Grid stabilisation –
How gas & hydrogen power plants can support grid operators

In short:

Keeping the electricity system stable is one of the growing challenges for grid operators. Apart from ensuring sufficient capacity to meet demand, the handling of unexpected imbalances has become a major concern. Gas and hydrogen power plants can be designed to run the generator as a synchronous condenser in times when the turbine is not in operation. Decoupling the turbine from its generator by means of a self-synchronous clutch, the plant can provide the necessary grid services like inertia, spinning reserve, reactive power control, adjustable voltage control and short-circuit power even when no active power is provided. Equipping power plants (required anyhow for ensuring capacity) with an option for synchronous condenser operation reduces the need for new and costly dedicated stand-alone solutions and maximises the value of Europe's power plant fleet.

A growing challenge: grid stabilisation

Integrating growing shares of variable renewables poses many challenges for the electricity grid. In addition to providing the necessary capacity for balancing demand and supply at times when intermittent renewable generation is low, there is also the challenge of dynamic grid stabilisation - mainly the provision of sufficient grid inertia, reactive power control, voltage control and the required level of short circuit power.

Grid stabilisation in the past was provided as a free of charge add-on by the traditional large power plants, operating as baseload in the grid. The many large turbine-based power plants with constantly running, so-called "rotating mass" provided sufficient inertia as Synchronous Inertial Response (SIR) to seamlessly stabilise the grid in unexpected moments of disruptions in the grid, keeping the frequency stable within the foreseen range while focusing on the generation of electricity.

Nowadays, there are less and less of these power plants running permanently in the grid. Most coal plants have been decommissioned or are on their way out and many grids do not include nuclear plants. At the same time, many large gas power plants operate only for limited time periods, providing residual load or acting as a fast-responding capacity back-up to variable renewables, starting only when additional electricity is required – not providing inertia and other grid services in times when not operating.

The increasing share of renewable generators based on inverter technology reduces the grid resilience while the stabilising thermal generators are taken off the power mix temporarily or permanently in deep decarbonisation.

Therefore, grid operators are increasingly worried about a lack of grid stabilising and signal shaping solutions, especially at times with abundant or excess renewable power production and are forced to find affordable solutions that ensure grid stability.

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What are the technological options?

Grid operators shall ensure the safe operation of their system, keeping the frequency and voltage within operational safety limits. In addition, they must organise specific back-up and safety measures and keep their electricity system in an operational condition. The measures required for a reliable and safe operation are typically based on equipment owned and operated by the system operators, and the frequency containment and restoration reserves are normally contracted as a paid ancillary service from fast acting, reliable electricity generators.

The dynamic stabilisation of frequency and voltage is in most cases ensured by using Flexible AC Transmission System (FACTS) solutions like power electronics, step up transformers, shunts, capacitors, and other active and passive technologies complemented by turbogenerators from thermal power plants. The decreasing amount of rotating mass, in combination with the increased requirements of dynamic balancing of frequency and voltage, and the lack of short circuit power, require additional investments, as outlined by ENTSO-E.

Consequently, grid operators have started to invest in stand-alone solutions for grid stabilising technologies like flywheels or synchronous condensers (effectively stand-alone generators synchronized with the grid), or combinations of several such technologies. Their only role is to ensure a resilient grid and provide stable reactive power. Moreover, they provide short circuit power and SIR during the short time frame before other options can be activated. There is also continued work to develop solutions using battery solutions and power electronics to provide synthetic inertia and voltage control, but the technological readiness level is still comparably low.

Similarly, grid connected generators of turbine-based gas and hydrogen power plants can easily and cost efficiently provide built-in inertia, reactive power, and other grid services during times of high renewable generation but also active power when needed.

How can gas and hydrogen power plants help?

Gas and hydrogen power plants will remain part of the energy system in many European areas. They will be needed to complement the generation of intermittent renewables for the moments when those cannot meet the electricity demand. Studies show that even after switching from natural gas to the use of green hydrogen, these power plants provide the most cost-efficient and reliable generation backup. Over time these power plants will show decreasing capacity factors, which means that the hours when they are synchronised to the grid decrease, limiting the availability of grid ancillary services.

Even when not using the turbine for generating electricity, the rotating mass of the large generator installed in the power plant alone (eventually supported by a flywheel) could provide the required inertia and other grid services to the electricity grid. To do so it simply requires that the turbine can be decoupled from the generator via a synchronous self-shifting clutch. With such a clutch, the generator can remain synchronised with the grid, while the turbine disconnects and shuts down.

The generator keeps spinning and acts as a synchronous condenser, providing constant spinning reserve, short circuit power, and reactive power, without consuming gas or hydrogen for the operation of the turbine. Only a small amount of power for auxiliary loads is still required in this operating condition (e.g. lube oil system, excitation system, etc.) which comes from the grid.

This is proven and available technology, defined in recognised standards like IEC 60034-3 and already installed in power plants around the world for more than 20 years. Only when additional “active” power is required will the clutch reconnect turbine and generator, and the turbine is started - in some designs even without the need to take the generator off the grid. This technology can be integrated in new power plants and in some cases, also retrofitted in existing thermal power plants.

In addition to the 24/7-use for ancillary services, the power plants can also be designed or retrofitted for black-start capabilities to allow grid restoration after serious events within the grid, as another option for multi-use within the safe and reliable grid environment.

What are the advantages compared to investments in separate specific grid stabilising technologies?

- Grid operator investments in dedicated grid stabilising solutions like flywheels and stand-alone synchronous condensers require new investments in dedicated technology, adequate grid connections, and costs for operation and maintenance.
- In comparison, using the capabilities of gas and hydrogen power plants that are anyhow required by the electricity system as a complement to renewables, provides a win-win situation.
- Grid operators can focus on their core competence and don't need to finance and operate the dedicated installations. Instead, they tender the service on the market as done with balancing energy and other grid services, resulting in much lower costs compared to owning stand-alone systems.
- New power plants will often be built at sites with existing grid connections and transformers, hence reducing the need for costly grid expansions. While generating electricity, they provide the required rotating mass and grid ancillary services. During the hours when no gas or hydrogen drives the turbine, the plant can still operate as a synchronous condenser to provide the ancillary services to the grid.
- Additional one-time investments are limited compared to separate stand-alone synchronous condenser or FACTS plants. Also, the additional operating and maintenance costs are somewhat lower compared with stand-alone stabilisation systems.
- The operators of gas and hydrogen power plants - who find it increasingly difficult to recover their investment costs from selling electricity when only operating as back-up - are provided the chance to generate additional revenues from selling grid services like reactive power control, short-circuit power, inertia, or voltage control. These steady income streams make plant investment decisions and amortisation easier.
- Governments in many European countries remunerate such gas and hydrogen plants via capacity mechanisms for "being available". Using the availability of the technology and bundling capacity payments and grid service payments would increase the economic efficiency of the system.

Thus, using decoupling-capable gas and hydrogen power plants for providing grid stabilisation as an alternative to separate, dedicated solutions, reduces the overall electricity system costs borne by energy consumers and governments.

ANNEX

Space requirements

Installing a self-synchronising clutch between a turbine and a generator in a large power plant normally requires around 2-3 metres additional space in-between both, depending on the size of the generating unit. For newly planned power plants the slightly enlarged foundation and building length will not pose a bigger problem – when retrofitting an existing plant this should be considered carefully. A retrofit requiring an extended foundation in combination with potentially necessary modifications on the shaft line may impose significant costs. Installing an additional flywheel may further increase the space requirements.

Availability of self-synchronising clutches

Self-synchronising clutches have been installed globally in hundreds of applications, not only for the connection of turbine and generator, but also for the connection of steam turbines in single shaft combined cycle power plants. They are offered by various turbine manufacturers and are available today for up to 400MW.

Investment Costs

Installing self-synchronising clutches in a new power plant will create limited additional investment costs - far below the costs of a stand-alone synchronous condenser station, which also occupies additional space and causes costs for the required property. Further modifications to the power plant design may include instrumentation and controls modifications for the expanded operational scope.

Operating costs

During the operation of the power plant as synchronous condenser without the provision of active power, the operational costs of the plant are marginally increased compared to a standalone synchronous condenser station.

The one or two additional bearings introduced with the clutch cause small friction losses, resulting in a marginal efficiency reduction during power generation.

There is no additional service requirement compared to a synchronous condenser station.

Plant configuration and optimisation

Power plants are built for an optimised operation under defined conditions. They can be optimised to generate active power at the lowest cost but also for providing grid services. The plant operator will decide for a specific optimised plant configuration based on expected income streams and an adequate return on investment. This may e.g. include the installation of a flywheel which creates additional friction losses but generates mass moment of inertia in return.

However, simply requiring all power plants to add self-synchronising clutches and a flywheel as a standard configuration will cause additional costs and may lead to system inefficiencies as not all plants will be at the most appropriate location to contract on the full array of grid services.
Instead, a reliable remuneration scheme for providing grid stabilising capabilities (markets for reactive power, inertia, short-circuit capability or reserve active power) creates market-driven investment incentives and allows power plant operators to optimise their plants and ensure system efficiencies.

Addition of flywheels

Adding a flywheel to the installation further increases the inertia time constant. The additional flywheel can be easily integrated during the planning phase. Flywheels are state-of-the-art and commercially available from various vendors.

Generator cooling requirements when operating as synchronous condenser

Using the generator as synchronous condenser creates heat. The additional cooling efforts relate to the installed cooling system, normally either air-, water- or hydrogen-cooling, depending on the size. Typically, for large generators the energy losses can be estimated to be 2-3 MW per approx. 300MVAr. The losses are usually lower than in power generation mode - accordingly there is no additional cost impact compared to the gas turbine power plant setup.

Repurposing “old” power plant installations as synchronous condensers

In cases with either no need for an older plant to still provide active power or no economically viable possibility to install a self-synchronising clutch, it is still possible to use the plants as synchronous condenser by permanently disconnecting turbine and generator. Various projects have already been carried out. Unfortunately, the older units have not been optimized for synchronous condensing, creating comparatively high operational expenses. If required, a flywheel can be added to enable the provision of further grid services.

Some examples in operation

Ankerlig & Gourikwa Power Station (South Africa) (since 2007)

Brindisi North A2A Power Station (retrofit 2020)

Millbrook Power - Drax Global (new build)

Information links provided by EUTurbines members:

- Ansaldo Energia
- Baker Hughes
- GE Vernova
- Siemens Energy