unifi consortium

universal interoperability for grid-forming inverters

Value Proposition for Grid-Forming (GFM) Inverters

What's Inside?

An overview of value that can be unlocked with the choice of GFM inverter technology in renewable integration projects across scales.

Topics covered

- Grid-forming Inverters overview
- Essential reliability service markets
- Black start capabilities
- Improved system reliability
- Improved system resilience

Grid-forming (GFM) Inverters Overview

The future power grid will include more inverter-based resources (IBRs) interfacing wind, solar, and batteries due to their cost-competitive nature and to fulfill societal system decarbonization goals. Our current power systems, which were originally designed around synchronous generators, need to adapt to assimilate higher percentages of IBRs. Grids with high levels of IBRs currently exist in small islanded systems but are quickly becoming a reality in larger systems. In these future grids, inverters will need to take on a more engaged role in ensuring system stability, frequency and voltage regulation, and black-start and islanding capabilities. These capabilities can be provided seamlessly by grid-forming (GFM) controls. In contrast, inverters deployed in grids today are dominantly offered with grid-following (GFL) controls which do not offer the full suite of these control capabilities readily.

GFM controls offer several technological advantages over GFL controls, including improved and stable operation in low system-strength regions, improved primary-frequency response (PFR) and fast-frequency response (FFR), and black-start capabilities, among others. These benefits can be translated into economic value, procured through three main value streams: participation in essential reliability-service markets, compensation for black-start capabilities, and improved system reliability and resilience. (See Figure 1.) Notably, these attributes span from unit-level owner benefits to system-wide operational benefits. We overview different aspects of these value streams in what follows.

1. Essential Reliability Services

- GFM IBRs can participate in essential reliability-service markets that include PFR or FFR.
- GFM controls can provide a stabilizing response, which may be compensated in future systems with high levels of IBRs.

2. Black-start Capabilities

- GFM IBRs that provide black-start capability can be compensated for offering that service.

3. Power Grid Reliability & Resilience

- GFM IBRs can offer improved system strength and stability and assist in power system restoration, which in turn can increase system reliability and resilience.
- GFM controls can help to increase the system hosting capacity, which enables continued seamless deployment of renewable technologies.

Figure 1: Summary of benefits of GFM inverters

Essential Grid Service Markets

IBRs, particularly batteries, can participate in essential reliability-service markets that include products for PFR and FFR. Both GFL and GFM IBRs can participate in these markets, but a benefit of GFM IBRs is that they include primary controls that are innately frequency sensitive. Therefore, they are naturally suitable to regulate and restore grid frequency. A market for frequency response (including PFR and FFR) that encourages IBR participation only exists in ERCOT today, but may expand to other ISOs/RTOs in the future.

Grid-following (GFL) Controls

- Maintain a constant output current phasor to control the active and reactive power injected by the IBR into the network in the sub-transient to transient time frame.
- They are inherently dependent on grid-strength and cannot operate in islanded mode or provide black-start capabilities.

VS.

Grid-forming (GFM) Controls

- Maintain a constant internal voltage phasor & frequency, which is controlled to maintain synchronism with other devices and to regulate IBR active and reactive power in the sub-transient to transient time frame.
- Can provide black start and continue operation even in the absence of synchronous generators.

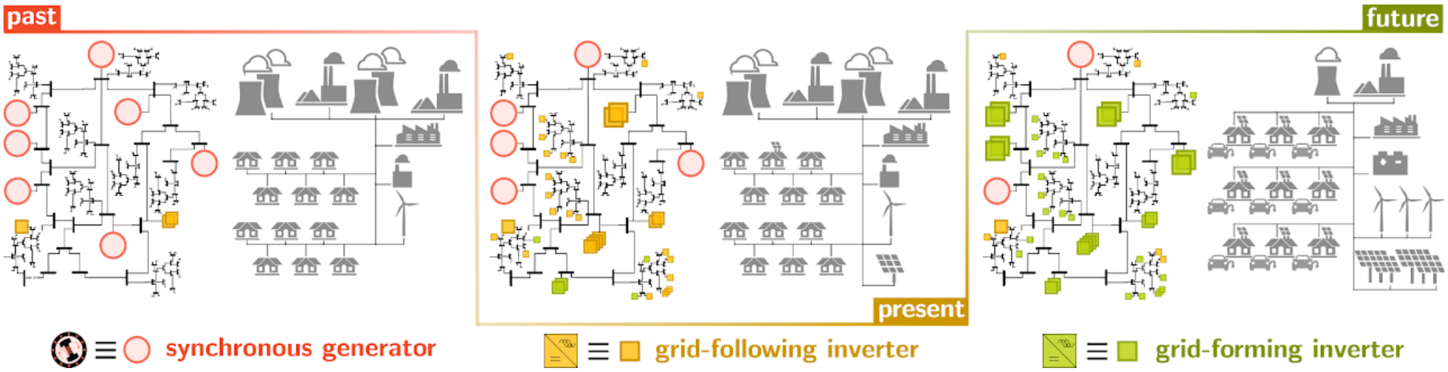

Figure 2: Trends of the past, current, and future power grid with respect to synchronous generators and inverter-based resources (IBRs)

GFM controls are particularly helpful in improving stability in weak grids. This will become increasingly important as more IBRs are added to the power grid (see Figure 2). Their response characteristics can be delivered within sub-transient time frames which can be beneficial to the power network. Furthermore, this could be less expensive than bringing additional synchronous generation into the system to meet a system's minimum inertia limit. GFM technologies can also rapidly supply real power, which can be advantageous over synchronous condensers that only supply reactive power. However, stability and inertia are not included in today's essential reliability markets.

Black-start Capabilities

Black start is the ability of a generation technology to restore power to parts of the grid following a blackout. Isolated resources can black start, forming microgrids that can then be reconnected. GFM controls can enable both black-start capability and islanded operation. Thus, if the generation source has the necessary capacity available, GFM IBRs can restore power to the grid without the need for synchronous generators or large-scale power plants.

While black start markets do not currently exist, in certain ISOs/RTOs, resources can offer black-start services and be paid as offered if they are black-start qualified. Requirements for black-start service differ across ISOs/RTOs, as does the expected compensation per MW of black-start service. Compensation can be provided through cost recovery tariffs or economic tariffs. IBRs may not qualify for black-start compensation in certain ISOs/RTOs where there is technology differentiation with a preference towards combustion turbines or hydropower plants.

Improved System Reliability

Reliability relates to the percentage of time the grid is both available and functional. GFM IBRs can help improve grid reliability since they offer better dynamic response in the face of abnormal or fault conditions. They can also be designed to damp oscillations in power systems that can cause instabilities in the grid.

Improved System Resilience

Power grid resilience is defined as the ability to anticipate, prepare for, and adapt to changing conditions; and withstand, respond to, and recover rapidly from disruptions. GFM IBRs have the capability to increase power grid resilience since they can offer black-start capability. This allows for power restoration through multiple microgrids, as each GFM resource can operate in islanded mode if there is sufficient generating capability (i.e., wind or solar resource or battery capacity) available. GFM controls can thus speed up power restoration times while providing a clean alternative to, e.g., diesel generators. GFM controls also allow IBRs to operate stably in low system-strength conditions, which can increase grid security and resilience against disturbances.

However, it is difficult to quantify the value of resilience. Metrics to quantify resilience include the value of lost load, loss of life, the loss of business revenue, and the loss of utility revenue, although such attributes are not quantifiably represented in contemporary electricity markets or revenue streams. Utilities can evaluate resilience investments through cost-benefit analyses, and the presence of GFM IBRs will factor into those benefits.

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