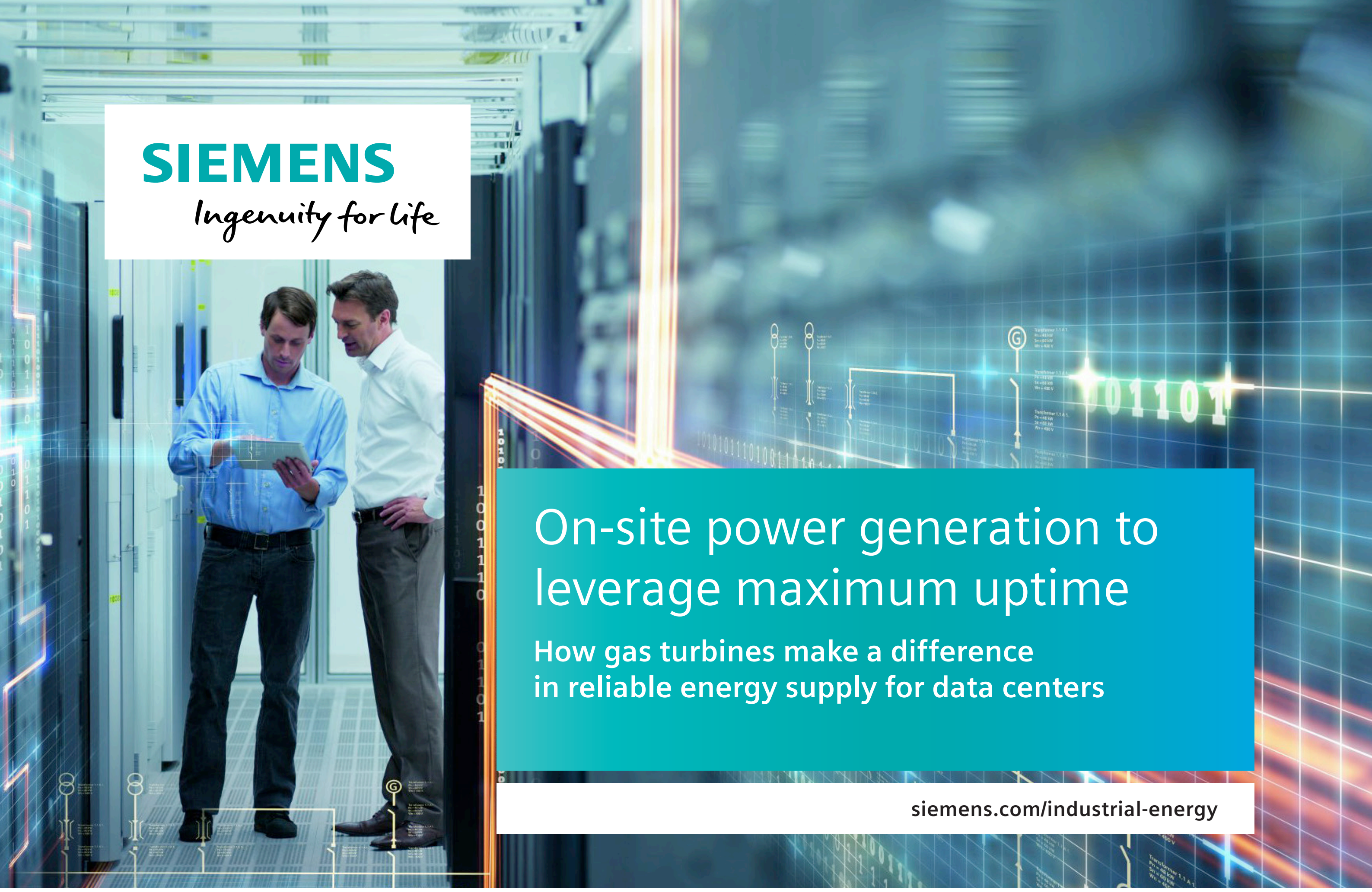

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On-site power generation to leverage maximum uptime

How gas turbines make a difference in reliable energy supply for data centers

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Content

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Executive summary

There was a time when data center operators, engineers, and consultants could safely focus on their core areas of data storage and data processing, safe in the knowledge that their power socket would deliver a sufficient and stable supply of energy to maintain and expand the data center business. Now, ensuring sufficient power, its reliable supply and steady quality from the grid have become strategic concerns.

Not only is the constant growth of data center infrastructure with its increasing demand for power outstripping grid capacity in some areas of the world; due to the increasing share of stochastic renewable in-feed, creating volatility and fluctuation, the availability and quality of power supply have dropped and might pose a threat to reliable data center operation.

One solution to this challenge facing the data center industry is on-site generation of electricity and cooling. Diesel generators have long been the go-to option for rapid backup power, which resulted in increased emissions of hazardous exhaust gases and pollutant particles. However, with the latest technological advances in highly efficient gas turbine technology, generating power on-site for the main supply of data centers has become far more attractive, solving grid challenges today and also in the long-term. In the future, these stable, low-emission on-site power generation solutions will be able to run exclusively on carbon-free fuels such as e-hydrogen.

It is thus high time for operators to get up to speed on how gas turbine power generation can benefit the data center business. To this end, this paper will (1) shed light on the market trends and challenges for on-site power generation for data centers, (2) provide valuable insights into gas turbine technology and power generation design, and (3) make the case for gas turbine lifecycle management, which helps to maximize the value from gas turbine power generation with fit-for-purpose operation and maintenance solutions.

1. Data centers and on-site power generation

The data center industry is evolving rapidly. Fueled by megatrends such as demographics, urbanization, globalization, and digitalization, data centers are increasing in number as well as size, and are – among other factors – driving the demand for energy in the future.

Already in the last decades, we have witnessed nothing less than a data revolution. IP-connected digital devices such as smartphones have become ubiquitous – estimates show that there will be 50 billion connected devices in circulation in the near future, generating 40 zettabytes of data[1)]. In addition, big data has developed into a valuable commodity, cloud computing is being embraced globally, and the internet-of-everything paradigm is just taking off, generating a need for ever more computing power, bandwidth, and storage (Figure 1).

As a result, the demand for new data centers has skyrocketed in recent years – a trend that will certainly continue into the next several years, amplified by the demographic growth forecast. The global population is set to surpass 10 billion by 2050[2)].This global change and the booming urbanization create a continuously increasing energy demand, as well as higher data traffic, driven by the extended and rising use of IP-connected consumer electronics (Figure 2).

With the advance of digitalization, data centers are becoming more strategically important, not just for IT management, but also for businesses and society as a whole. With more data stored in ever-bigger hyperscale data centers or colocation centers, their reliability is vital to the functioning of critical infrastructure. As they are charged with storing and safeguarding valuable and critical data 24/7, all year round, they have to prove they can provide at least 99.671 percent availability.

All these megatrends indicate a steep upward trajectory for the data center industry. However, given the ongoing climate change, this increased energy demand must be met in a way that complies with the global goals of decarbonization set out in the Paris Agreement. As data centers and their related networks could use as much as 51 percent of global electricity by 2030[3)],it is apparent that they have a vital role to play in mitigating climate change.

▸ **In order to fulfill its purpose, the data center industry has to put in place sufficient power generating capacity that is reliable as well as environmentally compatible.**

On-site generation has been traditionally used as an emergency backup solution to ensure availability in the case the grid fails. But that was back in the days when the availability of power from the grid was sufficient and the quality of power was excellent. As the engines had to be used as back-up only, their pollution was acceptable and did not require cleaning devices. Today's grid environment causes data centers to look for other, more reliable solutions providing power according to the data centers' requirements.

If you were to draw up a wish list for on-site power generation for the data center industry today, the key requirement would certainly be maximum, uninterrupted availability, but high power quality to avoid data errors, high power density, cost-efficiency, and a flexible, modular set-up would also be important prerequisites.

Furthermore, data centers grow organically with demand, adding capacity as needed – and their power generating capacity must follow suit. Data center operators may start with 20 or 50 megawatts and then decide to scale. In order to run their data centers profitably, they must identify the best viable solution for reliable and efficient power generation, both momentarily and the longer term.

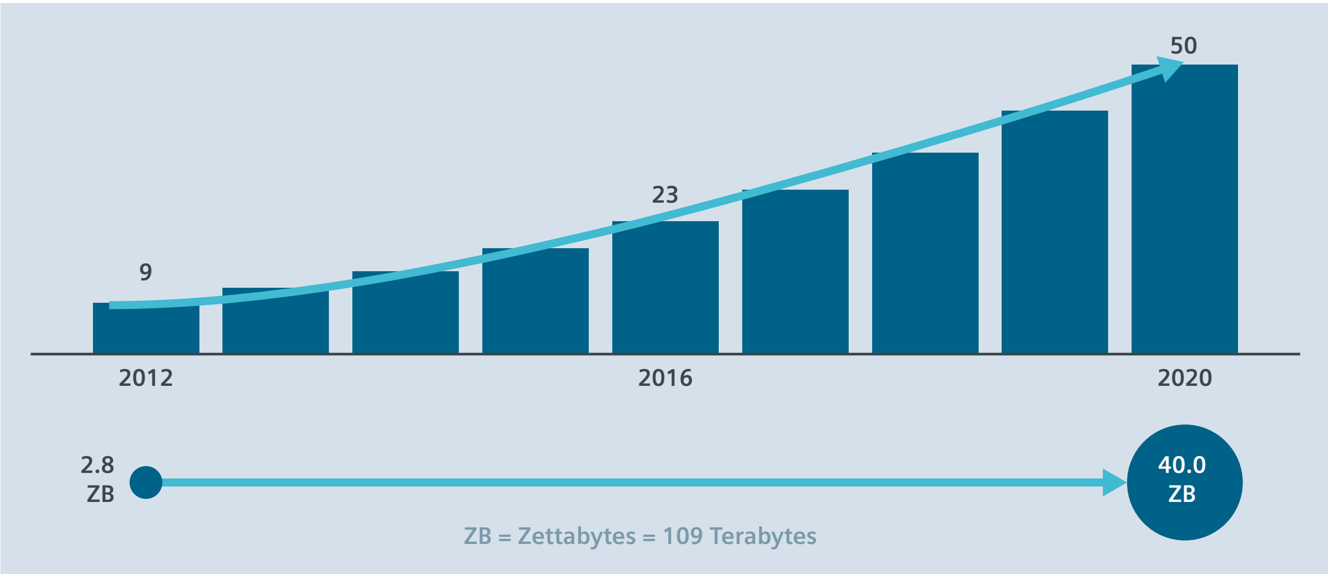


Figure 1: Digitalization is a major factor in the surge of data traffic

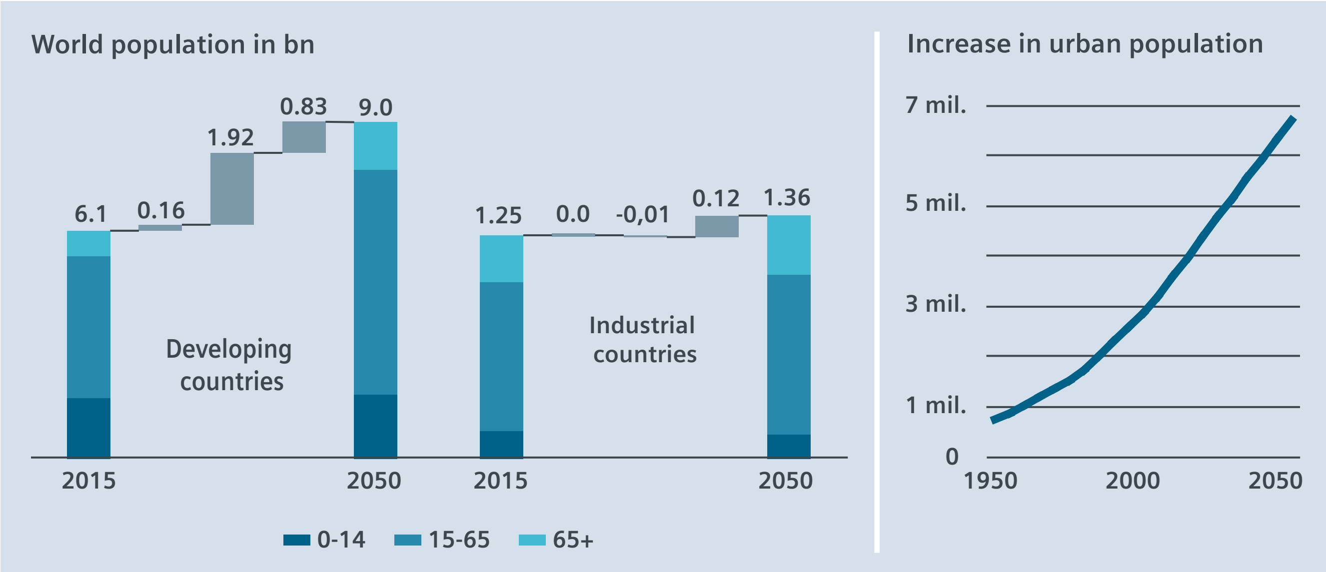


Figure 2: Demographics and urbanization are global megatrends that increase data traffic and drive the growth of the data center industry

Today, on-site power generation based on gas turbine technology provides the answer to all these requirements. The technology has evolved to the point where it can match the ramp-up times of legacy emergency power systems. And it also provides the more reliable and cost efficient, better-quality, and lower-carbon power generation option compared to the power from the local grid in many regions of the world, with very limited local pollutant emissions.

Reliable electricity in the grid is one of the basic drivers for maximum uptime in data centers and, in addition to costs, thus becomes the strongest argument for on-site power generation based on gas turbines. Their high operational flexibility and stability also allows the integration of a high share of renewables to further reduce the carbon footprint.

Cost saving can be achieved by on-site power generation based on gas turbine technologies in terms of eliminating expenditure for grid power and paying a lower price for highly reliable gas, by optimizing the carbon taxation or reducing the grid fees.

In cases where data centers expand rapidly, modular on-site generation capacity is also vital for ensuring sufficient power supply without overstretching the local grid. In addition, gas turbines are a smart, future-proof solution that is suitable for the transition into a carbon-free economy.

Already today, they are capable of using a significant share of hydrogen in their fuel mix, and they will be able to run on 100 percent hydrogen by 2030[4)] – and burner retrofits ensure that these capabilities will be available to all previous gas turbine models. The next chapter will delve deeper and explore the full potential of gas turbine technology for the data center industry.

▸ **Data centers have evolved into the factories of the 21st century, and they are very much driving the demand for energy. As such, they require dedicated, customized industrial power generation solutions.**

2. Gas turbine technology customized to data centers' needs

The previous chapter has outlined the data center industry's main requirements: availability, scalability, cost-efficiency, and decarbonization. Another pressing concern that needs to be taken into account in many projects, however, is the limited available space on location at modern data centers. Thus, power density is a further important criterion for certain developers and data center operators.

These requirements imply a whole new set of parameters for power generation design. Previously, when planning, e.g., for 70 or 150 megawatts of power generation capacity, one might have safely considered a large combined cycle power unit, with one large gas turbine and one steam turbine.

But the need for availability and scalability of power in data centers necessitates a set-up with a higher, redundant number of smaller gas turbines that can be installed and operated when required. As a substantial part of a data center's energy is used for cooling, the use of available thermal energy to produce cooling or additional power also needs to be factored in when designing the power generation.

Fortunately, gas turbine technology is flexible enough to allow adaptation to these requirements – while also producing much less carbon emissions than the sources traditionally used to power data centers. Natural gas-fired power generation already emits less carbon and other emissions than the grid average of most nations. A further reduction of the footprint can be achieved in combined cycle operation and by using bio-fuels or green hydrogen in combustion.

Gas turbine technology is designed to combine high availability and efficiency with operational flexibility and a very high power density. This is why, e.g., the aerospace industry changed its standard drives from combustion engines towards gas turbine technology.

The most basic set-up for power generation is the open cycle power plant, which consists of a gas turbine powered by a fuel that is converted to thermal energy. This energy is transferred into a mechanical moment, which drives a generator to produce electricity. The generation equipment provides low losses and a high power density, expressed in terms of megawatts produced per square meter. In the interests of achieving the best compromise between costs and efficiency, the thermal energy remaining

Good to know: The working principles of a gas turbine

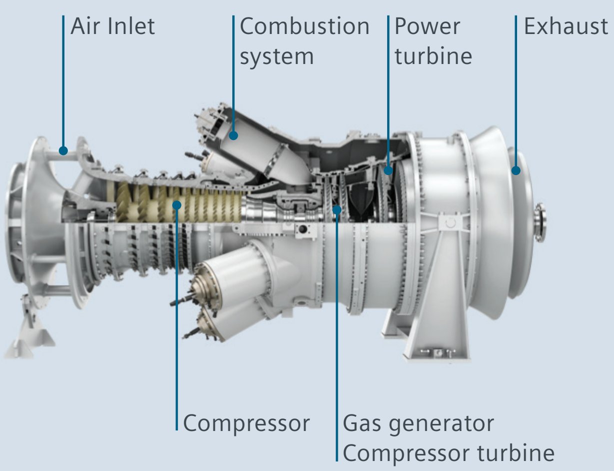
Initially, filtered air is sucked into the air inlet and compressed by the rotating compressor blades to 20–25 bar; in aeroderivative gas turbines, the air is even compressed up to 40 bar. Thus, the air is heated to approximately 400 degrees Celsius before entering the combustion area.

Then the combustion system injects the fuel and mixes it with the incoming jets of pre-heated, high-pressure air, and burns the fuel-air mixture at approximately 1,500–1,700 degrees Celsius in a controlled manner. The hot and pressurized exhaust gases drive the compressor and power turbine while expanding and cooling down.

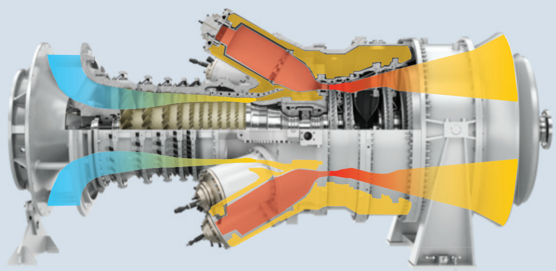
This results in a rotation force that drives the generator to produce the electricity.

When reaching the exhaust, the air will not yet have cooled down to ambient temperature, but exits the gas turbine with a temperature in the range of 450–600 degrees Celsius. This waste heat lends itself to further energy extraction.

Gas Turbine Components



Gas Turbine Princible



		Electricity	Typical fuel utilization
Simple cycle Gas turbine with boiler 	Max. power density Modularity & redundancy	33-43%	33-43%
Combined cycle Gas turbine with boiler and steam turbine 	Max. el efficiency OPEX & performance	48-58%	48-58%
Combined heat and power Gas turbine with boiler 	Max. fuel utilization OPEX & less emissions	33%	75-85%

Figure 3: Different gas-fired power generation applications for data centers

in the exhaust as waste can be put to further use for energy extraction or conversion.

Combined cycle (CC) technology additionally increases electrical efficiency by more than 15 percent by using the waste heat from the gas turbine to produce steam in a heat recovery steam generator (HRSG), which powers a steam turbine. This ingenious set-up requires slightly more space, but generates the highest amount of electricity from the fuel combusted in the process. Electrical efficiencies of up to 63 percent and more might be achieved.

But there are further ways to use the waste heat from the gas turbine combustion process. Following the HRSG, the waste heat can also be used in an absorption chiller, where a cooling medium evaporates, extracting the calorific energy and cooling the system – much like any conventional refrigerator in a private residence, but driven by heat as an energy source. This medium can be used for cooling data centers with their energy-intensive processes and hardware.

By making the calorific energy directly available for the data centers' cooling cycle – which traditionally consumes approximately half of the electricity used in such assets – this absorption technology substantially reduces data centers' electricity demand (see infobox on page 4).

Accordingly, gas turbine technology meets the requirements of the data center industry through a number of different applications:

- Open cycle set-up provides electrical efficiency and typical fuel utilization of 33 to 43 percent. This process offers the best power density, i.e., maximum generating capacity per area, and provides the highest availability ratings due to modular design.
- A combined cycle set-up, in turn, achieves electrical efficiency and typical fuel utilization of 48 to 58 percent. It can utilize an electrical chiller for cooling and offers benchmark levels of electrical efficiency, as well as low OPEX.
- At 33 percent electrical efficiency, a combined heat and power (CHP) set-up with cooling capacity, using gas turbines, HRSG, and an absorption chiller achieves the same basic electrical efficiency as an open cycle set-up. However, by utilizing a large share of the calorific energy, fuel utilization under a typical scenario stands at an industry-leading 75 to 85 percent. This is a perfect fit for hot regions with ambient temperatures of more than 30 degrees Celsius.
- Additionally, a combination of CC and CHP solutions can be implemented in regions with a low additional cooling demand. In this case, the HRSG will provide the steam for transformation into power in a steam turbine, using the waste heat of that process to drive an absorption chiller. This solution achieves an electrical efficiency of up to 58 percent and an overall fuel utilization of up to 85 percent (Figure 3).

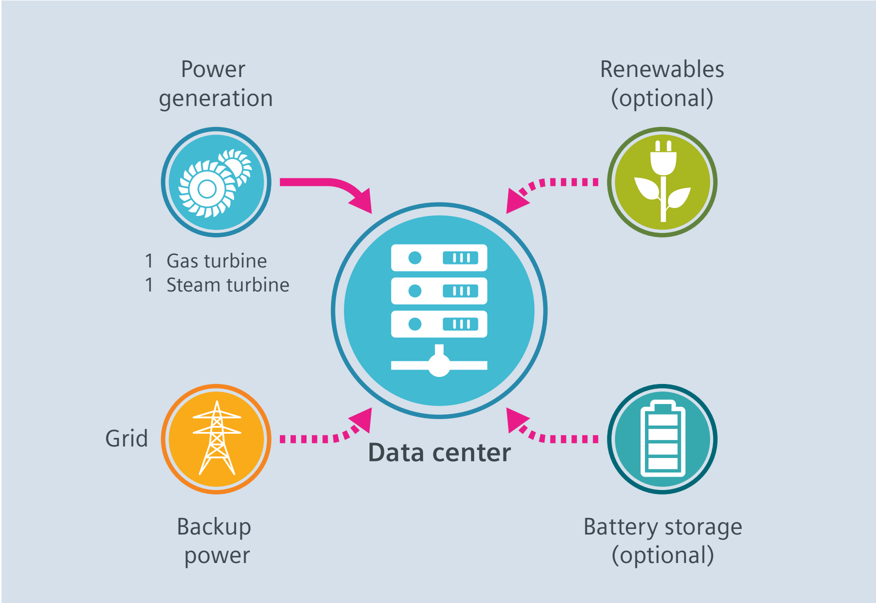
To sum up, on-site power generation using gas turbine technology offers exciting prospects for data center operators because it can balance out the increasing unreliability and fluctuations in the power grid caused by inverter-connected generation technologies. A failsafe performance can be ensured by redundancy. In addition, in most regions, the gas grid is much more reliable than the power grid. In terms of sustainability, gas turbines offer the highest levels of fuel efficiency in combined cycle mode or in a CHP with cooling set-up. Furthermore, they provide high power density and, crucially, high-quality power.

Due to the high quality of the electricity generated, gas turbines also allow renewable power generation to be integrated in a reliable fashion to improve compatibility with environmental considerations. With the operational flexibility of turbines, the residual load can be generated as required – and by providing real inertia for frequency stabilization, the design of the uninterrupted power supply (UPS) system can be cost-optimized compared to a grid-supplied solution.

▶ **State-of-the-art gas turbine technology ideally matches the needs of data centers – from initial planning and installation to maintenance and service. It offers a competitive advantage over the use of local power supply.**

Considering these technological principles, three different scenarios have been analyzed for large data centers:

1. Located in moderate ambient conditions with a stable grid supply providing a high availability
2. Located in hot ambient conditions with insufficient grid backup
3. Located in hot ambient conditions, placing a premium on reducing the need for cooling energy.

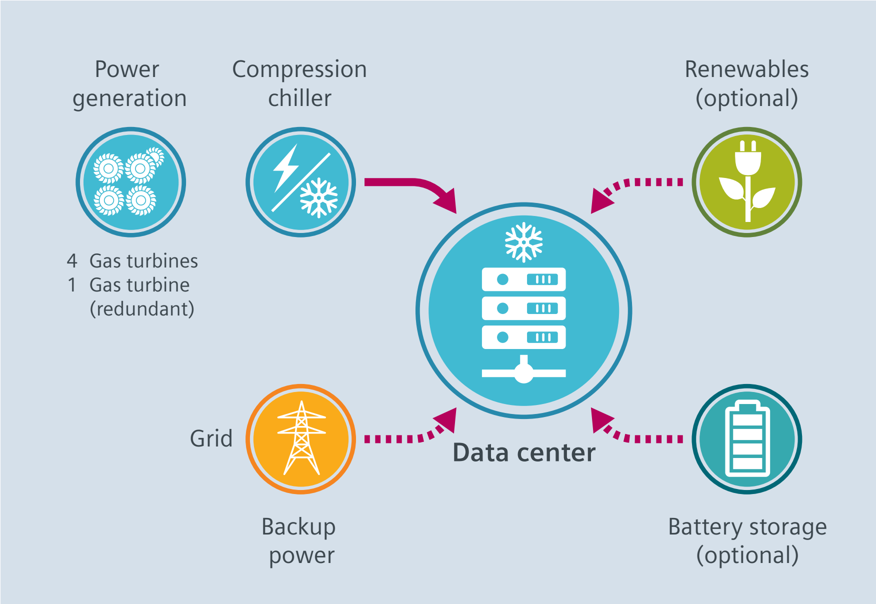


Scenario 1: Reliable on-site power generation in moderate ambient conditions

Picture a huge, well-established data center in North America or Europe, with a correspondingly high electricity demand. The grid might be available but, for the power consumed from the grid, high fees need to be considered. Sufficient space is available.

A project like this would require the best possible electrical efficiency, while expectations for system redundancy will be low because the operators can always fall back on a reliable grid that ensures a high availability of the asset in question. All indicators point towards a main power supply with a combined cycle power plant. This is a viable business case in places where gas is comparatively cheap and electricity tariffs are high.

A solution with one gas turbine plus one steam turbine would offer the highest power density combined with high fuel efficiency, resulting in low fuel costs. The gas turbines emit low levels of greenhouse gas (GHG) as well as other emissions; a comparatively high share of renewables could be integrated to reduce the data center’s carbon footprint even further. In the unlikely event that one gas turbine should fail, the data center will have to use the backup grid access. To increase redundancy, an optional battery energy storage system could provide power within under 5 seconds, which might reduce the use of the UPS and can also render an emergency system unnecessary.



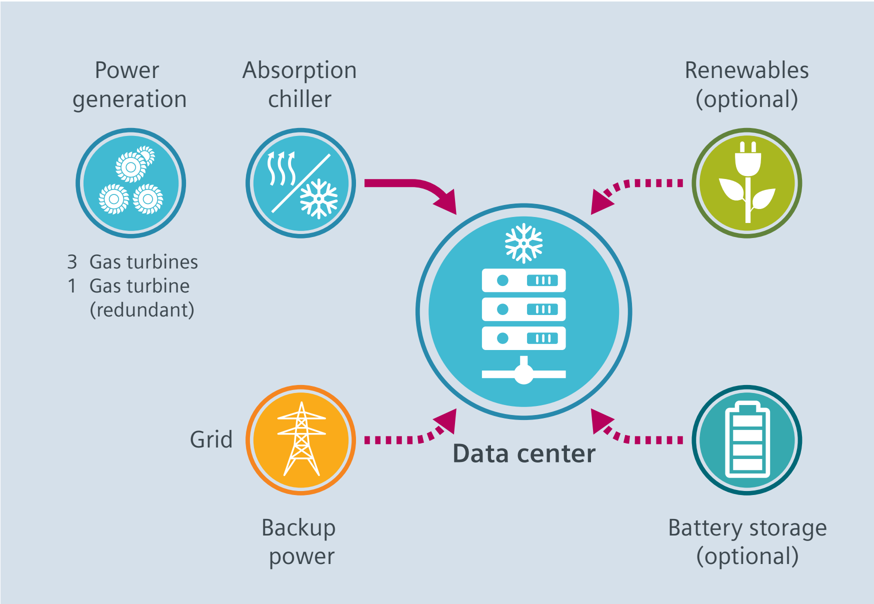
Scenario 2: Reliable on-site power generation in hot ambient conditions

Imagine a data center located in ambient conditions that require active cooling. The grid might not be able to supply sufficient or reliable power for the operation, or the power prices may be high while fuel prices are low. If the grid is not reliable, the on-site power generation will need to feature at least an (N+1) redundancy or higher, since any power equipment will need to be shut down for maintenance at some point.

This scenario envisages using four smaller gas turbines plus a spare one for backup that can be ramped up at any time. The required cooling is generated by redundant compression chillers. This additional power will need to meet the same standard of availability as the operation of the data center. Because the main power supply is the on-site generation, the demands on the power quality are high.

However, since gas turbines operate with high inertia, and the connected generator can be operated in a large range of reactive power, the variations of frequency and voltage can balance out locally generated renewable power while ensuring a high quality of power at all times. The asset's availability could be improved even further with an optional battery energy storage system.

Due to the modularity of the generation solution, the equipment can also be built in segments as the data center grows. In this case, it is important to consider the required availability already in the development phase. The data center can be scaled in minimum steps equivalent to half the gas turbine rating.



Scenario 3: Reliable on-site power generation in hot ambient conditions that radically reduces energy demand

The third scenario has the same requirements as envisioned in the second scenario.

This time, the solution has been optimized for best fuel utilization and minimal power demand in moderate to high ambient temperature locations. For this set-up, instead of fueling a steam turbine in combined cycle, the steam is used to operate an absorption chiller. The calorific energy extracted from the absorption process would be used in active cooling. In this scenario, the power required for compression chilling is no longer necessary. The fuel utilization can be boosted, and the equipment generating the electricity required for compression chilling can be dispensed with.

Accordingly, one less gas turbine would be required to power the same amount of data storage capacity as in the second scenario. The absolute amount of electricity generated would be lower – but fuel efficiency would be higher, making this set-up a winner in terms of sustainability: Due to the lower power demand, the power usage effectiveness (PUE) can be reduced. Again, this data center can add generating capacity as it grows.

Based on these application scenarios, what are the most important strategic considerations for data center operators? The design of a data center power generation solution depends on the priority of requirements.

If the most important requirement for data center operators is space – because space is at a premium and should be used chiefly for the operator's primary business, i.e., storing data – then power density is essential.

If the prime concern relates to fuel efficiency, then the solution of choice should be one that implements absorption cycle technology. As detailed above, further technological adjustments can be made to attain higher levels of reliability, efficiency, or sustainability.

Availability, however, is not negotiable in the data center business. Accessibility of up to 99.9996 percent must be guaranteed. This equates to a maximum downtime of just 25 minutes in one year. New data centers even have to guarantee that downtime does not exceed 2.5 minutes per year.

For complete security, uninterrupted power supply (UPS) would only need to bridge the time until the next gas turbine is started up, which can be as little as just one minute. In addition, due to the high availability and reliability of gas turbines, an increased redundancy with an (N+2) or (N+3) concept might even make diesel gensets as backup power obsolete.

▶ **If gas turbine technology can assure this degree of availability, data centers with gas-fired power generation will need only minimal back-up systems or none at all.**

How can availability be calculated?

The availability *av* is the probability of an equipment's uptime. In case of one unit, the unavailability *uav* is defined as

$$uav = \frac{\text{planned outages + unplanned outages}}{\text{overall time}}$$

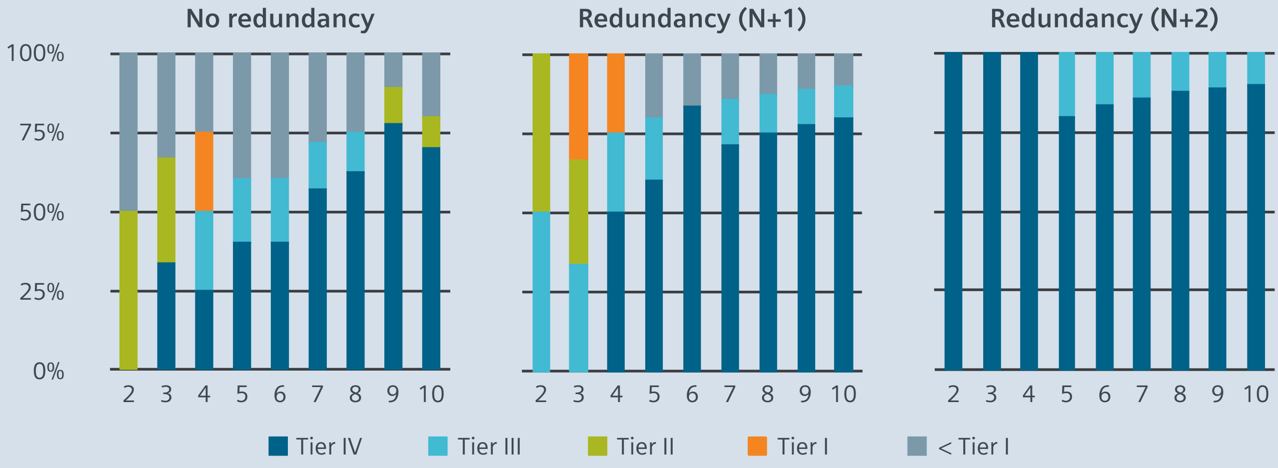
If more than one unit is installed, only the unplanned outage must be considered to calculate the unreliability

$$ure = \frac{\text{unplanned outages}}{\text{overall time}}$$

In the case of a redundant unit (N+1)-concept or higher, the starting reliability sr of the redundant system must be considered

$$sr = \frac{\text{number of successful starts}}{\text{number of attempted starts}}$$

Based on these definitions, the availability of the generation equipment can be calculated. While the probabilities for the different units and concepts vary, the following guaranteed availability for the tier levels can be offered based on an N, (N+1) and (N+2) concept:



Share of Tier levels which can be guaranteed depending of the number of generation units installed (between 2 and 10)

3. Lifecycle management of on-site power generation solutions

Having examined the different main technological possibilities of gas-fired power plants in the previous chapter, this part will be concerned with the planning and design, construction, and operation phases – in short, the whole lifecycle of the power plant.

Generally, data center operators will prefer to focus on their core business of operating data centers – designing, building, and servicing power generation infrastructure is not part of their typical area of responsibility.

This is where the Original Equipment Manufacturer (OEM) professionally supports with an advisory service - the Original Equipment Consultancy (OEC) approach. On the basis of sound knowledge and understanding of the operator's requirements and processes across the entire lifecycle, new value will be created. With the collection of external, technical and commercial data as well as a holistic analysis, the energy system is individually optimized and/or customized business models are developed. This positively affects availability of power, reductions of operating costs and decarbonization, to build and operate on-site power generation.

Data centers are certainly not the first industry to take power generation into their own hands: similar requirements have motivated various other industries with comparable needs in terms of availability, reliability, and quality of power – e.g., the oil and gas industry, critical infrastructures like hospitals, industrial parks, or municipal utilities – to seek out on-site power generation solutions. So how is it done?

Implementing an on-site power generation solution can be sub-divided into three steps – planning, building, and operating.

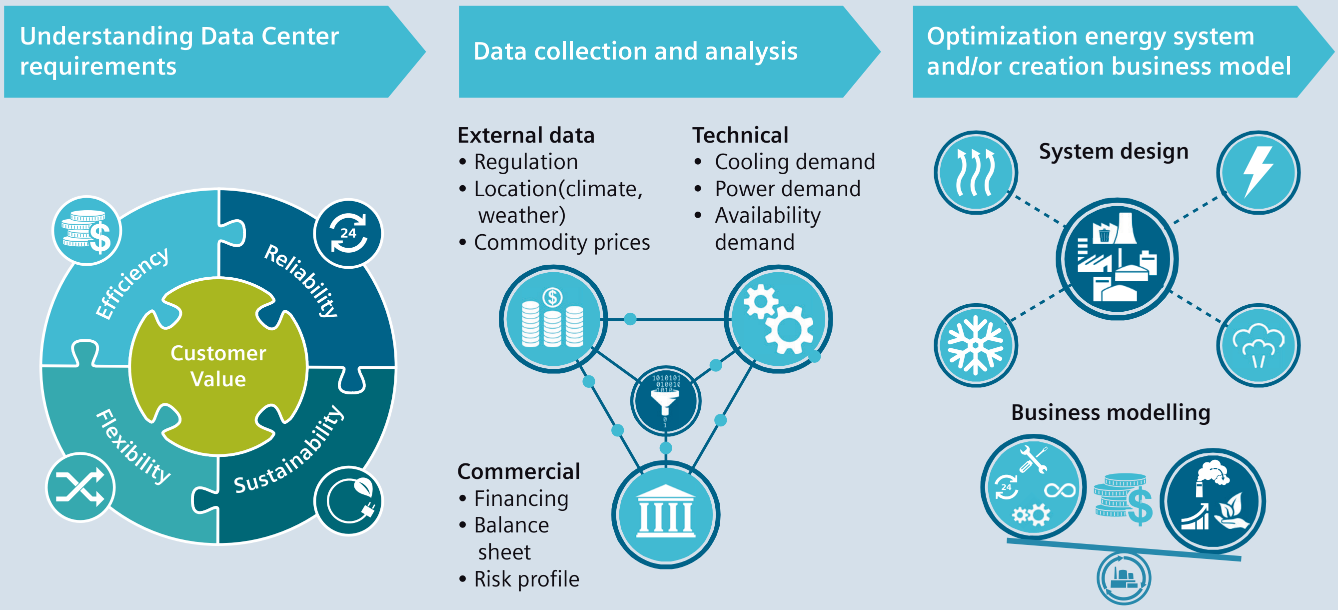
The first step is to work with a developer or an equipment consultant to gauge the scope and purpose of the power generation solution for the given site, and to design and plan it accordingly to initiate the permitting process. The goal is to identify the most suitable economic and technical solution.

Another important evaluation criterion for most projects will be the power density of the solution. As data centers are usually built close to critical com-

Original Equipment Consultancy: Value creation through customized solutions

Siemens Gas and Power Original Equipment Consultancy (OEC) combines a thorough understanding of the customer's competitive requirements with an expertise in heat-driven process industries and implementation know-how that only an OEM can provide.

In the OEC process, the sound analysis of the individual customer's technical, commercial, and external data forms the basis for a customized power generation solution designed to fit the customer's specific business case. This design process results in an optimized energy system and a business model adapted for enhanced competitiveness.With OEC, customers get all the support they need for the successful step-by-step implementation of an on-site power generation solution from a single source.



putational infrastructure, space is very often limited. Hence, the less space the power equipment will require, the more space will be available for the operation of such a facility. In most cases, a higher initial expenditure or lower electrical efficiency might still result in higher profits if operators choose the equipment with the highest power density.

Once the main options are identified, the planning and permitting phase should be initiated. The availability of fuel and water must be ensured; a grid connection must be planned in case of power surplus or low temperature waste heat; and financial aspects have to be evaluated.

During the permission phase, it is crucial to consider the local requirements for gas emissions. The overall impact on the greenhouse effect must be evaluated, also taking into account unburned hydrocarbons, which have a much higher impact than CO_2. Local regulations might also vary concerning hazardous gases such as NOx, SOx, heavy metals, particulate matter, etc. In addition, various regulations and requirements for operating power plants have to be observed – in general, they relate to environmental requirements, in particular regulations applicable in residential areas. All in all, power generation based on gas turbine technology provides the lowest environmental footprint across all generation technologies. In most instances, cost-intensive catalyst technologies are no longer necessary.

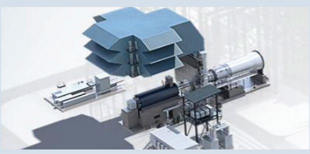
To offer the best possible support in this early phase, the equipment consultant or OEM needs to understand the technical, site-specific, and commercial requirements of the data center operator or developer in order to find the right solution that complies with all applicable regulations.

As discussed in the previous chapter, gas-fired power generation solutions can be customized to many different application scenarios and ambient conditions.

▶ **In a nutshell, the planning and permitting phase is about technical, business-related, and operational consultation with the purpose of designing a power generation solution and creating a corresponding business model.**

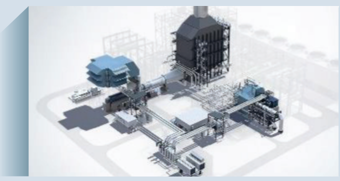
Typical OEM scopes of delivery of on-site power generation solutions

Power package:
If a third-party EPC is chosen, the OEM may deliver the gas turbine (GT) and steam turbine (ST) and the corresponding generators, the fuel gas system, and electrical equipment. This power package can then be integrated into a new or existing power plant by any EPC.



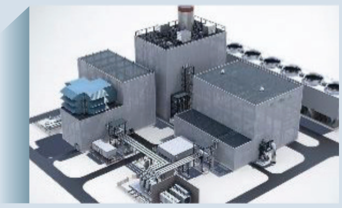
- GT and ST packages incl. auxiliaries
- Fuel gas system
- GT and ST generators incl. auxiliaries
- Electrical and I&C

Power island:
If the EPC requires a larger scope of delivery, the OEM can also deliver the whole set of combined cycle technology, including the heat recovery steam generator (HRSG) and condenser, as well as the substation. This would ensure that the OEM's know-how from many projects and years of operating experience is integrated and the different components are optimized across all technologies and interfaces.



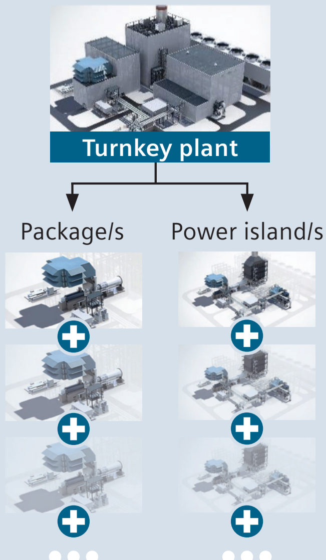
- HRSG
- Condenser
- Feed pumps
- Fuel pre-heater with filter, metering station etc.

Turnkey power plant:
Finally, as the most comprehensive offering, the solution provider can also construct and deliver the entire power plant, turnkey-ready. Here, the OEM is in charge of the entire planning, engineering, procurement, construction, and commissioning process – including buildings, roads, and other infrastructure.



- Plant cooling systems
- Water treatment
- DCS
- Buildings/structures

Modular expansion:
Of course, the generation capacity of an existing power plant can be expanded at any time by adding further power islands or power packages. This method is well-established and has been implemented for various types of customers with high expectations regarding flexibility and availability.



Grow as needed

Depending on the project requirements, customized scopes and power generation solutions are available for all purposes and customer requirements

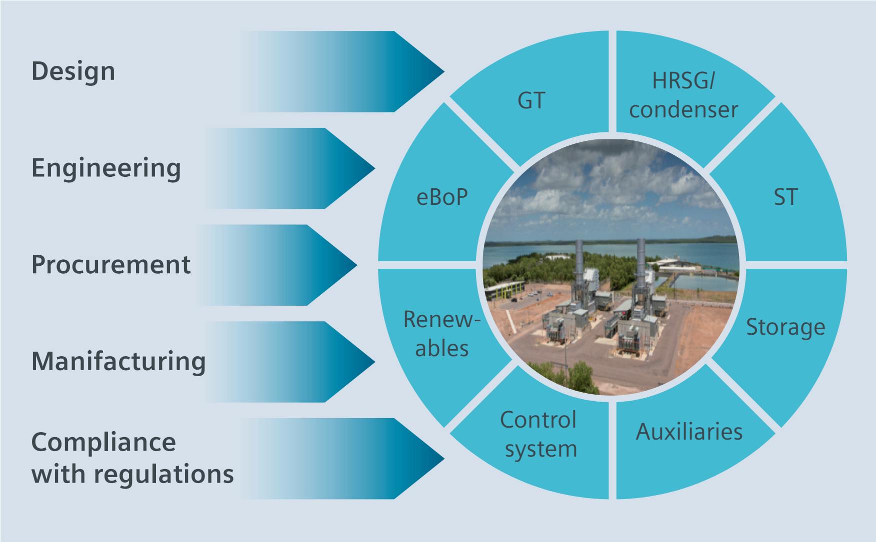


Figure 4: EPC is about the seamless integration of different areas of expertise to ensure smooth and speedy project implementation

Once the appropriate type of power generation solution, as well as its scope, has been drafted and evaluated, the next step is Engineering, Procurement, and Construction (EPC). Here, the implementation of the power generation project is planned and executed. The EPC scope can be provided by the OEM, but also by an established EPC company that works in close cooperation with the OEM. Depending on the scope of the solution, it may encompass anything from the ordering, delivery, and installation of equipment to the entire construction site management and erection of all required infrastructure, including the commissioning.

In the engineering part of EPC, the design of the power plant is detailed and finalized, and all preparatory engineering executed. In this process, the entire power generation solution has to be aligned, which may include a gas turbine, HRSG, and a steam turbine, as well as fuel storage, auxiliary systems, electrical balance of plant, pollution reduction devices, the control system, and potentially also the integration of renewables.

Attention must also be paid to noise emissions in order to comply with the noise exposure thresholds that apply to the data center staff and possibly also local residents. To this end, expensive enclosures or passive noise reduction walls have proven effective across the whole frequency range of noise emissions.

The procurement process, in turn, is designed to ensure that parts and equipment arrive on time during construction to avoid costly storage. The same sequential precision applies to the manufacturing, erection, and commissioning of the rotating equipment in order to start generating electricity – and thus value – shortly after purchase. Following the commissioning phase, further adjustments are made during a multi-year warranty period to ensure the best possible operating parameters.

This entire process needs to be managed with precision and pragmatism to ensure speedy, high-quality project implementation. By choosing an OEM as a partner, data center operators can rely on industry-leading know-how in relevant EPC (see figure 4).

▶ **In a nutshell, EPC is all about the seamless implementation of the power generation solution and encompasses five main areas – design, engineering, procurement, manufacturing, and regulations.**

Finally, the third and most important phase is the commercial operation and maintenance (O&M) of the power generation equipment. During this phase, the operation conditions are monitored and adjusted to changing conditions, management systems are integrated, and a maintenance plan is rolled out in order to ensure availability of the generation capacity and, hence, of the data center. As with any engine, the way to get the best performance and the longest service life out of the equipment is to run and maintain it professionally and diligently.

In O&M, the advantages of redundancy in power plant design really come into play. The resulting flexibility ensures the required capacity of power generation even in disrupted operation conditions or in back-up generation mode, as well as during the maintenance measures.

Should one turbine package experience an unplanned outage, the redundant, not spinning unit can be ramped up in less than 20 minutes (fast tur-

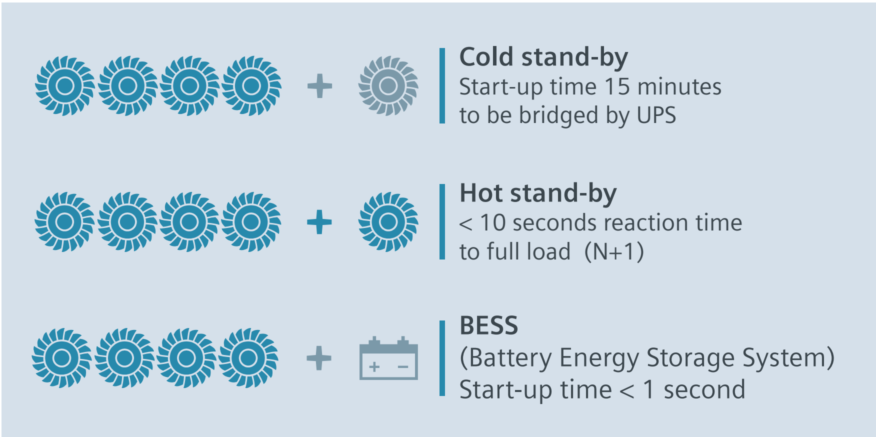


Figure 5: Impact of the operation mode of the redundancy system on start-up time

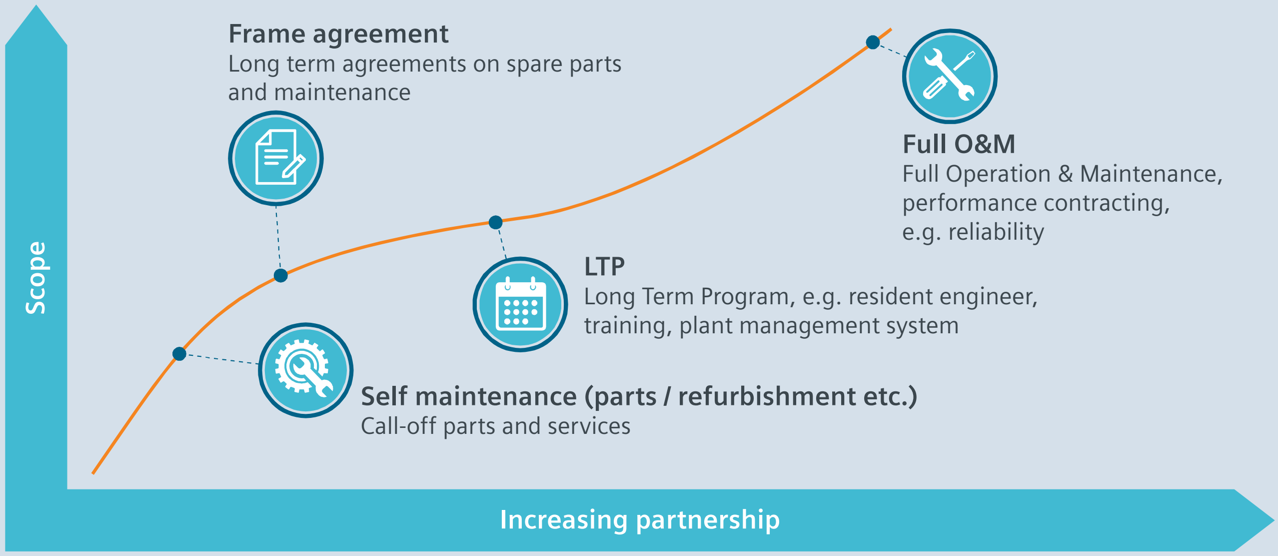
O&M service packages

The low-key option is **self-operation and -maintenance**: Strategic spare parts are part of the original scope of supply, call-off parts are guaranteed to be available within a defined period of time.

A **frame agreement** offers a longer-term contract with an Original Equipment Manufacturer (OEM) to ensure the sustained availability of spare parts and maintenance services.

A **Long Term Program** (LTP) additionally includes training packages for employed or contracted operators, resident service engineers, and/or operators, as well as a remote plant management system. It also ensures access to the latest retrofits for performance and fuel flexibility upgrades.

It is also possible to hand over the **full plant Operation & Maintenance (O&M)** to a service partner or the OEM. A contract of this type would typically be based on guaranteed performance parameters, e.g., concerning capacity, reliability, and availability.



Different packages of service products are customized to the data center industry's needs

bine types even in less than 5 minutes). This gap has to be bridged by the uninterrupted power supply (UPS) system previously defined at the design stage. Optionally, a much less expensive additional battery energy storage system could be used that can make up for the loss in generation within less than 1 second.

The operating regime of the power plant can also be adjusted to realize cost savings in the UPS system. All (N+1) units can be synchronized and operated at partial load, with the option of increasing the performance to full load should one turbine unexpectedly shut down. In this event, the remaining units can increase their output within a few seconds to full load so the UPS system can be designed to bridge merely a few seconds.

This operating regime can also be used to reduce the risk of loss of availability during backup system maintenance. A (N+2) or higher concept would raise the availability of the on-site generation equipment to a level that could even eliminate the need for a backup system for the full power demand in operation and for maintenance. The preferred mode of operation depends strongly on the risk levels for the operation of the data center and the investment costs.

Naturally, each feature of major power generation equipment requires periodical and planned maintenance. Compared to other power generation technology, gas turbines are designed to ensure that the generation capacity and the data center's availability, reliability, and, of course, safety are never compromised. The auxiliary equipment necessary for the operation of the turbines and generators can also be designed redundantly so that they can be serviced during power plant operation.

The duration of maintenance work on major equipment such as the turbine, gear box and generator varies greatly depending on the scope. Minor inspections can be conducted in a matter of a few hours. A hot gas path inspection takes up to two days and involves an endoscopic inspection of the gas turbine. Major overhauls require the inspection and exchange of parts in one unit. They usually take up to two weeks' time if spare parts are available on site.

In order to minimize the outage of a single turbine package, one option is to replace the entire turbine and carry out the service offline, while operating the spare turbine. This process takes a maximum of 2–3 days and is already common practice in industries with high availability requirements.

However, in order to safeguard the system's redundancy, it must be ensured that a maximum of one package is in maintenance while the others are in operation, starting from the time of the maintenance measures (Figure 5).

- **In a nutshell, O&M is about ensuring smooth operation and the availability of power generation capacity at all times. Solutions in O&M are available in different scopes and with supplier partnerships of different intensity and duration suited to the specific requirements of a data center.**

Operating a power plant is key for a safe and reliable data center operation. Gas-fired power generation is a proven, highly reliable technology that has demonstrated its robustness in millions of hours of commercial operation in many critical industries and under all ambient conditions worldwide. Equally, the feasibility and reliability of O&M agreements in commercial power generation have been demonstrated in many applications all over the globe.

Ultimately, data center operators need to evaluate whether implementing on-site power generation is beneficial to their business model. Should power generation become a balance or off-balance sheet item?

To what extent should power generation become part of the data center business or will it be established as a business enabler in times of unstable grids and declining power quality in the grid?

The good news is that for any degree of involvement in the process, experienced OEC experts, reliable EPCs, and the corresponding innovative industrial power plant and O&M packages are available to ensure efficient and reliable lifecycle management of gas turbine-driven power plant equipment.

4. Conclusion

Figure 6: The benefits of on-site gas-fired power generation

The data center industry has grown to become one of the key pillars of our digitalized economy, and indeed our society; its reliability is of strategic importance to the functioning of critical infrastructure. This growth has come with an enormous responsibility and an increasing need for more, better-quality, and more cost-efficient electricity than most local grids can supply.

Just as other process industries in the past, the data center industry is now faced with the need to implement its own on-site power generation solutions to ensure the required availability level. Luckily, highly efficient and reliable gas turbine technology offers the answers to the industry's requirements, such as maximum power availability, power stability, power quality, and high power density.

Modular and scalable power generation design creates solutions that can be customized to specific local conditions and requirements, such as high ambient temperatures, limited space, high electrical efficiency, modularity for cost-efficient growth, or the integration of high shares of renewable energies.

Much like gas turbine technology itself, the planning, implementation, and operation and maintenance (O&M) of these on-site power plants is a proven process that has been applied by many industrial customers worldwide. Different construction and O&M packages, customized to the specific need of each customer, are available to ensure that data center operators will be able to find the support they need over the entire lifecycle of their gas turbine equipment.

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