

# A Path Toward the Development and Commercialization of Grid-Forming Inverters

## A BRIEF FROM ESIG

Wind, solar, and battery storage are connected to the grid with inverters, powerful electronic devices that convert the electricity from these sources into electricity that can be fed onto the grid. The majority of today's inverters are *grid-following*: in order to operate stably, they require the presence of a grid with high system strength, which is determined, today, by comparing the maximum possible fault current to the inverter rating at the point of interconnection. High system strength has traditionally been provided by power plants such as coal, natural gas, or nuclear plants with rotating generators synchronized with the grid.

As power systems add increasing amounts of inverter-based resources (IBRs)—predominantly from solar, wind, and batteries—more regions experience IBR levels surpassing 50 to 60 percent of system demand. By 2025, eight European countries, for example, are projected to experience periods in which IBRs serve 100 percent of the load (figure 1). As power systems add solar, wind, and batteries and take traditional power plants offline, system strength will decline in some regions. Consequently, in regions experiencing high instantaneous levels of renewables and other IBRs, the grid may not always possess the system strength required by today's grid-following inverters. More advanced technology is needed, and *grid-forming* inverters may play an important role.

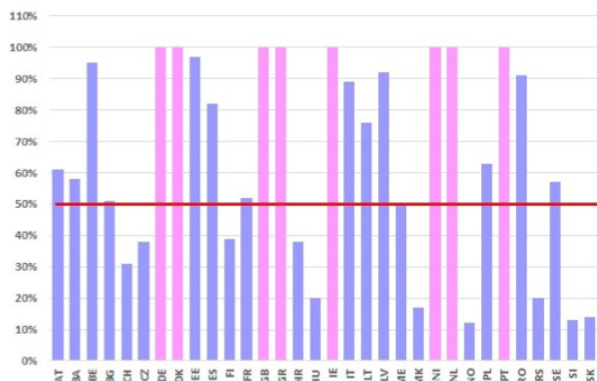


Figure 1. Forecast in 2016 of the highest hourly levels of IBRs in Europe by 2025.

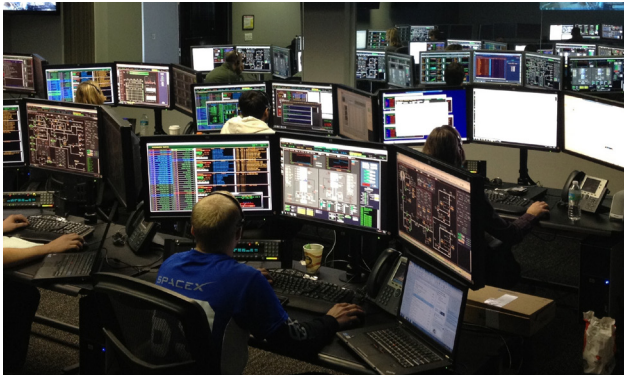
For manufacturers to meet this demand for grid-forming inverters in the coming years, technical specifications must be defined and harmonized quite soon. Multiple approaches and pathways are possible, and the choices require coordination that must be grounded in discussions among system operators, inverter manufacturers, and policymakers.

## System Needs

When a large power plant unexpectedly disconnects from the grid, the grid frequency falls because energy is extracted from the synchronized spinning masses of the remaining traditional power plants to compensate for the loss of generation. This characteristic of conventional synchronous generators, commonly called synchronous inertia, does not stop the frequency from falling, but it does ensure that the frequency will fall at a gradual rate as the energy is extracted from—and causes a slowing of—many large spinning masses.

All generators on the system can see that frequency is falling and use this as a signal that something has occurred. The gradual decrease in frequency provides time (multiple seconds) so that other generators, both conventional generators and today's grid-following inverters, can adjust their power output to contribute to the rebalancing of the grid. However, as traditional power plants become fewer in number, less conventional synchronous inertia means that system frequency may fall faster after grid disturbances. This provides less time for other power plants to detect and respond to the disturbance and potentially could cause some of today's grid-following inverters to lose their synchronization or stability with the system, and disconnect. Inverters are needed that can respond to events with faster dynamics and maintain stable synchronization even in situations with lower system strength.

Currently, some regions with high levels of IBRs maintain grid stability by limiting the maximum level of power production from IBRs or by keeping a certain number of traditional power plants connected to the grid at all times. As levels of renewables rise, the power system needs a subset of inverters able to support the operation of the grid under disturbed and emergency conditions: to have the capability of maintaining system stability during conditions of lower system strength and lower synchronous inertia. It has been estimated that with 10 to 30 percent of IBRs using grid-forming inverters, the grid could be stable with more than 90 percent of generation coming from IBRs.



Grid-forming inverters (and many of today's existing grid-following inverters) can also play a role akin to the synchronous inertia of traditional power plants by electronically providing a fast frequency response. Grid-forming inverters can be designed with an even higher tolerance for voltage and frequency deviations and respond to these conditions in ways that benefit the system. And, with an adequate amount of energy storage, grid-forming inverters can be designed to provide system restoration services after a black out.

## Manufacturers' Needs

Inverter manufacturers, like the developers of any manufactured product, consider new products and capabilities when there is market value in doing so. Currently, manufacturers lack the market demand and guidance to develop grid-forming capability in their standard products. The costs for developing and manufacturing grid-forming inverters are higher than for today's inverters, due to the need for an energy buffer, oversized equipment, and new control strategies. Moreover, expectations for the functionality and performance of grid-forming inverters are not uniform across power systems, which also drives up the development cost.

Commonly agreed-upon requirements are needed to guide manufacturers in developing and supporting a widely used set of products and reducing complexity for product applications. In addition, market-based approaches should be developed by system operators to value the system benefits from grid-forming technology (e.g., frequency support and black start capability), similar to the market incentives for traditional power plants providing these services. The new generation of grid-forming inverters would also benefit IBR development

more broadly, allowing developers to build projects in areas with lower system strength without the onerous studies and efforts that may otherwise be needed to ensure stable operation of the inverters in such regions.

Manufacturers, grid operators, and policymakers must maintain an ongoing dialogue about the conditions under which grid-forming technology is needed and the desired performance of these devices. Manufacturers can then develop the necessary capabilities, balancing performance objectives and costs most efficiently. Manufacturers also need to work closely with grid operators and developers to understand how to best leverage the new capability in different situations, whether through simulation or operational practice. Such collaboration is crucial for optimizing the effectiveness of additional technical capabilities and for managing the cost of grid-forming technology deployment.

## Looking Ahead

Several projects, mainly in small isolated power systems, successfully demonstrate the feasibility of grid-forming technology. However, manufacturers require stronger incentives to develop commercial grid-forming inverters for bulk power system applications overall. In addition to a need for market signals, technical requirements need to be transparently discussed, and detailed cost-benefit analyses must be carried out, examining different combinations of grid-forming IBRs, grid-following IBRs, and traditional power plants.

Grid operators, manufacturers, researchers, and policymakers will need to continue to discuss conditions under which grid-forming technology is needed, and the performance requirements should be clearly defined in grid codes or standards. Manufacturers can then develop equipment with new capabilities that balance performance and costs. This dialogue is crucial for maintaining secure and efficient system operation with high levels of renewables.

*Adapted from Julia Matevosyan, Babak Badrzadeh, Thibault Prevost, Eckard Quitmann, Deepak Ramasubramanian, Helge Urdal, Sebastian Achilles, Jason MacDowell, Shun Hsien Huang, Vijay Vital, Jon O'Sullivan, and Ryan Quint, "Grid-Forming Inverters: Are They the Key for High Renewable Penetration?" IEEE Power and Energy Magazine November-December 2019. Guest editor, Charlie Smith, ESIG. DOI: 10.1109/MPE.2019.2933072.*