GRID FIRMING TECHNOLOGIES: ADVANCING SUSTAINABILITY STRATEGIES BY PROVIDING A PATHWAY TO INCREASED RENEWABLE GENERATION

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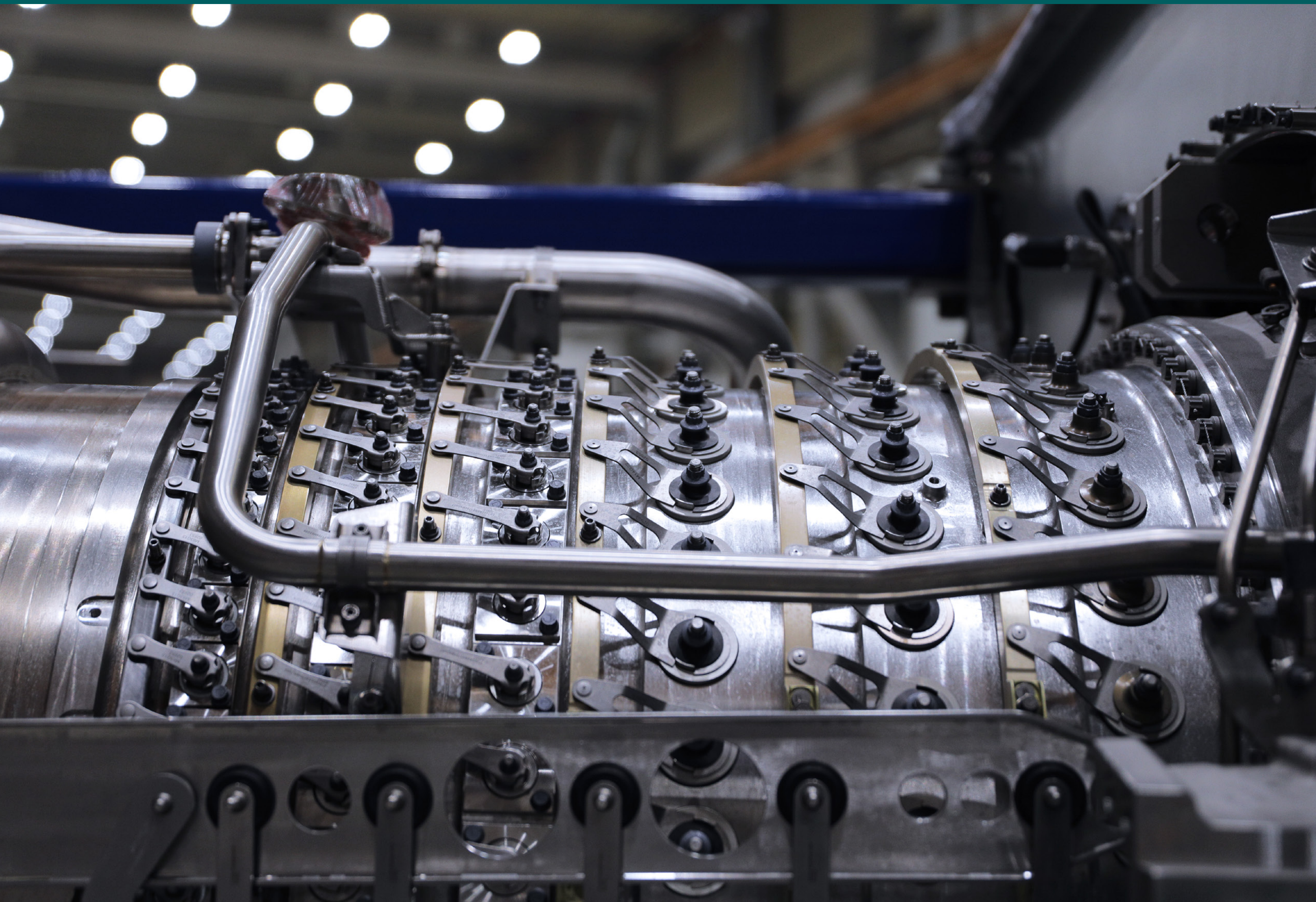


Executive Summary:

Deployment of increased variable renewable generation into electricity grids necessitates that planners and grid operators balance sustainability and reliability goals. As synchronous generators, which have historically provided grid stability, are supplanted by inverter-based renewable sources, alternative technologies must assume this critical stabilizing role. This paper explores the current availability of gas turbines equipped with synchronous condensing capabilities and batteries utilizing grid-forming inverters as viable solutions to enhance grid stability, thereby helping to ensure a more reliable and sustainable electricity supply.

Introduction

Inverter-based renewable energy sources such as wind and solar are becoming a more abundant source of energy supplied in grids displacing and driving retirement of large synchronous generators. Historically, synchronous generators were the main provider of generation and inherently provided essential system security services such as inertia and fault current. Inertia underpins system security by dampening frequency fluctuations and enhancing fault ride through capability. Fault current is essential to effectively identify and isolate electrical faults from operating loads in protection systems to balance system safety with reliability. Gas turbines with synchronous condensing capability and grid-forming inverters offer features that can provide essential grid stability services. This paper supports early adoption of gas turbines with synchronous condensing and grid-forming inverters.

Grid operators are encouraged to establish incentives and standards to support deployment of these technologies. Timely investment in the grid can help avoid obstacles limiting deployment of inverter-based generation and increase preparedness for the retirement of synchronous generators.

Overview of Grid Firming Technologies:

GE Vernova provides a range of products that provide grid stabilizing services. Table 1below is a heat map of the grid stabilizing services offered by gas turbines with synchronous condensing, grid-forming inverters and grid following inverters.

	Gas turbine with synchronous condensing	Stand-alone synchronous condenser	Grid forming inverter + battery	Grid following inverter + wind or solar
Reserve capacity	Long duration	No	Short duration	Variable
Inertia	High	High	Synthetic	Synthetic with wind turbines
System strength (fault current)	High	High	Limited	Limited
Voltage support	High	High	High	Limited
Frequency Control Ancillary Services (FCAS)	Response in power generation mode	No	Very fast response capability	Limited
System Restart Ancillary Services (SRAS)	High	No	Limited	No

Table 1: Overview of system strength services

Need for Grid Firming Technologies:

To help meet reliability targets efficiently, grid operators should continually measure and assess the requirement of grid stabilizing services and review and adapt mechanisms for procurement of essential grid stability services such as:

- Reserve capacity
- Inertia
- Frequency response
- System strength (fault current)
- Voltage support
- Frequency Control Ancillary Services (FCAS)
- System Restart Ancillary Services (SRAS)

Incentives for Gas Turbines with Synchronous Condensing Capability

There is currently a lot of interest in gas turbines with synchronous condensing capability because of the benefits that they can offer to the grid. Due to a lack of industry incentives for generators to monetize synchronous condensing services, many power stations continue to be constructed without this feature. Many existing gas turbines could also be retrofitted to provide this capability as an alternative to building stand-alone synchronous condensing units.

Gas turbines with synchronous condensing capability can provide significant grid stability services to increase grid stability and help enable increased renewable energy deployment, but methods to incentivise the implementation will be required.

Incentives for Grid-Forming Inverters

Similarly to gas turbines with synchronous condensers, grid-forming inverters also have benefits to offer to the grid. In the current landscape, most projects are built with grid following inverters. The primary opportunity would be grid-forming inverters combined with batteries in weak grids. Improving mechanisms to monetize grid-forming inverter benefits as well as changes to grid connections standards could see wider deployment of grid-forming inverters which will in turn help increase grid stability. They can also be adopted for solar and wind farms without batteries to increase grid stability primarily in areas with a weak grid.

Where required, grid-forming inverters could also replace grid following inverters in existing plants to upgrade the performance to grid-forming capability.

Grid-forming inverters can provide significant grid stabilizing services to increase grid stability and enable increased renewable energy deployment. However, methods to incentivise the implementation or changes to the grid connection standards would be required to increase their deployment.

Synchronous Condensing Capability

During operation in power generation mode, the gas turbine generator will start and synchronize with the grid. In power generation mode, the generator consumes fuel and provides active power (the real power that does work) and reactive power (power that does no useful work generally from inductive or capacitive loads) as well as inertia and fault current. Gas turbine generators without synchronous condensing capability typically start up and connect to the grid during peak power demand and shutdown and disconnect from the grid at other times which often coincides with periods of high renewable generation when inertia and fault current are most needed.

Synchronous condenser mode enables the gas turbine to shut down with the generator synchronized to the grid. The generator will act like a motor, drawing a small amount of electrical power to drive the generator. In this condition the generator doesn't produce active power but will provide reactive power, inertia and fault current.

Activation of Synchronous Condenser Mode

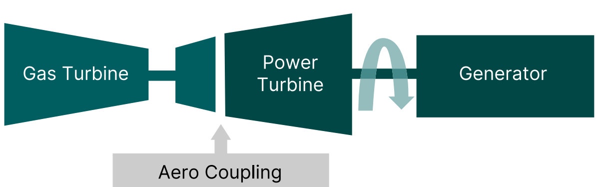
Synchronous condenser mode can be activated during power generation or from standstill. The gas turbine is running or will start to drive the generator to synchronization. Active power is reduced to zero and the gas turbine is shut down whilst the generator remains synchronized. Shutting down the gas turbine causes the clutch to dis-engage, enabling the generator to rotate independently.

Some gas turbine models have a free spinning power turbine with an aero coupling to the gas turbine; in such case clutch-less synchronous condensing is offered where the power turbine remain connected to the generator in synchronous condensing whilst the gas turbine is shut down.

Standard Engineered Synchronous Condensing Options

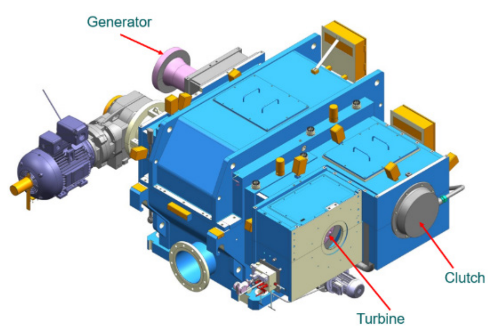
To help meet industry demand, GE Vernova aeroderivative gas turbine packages now include a standard engineered option for synchronous condensing as outlined below.

LM2500XPRESS*/TM2500* clutchless



Free-spinning power turbine and aero coupling, enabling clutchless synchronous condensing

LM6000VELOX* with clutch



Integrated clutch within the gearbox, preserving the same footprint and auxiliary systems

A good example of a recent customer who installed this option is Dominion in South Carolina, USA. The customer replaced older peaking generation units with LM6000VELOX* gas turbine generators with an array of operational flexibility capabilities including dual-fuel, fast-start, synchronous condensing, and black start. This aims to improve reliability and help meet peak electricity demand and to provide grid stability during periods of high renewable generation.

https://www.gevernova.com/news/press-releases/ge-vernova-announces-first-commercial-operation-its-lm6000velox-package-dominion

Retrofitting Existing Gas Turbines with Synchronous Condensing

Many existing gas turbines would have the ability to be retrofitted to provide synchronous condensing capability as an alternative to installing standalone synchronous condensing units. Retrofit of an existing turbine for synchronous condensing capability should involve consultation with the OEM to integrate controls and protection and verify that important checks such as rotor dynamics are completed. GE Vernova is well suited to support customers with options for retrofitting synchronous condensing capability.

Figure 1: LM6000* gas turbine generator constructed with synchronous condensing capability

How Grid-Following Inverters can Contribute to Grid Instability

The majority of wind, solar, and battery storage projects today have been deployed using grid-following inverters. Grid-following inverters require the presence of a strong external grid for controlling their current and power output. As traditional synchronous generators, which have historically provided grid stability, are supplanted by renewable sources, grid-following inverters can become unstable. In situations such as faults on grids with low inertia and fault current, these grid following inverters can lose the ability to maintain stability, resulting in voltage and power oscillations in the grid that can lead to disconnection of power plants and sections of the grid, and unmitigated can contribute to a blackout.

How Grid-Forming Inverters can Contribute to Grid Stability

Grid-forming inverters, also known as voltage source inverters, create their own voltage and use advanced control techniques to provide dynamics very similar to those of synchronous machines. As such grid-forming inverters appear to the grid as a voltage source behind an impedance akin to synchronous machines. This characteristic enables grid-forming inverters especially when integrated with a battery to maintain stable operation at very low grid strengths, even with zero synchronous generation. Below is a heat map of the characteristics of grid-forming vs grid-following inverters.

	Grid-Forming	Grid-Following
Voltage source for synchronization	Creates its own voltage	Needed
Short circuit ratio capability	Can operate in a weaker grid	Requires stronger grid
Typical fault current contribution delay	Faster	Fast
Fast frequency response	Fast response using rate of change of frequency and frequency	Limited response using power vs frequency
Island mode capable	Yes	No
Black start and grid restoration capability	Yes	No

Grid-forming inverters can increase grid stability to support the deployment of renewable energy and retirement of synchronous generators. While the current focus for grid-forming is batteries, applications for grid-forming inverters could be applicable to wind, solar or hybrid particularly in weak grids.

Conclusion

As synchronous generators, which have historically provided grid stability, are supplanted by variable renewable sources such as solar and wind, deployment of gas turbines with synchronous condensing capability and batteries with grid-forming inverters is essential to increase grid stability and to help meet reliability targets. To facilitate their widespread deployment, it is imperative to establish a supportive marketplace, incentives, and standards that encourage adoption. The implementation of these stabilizing technologies can support the grid to reliably accommodate high levels of renewable generation while facilitating the phased retirement of conventional synchronous generation assets.

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