Electronic Design

By LEE GOLDBERG, Contributing Editor

Grid-Forming Inverters: The Missing Ingredient for Sustainable Power Grids?

Learn about the technology that underpins grid-forming inverters, and how their unique capabilities can help utilities get renewable energy into their energy mix while creating more resilient distributed generating networks.

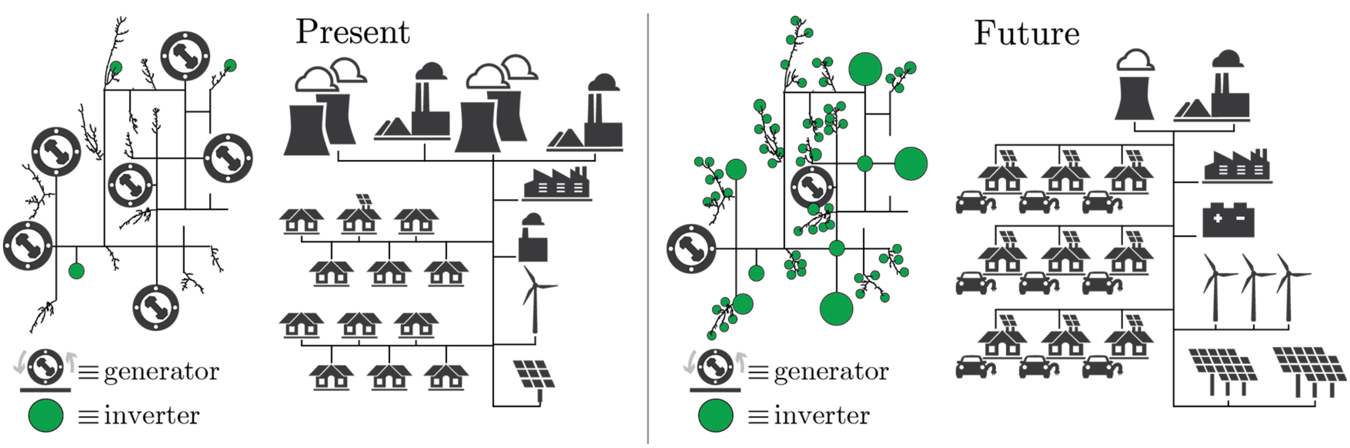
Despite the challenges it's creating for some existing industries, the transition to a sustainable economy is in the process of hundreds of billions of dollars in new opportunities for products that will enable a low-carbon energy infrastructure.

While the equipment employed to generate wind, solar, and other renewable-energy sources are the most obvious beneficiaries of the "Green Boom," the products and technologies used to store, manage, and deliver that power are also in great demand. This includes so-called "grid-forming inverters (GFIs)," a special type of inverter that can provide existing electrical generation and distribution networks with distributed regulation capabilities. They enable these networks to work more efficiently with the rapidly varying power levels that can sometimes occur in wind and solar farms.

Following vs. Forming Inverters

Virtually all of today's installed wind and solar power farms, and their accompanying battery storage systems that are connected to a larger power distribution network, use "grid-following" inverters. These measure the grid's AC voltage waveform and inject the current levels needed to synchronize the local source with it. This is because utilities have relied primarily on the rotational inertia of their mechanical generating equipment to stabilize the grid.[1]

Large synchronous machines have sometimes been used to provide power factor correction (PFC) at some problematic

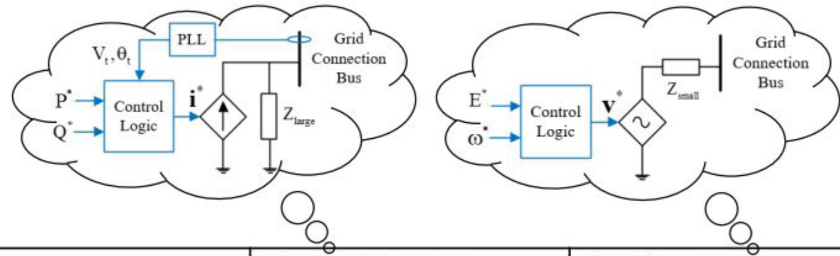


The grid-forming inverters' ability to contribute to grid stability and resiliency will enable utilities to integrate much more renewable energy into their generating fleets. [(Source: Prescon Engineering Pvt Limited)] load points. However, their high cost means that the centralized generating equipment itself must provide virtually all of the stabilization.

The inverters used in virtually all of today's renewable generating assets are phase-locked-loop controlled current sources, designed to increase or decrease their output based on the primary grid's voltage and phase angle.[3]

While this approach works well under normal conditions, it requires that the grid must be online to provide its "heartbeat" waveform required by the inverter to synchronize its output. This means that even though a solar or wind farm might be fully functional during a technical problem or natural disaster, grid operators must first bring a conventional energy source, like a coal or natural gas plant, back on line before the renewable sources, or their storage systems, can be accessed.

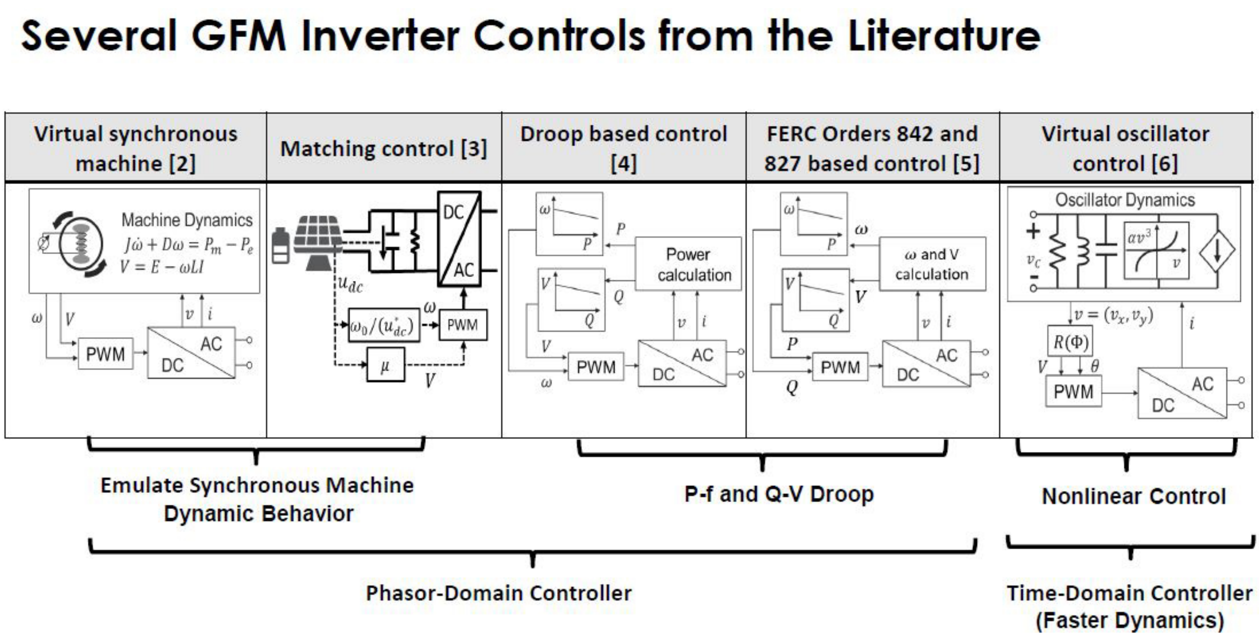
In contrast, "grid-forming" technology refers to a control paradigm in which the inverter synthesizes a voltage phasor that's controlled relative to the grid's voltage phasor to achieve the desired current and power flow.[2]



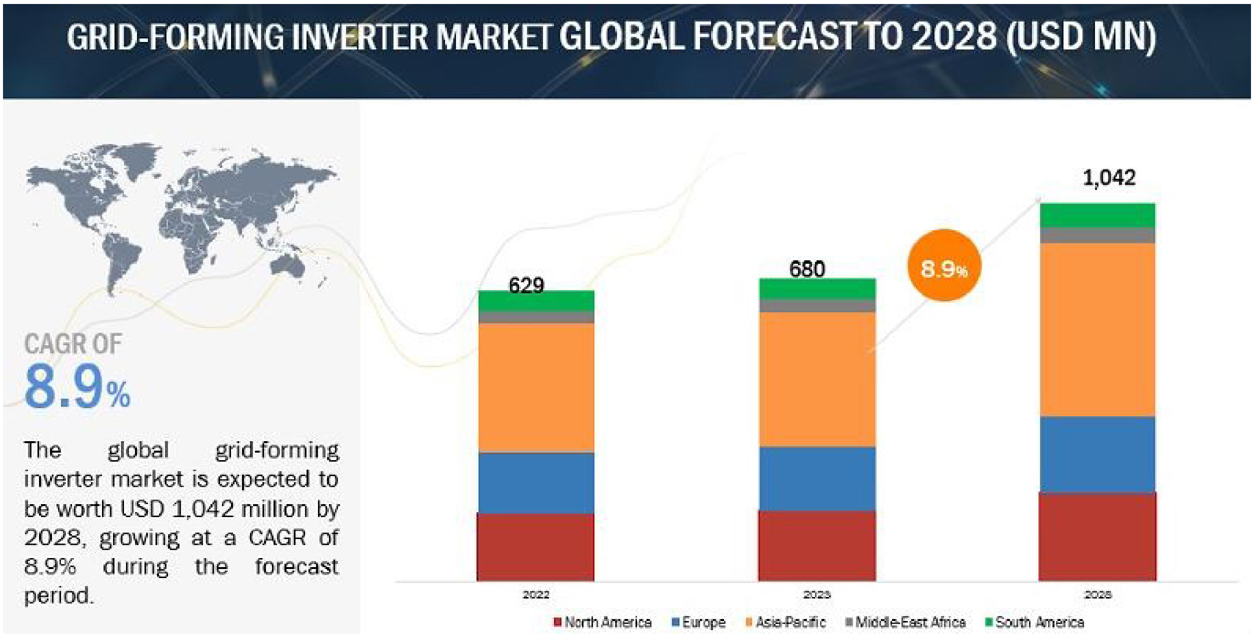
	Grid-following inverter	Grid-forming inverter
Basic control objectives	Deliver a specified amount of power to an energized grid	Set up grid voltage and frequency
Output quantity controlled	ac current magnitude and phase angle	ac voltage magnitude and frequency
Require a stiff and stable voltage at the terminal?	Yes	No
Control elements present	Compulsorily has a PLL	Compulsorily does not have a PLL

There are many nuances within each statement above that may blur the line between grid following and grid forming

A comparison of the characteristics of grid-following and grid-forming inverters. (Source: EPRI)



A sampler of grid-forming inverter architectures. (Source: NREL)



The grid-forming inverter market is expected to have a CAGR of nearly 9%, making it a $1B+ industry by 2028. (Source: MarketsandMarkets)

As a result, GFIs can interact with the grid by sensing changes in its amplitude and frequency, and then respond in real-time to adjust its output frequency by injecting more or less power as needed to stabilize the entire network. This allows GFIs to help power grids accommodate the constantly varying outputs of wind and solar farms.

And, since GFIs can synthesize their own output waveforms, they're able to operate in standalone mode if the grid they're attached to should fail. This makes them an excellent building block for creating highly resilient "microgrids," defined as a group of interconnected loads and distributed energy resources that appears to the grid as a single controllable entity.

Their grid-forming properties allow them to operate as part of a larger generation/distribution grid, or disconnect and operate in so-called "island mode." Thus, they can be independently restarted when a natural disaster or some other calamity brings down the larger network. Devolving control of the grid's now-centralized regulation functions into a distributed, interactive architecture would enable still-functioning generating assets to continue to deliver power during widespread outages, and speed recovery to normal operation.

Challenges with GFIs and Microgrid Adoption

GFI technology has been used in standalone microgrid applications (not tied to a primary grid) for a decade or more, with a growing number of successful installations in Europe, the Caribbean, Australia, Asia, and the U.S. But a number of issues remain before integrating large numbers of microgrids and other distributed generating resources into large power grids is practical. Part of the difficulty is that, until now, no standards or guidelines govern the design, function, and operation of GFIs.[4]

The U.S. Department of Energy (DoE) has begun to tackle this problem with a $25 million initiative aimed at overcoming the issues that have made it difficult to adopt grid-forming inverters into the U.S. power system. Now in its second year of operation, a consortium, led by the National Renewable Energy Laboratory known as UNIFI, for "universal interoperability for grid-forming inverters," has focused on fundamental issues, such as interoperability, reliability, and providing a roadmap for integrating the technology into existing infrastructures.[5]

That includes a set of guidelines on how GFIs should interact with the power grid, and each other. UNIFI already released a set of draft standards in late 2022, intended as the first step toward a national grid code that includes technical specifications GFI for equipment and related technologies. Release of a second, updated version is anticipated for the end of 2023.[1]

To better inform its efforts, UNIFI purchased a representative sampling of grid-forming inverters from several manufacturers and ran an extensive series of performance and interoperability tests on them at the National Renewable Energy Lab's (NREL) laboratory in Golden, Colorado. The tests involve connecting them to an existing 1-MW power system and carefully evaluating how they work together (or don't) while operating on the same grid.

UNIFI is also evaluating the performance of a large fleet of GFIs from two other manufacturers that are already in service in a 20-MW co-generation system located on the island of Kauai, Hawaii. This study hopes to gain insights into how inverters from different manufacturers can be smoothly integrated into a large power grid. In addition, it's looking at what modifications to their controller's firmware will be required so that they coordinate with each other as they collectively adapt to changing grid conditions.

Establishing standards for the performance and interoperability of GFIs will greatly accelerate both the maturation of the technology and the rate that they're integrated into energy grids across the globe. As a result, power grids will be able to use a much greater percentage of renewable energy in their grids, and find it much easier to begin decentralizing their networks through the use of micro-grids.

A Booming Market

In addition to accelerating the emergence of greener, more resilient grids, grid-forming inverters represent a significant opportunity for the power equipment industry. A recent study published by MarketsandMarkets anticipates that the global grid-forming inverter market is expected to grow from an estimated U.S$680 million in 2023 to U.S.$1,042 million by 2028, at a CAGR of 8.9% from 2023 to 2028.[6] This is another significant indicator that fortune will favor the bold during the transition to a sustainable economy.

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