Julie Cohn, Non-Resident Scholar, Center for Energy Studies at the Baker Institute for Public Policy, Rice University, and Research Historian, Center for Public History at the University of Houston.

Updates on Education & Outreach

UNIFI team members have organized tutorials at conferences, high school symposia, teacher training events, field trips, IEEE webinars, and we have actively participated in several academic and industry workshops around the world. Through our website, you can access the 2023 EPRI Tutorial on grid-forming technologies, a tutorial presented by UNIFI members at the 2023 IEEE Power and Energy Society General Meeting, and a tutorial presented by UNIFI members for the IEEE Industry Applications Society (IAS). •

• UNIFI team presenting a tutorial at the 2023 IEEE PES General Meeting in Orlando, FL [Credit: Brian Johnson] •

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. •

for membership benefits and other inquiries, please contact Benjamin Kroposki