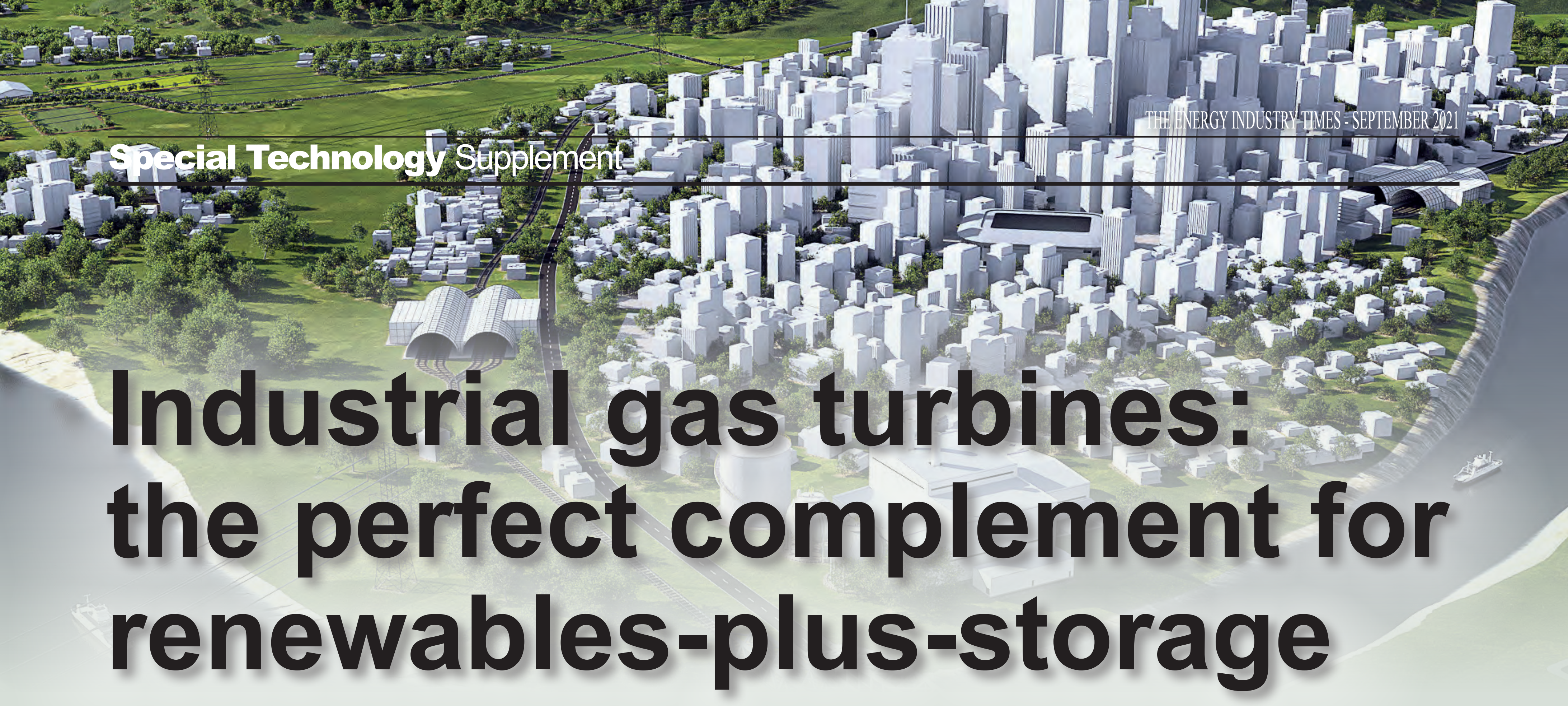


# Industrial gas turbines: the perfect complement for renewables-plus-storage

With the growth in variable renewables, energy storage is expected to be the key technology for providing grid support and shifting renewable power to when it's needed. Siemens Energy's Anders Stuxberg explains to ***TEI Times*** why industrial gas turbines will be crucial in complementing renewables-plus-storage in an optimised system. **Junior Isles**

With the urgent need to combat climate change, wind and solar power are growing at a phenomenal rate. According to the International Energy Agency, renewables will meet 80 per cent of global electricity demand growth during the next decade. Solar PV, for example, dubbed by the IEA as "the new king" of electricity supply, grows by an average of 13 per cent per year between 2020 and 2030, meeting almost one-third of electricity demand growth over the period.

The variable nature of wind and solar, however, presents challenges in terms of grid stability and how best to provide backup power for when the wind is not blowing or the sun is not shining.

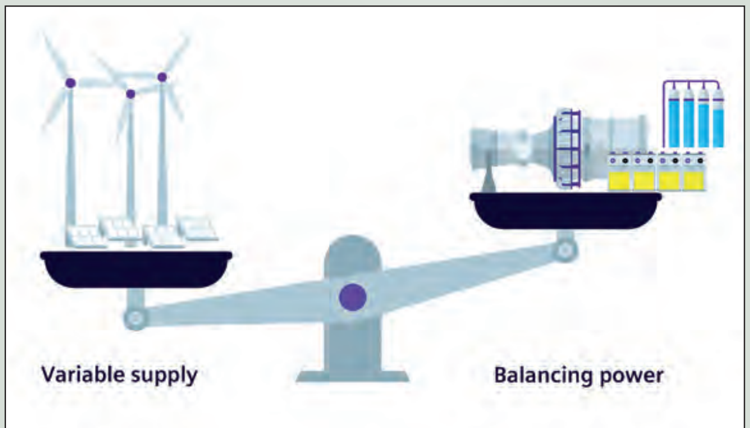
With targets set for reaching zero carbon emissions in the electricity sector, clearly the goal must be to support renewables as far as possible with energy storage – a zero carbon source of grid flexibility. The question, however, is what generating assets to deploy alongside storage, and how to achieve the best mix of storage and those assets in terms of cost and operability.

Anders Stuxberg, Specialist in Power Plant Process Integration at Siemens Energy AB said: "Gas turbines (GTs) will be the technology of choice to be dispatched when storage power capacities are insufficient for the demand and also when the storage becomes emptied. If you look at balancing supply and demand through the grid in general, you have to look at it over a number of different timeframes. The system has to be managed, second-by-second, minute-by-minute, hour-by-hour, using different technologies. You also have to look at balancing over longer timeframes… The question is how to optimise these storage and generating resources. Storage will handle the bulk of energy for balancing, but there will not be a business case to try to cover everything with storage alone, you will need to complement it with GTs.

"By implementing storage, the operating profile for GT-based plants will be significantly changed. GTs will be a cornerstone of the grid infrastructure but with a new role in future compared to what we have been used to seeing. You will see a shift to backup power instead of peaking units and flexible mid-merit combined cycle plants instead of baseload plants; this will favour industrial GTs for new installations. Industrial gas turbines are also suited to use hydrogen as fuel and fuels produced through power-to-X schemes," said Stuxberg.

With storage expected to take centre-stage in maximising the integration of renewables and distributed generating sources, the market for the technology is forecasted to grow exponentially over the next decade *(see box)*.

Regardless of which of the various storage solutions is selected, however, they are all generally limited by two parameters: power capacity and energy capacity, i.e. duration of storage at full power. Stuxberg noted that when optimising storage solutions, power plant owners will size for the most frequent instances that give the most energy trade volume and then leave the residual load to some other technology.




*Don't let balancing power capacity get out of balance*

**Storage will handle the bulk of energy for balancing but it will need to be complemented with GTs**

He said: "There will be many days the energy in the storage is insufficient for the demand and many days when storage systems have less power capacity than needed, at least during part of the dispatch duration. So other technologies will be called for both at surge of power and of energy, there will be a play between different types of storage solutions and capacity backup."

He also noted: "Storage technologies that can shift operating mode after the storage is emptied – continuing power production by firing a supplementary fuel – will also play a role in backup supply, i.e. double benefits to the system. Examples are: power-to-hydrogen-to-power where the hydrogen-to power unit (gas turbine) operates on e-methanol when the gas storage is emptied, or a thermal storage plant that also can run by firing of e-ammonia when the thermal storage is emptied."

Stuxberg says there will also be competition between storage and demand response (DR). If altering the time of energy use (e.g. smart charging electric cars) does not damage business, then DR will be more efficient and cost competitive than storage.

Many types of DR will, however, be limited in much the same way as storage. For example, duration – mainly limited by the nature of the demand that has been put on hold – will normally be limited to a number of hours. The amount of DR that will be available naturally depends on the price incentive, the volatility of energy prices for final consumers, and the use of smart meters.

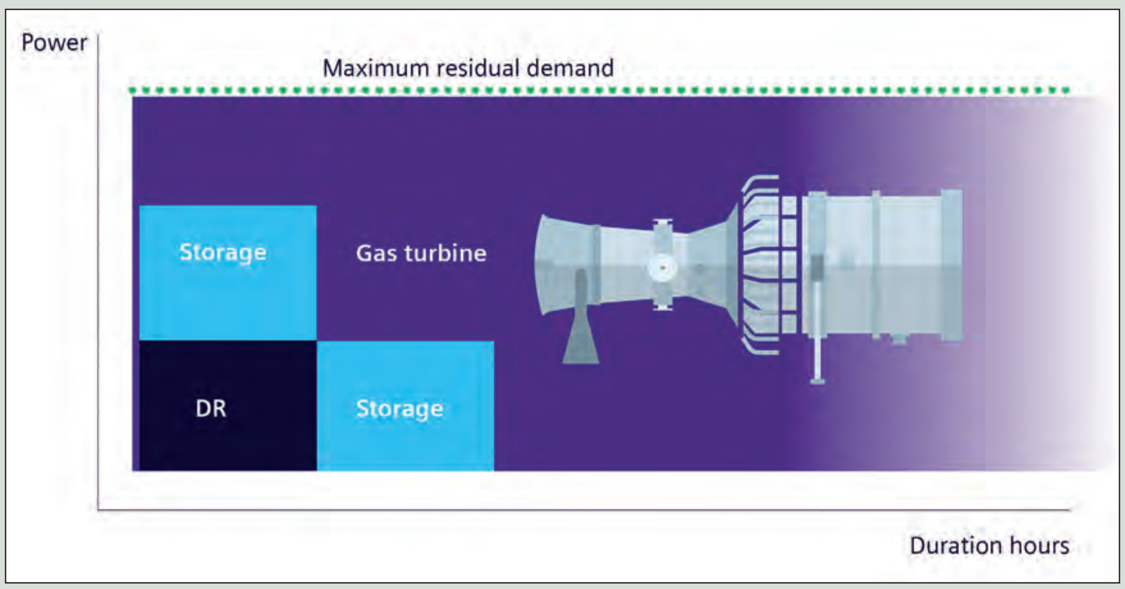
"When you look at the demand for balancing power, storage solutions are efficient systems, with up to 80 per cent of the energy coming back [from the storage]. But it is not economical to design an energy storage system for all possible situations. And when you empty the storage, you have to fill-in with something else," said Stuxberg.

That "something else", he says, will typically be (fuel fired) thermal plants, i.e. the backup power capacity that must exist in the grid anyway to ensure reliable supply when there is no wind or solar for a long period.

There are several options as to which technology, or group of technologies, can support renewables-plus-storage depending on the scenario. For example, arguments are sometimes made for fuel cells while other experts present compelling cases for fast-start generating assets such as gas turbines and reciprocating engines.

Stuxberg believes industrial gas turbines are currently the best all-round option. He commented: "In a deeply decarbonised energy system, gas turbines will play a key role both for mid-merit power supply and as backup power. Although some argue that fuel cells will take that role, that can only happen if fuel cells for a fully functional and installed power generation plant become cheaper than gas turbines. We are not there today and I believe that if it happens, it will take many decades. Fuel cells, though, are already a good option for microgrids and mobility applications.

The requirement that backup power also should be fuel flexible, e.g. use both hydrogen and liquid renewable




**Power plant owners will optimise storage solutions size for the most frequent instances that give the most energy trade volume and leave the residual load to another technology**

fuel is also a cost issue, if not a problem, for fuel cell plants.

"Reciprocating engines compared with gas turbines have pros and cons. In short, they are less efficient than combined cycles and are more expensive per capacity than simple cycle GTs, with the exception of emergency diesels gensets, which have a shorter lifespan. For mid-merit operation, maintenance cost is an important factor to consider – industrial GTs have lower maintenance cost than, e.g. recip engines or fuel cells."

He also notes that conventional boilers with steam plants are too inflexible to handle the frequent starts and stops to balance residual power demand. Further, their efficiency is low, especially if designed for renewable fuels such as biomass.

Based on the shortcomings of these technologies, Stuxberg believes the focus for grid balancing should therefore be on a blend of industrial gas turbines (IGTs) and storage solutions and a probable future dispatch profile for those assets.

IGTs in the range up to 70 MW are typically used in a number of applications. CHP applications are common across the whole range due to their ability to meet heat demand. The smaller machines may be deployed in settings like hospitals, universities, small industries and O&G, to provide power in areas where the grid is not completely stable or onsite generation is required. Medium-sized machines in the upper range of 30-70 MW may be used by, independent power producers (IPPs), industrial CHP asset owners, the O&G industry, municipalities producing electrical power for the grid and heat for district heating networks, as well as utilities.

Stuxberg believes the operating profile of IGTs in the future will not be same as the peaking units of today. Units in the future he says might start-up and shut down once a day during parts of the year, be in standby other periods and also occasionally run for a longer period, as opposed to cycling several times per day.

With storage expected to be the first option for supplying multiple daily power peaks, operators must then decide how gas turbines will operate to complement this storage.

Stuxberg foresees gas turbines being dispatched when the energy required exceeds what is available in the storage. This will likely be after the large afternoon/early night peak or possibly in the morning. Gas turbines will also be called for when all storage solutions are already providing near full power capacity, i.e. typically during the evening peak.

He explained: "If GTs are being called on every day for one of the two reasons, power surge or energy surge, then that's a signal to storage investors that here you have an attractive business opportunity – just buy some more capacity. It's low-hanging fruit. So my conclusion is that GTs will typically start once every 2-4 days on average; some days they might be called on twice and many other days not at all.

"Traditional peaking plants and base load plants will no longer be suitable for this kind of market. So if we have a GT on the system to ensure backup anyway, the question is: should you operate it for more hours, which means more fuel consumption, or should you make the storage slightly bigger?"

According to Stuxberg, that optimisation determines how the gas turbine is operated, the type of turbine selected and whether the plant should be simple cycle or combined cycle.

He explained: "Generally, each addition of duration for a storage technology comes at an added investment, which needs to be paid for by less and less events since long duration events are less frequent than shorter events. The marginal cost of longer operation for a GT plant firing renewable fuel on the other hand is constant as it just adds fuel consumption (fuel storage is relatively cheap). The duration at the cross-over point between technologies depends on event probability, a number of economic factors and choice of technology. The decreasing probability of long events explains why even pumped hydro plants, at present, often are sized to fit just one day cycles."

He added: "Grid balancing of up to a couple hundred megawatts would be fairly common. This could be divided across a number of machines so you can follow demand better without running machines at part-load."

Such an installation would have to be capable of meeting several requirements. Firstly, it should be capable of starting "reasonably" fast.

"If there is some kind of communication protocol (using new IT solutions and advanced forecasting tools) in the market telling GT operators to start in fair time before stored energy runs out, then very fast GT start is not required, 20 minutes should suffice," said Stuxberg. "Also when power capacity becomes the issue, it should on most occasions be possible to predict when to dispatch GTs. However, power peaks come faster than drainage of energy, so here dispatch centres can reserve some power in the storage by starting the GTs a bit in advance when a demand ramp-up is expected. Here a fast GT start pays off a little as there is less need to reserve power from storage dispatch and thus there is a bit less operation of the GTs, which could be assumed to produce slightly more expensive power than the storage system. If the dispatch is just based on a commercial energy trade, then hybrid plants comprising a combination of e.g. renewable power, storage and GT may be a good business as smarter dispatch can be achieved."

Typically, many gas turbines will be installed in an electric grid to provide the necessary backup power. The dispatch order for these will be based on cost or environmental footprint. Since the requirement will be for a fairly low dispatch rate, Stuxberg says a large portion of dispatch may be based on capacity auctions where a fixed compensation for just existing as available backup is paid out.

If efficiency is also credited, e.g. by dispatch order, then a fair portion of these cycling GTs will be configured as combined cycle. However, the bottoming steam cycle must then be suited to frequent starts, i.e. fast and with low start-up cost. Stuxberg notes that in a future where these mid-merit plants need to operate on renewable fuel, which will be expensive, a bottoming cycle will be required for many of these plants for the sake of opex. The remaining plants, which will have a low dispatch rate of, say, less than 500 hours per year, will not be so sensitive to efficiency but will need to have low capex and fixed standstill cost.

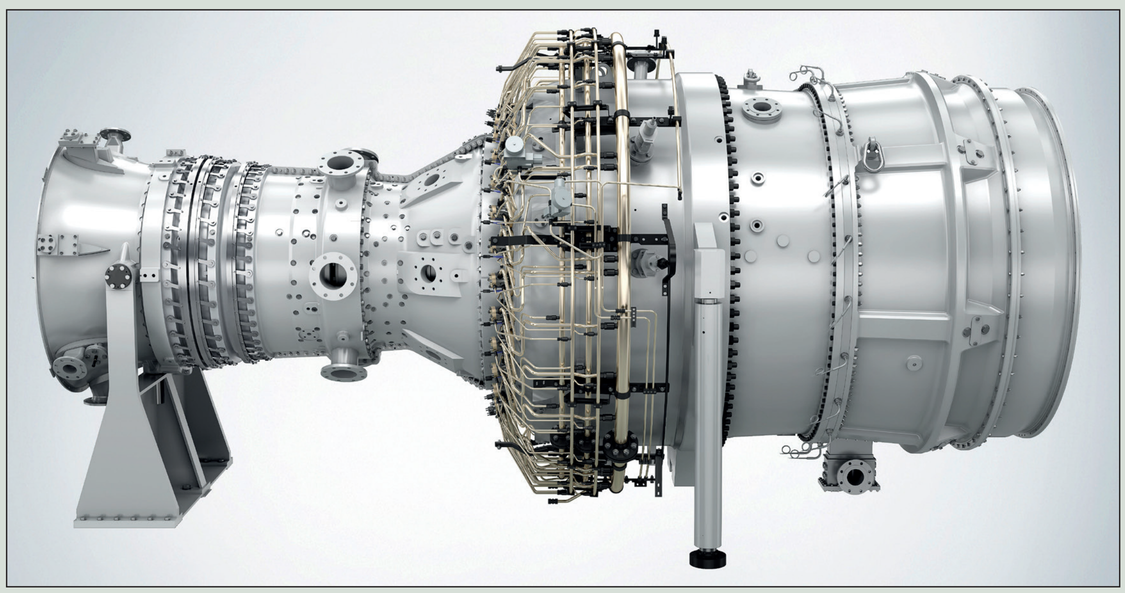
"So, for the power generation business, we will see two typical types of GT plants for the future: combined cycle plants for cycling operation, dispatching in a mid-merit pattern of somewhere between 1000 and 3000 hours per year; and simple cycle plants, with dispatch often less than 500 hours per year. The traditional base load plant is thus replaced by a very flexible mid-merit plant, while the traditional peaking plant is replaced by demand response and storage solutions plus a large quantity of backup power."

**Stuxberg: in a deeply decarbonised energy system, gas turbines will play a key role both for mid-merit power supply and as backup power**

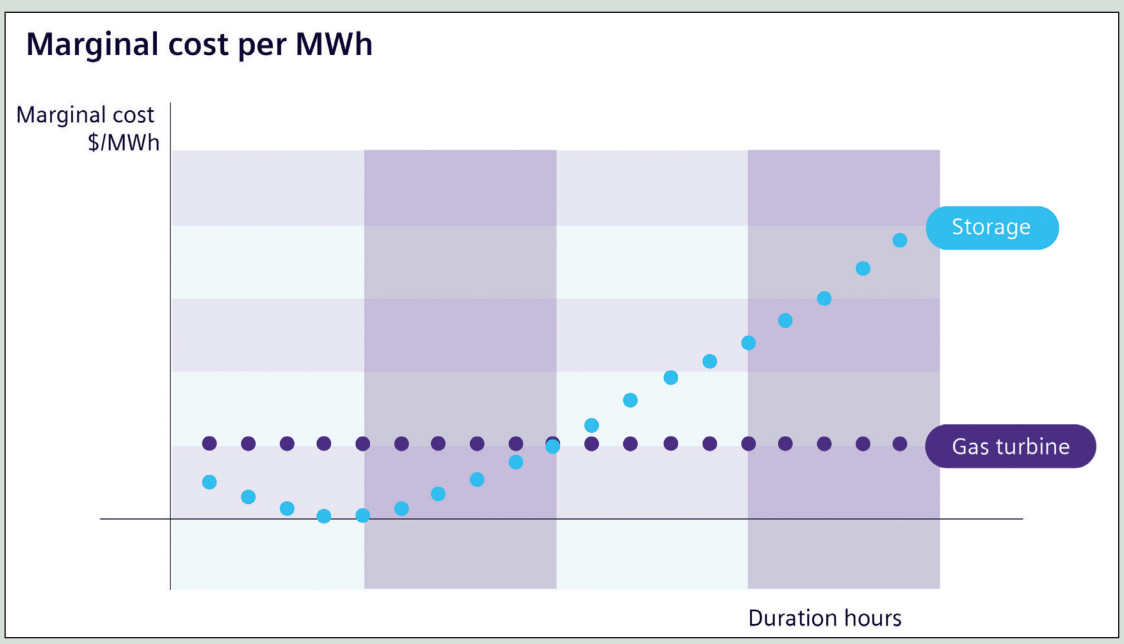
His absolute conviction is that industrial gas turbines present the best suitability to this type of future duty for both these plant types. "They have very high reliability due to simplicity in design concept, high combined cycle efficiency, low price, low maintenance cost, good fuel flexibility and much better grid stabilisation characteristics (by high inertia and strong control response) than aeroderivative GTs or recip engines," he said.

For both these plant types, his expectation is that there will be an average of one start every one to four days, most frequent for the mid-merit type. Stuxberg predicts a wide operating regime for such gas turbine plants. For demand response (DR) and for energy storage systems, he noted that they will dominate dispatch of balancing power for short duration and during periods of low demand for residual power.

He noted, however: "When looking at capacity it is hard to rule out rare events with low probability, thus installed GT power capacity in the grid will need to be large. The scale of backup capacity needed depends predominantly on the capacity factor



**IGTs such as the SGT-800 are typically used in a number of applications**




**The dispatch order for GTs in the grid for backup will be based on cost or environmental footprint**

# The energy storage market is forecasted to grow exponentially

All storage technologies can store surplus renewable energy and return it to the grid later, thus avoiding curtailment and increasing the use of renewable power.

According to analysis from IHS Markit, annual installations of energy storage capacity globally will exceed 10 GW in 2021, more than doubling the 4.5 GW increase in 2020. The existing capacity in stationary energy storage is dominated by pumped-storage hydropower (PSH), but because of decreasing prices, new projects are generally lithium-ion (Li-ion) batteries.

PSH capacity additions are predicted to remain constant at 5-10 GW per year, while battery capacity is expected to grow from 2.3 GW/year in 2018 to above 30 GW/year in 2050. Total installed storage capacity was around 170 GW in 2019, a figure that is expected to reach 950 GW by 2050, according to IHS Markit.

Another report – 'The Energy Storage Grand Challenge Energy Storage Market Report 2020' – published by the US Department of Energy forecasts a 27 per cent compound annual growth rate (CAGR) for grid-related storage through to 2030. It projects annual grid-related global employment to increase about 15 times from around 10 GWh in 2019 to almost 160 GWh in 2030.

The type of storage deployed will depend on grid design and the distribution of generating plants and loads unique to each grid. The technology selected depends on which offers the best economic and operational capability according to the services, range of capacity and energy discharge duration needed.

Super-capacitors and rotating grid stabilisers (flywheels and synchronous condensers) provide instantaneous system responses and grid control. Both technologies are aimed at applications in the range of approximately 1-100 MW.

Pumped storage hydro is the most dominant energy storage solution in terms of globally installed megawatt capacity, representing some 93 per cent of the operating system. It is a gigawatt-scale technology mostly used for energy shifting and high-capacity firming with storage durations of around days or weeks with minimal energy losses.

Further, capacity and operating reserve is provided when the asset is connected to the grid. But although a mature and widespread technology, its main drawback is the required topology of the site (large height differences are needed) and its physical impact on the environment.

Thermal energy storage (TES) can improve utilisation of waste heat, assist in the electrification of process heat supply, or store renewable energy for re-electrification using a steam turbine. TES can also be integrated with thermal generation plants, e.g. a combined cycle plant. A wide variety of heat storage media are available, including liquids such as molten salt and pressurised water, or solids such as stone, steel, concrete, or sand.

Liquid air energy storage (LAES) and compressed air energy storage (CAES) are further technologies aimed at gigawatt-scale applications. LAES is based on the cryogenic liquefaction of air when it is compressed with the use of (preferably) renewable electricity. The liquid and the produced heat can be easily stored and discharged when needed for re-electrification. CAES works similar but stores compressed air. By adding a thermal storage to this technology, the overall efficiency is improved.

Li-Ion batteries are currently the technology of choice driven by their cost-effectiveness and speed characteristics. They offer several applications, such as frequency response, flexibility enhancements of conventional power generation assets, black start capabilities or energy arbitrage. Their sweet spot is up to around 250 MW and 5 hours of duration.

of wind and solar and level of long distance power transmission. Up to about 50 per cent of grid capacity may be expected; in isolated grids or grids with weak connection to other grids one may even argue for 100 per cent. When you also look at resilience and tolerance for grid failures most of the GT installations should be distributed in the grid, this favours mid-sized gas turbines as well as flexible CHP. In large, high capacity grids, large GTs will also be attractive for backup power capacity due to low specific investment.

"When looking at energy supply rather than the installed capacity, demand response and storage will dispatch maybe 80 per cent of all energy needed for grid balancing and GTs only the remaining 20 per cent. Those GTs should preferably operate on renewable fuel." he added.

The figure below shows demand as well as solar and wind supply in a simplified fictitious medium size grid. On the left, wind supply during an average day, where energy fed into storage covers about 85 per cent of the balancing need. On the right, where wind supply is low, thermal power generation is needed to replace lower wind supply during the evening through to morning and for the balancing duty that storage solutions would otherwise provide, as there is no surplus renewable power during the day for charging the storage. Here, high efficiency storage is charged from high efficiency mid-merit GT plants during the day, as this limits the need of thermal plant capacity during the peaks. The result is that the required thermal plant capacity is about twice the capacity of installed storage.

If DR is added, it would reduce the required amount of storage as well as the power capacity for storage charging/discharging during an average wind day. In the low wind scenario, it would also reduce the need for installed thermal capacity, as it flattens the thermal power supply.

"Naturally reality is more complex than these simple scenarios, with seasonal variations on both demand and supply, effects of clouding, fast fluctuations, grid disturbances etc.," noted Stuxberg.

Fuel flexibility also has to be a key consideration. If a machine is operated for less than 1000 hours/year, the impact of fuel consumption on environment and economics is relatively small. However, the goal is to run turbines on renewable fuels, and uncertain policy in the long-term outlook in this area is a challenge.

Stuxberg said: "There are a number of optional renewable fuels for use in GTs, hydrogen being one of the top candidates, but today we don't know which of these will be economical or available in the future and obviously it will always depend on the site location and operating profile. But the point is, industrial gas turbines are flexible"

The market for IGT-based grid balancing assets is huge – anywhere in the world where there is renewables growth calling for day-to-day renewables support, while offering emergency backup for the grid. There is also room for large frame gas turbines, where countries have large robust grids.

"In Sweden, we have a lot of hydropower but when we close down nuclear capacity and replace with wind farms, there isn't enough capacity to handle the residual power peaks. There we will see a large demand for [GT] backup power. Those machines would probably operate for less than 10 per cent of the time. In many markets today, there is no compensation for having capacity in place and that is an issue.

"Grid integrity and resilience via sufficient backup should mainly be seen as part of the grid infrastructure rather than energy trade. Solving backup power supply with existing coal fired plants is a route that has already proven a failure as it counteracts the greenhouse gas savings from renewable power, i.e. incentives for investment in more suitable backup technology is needed" said Stuxberg.

He concluded: "Renewables and storage systems will play the major future role for energy supply but that requires a lot of flexible backup and for that gas turbines are the most cost effective today – if you need to build capacity today; it's gas turbines.

"We can only speculate on what will happen in the future through development of other technologies. But we need to change the energy system now. With the environmental challenge, we cannot wait 30 years; so we have to base it on the technology we have today and industrial gas turbines is an available technology well fit for the purpose. Backup power also needs to be installed ahead of renewable implementation to ensure grid resilience, so the need is urgent."

**Demand, solar and wind supply in a simplified fictitious medium size grid**