JENBACHER

GRID STABILITY

Supporting the energy transition with Jenbacher solutions

As the world shifts to renewables, their impact on the electric grid's design and operation grows profound. This transition, driven by various factors including new participants in the energy sector, triggers demand for additional services such as grid balancing. INNIO Group supports this development with Jenbacher energy solutions, reinforcing grid operations and maintaining resilience.

TABLE OF CONTENT

1.

INTRODUCTION

1. INTRODUCTION

According to the International Energy Agency (IEA) and its Net Zero Emissions Roadmap, a change in the energy sector and its main energy sources must occur to achieve the sector goal of net zero CO_2 emissions by 2050. The focus must be on ramping up renewables, improving energy efficiency, and cutting methane emissions.

To reduce emissions, the electricity generation trend worldwide has been to considerably increase the use of renewables while decreasing reliance on fossil fuels. This includes the retirement of large coal-fired power plants, driving the need to expand both renewable generation and decentralized flexible gas engine-powered generation plants.

As a result, the electrical topology has greatly changed and the landscape for connecting power generation units to the grid has significantly evolved over the past decades, particularly at the electrical distribution level. This evolution is driven by technological advancements, regulatory changes and, as mentioned, the increasing integration of renewable energy sources which have directly impacted the stability of the grid due to their intermittent nature and the reduction in both inertia and short circuit contribution coming from the diminishing synchronous generation. This has made it increasingly challenging for power plant owners to obtain permissions for connection to the grid due to the complexity of the process and the number of requirements that must be met—and demonstrated—by the power generation assets.

The transition toward an energy system mainly fed by renewable energy sources (RES) carries a set of challenges that could be overcome by using dispatchable, decentralized, weather-independent technologies. Gas engine technology used within cogeneration plants offer fuel flexibility possibilities and can be operated on up to 100% hydrogen to support the journey towards net zero.

INNIO Group's Jenbacher generating sets can be used to participate in real time or spot energy markets (as peaker plants) and/or in capability markets (as ancillary service providers) thanks to their technical capabilities (ramp rates, start times, reliability—just to name a few) and flexibility they provide when sizing a plant (multiple units vs. single units) or when using different energy sources.

The following graphs show the trend seen in the last 20-plus years of the power generation landscape. They reveal that, along with an increase in renewables, gas-powered plants remain relevant and necessary for the correct operation of the grid, clearly showing the importance of this technology in the energy landscape and grid topology.

Cumulative installed capacity in North America

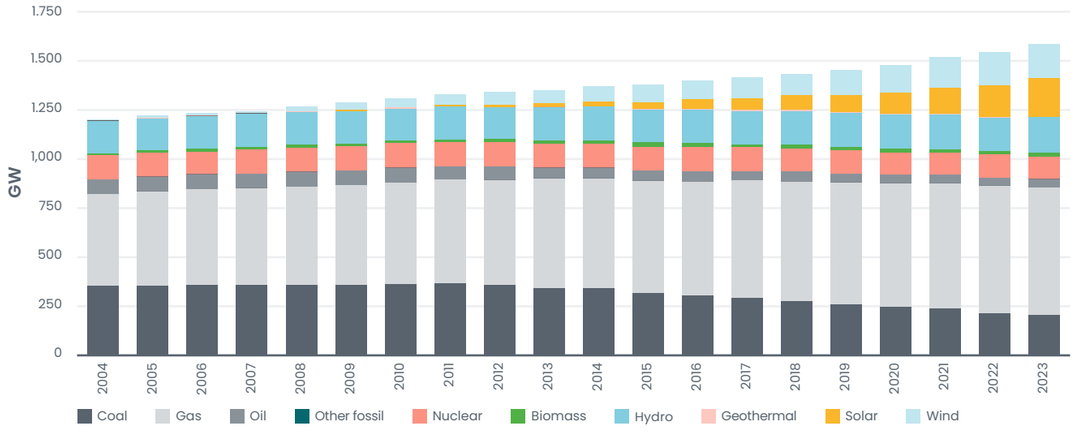

Figure 1: North America cumulative installed capacity development 2004-2023
Source: BloombergNEF
Note: Includes, U.S., Canada, and Mexico

Cumulative installed capacity in Europe

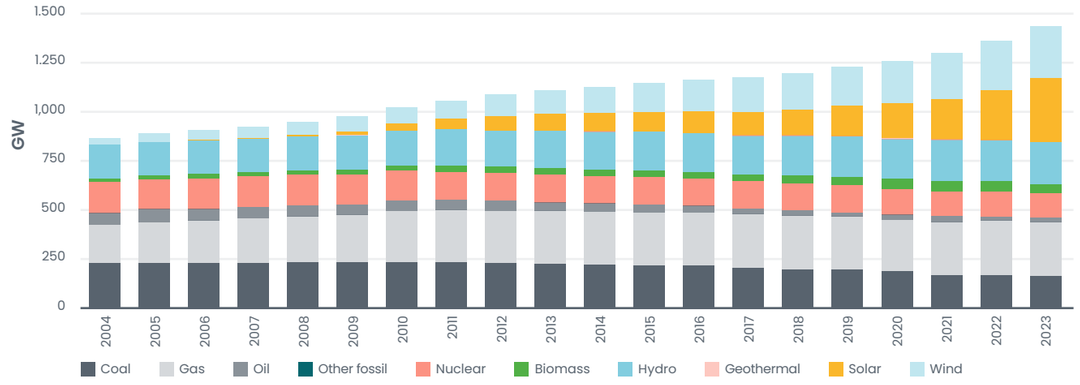

Figure 2: Europe cumulative installed capacity development 2004-2023
Source: BloombergNEF
Note: Includes Albania, Andorra, Austria, Belarus, Belgioum, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Faroe Islands, Finland, France, Germany, Gibraltar, Greece, Hungary, Iceland, Ireland, Isle of Man, Italy, Kosovo, Latvia, Liechtenstein, Lithuania, Luxemburg, Malta, Moldova, Monaco, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom

This report provides a condensed summary of the developments and capabilities offered by INNIO Group's Jenbacher solutions to both facilitate the connection process for our customers (ensure compliance with grid codes and standards) and to obtain access to ancillary service markets.

2.

OVERVIEW OF ELECTRICAL CAPABILITIES FOR GRID STABILITY SUPPORT AND MARKET OPERATION

2. OVERVIEW OF ELECTRICAL CAPABILITIES FOR GRID STABILITY SUPPORT AND MARKET OPERATION

One reason INNIO Group's Jenbacher generating sets represent an excellent option for use in power plants is their ability to help fulfill grid stability requirements while helping the power plant to comply with the strict technical requirements necessary for participation in energy markets.

Because plants that provide peaking or ancillary services must start up and shut down rapidly to meet fluctuating demand, INNIO Group's Jenbacher solutions are an excellent option. They can help maintain the reliability of the power grid, especially during periods of high demand such as hot summer afternoons when air conditioners drive up electricity consumption or when load unbalances occur in the main electrical system due to highly volatile renewable generation.

Jenbacher units can be used in many electrical market types, depending on the specific rules and structures in each region. Here's how they interact with each market:

- **Day-ahead market:** As the name suggests, this market works by having participants buy and sell electrical energy 24 to 36 hours before the actual delivery. As a plant operator, factors like weather forecasts can be used to predict periods of high demand, which allows them to bid capacity into the market accordingly.
- **Intraday market:** This market's characteristic is that electrical energy trading occurs after the day-ahead market closes but before real-time delivery (typically between 5 and 60 minutes before delivery), meaning more volatile (and in some cases higher) prices. Power plants using Jenbacher generating sets are well-suited for the intraday market because of their ability to start up and shut down rapidly. They can respond to real-time changes in demand and supply conditions and take advantage of price spikes that occur when demand is high. The availability of Jenbacher units, their technical capabilities, and the added reliability coming from using multi-unit power plants helps ensure participation.
- **Balancing market:** In this market, which operates in real time, the system operator procures balancing energy from the participating power plants to help maintain system frequency and stability. The power plants that participate play a crucial role, with the ability to quickly ramp up their output to provide balancing energy when there is an unexpected shortfall in supply or a sudden increase in demand. In addition, they provide increasingly critical ancillary services, such as voltage control and electrical inertia, as RES are introduced in greater numbers into the grid.

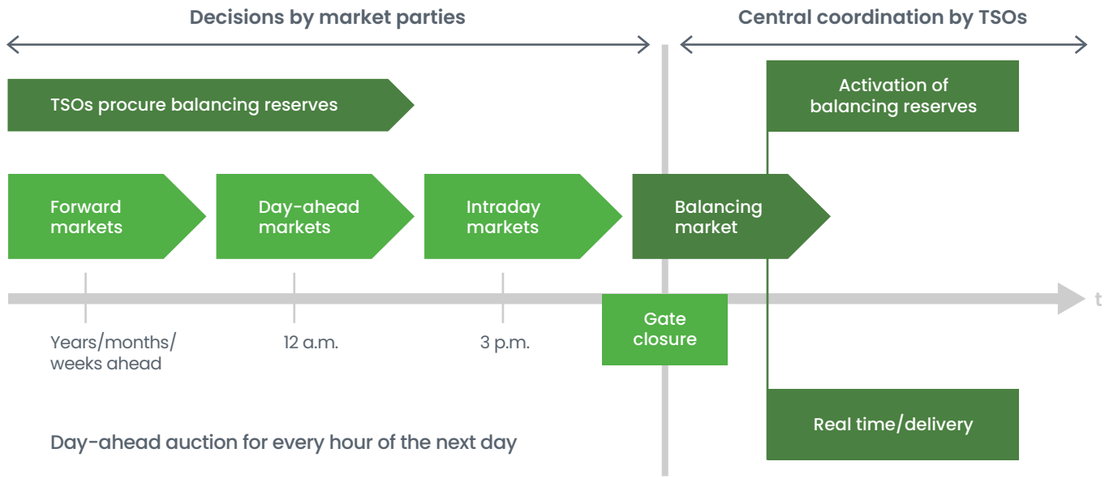

Figure 3: Example of different time frames of the wholesale and balancing markets; TSO: Transmission System Operator
Source: ENTSO-E Market Report 2023

2.1 Benefits of Jenbacher generating sets

INNIO Group's Jenbacher generating sets offer the following benefits:

- **Fast start-up and ramp rates:** Depending on the Jenbacher engine type, the engines can start up and reach full load in less than 5 minutes, 3 minutes, or even faster. This makes them particularly suitable for responding to sudden increases in electricity demand.
- **Flexibility:** The generating sets can efficiently operate at partial loads, allowing them to ramp up or down as demand fluctuates. This flexibility is valuable in balancing supply and demand in real time. This flexibility is increased when operating a plant with multiple units, as they can be operated to achieve even higher efficiencies.
- **Reliability:** Gas engine power plants are known for their reliability and can provide a dependable source of power during peak demand periods, especially when installed as multiple unit plants.
- **Lower emissions:** Compared to coal-fired plants, Jenbacher generating sets emit significantly less carbon dioxide and other emissions. Jenbacher generating set emission values are determined by state of the art technology and can use an SCR (Selective Catalytic Reduction) system if needed to achieve NO_x levels < 100 mg/Nm^3 @5%O_2 dry exhaust in natural gas operation.
- **Economic efficiency:** Jenbacher generating sets can be economically efficient due to their ability to start and stop quickly, avoiding operating times of unfavorable energy prices, and operate as flexible combined heat and power (CHP) plants.
- **Grid support services:** In addition to providing peaking power, gas engines also can provide valuable grid support services such as frequency and voltage regulation.
- **Fuel flexibility:** Jenbacher generating sets have the advantage of fuel flexibility. Already today a significant share of the installed Jenbacher generating sets run on biogas and biomethane, and they can run on other green gases like hydrogen, and other e-fuels. This flexibility allows them to adapt to changing fuel availability and contribute to the transition toward cleaner energy sources. This includes the possibility to upgrade Jenbacher generating sets to operate with 100% H_2 (depending on engine version and production date).
- **Innovative digital solutions:** INNIO Group's myPlant digital platform drives increased resilience and efficiency through real-time monitoring, energy management, and predictive maintenance, increasing uptime and reducing operational costs.

2.2 INNIO Group's grid expertise

To better understand the capabilities that make INNIO Group's Jenbacher generating sets the preferred solution for a plant focused on supporting the energy transition and stabilizing the grid, the following key areas were defined:

- **Technical capabilities:** refers to functionalities that help ensure operation according to grid operator requirements (defined within grid codes and connection agreements) and support the stability of the electrical system. INNIO Group's Jenbacher solutions are designed to operate according to these requirements to allow a smooth and fast grid connection process.
- **Operational capabilities:** refers to capabilities needed to participate in the different balancing markets and provide the needed ancillary services. INNIO Group's Jenbacher technology is the right choice for peaking and ancillary service applications, as it is prepared to comply with both the needs of the system and the prequalification processes imposed by grid operators.
- **Compliance capabilities:** refers to the capability to demonstrate compliance against a technical requirement or grid code, which is a critical step in obtaining a connection permit. INNIO Group has demonstrated ample connection and compliance experience, from the provision of relevant certificates to simulation studies and testing reports.

The following chapters will dig deeper into each of these areas and explain the clear advantages that they bring.

3.

TECHNICAL CAPABILITIES TO FULFILL GRID CODES

3. TECHNICAL CAPABILITIES TO FULFILL GRID CODES

To help the grid remain stable, grid codes require a series of technical capabilities from any generation source connecting to the grid. System operators have made grid codes more stringent to help ensure grid stability and reliability. These codes now cover a broad range of technical and operational criteria that apply not only to larger power plants but to all units connecting to the distribution or transmission system. These criteria include frequency and voltage control, reactive power management, and fault ride-through capabilities. INNIO Group has developed grid code solutions and functionalities for well over a decade, helping to ensure the availability of the needed functions and assuring the correct behavior of the gas engine generation set when connected to the grid.

These are the fundamental technical requirements that generation units must meet to operate effectively within the grid. Noncompliance or unavailability of these functions **will impede the power plant from connecting to the grid.**

An excellent example using INNIO Group's Jenbacher generation sets occurred in 2021, when our engine sets helped avert a European blackout. On January 8 of that year, the European power grid experienced a sudden and critical drop in electrical frequency. However, European grid operators took immediate steps, including further splitting up Europe's interconnected power system. Stable frequency was regained within a few minutes, and a blackout was avoided. An active part of the operation was played by around 4,000 flexible, fast-start, dispatchable Jenbacher gas engines with a combined output of nearly 6 GW.[1]

3.1 Frequency control

Generation units must be able to help maintain stable frequency under normal and emergency conditions. A series of functions is required that automatically modify power output by reducing it in the event of over-frequencies and increasing it in the event of under-frequencies.

The available functions are:

- **FSM (Frequency Sensitive Mode):** This operates around the nominal frequency as soon as the deviation from nominal has gone beyond a predefined (and settable) deadband following a predefined (and settable) droop (defines how much power change will occur for every Hz change occurring).

- **LFSM (Limited Frequency Sensitive Mode, which is subdivided into LFSM-O and LFSM-U):** Very similar to the FSM function, it becomes active in the event of larger frequency deviations (typically beyond ± 200 mHz). Each sub function (LFSM-O and LFSM-U) has independent deadbands and droops (all settable).

The following figure shows a representation of both functions and their operation area:

INNIO Group's Jenbacher units are set according to local regulations and can fulfill all related requirements, including ramp rates, maximum delays, and maximum operation limits.

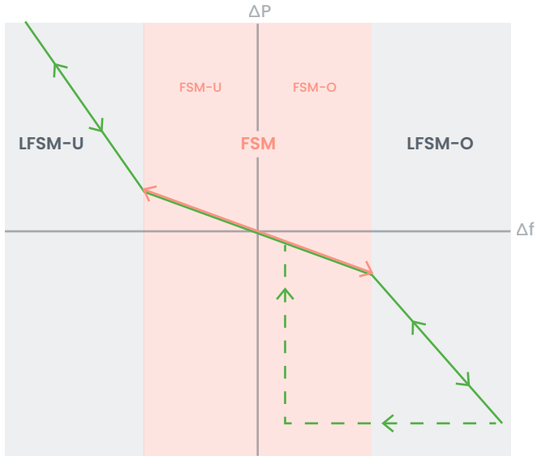

Figure 4: Frequency-related functionality
Source: INNIO Group

[1] **Source:** innio.com/en/news-media/press-releases/4-000-decentralized-innio-gas-engines-help-stabilize-european-power-grid

3.2 Reactive power management

To maintain the system voltage (and reactive power flow) to help ensure efficient power transmission and maintain system stability, grid codes specify that power generation plants must be able to both provide and consume reactive power in a specific range at all the generator's possible operation points. This means that the units need to either operate at a specific reactive power (Q) setpoint, power factor (cosphi) setpoint or voltage setpoint; any of these operation modes depend on the ability of the unit to provide or consume reactive power.

In addition to this, units within a plant are required to operate in different modes depending on the needs of the electrical system and commands from the system operator. Units are required to have an automatic voltage regulator (AVR) with an extensive list of limiters and capabilities, including power system stabilizer (PSS) functionality.

INNIO Group's Jenbacher units are designed to comply with both the customer's and the country's requirements, as the generator used is tailored to the reactive power needs specified. Jenbacher units use an advanced AVR that can satisfy all functional requirements specified by system operators.

Each unit can operate with any of the following functions:

- **Power factor setpoint:** defines the power factor at which the unit must operate

- **Power factor control based on active power—cosphi (P):** changes the power factor setpoint based on the active power setpoint at which the unit is operating; the function is set according to system operator requirements.

- **Power factor control based on voltage—cosphi (U):** changes the power factor setpoint based on the voltage at which the unit is operating; the function is set according to system operator requirements.

- **Reactive power setpoint:** defines the reactive at which the unit must operate.

- **Reactive power based on active power—Q (P):** changes the reactive power setpoint based on the active power setpoint at which the unit is operating; the function is set according to system operator requirements.

- **Reactive power based on voltage—Q (U):** changes the reactive power setpoint based on the voltage at which the unit is operating; the function is set according to system operator requirements.

- **Voltage setpoint:** defines the voltage needed and automatically moves the reactive power within the limits of the generator to reach (or maintain) the voltage as needed.

When multiple units are used within a plant, the Jenbacher master controller can provide all the functions at the defined point of connection (PoC). If an existing plant controller is used, Jenbacher generating sets can receive setpoint for active power (P) and reactive power (Q) to operate as needed.

INNIO Group's Jenbacher gas-driven power generation units are both set and designed with country-specific reactive power management requirements and functions.

3.3 Fault ride-through capabilities

A key design criterion for power generation units is the ability to withstand grid disturbances without disconnecting from the grid. If a short circuit (or similar fault) occurs in the grid and generators are disconnected, a large-scale mains failure ending in a general blackout can occur. To avoid this and other similar scenarios, dynamic grid code requirements for network support are defined in the form of Fault Ride Through (FRT) withstand curves.

In the event of a voltage dip (caused by a fault), the power plant must provide grid support for a specified period in accordance with country-specific FRT requirements by avoiding disconnection (loss of stability) and by injecting reactive power to help maintain (or raise) the voltage.

FRT profiles differ by country and/or point of connection voltage level and can be defined with either the term **Under Voltage Ride Through (UVRT) or Over Voltage Ride Through (OVRT).**

UVRT, previously referred to as Low Voltage Ride Through or LVRT, is used in standards to designate the action of “riding through” a voltage drop. The action of riding through network overvoltage faults is known as an OVRT. The following figure shows different examples that can be found in grid codes regarding this requirement.

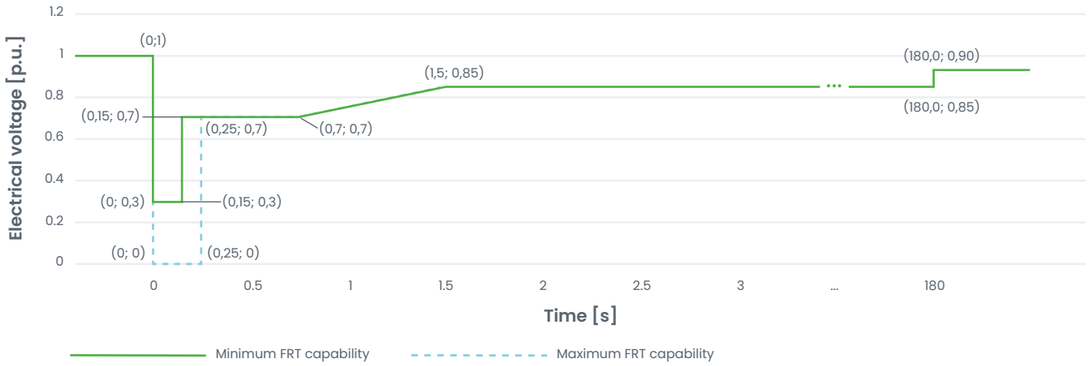

Figure 5: FRT capability of INNIO Group’s Jenbacher power generation units

INNIO Group’s Jenbacher power generation units are designed to both withstand and support the grid during FRT events. Many years of extensive testing and development on the hardware and control algorithms help ensure their excellent performance should a fault occur.

4.

OPERATIONAL CAPABILITIES FOR PEAKING AND ANCILLARY SERVICES

4. OPERATIONAL CAPABILITIES FOR PEAKING AND ANCILLARY SERVICES

With the greater share of renewable power generation, gas engine-driven power plants are increasingly being utilized for seasonal and peaking operations. Although their operating hours per year are lower, these plants still must provide additional ancillary services. As a result, these power plants must handle both the increase in flexible and dispatchable power generation and the power reserve needs coming from power unbalances caused by sudden increases in load or loss of generation.

Gas engine-driven power generation units that are part of balancing and dispatchable power plants can provide rapid start-up in the event of renewable generation fluctuations and/or changes on the consumption side. INNIO Group's Jenbacher units are well suited to provide ancillary services and participate in ancillary service markets.

4.1 Grid support functions (ancillary services)

Balancing markets are closely related to several ancillary services that help maintain the balance between electricity supply and demand in real time. The specific services can vary by region and market design, and are divided as follows:

- **Frequency support:** These reserves are called upon based on frequency deviations, either automatically or from a signal from the system operator. They typically are classified as follows:
  - Frequency containment reserves (FCR) or primary reserve: These are activated automatically and immediately to contain a deviation of system frequency after an imbalance occurs. INNIO Group's Jenbacher units can provide this frequency regulation as long as they are connected in parallel to the grid and the corresponding margin has been considered and parametrized.
  - Frequency restoration reserves (FRR) or secondary reserve: These are activated after FCR to restore the system frequency to its nominal value and replace the activated FCR. FRR can be divided further into automatic FRR (aFRR), which is activated automatically and as quickly as possible, and manual FRR (mFRR), which is manually activated by the system operator. Jenbacher units can be used for both aFRR and mFRR services because of their excellent start-up capabilities and the availability of super-fast start generation sets (start time until synchronization within 30 seconds in grid-parallel mode).
  - Replacement reserves (RR) or tertiary reserve: Activated to restore or support FRR to their nominal level, these are slower to activate and are used over a longer time. Power plants using INNIO Group's Jenbacher power generation units can receive this start signal and easily comply with the start-up and ramp-up requirements.
- **Voltage support:** This ancillary service is used by system operators to maintain voltage levels across the grid. INNIO Group's Jenbacher units use synchronous generators with an advanced AVR system and unit controller that provide a wide range to both consume and produce reactive power within the minimum and maximum active power limits. An additional capability that soon will be available is the possibility to operate as synchronous condenser using a specially designed clutch that allows the engine to disengage and the generator to keep producing reactive power while the active power output goes to zero.

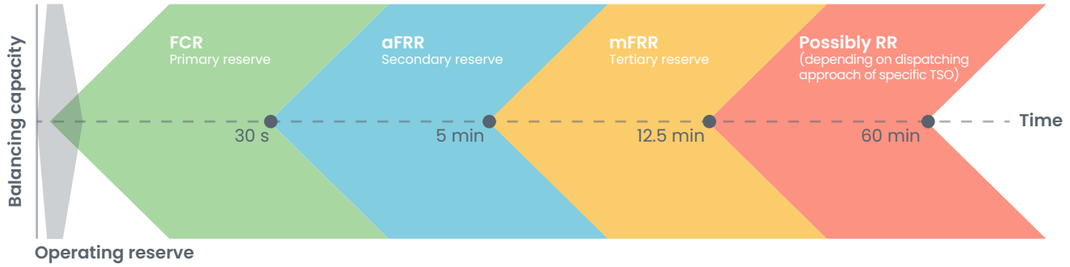

Figure 6: Frequency balancing service according to the system envisioned by ENTSO-E
Source: next-kraftwerke.com

- **Black start:** This ancillary service is used to re-energize the power grid in the event of a blackout. INNIO Group's Jenbacher units can provide this service if a specific design is implemented in both the power generation units and the overall plant to allow auxiliary power when the grid is down. INNIO Group has experience with this service and has demonstrated its operation through testing in conjunction with grid system operators.
- **Inertia provision:** With the increase in renewables (power electronic-based generation), the electrical system's inertia is diminished, causing greater frequency excursions and higher rate of change of frequency (ROCOF) events. To compensate for this, generation with rotating masses is needed. INNIO Group's Jenbacher units use synchronous generators that automatically add inertia when connected to the grid. In addition, the possibility to operate the generator as a synchronous condenser will soon be available, so even when the gas engine is shut down (no active power production), inertia can always be provided. This service is still evolving in many electricity markets worldwide, which means that the payment conditions are still under discussion (e.g. capacity payment for connected inertia, or payment only when NO prime mover is in operation and kinetic energy is being provided). The takeaway: Many countries are considering ways to value and compensate inertia as a distinct service.

4.2 Startup and ramping capabilities

A key characteristic for power generation units being used for balancing, peaking, and ancillary service applications is their capability to start up in a reliable and fast manner multiple times a day, as they need to counteract the volatility of renewables that may appear within short time frames. Jenbacher gas engine power generation units can start up in less than a minute[2] and have no limitations set by INNIO Group on the number of start within a day.

To understand how Jenbacher technology connects to the grid, the following figure shows the start-up process:

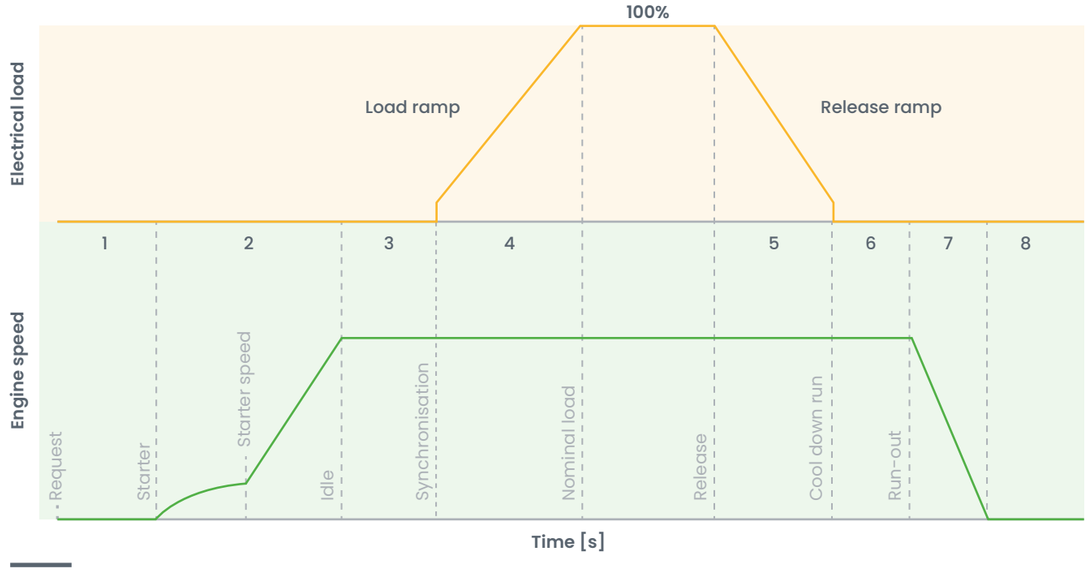

Figure 7: Start-up/shutdown process

[2] This applies to the Jenbacher generating set models shown in Table 1

INNIO Group's Jenbacher solutions all share the same process shown but, depending on the needed application and specific engine used, the times can change. For peaking and balancing services in particluar, INNIO Group offers Jenbacher engines with different start options:

Standard start	< 60 sec. until synchronization with the grid and < 180 sec. to nominal load for Jenbacher 1 MW to 4.5 MW units
Fast start	< 50 sec. until synchronization with the grid and < 120 sec. to nominal load for Jenbacher 1 MW to 3.3 MW units
Super-fast start	< 30 sec. until synchronization with the grid and < 100 sec. to nominal load for the Jenbacher 3.1 MW unit

Table 1: Different start options for Jenbacher engines types for peaking and balancing services

In order to start the engines as needed, the engine's internal oil and water temperature must be above a certain treshold level (implying a certain operation of some auxiliaries). If these conditions are met, the units are ready to participate as needed for reliable operation.

Some ancillary services and markets require plants to participate in demand response programs, adjusting their output in response to signals from the grid operator or based on changes in grid frequency. INNIO Group's Jenbacher generating sets can quickly ramp up and down in response to changes in demand or external signals, a capability that is particularly important given the intermittent nature of many renewable energy sources and the requirements defined in the pre-qualification processes.

The following figure shows ramp-up capabilities available for selected Jenbacher engine types:

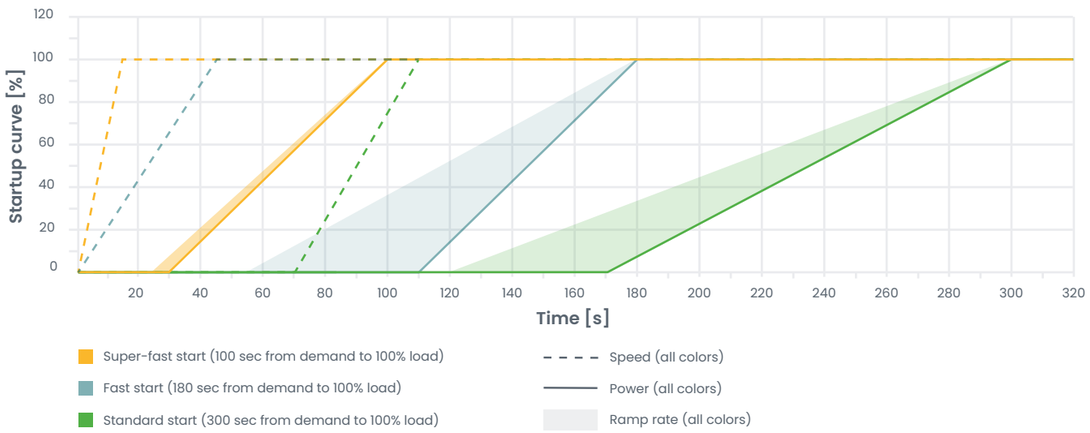

Figure 8: Ramp-up capabilities of selected Jenbacher engines in grid-parallel mode

5.

COMPLIANCE CAPABILITIES

5. COMPLIANCE CAPABILITIES

Grid code compliance is of utmost importance as our customers obtain permission to connect to the electrical grid. Compliance is demonstrated by providing documentation created internally or by a third party based on testing and simulations that show the correct static and dynamic performance as defined in the relevant technical document (grid code, standard, operational procedure, etc).

When providing ancillary services, a process to qualify and show the units can provide the needed capabilities also is requested before participation is allowed in such markets. This process is defined by the relevant grid operator requesting the service.

Grid code and capability compliance ensure that these units can operate safely and as expected within the grid while also complying with the technical requirements regarding power (active or reactive) delivery when called upon. Jenbacher generating sets are designed and can be operated with this in mind, thanks to the extensive development efforts throughout the years and the ample experience with grid codes and their implementation.

The importance of compliance can be viewed from two main perspectives:

1. **Operational assurance and safety:** Grid codes and ancillary capability documents are designed to ensure that power generation units within a plant can operate without causing disruptions or instability to the grid. They set out the technical and operational criteria that units must meet, such as frequency and voltage operation ranges and control, fault ride-through capabilities, reactive power management, and power ramping needs. Compliance with these codes and documents is essential for maintaining the safety of the grid and assuring correct plant operation during emergency situations.
2. **Regulatory requirement:** Grid code and ancillary capability compliance are regulatory requirements for connecting power generation units to the grid and for providing ancillary services. Failure to comply can result in penalties, including fines and refusal to connect to the grid. Therefore, it is mandatory for generation units to meet these requirements. INNIO Group's Jenbacher power generation units can comply with grid code requirements and ancillary capabilities, and they can provide the corresponding compliance proof and documentation, which offers a significant competitive advantage:

   — **Faster time to market:** INNIO Group can demonstrate compliance with grid codes, which can streamline the connection, and ancillary service provision processes, reducing delays and getting units connected to the grid more quickly.

   — **Expanded market access:** Compliance with grid codes also can open access to markets where these codes are enforced. This is particularly important in areas such as the European Union, where grid code-specific certificates are required by several member states to allow connection to the grid.

   — **Risk mitigation:** By ensuring compliance with grid codes, the risk of penalties and disconnection from the grid is mitigated by providing the necessary documentation and proof. This can help customers avoid costly disruptions and potential asset damage.

Grid code and ancillary capability compliance are not just regulatory requirements, but also strategic when it comes to quick and effective grid connection and balancing market access.

5.1 Certification and on-site testing

INNIO Group has ample experience with grid code certification and testing and, when applicable, can provide the needed grid code-specific unit certificates or support for special grid code or capability testing.

These certificates are obtained through the work with external parties such as testing laboratories and certifiers that comply with the needed accreditations.

INNIO Group holds many different grid code-related compliance certificates/homologation as of 2024, and among these are the following (non exhaustive list):

Germany

— Einheitenzertifikat VDE-AR-N 4110 for Jenbacher Type 2, Type 3, Type 4, Type 6, and Type 9 engines

— Einheitenzertifikat VDE-AR-N 4120 for Jenbacher Type 6 and Type 9 engines

— Component certificate for GPC/EZA according to VDE-AR-N 4110/4120

Italy

— Statement of compliance for Norma CEI 0-16; V2:2021-06 (Italy) for Jenbacher Type 2, Type 3, Type 4, Type 6, and Type 9 engines

Belgium & The Netherlands

— Homologation for Synergrid via C10/26—DECLARATION OF CONFORMITY for power-generating units GLV ed2.12 (12/2019) for Jenbacher Type 2, Type 3, Type 4, and Type 6 engines

Poland

— Equipment certificate according to PTPiREE, 2021-04: Conditions and procedures for using certificates in the process of connecting power generating modules to power networks and PSE, 2018-12: Requirements of general application resulting from Commission Regulation (EU) 2016/631 of 14 April 2016 for Jenbacher Type 2, Type 3, Type 4, Type 6, and Type 9 engines applicable to SPGMs Type B, C, D

Spain

— Unit certificate following the rules of "Technical standard of monitoring the compliance of power generating modules according to EU Regulation 2016/631" version 2.1 for Jenbacher Type 3, Type 4, and Type 6 engines

INNIO Group can provide support for the connection process by providing the needed documentation corresponding to the power generation units as defined by the system operator (based on a timeline and cost discussed for each individual case when applicable).

Additionally, INNIO Group can provide support for on-site testing with experienced personal, build in interfaces to facilitate the tests (e.g. setpoint of external frequency signal) and in the form of testing procedures that follow local requirements; Our ample expertise and preparation will prove a valuable asset when connecting to the grid.

5.2 Documentation

During the compliance process for obtaining connection or prequalifying for ancillary services, specific documentation from the power generation units must be provided. This can range from manufacturer declarations to specific testing or simulation reports.

INNIO Group can provide the needed documentation (including but not limited to testing and simulation reports, simulation models in several simulation tools and available certificates) with in-house expertise and can support customers in discussions with system operators for a smooth connection process.

6.

ADVANTAGES OF GAS ENGINE-POWERED PLANTS

6. ADVANTAGES OF GAS ENGINE-POWERED PLANTS

When planning a peaking or balancing plant that will participate in electricity markets and operate as an ancillary service provider, the technology selection process is key to yield a high return on investment. The following benefits can be identified when operating a gas engine power plant consisting of multiple units versus a power plants consisting of a single large unit:

- **Flexible power plant sizing:** Gas engine power plants are typically multi-unit power plants and can be built to any megawatt size, making them especially suitable for any size power plant.
- **Flexible plant operation:** The multi-unit gas engine plant concept allows for extraordinary operational flexibility. The plant output (needed setpoint) defines the number of engines in operation, enabling excellent efficiency with operation at or near full load.
- **Effect on ambient conditions:** Jenbacher engines are less sensitive to altitude, ambient temperature, and humidity. They can run with stable output and efficiency over a wide range of ambient conditions.
- **Reliability and availability:** INNIO Group's Jenbacher engines have low forced outage rates due to continuous online monitoring, and they achieve high availability rates due to predictive maintenance scheduling.
- **Availability with multi-engine plants:** Operating a fleet of multiple gas generator sets with additional units provides increased reliability and availability. Additionally, it allows the plant's minimum load to be considerably lower than that of a single unit power plant.
- **Complement to renewables:** Gas engine-powered plants are excellent complements to intermittent renewables due to their flexibility, reliability, efficiency, and cost-effectiveness.
- **Fuel flexibility:** Jenbacher engines can run on a variety of energy sources, including natural gas, biogas, biomethane, hydrogen, and other renewable fuels supporting operators on their way to net zero.
- **Grid code fulfilment:** INNIO Group's Jenbacher engine power plants have enhanced capabilities to fulfill grid codes. Their resilience against rate of change of frequency (ROCOF) events is also an advantage, making them available in a system heavily populated by RES where more frequent and larger frequency excursions will occur.
- **Fast construction and commissioning:** INNIO Group's Jenbacher engine power plants often have a standardized, modular design for quicker construction, making them faster to build than other types of power plants.

The following table shows a short summary of benefits when using Jenbacher generating sets for peaking and ancillary services:

Characteristic	Jenbacher generating set	Technical and economic benefits
Efficiency peak load	Up to 48%, also in system partial load up to 5% of total output (e.g. in 50 MW configuration)	High efficiency at full load and partial load
Time to load transfer, time to full load start limitation	< 30 sec until synchronization < 2–3 min until full load, no start limitation, several times per hour	Electricity markets that can be accessed from standby: day-ahead, intraday, secondary control power
Required gas pressure	Min. 300 mbar for standard start engines, min. 6 bar for fast start engines, min. 12 bar for operation on 100% H_2	Medium-pressure gas pipeline can be used, no hydrogen backbone required
Consistent performance even at high ambient temperatures (up to over 40°C)	Full load	High availability almost independent of the weather
CAPEX	Cheaper than CHP with combined cycle or aeroderivative units	Favorable CAPEX due to high standardization
Start availability	> 99% for the entire system	High availability for electricity markets, low balancing group risk
"Ready for H_2" and H2-Engines	"Ready for H_2" when ordered, Jenbacher Type 6 as H2-Engine (100% H_2) in 2025, no pilot fuel required for start-up	High chances of success in tendering processes requesting hydrogen operation
Service structure	Close-knit service structure for Jenbacher engines	High standardization of the system components results in high availability

Table 2: Technical characteristics and their benefits as a peaker for selected Jenbacher generating sets

7.

CONCLUSION

7. CONCLUSION

The energy sector is going through a transformation due to the high renewable penetration in the power grid, and while essential for addressing climate change, presents significant challenges for grid stability and reliability; the need for plants that can provide reliable ancillary services and can increase the grid robustness by adding inertia and short circuit power is a clear must in today's electrical power system. INNIO Group addresses these challenges with its Jenbacher solutions that meet the needed technical, operational and compliance requirements requested by grid operators when considering the connection of peaking and balancing plants.

Figure 9: INNIO Group's Jenbacher solutions' capabilities

INNIO Group's Jenbacher technology offers a solution that addresses these challenges while providing:

Technical excellence and grid support

- Grid code compliance capabilities that ensure a smooth connection process
- Robust fault ride-through capabilities to maintain grid stability during disturbances
- Frequency and voltage control functions to support grid reliability
- Flexible reactive power management capabilities that adapt to varying grid conditions
- Generator designs that can be adjusted to cover the demanding frequency and voltage operation range and reactive power needs of the grid

Operational versatility

- Fast start-up times (as quick as 30 seconds) that enable rapid response to grid demands
- Multiple operating modes to support various market participation strategies
- Excellent ramping capabilities to facilitate integration with renewable energy sources
- Ability to provide multiple ancillary services enhances value proposition (including upcoming services like inertia reserve)

Market participation benefits

- Well-suited for participation in day-ahead, intraday, and balancing markets
- Capable of providing various ancillary services including frequency support, voltage support, and black start capabilities
- Multiple-unit configuration offers enhanced reliability and operational flexibility
- Proven track record in supporting grid stability during critical events

Future-ready technology

- Fuel flexibility, including hydrogen compatibility (up to 100% H_2 capability for selected engine types), supports transition to carbon-neutral operation
- Innovative digital solutions drive increased resilience and efficiency
- Modular design allows for scalable implementation
- Demonstrated compliance with evolving grid codes and standards

With over a decade of development experience based on global grid operator connection requirements, INNIO Group's in-house expertise ensures that our products not only satisfy the necessary technical requirements but also come with comprehensive support throughout the connection process, including documentation and on-site testing assistance.

As the energy transition continues to accelerate, INNIO Group's Jenbacher gas engine technology represents the preferred solution for peaking and balancing plants, meeting technical, operational, and compliance requirements demanded by grid operators. Through its combination of technical capabilities, operational flexibility, and future-proofed features, this technology provides power plant operators with a robust platform for supporting grid operations on their way to net zero while helping to ensure success in both current and future energy markets.

LITERATURE

Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators.
Retrieved from eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:JOL_2016_112_R_0001#d1e311-1-1

ENTSO-E Market Report 2024.
Retrieved from ee-public-nc-downloads.azureedge.net/strapi-test-assets/strapi-assets/entso_e_market_report_2024_240628_14b2aab71f.pdf

Glossary from the U.S. Energy Information Administration.
Retrieved from eia.gov/tools/glossary/?id=electricity

Regulation (EU) 2019/943 of the european parliament and of the council of 5 June 2019 on the internal market for electricity.
Retrieved from eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0943

What is aFRR (automatic frequency restoration reserve)?
Retrieved from next-kraftwerke.com/knowledge/afrr

LITERATURE

About INNIO Group

JENBACHER

INNIO Group is a leading energy solution and service provider that empowers industries and communities to make sustainable energy work today. With its Jenbacher and Waukesha product brands and its AI-powered myPlant digital platform, INNIO Group offers innovative solutions for the power generation and compression segments that help industries and communities generate and manage energy sustainably while navigating the fast-changing landscape of traditional and green energy sources. INNIO Group is individual in scope, but global in scale. With its flexible, scalable, and resilient energy solutions and services, INNIO Group enables its customers to manage the energy transition along the energy value chain wherever they are in their transition journey.

INNIO Group is headquartered in Jenbach (Austria), with other primary operations in Waukesha (Wisconsin, U.S.) and Welland (Ontario, Canada). Through a service network in more than 100 countries, a team of more than 4,000 experts provides life-cycle support to the more than 57,000 engines that INNIO Group has delivered globally.

INNIO Group's ESG strategy has been recognized and awarded by esteemed rating agencies such as Sustainalytics and EcoVadis. Additionally, the company's near-term climate targets until 2030 have been validated by the Science Based Targets initiative (SBTi).

For more information, visit INNIO Group's website at **innio.com**

Follow INNIO Group and its brands on 𝕏 (formerly known as Twitter) and in

ready for H_2

ENERGY SOLUTIONS.
EVERYWHERE, EVERY TIME.

Online version available

In general, "Ready for H_2," Jenbacher units can be converted to operate on up to 100% hydrogen in the future. Details on the cost and timeline for a future conversion may vary and need to be clarified individually.

"Optimization/optimize" refers to the automatically generated recommendations for action by the myPlant energy management solution to improve the status quo of electricity trading and resource-efficient plant operation.

Jenbacher is part of the INNIO Group

I JB-3 24 026-EN

PLATINUM Top 1% ecovadis Sustainability Rating JUL 2024

SUSTAINALYTICS ESG 2024 INDUSTRY TOP RATED