

Grid forming energy storage: strengthening stability in renewable power systems

As renewable generation grows, traditional sources of grid stability are declining. Grid forming energy storage can actively regulate voltage and frequency, support weak grids and provide black start and dynamic ride through capabilities, helping integrate higher shares of renewables reliably.



The global shift toward renewable energy is fundamentally reshaping the architecture and operational dynamics of modern power systems. Traditionally, grid stability has been maintained by synchronous generators in thermal and hydroelectric power plants.

These electromechanical machines inherently supply rotational inertia, voltage regulation and fault current contribution, helping stabilize system frequency and voltage.

In contrast, inverter based resources, including solar and most battery systems, do not inherently provide these stabilizing characteristics. As a result, system inertia declines, grid strength weakens and the network becomes more sensitive to disturbances.

Why advanced control technologies are needed

Lower system inertia introduces technical challenges, including higher rates of change of frequency (RoCoF), reduced fault current,

increased voltage sensitivity and greater susceptibility to oscillatory instability and transient disturbances.

Ensuring secure and reliable operation in this context requires advanced control strategies and technologies that actively support system stability while enabling the integration of large shares of renewable energy. Grid forming energy storage systems have emerged as a critical technology to address these challenges, providing active regulation of voltage and frequency in low inertia power systems.

Regulatory context for grid forming storage

Regulatory frameworks are adapting to support the reliable integration of inverter based resources. For instance, the European Network Code on Requirements for Generators (NC RfG 2.0) encourages strategic adoption of inverter based resources with grid forming capabilities.

These systems differ from conventional grid following inverters, which rely on an external grid reference for synchronization. Grid forming units actively establish and regulate grid voltage and frequency, allowing them to stabilize networks and support higher penetration of renewable resources.

Core technical functions of grid forming units

Modern grid forming energy storage systems incorporate multiple technical functions. These include supporting grid strength, short term overload capacity, phase jump tolerance, dynamic voltage regulation, fast frequency response, inertia emulation, damping control, seamless transitions between grid connected and off grid operation and black start capability.

Their design allows them to operate effectively under ultraweak grid conditions, where short circuit ratios (SCR) fall below 1.1, a scenario that challenges conventional converters due to limited system strength and reduced voltage stability margins. By injecting fault current rapidly and dynamically, these systems enhance grid stability and facilitate the integration of higher shares of renewables.

Handling disturbances and maintaining stability

During short circuit events or momentary voltage dips, the systems can provide temporary overloads of up to 3 In for 10 seconds at the system level, with repeated capability after a 120 second recovery cycle.

They also support low voltage ride through (LVRT), high voltage ride through (HVRT) and continuous fault ride through, maintaining operation under extreme voltage conditions. Phase jump tolerance allows the system to respond to abrupt changes in the grid or output voltage, such as those caused by faults, load shifts or control adjustments.

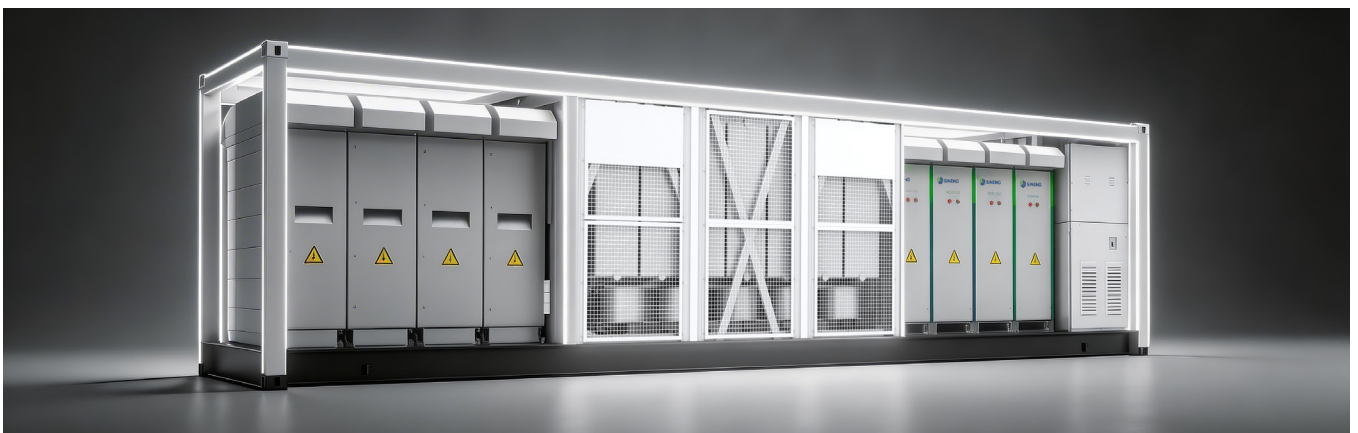
By injecting or absorbing active power in response to phase angle variations, the technology maintains continuous operation for phase shifts within ± 60 degrees.

Voltage stabilization is further supported through dynamic reactive power management. Systems can accommodate deviations of $\pm 5\%$ Un under small disturbances and $\pm 10\%$ Un under larger fluctuations.

Active power is regulated to emulate inertia, suppressing rapid frequency changes based on system RoCoF. Damping control mitigates oscillations and contributes to overall frequency stability. Transitions between grid connected and islanded operation occur seamlessly at millisecond level precision, ensuring uninterrupted power delivery.

Black start functionality allows units to independently establish voltage and frequency without external grid support, enabling rapid system restoration after





outages. Multiunit parallel operation is supported, with maximum voltage ramp rates of $\geq 10\%$ Un/s, allowing flexible scaling of power output.

System configurations and scalability

Grid forming storage solutions are offered in a variety of configurations. Modular string units range from 250 kW to 430 kW, allowing scalability and rack level management, while central units provide 1,250 kW to 1,725 kW with high power density and optimized efficiency.

Containerized systems integrate transformers and switchgear to deliver 10 to 13.8 MW per 40 ft unit, making it possible to deploy grid forming functionality across diverse project scales. Multiunit parallel operation enables flexible scaling, integration of multiple battery chemistries and deployment in projects of varying size and complexity.

Field deployment and real-world validation

These technologies have been applied in multiple technically demanding projects. Examples include a 50 MW / 200 MWh microgrid in Xinjiang, a 6 MW / 24 MWh high-altitude installation in Tibet above 4,500 meters, and a 300 MW / 1,200 MWh hybrid energy storage power station in Ordos, which combines Lithium Iron Phosphate and Vanadium Flow Batteries.

In each case, the units have provided reliable operation under weak grid and extreme environmental conditions, highlighting their ability to support renewable integration at scale.

Further technical validation was conducted at a 100 MW / 200 MWh energy storage station in Changsha City under supervision by DNV. Frequency and voltage adaptability, power control, inertia response, primary frequency regulation, damping control, black start capability, overload capacity, continuous HVRT/LVRT and phase jump tolerance were all systematically tested across hundreds of operating scenarios.

The results confirm that advanced grid forming storage technologies can meet stringent technical requirements and are ready for deployment in commercial scale applications.

Strategic benefits for renewable integration

Beyond technical performance, grid forming energy storage contributes strategically to the integration of renewables. By providing synthetic inertia, voltage support and fault current, these systems help maintain stability in low inertia networks, which is particularly important in regions with high shares of solar and wind generation where conventional synchronous generation is limited.

They also enable flexible system design, supporting microgrids, hybrid energy hubs

and islanded operations without compromising reliability.

Operators can deploy multiple units in parallel to scale power output, integrate different battery chemistries, or provide ancillary services such as frequency regulation and reactive power compensation.

This flexibility not only enhances operational resilience but also improves the economic performance of renewable projects by reducing curtailment and maximizing utilization of installed capacity.

Looking ahead: a cornerstone of decarbonized power systems

Grid forming energy storage is expected to play a central role in decarbonized power systems worldwide. Its combination of operational reliability, scalability and advanced control capabilities allows both large utilities and smaller distributed networks to accommodate growing renewable generation while maintaining system stability and secure power delivery.

Continued innovation, rigorous engineering, and real-world validation will ensure these systems remain essential enablers of the energy transition, providing the stability and flexibility necessary for a renewable dominated grid.

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