NR BESS GRID-FORMING FUNCTIONAL DEMONSTRATION

Cutting-edge Technology for Clean Power Integration.

NR ELECTRIC CO., LTD.

Background

As wind and solar power plants increases with large amount of Power Electronic Interfaced Generation units, there has been great changes in the operating characteristics of contemporary power systems. These challenges go beyond the classical definitions of frequency, rotor angle and voltage stability.

In addition to intermittence of renewable resources due to weather factors, they also vary in scale from residential-scale rooftop systems (a few kilowatts) to utility-scale power plants (hundreds or even a few kilowatts, gigawatts), and they are directly connected to the high- voltage transmission system throughout the distribution network. Such high penetration rate of Power Electronic Interface Generation units has brought challenges observed like frequency & voltage stability and undamped converter control interaction.

The grid-following/GFL renewable units, based on phase-locked control technology, do not participate in the automatic power distribution, while the unbalanced power is all borne by the traditional synchronous generator units, that is, the grid-forming/GFM units. The installation reduction and the increasing retirements of traditional synchronous units leads to highlight the frequency & voltage problem.

With the rapid decline of electrochemical cost in recent years, electrochemical energy storage has brought the possibility to solve the power balance and stability problems of large power grids, while conventional energy storage can usually only solve the problems of peak regulation, frequency and voltage regulation of the grid. It is difficult to provide effective inertia, difficult to solve the problem of transient voltage, and even more difficult to improve the impedance characteristics of the system.

A stable large power grid requires the construction of synchronous potential is currently feasible and can solve the grid stability problems of high proportion renewable energy in the future. The power electronic converter based on grid forming technology has similar external characteristics to conventional synchronous units, and can provide all the functions of conventional units, such as inertia support, frequency and voltage regulation, and increase short-circuit capacity. It has broad application prospects in the construction of renewable power systems in the future.

Grid-Forming BESS

Grid Forming (GFM) technology changes the power flow by controlling the amplitude and phase angle of the internal potential, act as the characteristics of a voltage source, together with parallel operation of multiple inverters. This control technology can truly play a supporting role as a voltage source in the power grid; while conventional inverters inject current into the system through phase locking loop, showing the characteristics of grid-following (GFL) current source so difficult to support high penetration of renewable resource grid.

Table 1. Comparison of Grid-Following and Grid-Forming Controls

	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

The power conversion system (PCS) using the grid-forming control technology can simulate the amplitude and phase angle like the conventional synchronous generator. When running with other power sources at the same time, the grid-forming type PCS needs to solve the problem of self-synchronization between multiple voltage sources. Virtual Synchronous Generator (VSG) technology is the most commonly used one. The self-synchronization control of the grid-forming type PCS is introduced into the rotor motion equation of the conventional synchronous generator, which can provide inertia support for the system after the system disturbance like a conventional unit. The external characteristics of the grid-forming control technology are closer to the conventional synchronous generator. The comparison between the VSG and the conventional unit is as follows:

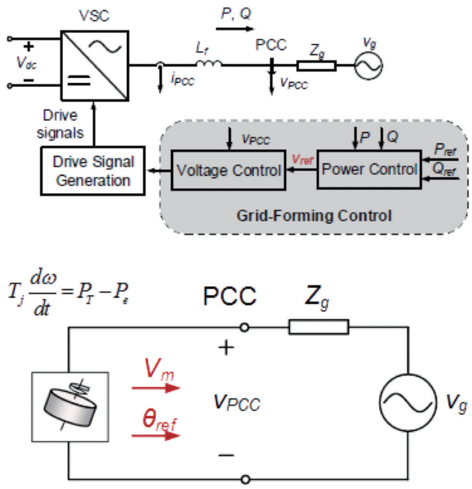

Fig.1 VSG Principle Circuit

NR can provide integrated solutions for energy storage power plants, including: energy storage power plant grid-connected secondary protection & control equipment, energy storage energy management system (EMS), power management system (PMS), power conversion system (PCS) , battery management system (BMS) and fire protection system, etc.

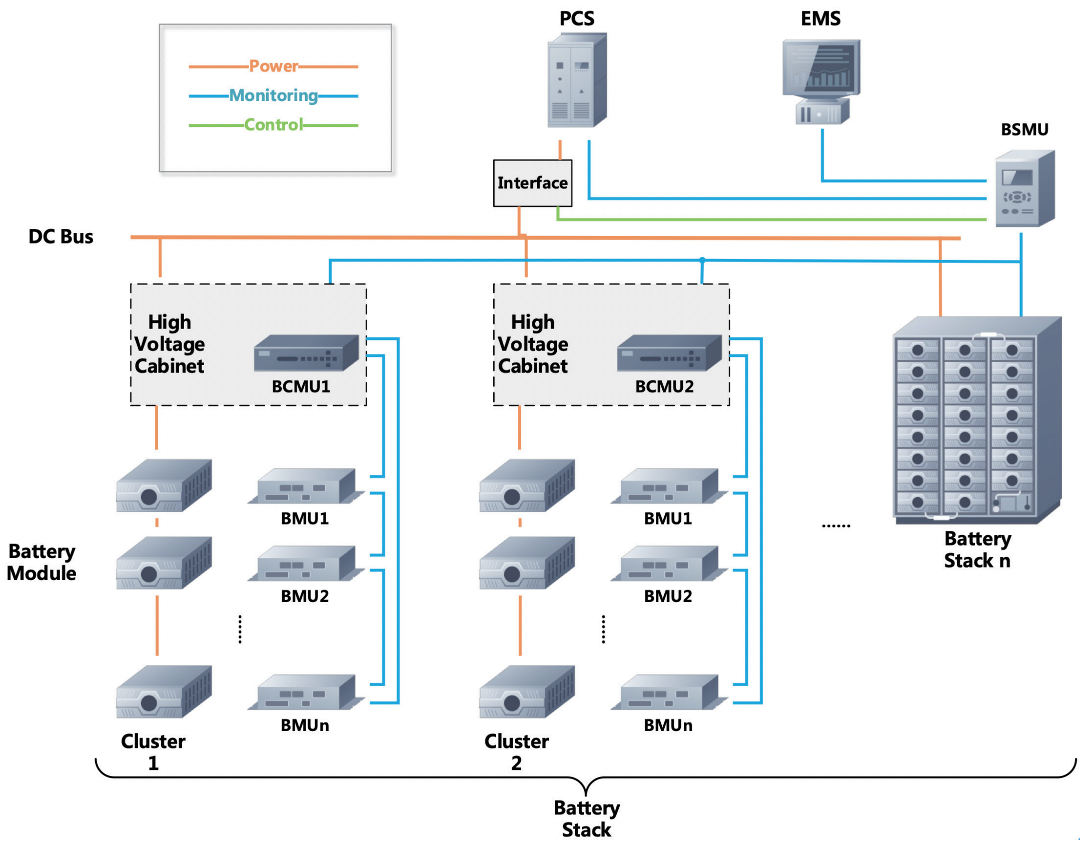

Fig.2 NR BESS Architecture

The grid-forming technology requires an energy source to give full play to the advantages of the grid-forming technology. The chemical energy storage, which is currently relatively mature, is an ideal medium for applying the grid-forming technology. The virtual synchronous generator (VSG) constructed based on the energy storage PCS can Implement the following functions:

1) It can simulate the external characteristics of rotating electrical machines, realize multi-power synchronous operation without phase-locked loop, automatic power distribution, provide inertia and short-circuit capacity for the system.

2) It can provide high-performance primary frequency regulation, voltage regulation, damping control and other functions to improve the stability of grid frequency, voltage, and power angle.

3) Improve the harmonic impedance characteristics of the system and reduce the risk of secondary super-synchronization and medium and high frequency oscillation of the power grid.

4) The Grid-Forming energy storage simulates conventional generator control, and can improve the shortcomings of conventional generator control, such as improving damping control, speed regulation control and excitation control performance, and can further increase DC component and active short-circuit current suppression according to system requirements.

Table2 Comparison of Grid Forming BESS, conventional BESS and synchronous generator

Metric Index	Power Grid Requirement	Grid-Forming BESS	Synchronous Generator	Conventional BESS
Frequency	Primary Frequency Regulation	★★★★★	★★★★☆	★★★★★
	Synchronous Inertia Support (Reduce frequency change rate)	★★★★★	★★★★★	★
	Secondary Frequency Regulation (AGC)	★★★★★	★★★★☆	★★★★★
Voltage	Short-circuit Capacity (System Strength)	★★★★★	★★★★★	★
	Transient/Dynamic Voltage Regulation	★★★★★	★★★★★	★★☆
	Steady state reactive power regulation（AVC）	★★★★★	★★★★☆	★★★★★
Others	Black Start	★★★★★	★★★☆☆	
	Impedance Characteristic	★★★★★	★★★★★	★
	DC Component	★★★★★	★★★☆☆	★★★★★

Grid-Forming Functional Demonstration

The characteristics of the Grid-Forming inverter unit are close to the synchronous generator unit. Which is more, digital makes its control more flexible than synchronous generators units.

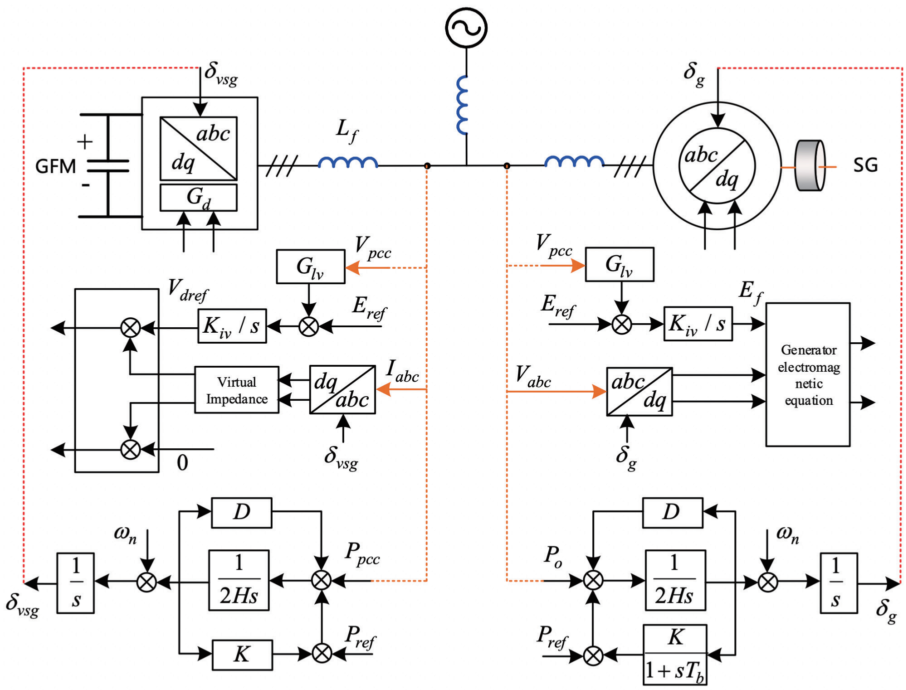

Fig.3 Battery ESS GFM vs. Synchronous Generator GFM

NR has designed an innovative virtual synchronous control pattern based on the combination of virtual reactance and virtual admittance, also improved the operation stability of the energy storage controller, so that we can flexibly implement configuration of relevant functions according to the AC system's Grid-Forming requirements.

Three BESS inverters in parallel with each rated 500kW are simulated on real-time simulator/RTDS, while physical BESS control units are installed as hardware-in-loop. The GFM function results are demonstrated as below.

Fig.4 Hardware-in-loop test on RTDs

Primary Frequency Regulation Demonstration

When the system frequency deviation value is greater than the set dead zone, the energy storage converter shall be able to adjust the active output and participate in the primary frequency regulation of the power grid. The specific requirements are as follows: The absolute value of the active frequency regulation dead zone of the converter should be in the range of 0.033Hz~0.1Hz. When the system frequency drops, the energy storage converter shall increase the active power output according to the primary frequency modulation curve; when the system frequency increases, the energy storage converter shall reduce the active power output according to the primary frequency modulation curve; the allowable error of the active power response shall be within ± within 2% of rated power.

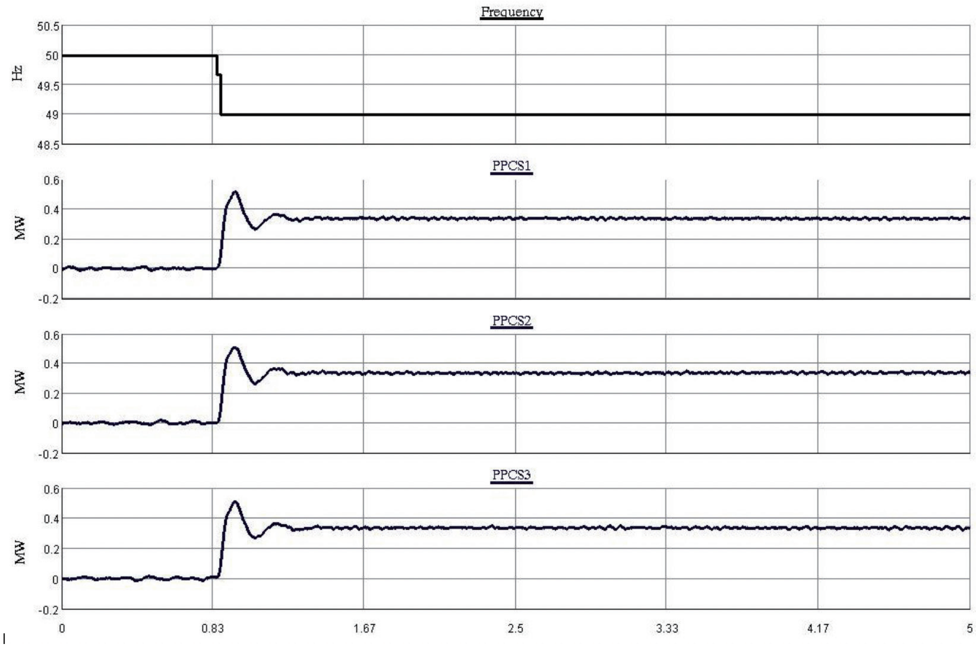

Fig.5 Active power output among three inverters at frequency deviation

Primary Voltage Regulation Demonstration

When the system voltage deviation value is greater than the set dead zone, the energy storage converter shall be able to adjust the reactive output and participate in the primary voltage regulation of the power grid. The specific requirements are as follows: When the system voltage drops, the energy storage converter shall be based on the primary voltage curve to increase the reactive power output; when the system voltage rises, the energy storage converter shall reduce the reactive power output according to the primary voltage curve; the allowable error of the reactive power response should be within ±2%of rated power.

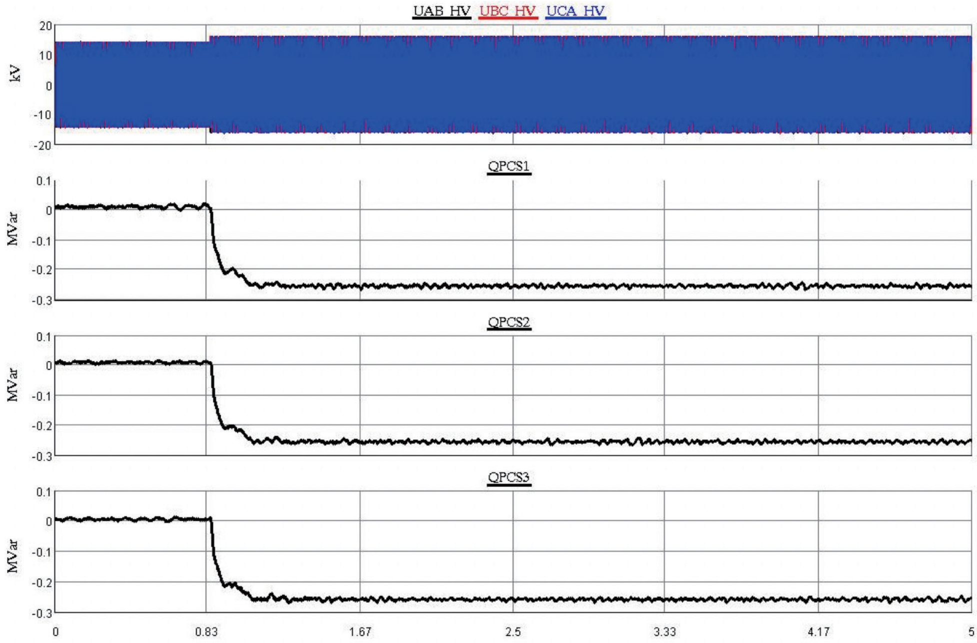

Fig.6 Reactive power output among three inverters at voltage deviation

Inertia and Damping Regulation Demonstration

The energy storage converter shall have the inertia response function. When the system frequency change rate is greater than the set value of the system frequency change rate, the energy storage converter shall automatically adjust the active power to suppress the rapid change of the grid frequency.

The energy storage converter shall have a damping control function to simulate the damping characteristics of a synchronous machine, so that the power oscillation amplitude caused by external effects or the inherent reasons of the power system itself is gradually reduced, and the dynamic stability of the power system is improved.

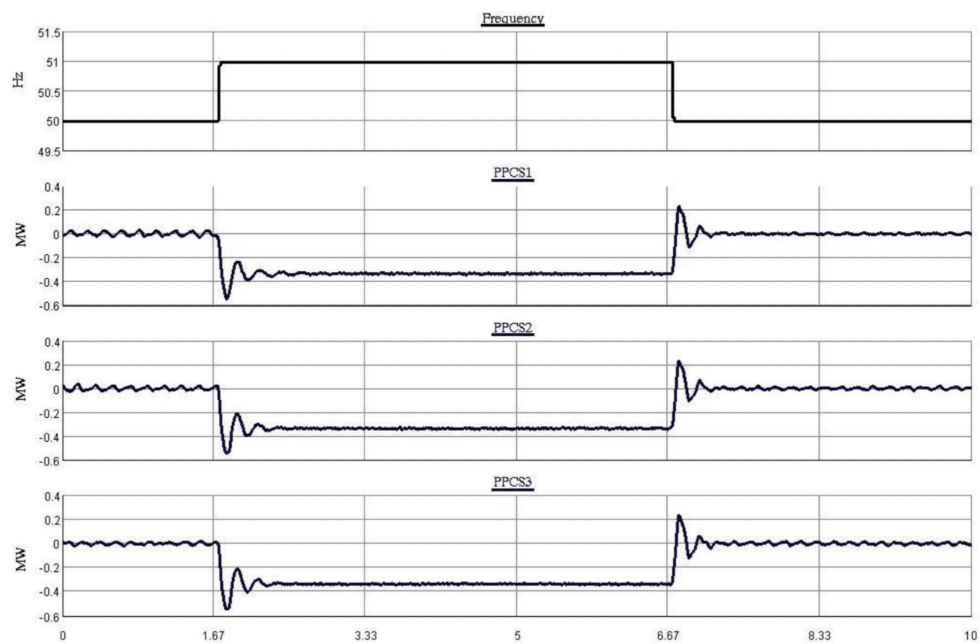

Fig.7 Response curve at inertia time constant 0.6s and damping factor 1.0

Blackstart Demonstration

The energy storage converter shall be able to start at zero voltage after blackout and run continuously and stably with load.

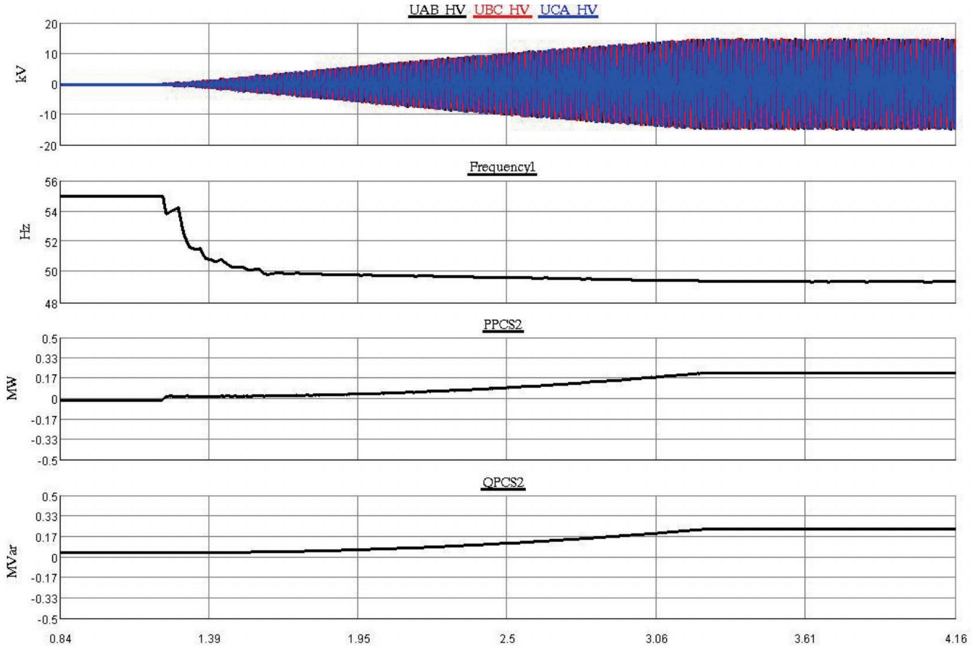

Fig.8 Blackstart process under loads after blackout

Conclusion

NR GFM BESS system comprises a synchronous internal voltage source behind an impedance, capable of contributing to inertia power, damping power, fault ride through, independently controllable of active and reactive power.

- Setup System Voltage: Ability to establish voltage independently without relying on external systems to meet the voltage forming capability of the strong and weak power grids and islanded power grids.
- Inertia and damping response： Provides synchronous voltage source inertial response, including inertial active power, damping active power, and power angle jump active power.
- Overload and fault ride-through functions： With overload and overcurrent limit functions to maintain voltage source characteristics during overload and overcurrent limit.
- Improve the power quality: It can share the asymmetric current and reduce the harmonic distortion to improve the power quality.

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