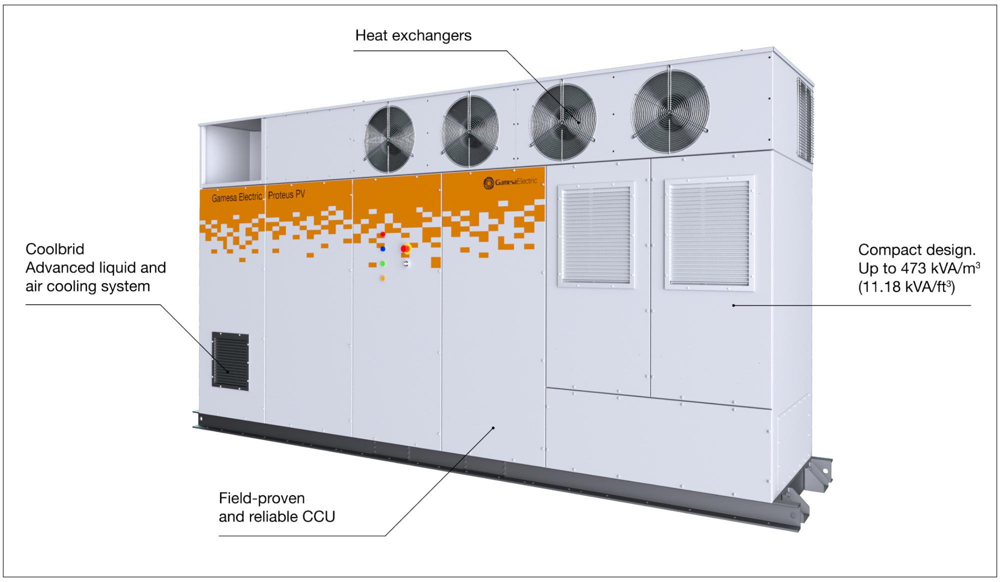
Advanced Grid Functionalities in State-of-the-Art Inverters for Solar Photovoltaic Systems

Inverter Technology | Gamesa Electric's latest white paper explores the advanced functionalities that solar and battery inverters should be able to provide to enable greater integration of renewables into the grid and thus contribute as a key element to enhanced grid reliability and stability.

The world is going through a significant transformation in the energy sector as renewable energy sources, distributed generation, decarbonisation, and demand increase are rapidly changing traditional sources of energy. In this context, solar photovoltaic (PV) and battery storage inverters must fill the gap left by synchronous generators and be able to offer the same services to ensure stable and secure grid operation.

The reduced inertia present in the grid, due to the decommissioning of large power plants and the intermittency of renewables, poses significant challenges to its stability. As a result, frequency variations caused by momentary imbalances are higher and recur more often.

In this article, we will discuss the grid functionalities that state-of-the-art inverters should offer in order to meet the most demanding grid requirements. We will take a look at the challenges faced by grid operators and the contribution of the Proteus family of state-of-the-art inverters from Gamesa Electric to address these challenges.



A Gamesa Electric PV converter of the Proteus product family

Grid stability and control

In traditional generators, the most widely used device is the synchronous generator, an electrical machine whose shaft speed has a direct relationship with the frequency of the grid. This allows it to adjust its voltage output and respond to changes in grid frequency by modifying its operating point. These devices greatly contribute to the power grid stability due to the damping they provide against disturbances. The stability of any power grid is achieved by controlling parameters such as voltage control, frequency control, and rotor angle control.

Voltage control is performed by controlling the reactive power through devices such as synchronous generators (which allow the dynamic control), capacitor banks, or inductive loads. Frequency control is achieved by balancing the power generated and the power consumed, ensuring a steady grid frequency. Variations of any value will cause a frequency change that has to be corrected by modifying the active power. The rotor angle control is related to the stability of the synchronous generator's rotor angle and its capacity to keep synchronism after a disturbance.

Challenges faced by grid operators

The decarbonisation process of the energy sector is leading to the substitution of traditional large generators by renewable energy sources such as solar, wind, and energy storage, based on power-lowered decentralised units composed of electronically controlled devices (power converters). The progressive substitution of large generators is becoming an increasing challenge for transmission system operators (TSOs), which must ensure grid reliability and stability despite the entry of these new players while maintaining a null impact on end-users.

As a result, TSOs are forced to impose new features and functionalities on these new energy sources to ensure proper grid operability, coining new terms such as smart grid, grid-forming, or black-start.

Power plectronic converters and grid stability

The addition of new energy sources based on power electronic converters to replace rotating electrical machines is leading to variations in the grid behaviour during frequency control regulations. Power electronic converters have a completely different performance compared to rotating machines.

On the one hand, they have a very short timescale response, and on the other, they do not contribute to system damping created after a frequency change due to the absence of massive rotating shafts. This decrease in inertia capacity affects grid control and, in the worst case, it could destabilise it. To address this, grid opera-

Functionality	Grid-feeding inverter	Grid-forming Offgrid	Grid-forming Ongrid[2]
Voltage regulation	✓	✓	✓
Power factor control	✓	X	✓
Active power ramp rate	✓	X	✓
External setpoints (secondary frequency control, energy shifting, trading...)	✓	X	✓
SI (Synthetic Inertia)[3]	✓	✓	✓
PFR (Primary Frequency Response)[4]	✓	✓	✓
FRT (Fault Ride-Through)	✓	✓	✓
POD (Power Oscillation Damping)	✓	X	✓
Islanding operation	X	✓	✓
Black-start	X	✓	X
VSM (Virtual Synchronous Machine)	X	✓	✓

tors are imposing grid support capabilities to ensure grid stability.

Grid-following inverters are capable of provide synthetic inertia (also known as virtual inertia), where the electronic device can emulate the inertia that used to be provided by rotating machines. However, providing virtual inertia is not enough, it is necessary to provide additional ancillary services to ensure grid stability, such as fast frequency response, black-start, or power quality support.

Advanced grid functionalities in state-of-the-art inverters

In this context, state-of-the-art inverters are the new generation of equipment that incorporates the necessary functionalities to be active elements in grid operation. These functionalities include Fast Frequency Response (FFR) and Black-Start, among others.

In grid-forming mode, the converter is a voltage source (it can create the electrical grid by itself) with the ability to control both the active and reactive power, thus creating and maintaining a stable grid voltage and frequency. The control strategy used is known as Virtual Synchronous Machine (VSM) where the inverter control can emulate the synchronous generator performance.

Fast Frequency Response (FFR) is a service provided by power converters to compensate for short-term frequency deviations in the grid. This service requires a fast response time from the converter to ensure grid stability. FFR is essential because small deviations in frequency can cause large changes in the grid and lead to instability.

For example, if the frequency of the grid decreases, the active power generated by the power converters must increase to compensate for the deviation. Conversely, if the frequency of the grid increases, the active power generated by the power converters must decrease. Without the ability to respond quickly to frequency changes, the power converter would be unable to stabilise the grid, leading to power outages.

The response must be fast enough, which is why they are normally requested at the inverter level to avoid communication delays. However, one of the main advantages of the Gamesa Electric Orchestra controller is that its quick response time allows it to perform the FFR functionality at plant level rather than at the inverter level.

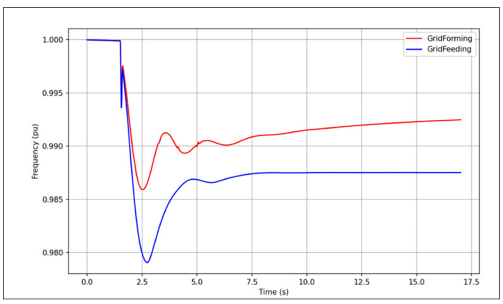
Black-start is a service that allows the power converter to restart the grid after a blackout. In the event of a blackout, the power converter must be able to start generating power immediately, even without a grid connection, to restore power to critical loads. This requires the power converter to be able to operate in island mode, where it generates power independently of the grid, and then resynchronise with the grid once power has been restored. Black-start is an essential service because it ensures that power can be restored quickly after a blackout, preventing extended power outages.

Gamesa Electric's Proteus family of inverters is designed to meet the most demanding grid requirements and offers all of the advanced functionalities required for grid support. The Proteus inverters are capable of operating in both grid-following and grid-forming modes, providing the flexibility required to meet the needs of the grid. In addition, the Proteus inverters offer fast response times and the ability to provide virtual inertia, ensuring that the grid remains stable even in the face of large frequency deviations.

To demonstrate the capabilities of the Proteus inverters, Gamesa Electric conducted a series of real-world tests on the equipment. The tests were designed to simulate a variety of grid conditions, including black-start scenarios and frequency deviation events. The results of the tests showed that the Proteus inverters were able to respond quickly to changes in grid conditions and provide the necessary ancillary services to ensure grid stability.

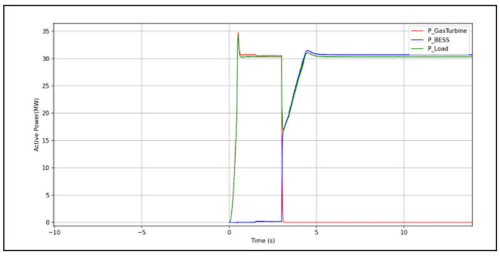
In conclusion, the transition to cleaner energy sources is essential for achieving a zero-carbon future, but it also presents significant challenges for the power grid. The reduced inertia of the grid due to the decommissioning of large power plants and the intermittency of renewable sources has made it necessary for PV and battery storage inverters to fill the gap left by synchronous generators and provide the necessary grid support services to ensure stable and secure grid operation. Grid-forming inverters such as Gamesa Electric's Proteus family offer the advanced functionalities required for grid support, including fast frequency response, black-start, and power quality.

The White Paper can be viewed on Gamesa Electric website: **www.gamesaelectric.com**

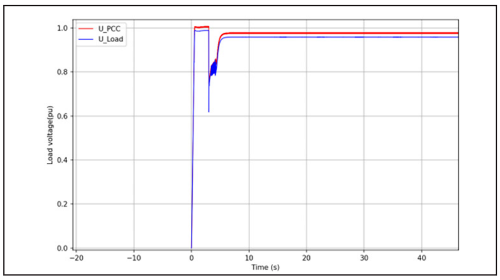


Grid-feeding with FFR droop vs Grid-forming with FFR droop

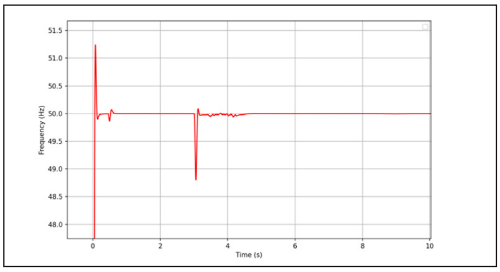
The power response of a BESS with grid-forming is greater and faster than grid-feeding operation, since a system with VSM has greater inertia as well as greater damping. Therefore, in addition to the power that the BESS injects thanks to the droop, another very rapid increase in active power is added due to the contribution of the inherent virtual inertia of the VSM.



Power evolution. After gas turbine power dropping (red line) the load power (green line) is quickly restored by Proteus PCS (blue line).



Voltage and frequency variation. The grid is recovered and controlled by BESS working as *grid-forming* (parallel operation). Microgrid can be sustained over a long period of time while waiting for the gas turbine or any other synchronous generator to recover from a fault.



Q&A with Juan Barandiaran

Following publication of the white paper, Andre Lamberti caught up with Gamesa Electric's CEO Juan Barandiaran and spoke with him about the history of the company and the development of the technology it deploys.

PV Tech Power: Can you give a brief outline of Gamesa Electric's journey towards equipping the renewable energy sector?

Juan Barandiaran: Gamesa Electric has a long tradition as a manufacturer of electrical equipment with a long experience of more than 90 years in the business and a track record of more than 60GW manufactured. Its creation dates back to 1930 when it started as a small manufacturer of electric motors and generators. The milestone that set its course towards renewable energies was the acquisition of the company 20 years ago by what is today Siemens Gamesa. As part of Siemens Gamesa, Gamesa Electric expanded its product portfolio by adding inverters and converters for wind, solar, storage and hydrogen applications to the aforementioned generators.

Today, Gamesa Electric has eight production sites on three continents and employs more than 800 people, a quarter of whom are engineers. Its business is mainly wind power, but in 2022 it tripled its orders for solar and storage inverters, partly thanks to the great success of its Proteus product.

When did the company first consider making grid-forming and black-start inverters? How has the technology developed since then?

Our engineers started years ago developing software that would allow inverters to be an active element in grid stability, but the fact is that the demand from the market and customers has come later, when the penetration of renewables forced the search for technical solutions that allow intermittent renewable sources to offer grid services similar to those traditionally offered by conventional power plants.

In countries such as Australia, these functionalities are already required and valued by the market and the trend of retiring conventional synchronous generators, and adding renewable generation will lead more and more markets to establish requirements related to the advanced grid functionalities provided by grid-forming inverters.

In addition to compliance with future grid codes, we anticipate that customers will demand this technology in order to access additional revenue streams through ancillary grid services.

How does Gamesa Electric's grid-forming technology differ from what is already in place? Do you see it ultimately replacing traditional grid generators?

There are no technological limitations that prevent us from seeing a 100% renewable electricity mix at some point. The limitations are probably permitting-bottleneck-related, grid-related or in terms of supply chain capacity, but the technology exists and is fully capable of replacing conventional generators.

As for Gamesa Electric's experience, I would say that what makes it stand out the most is the experience accumulated over years of development, validation and real projects. Siemens Gamesa has a hybrid wind, solar and storage farm where it tests and validates all developments.

In addition, Gamesa Electric has already implemented advanced functionalities in its converters in commercial wind projects. All this experience results in continuous improvements applied to our Proteus and Orchestra products.

What are the main challenges to the renewables industry adopting the technology?

It is important not to underestimate the calibre of the challenge ahead. We are talking about replacing in a few years a conventional generation fleet that has taken decades to build, especially in the more developed countries. Undoubtedly, grid-forming technology in renewable sources is a key part of the energy transition, but there are other equally key areas such as storage, demand-side management and smart grids, among others.

I believe the main challenge we face in the sector is to be able to fit all the pieces together and to do so with the necessary speed to meet the net-zero objectives. Therefore, the challenge goes beyond the purely technological and has very important operational and policy aspects.

Where do you see the biggest opportunities in the European market and why?

Europe has just increased its target for the share of renewables in total energy consumption to 45%. To get closer to this ambitious target, a massive deployment of renewables will be needed alongside the electrification of society. This process of 'renewable electrification' is already providing great opportunities and will undoubtedly create even more.

In addition to well-known and mature technologies such as wind and solar, we will see massive deployments of different types of storage, not forgetting the key role that hydrogen can play as an energy vector not only for storing energy but also for decarbonising hard-to-abate industries.

The market will undoubtedly grow exponentially, and it is therefore crucial that the legislative proposals made in recent months to protect and support Europe's renewable industry are successful, as it will be very difficult to meet this challenge without a strong and healthy local supply chain. ■

Author

Juan Barandiaran is the CEO of Gamesa Electric, a global power electronics leader in the renewable energy industry. With engineering and MBA background and over 30 years of experience, Barandiaran has a proven track record of successfully leading and directing various companies and divisions within Gamesa, including wind, photovoltaics, energy storage and hydroelectric generation. Under his leadership, Gamesa Electric has expanded its operations to multiple countries and increased its market share in these sectors. Barandiaran is known for his strategic vision, strong leadership skills, and commitment to innovation and sustainability. He also serves as VP of CIC energiGUNE energy storage research centre.