Smart Power Generation for data centers

Using natural gas to lower emissions and create revenue

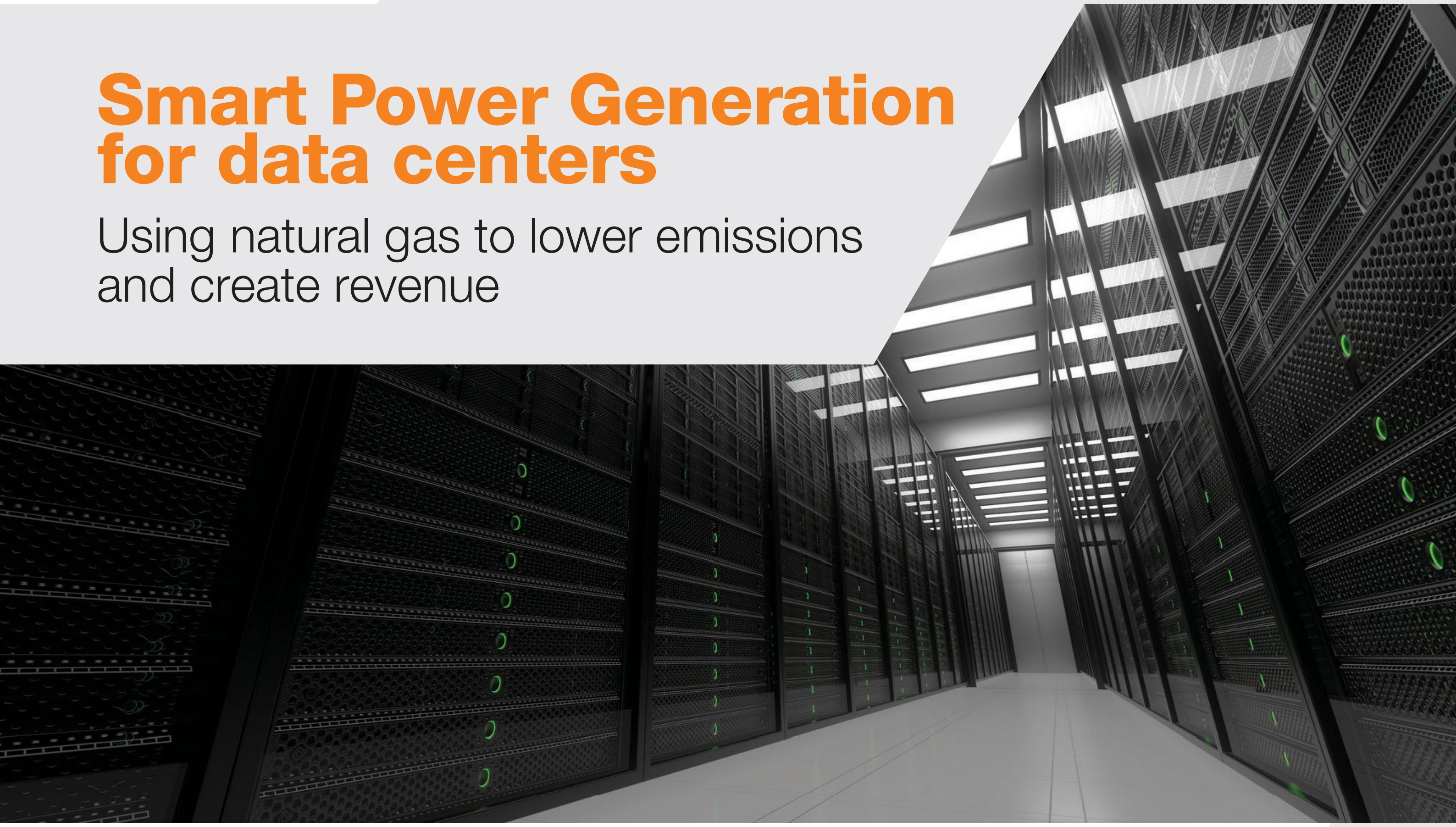

TABLE OF CONTENTS

1. Executive summary

Every data center needs extremely reliable, but also affordable power supply. Traditionally this is provided by a combination of grid electricity, ensuring affordability, and emergency diesel generators, guaranteeing reliability. Unfortunately this mechanism has certain drawbacks: from dependency on increasingly unstable power prices to high local emissions from diesel generators, which sometimes might even lead to problems obtaining environmental permits.

This paper describes a solution to those challenges – the use of modern gas-fired engines to provide affordable, reliable power supply. State-of-the-art gas engines are capable of starting up just as fast as diesel engines, but unlike those, they are able to competitively generate power not only in emergencies, thus recouping their costs and even generating additional profits.

The following sections describe the concept, technologies involved and key operational concepts for a modern gas-fired data center power plant.

2. Introduction

Data centers rely on a supply of electricity. In the vast majority of cases, data centers are expected to operate much more reliably than the power grids that supports them. Therefore practically every data center is provided with an on-site power generation facility to be used in the event of grid failure. This is normally done by installing emergency diesel generators, which are relatively cheap and involve simple and reliable technology, that can provide required power almost instantly. At the same time, they use fuel that is not environmentally friendly, relatively expensive in most areas of the world, and most of the time they just sit there doing nothing except generating costs. This is typically understood as a necessary cost of security, a type of insurance policy. Traditionally, emergency diesel generation has been the solution of choice for all sensitive facilities, from nuclear power plants to hospitals to chemical factories for many decades already, adopted long before the birth of IT sector as we know it. It gets the job done just as it did fifty years ago.

Yet in the second decade of the 21st century some things can be done smarter. Emergency power supply is exactly one of those things. This paper explains how to replace the cost of “diesel insurance” with a solution that both meets the same operational needs, but would also be a profitable and environment-friendly component of a data center project. The solution is actually very simple: it involves replacing the engine-generator sets suitable only for emergencies with ones able to operate efficiently whenever this makes economic sense, even continuously, if desirable. For this, of course, a change of fuel is needed: from oil to gas.

3. Emergency power supply – choice of technology

Selection of a power generation technology for reliable emergency power supply applications is severely restricted by quite extreme functional requirements. There are four essential ones:

- Very rapid automatic startup
- Modularity of capacity
- Ability to run on locally stored fuel
- Technological maturity

The first requirement stems from the need to provide on-site power generation as quickly as possible in the event of a loss of grid power supply. Of course no matter what technology is used, a certain gap will inevitably occur. This gap is covered by energy stored in some local storage system. Nonetheless, methods of storing electricity are still scarce and very expensive. In practice, data centers utilize Uninterruptible Power Supply (UPS) systems based on electrochemical batteries. They are typically dimensioned to last for a couple of minutes and are very expensive. Effectively this means that the power generation technology should be as fast as possible, ensuring that the battery system is only as big as absolutely necessary.

The second requirement comes from a need to have some spare or redundant generation capacity. Redundancy is needed, as components of an emergency power generation system will inevitably need certain maintenance procedures, just like any other machinery. Additionally, there is always a probability of failure. Hence, a good emergency power supply system needs spare capacity in a separate independent generator set, sufficient to cover the capacity lost due to maintenance or isolated failure. This leads to a preference for relatively (i.e. in relation to the total capacity) small modules for economic reasons: to ensure that redundant modules do not needlessly increase the investment cost.

The third requirement is a matter of independence – when trying to secure yourself against grid disruptions you do not want to be dependent on any other external system. Thus, the facility needs some locally stored fuel to ensure an uninterrupted supply for certain amount of time until the external power supply can be restored.

Finally, the requirement of maturity is natural for a system where reliability is of fundamental importance.

Until very recently, there was practically only one answer to this set of requirements. First off, there used to be only two mature power generation technologies capable of starting up and reaching full or nearly full power within one minute: water turbines and diesel engines. Water turbines, while extremely agile, are only suitable for use in a few geographically-favorable locations. This left only diesels. The modularity requirement combined with typical data center power demands and the focus on the overnight costs of installation restricted this even further to relatively small high-speed diesel engines running on light fuel oil stored on-site.

Unfortunately, as mentioned in the introduction, this choice effectively means that in most cases an emergency power generation system needs to remain just that and nothing more. In most situations, local regulations (especially environmental), as well as economic conditions will not allow the operation of a diesel plant unless absolutely necessary. This is unfortunate, especially nowadays, when power grids with more and more intermittent renewables connected – such as wind and solar power plants, actually have an increasing demand for fast-reacting emergency or balancing generation, something which the emergency generators could, in theory, provide when the grid works normally.

So far, this functional limitation has been accepted as a fact of life and a result of natural technical limitations, and the related cost regarded as a necessary factor similar to insurance. However, technical advancement is about to change this.

4. The gas solution

Despite the technical advancement in many power generation technologies, a reciprocating engine still remains the only solution capable of meeting emergency power supply requirements. But such an engine does not have to run on diesel fuel anymore – now there is a cleaner and more economically effective alternative: natural gas.

Industrial reciprocating engines running on natural gas are not a new concept. Early machines of this type were used at the beginning of the 20^{th} century, but those were huge, bulky, low-speed machines with nothing in common with modern agile and flexible units. The development of gas engine technology as we know it today started somewhere in the 1980s. In the 1990s, it was already becoming quite popular in local distributed power generation, as it attained efficiency levels impossible to match for any other small-scale technology. In the early years of the 21^{st} century gas engine technology advanced further, earning an important place in a modern power system. Compared to other fuel-based technologies used in large-scale commercial power industry, gas engines are fast to start, cheap to build and extremely flexible. This led to widespread use in the role of intermediate-load or peaking power stations all over the world, not only in distributed generation, but in fairly large power plants as well: the largest engine power plant to date has an installed capacity of around 600 MW.

Fig. 1. Plains End power station in Colorado. This facility with a combined output of 231 MW is an example of a modern gas-fired commercial power plant based on gas engines. It has been in operation since 2001 (section I) and 2006 (section II), providing a way to balance unstable wind power output.

Yet until quite recently gas engines had a major flaw compared to diesels: the starting time. While ten minutes – the state of the art just a few years ago – is very impressive in the world of commercial power generation and faster than any other technology except diesel or hydro, for an emergency power generation system this would be way too slow. In fact, this is more than ten times slower than any decent emergency diesel generator.

However, during recent years, huge progress has been made in this area. In general, the increasingly volatile electricity markets have forced equipment vendors to improve the flexibility of all power generation technologies, but in case of the gas engines the progress has been perhaps the most impressive. Over just a few years, standard series-built medium-speed gas engines had their start-up times reduced from ten minutes to just two. This was still longer than diesel, but the difference was no longer an order of magnitude. And even this has been further reduced by now. Recent development and testing has conclusively demonstrated that state-of-the-art gas engines may be started and brought to full power in considerably less than one minute of the starting order, which brings them within the world of emergency power supply. Exemplary and representative start-up sequences obtained during actual engine tests performed by Wärtsilä are shown in Fig. 2.

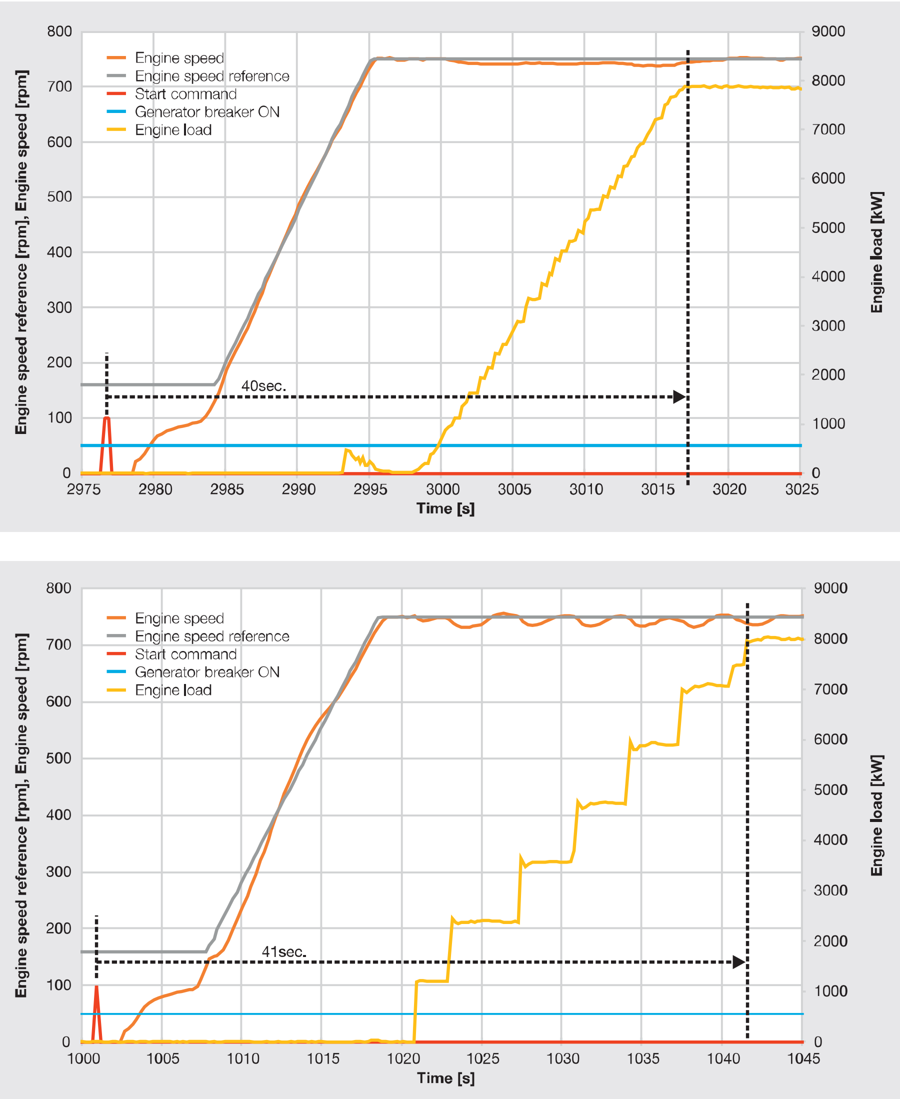

Fig. 2. Start-up curves of a modern medium-speed gas engine. These are direct screenshots from engine control systems and were made during tests of a rapid start-up of a medium-speed gas engine operating in island mode. The top diagram shows a case of linear loading, while the bottom one involved pre-programmed load steps. In both cases start-up duration (40 and 41 seconds respectively) is measured from the start command until full output. Testing was performed in island mode.

Of course, this still leaves the issue of fuel storage. However, recent progress has also been significant here. Recent years have seen emergence of small-scale affordable gas storage technologies, especially in form of liquefied natural gas (LNG). LNG systems have been adopted in various applications, notably on some ships, where gas is getting increasingly popular as environment-friendly alternative to fuel oils. Small-scale LNG storage and regasification plants are so reliable and safe that they are currently being installed on passenger ships.

Fig. 3. MS Viking Grace, a cruise ferry powered by liquefied natural gas, has been safely carrying passengers since January 2013.

Therefore, now and finally, diesel engines have an alternative as a source of backup power. However, adopting gas goes far beyond just providing a different equivalent solution. Natural gas is the "cleanest" of all fossil fuels. First of all, using gas means less CO_2. This is an inherent feature of natural gas as a fuel. The higher hydrogen-to-carbon ratio in its constituent compounds means that the exhaust gas contains less carbon dioxide and more climate-neutral water vapor. When combined with high efficiency of modern industrial gas engines (which is among the highest of all power generation technologies and higher than the diesel engines currently used for emergency power generation), this means that using electricity generated by gas engines has a considerably lower carbon footprint than using diesel-generated power. In fact, the carbon footprint is much lower than that of grid electricity in most countries. This means, operating the generating sets continuously instead of relying on grid would have a positive effect on the carbon footprint of the data center (see Fig. 4).

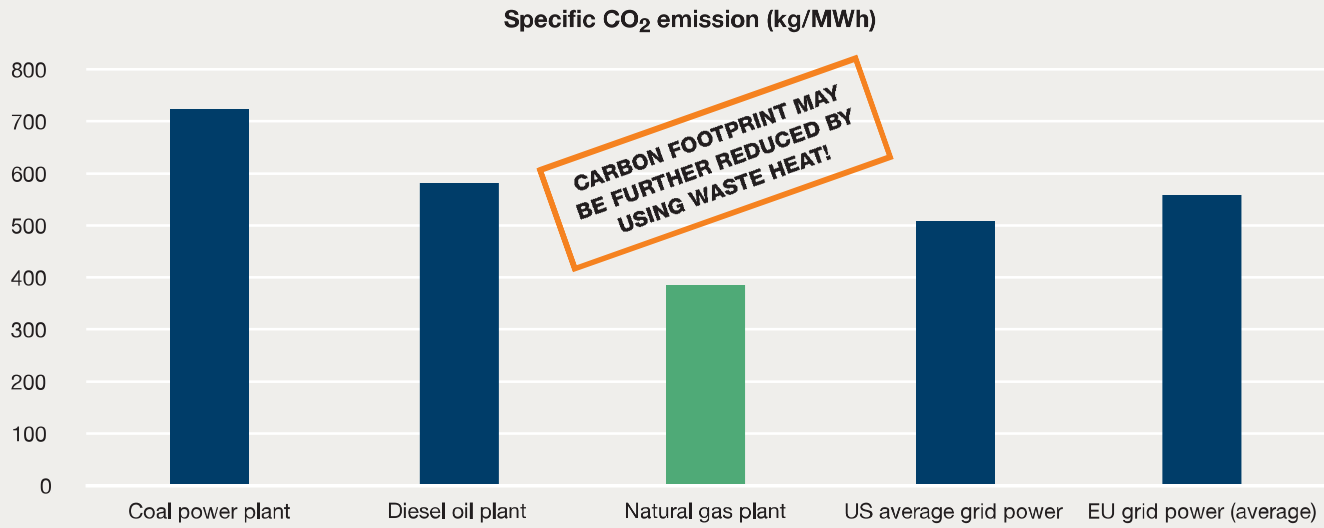

Fig. 4. Carbon footprint of different sources of electricity. Note that generating power with on-site natural gas power plant has lower footprint than the grid electricity.

Of course emissions are not only about CO_2. However, nitrogen oxide emissions from gas engines are also considerably lower than from diesels, and there is practically no emission of sulfur oxides (as natural gas contains no sulfur) or particulate matter (again – no sources in fuel) – see Fig. 5. All this, combined with the fact that in majority of the markets the cost of natural gas allows its use for commercial power generation, means that gas engines installed at a data center would not be limited to emergency power generation and could actually start earning money, as further explained in the following chapter.

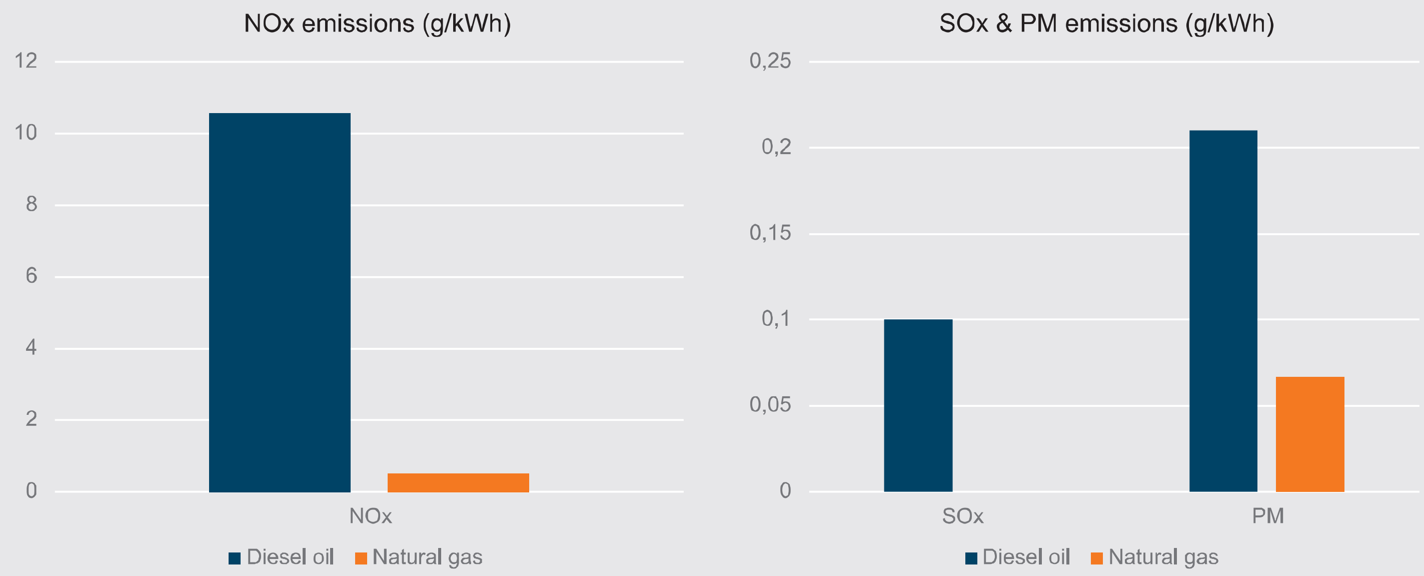

Fig. 5. Gas is a much cleaner fuel than fuel oil. Power generation from natural gas causes much lower emissions of all pollutants. Therefore, gas power plants may be freely operated not only in emergency situations. Note that the values provided are achievable with engine tuning alone; NO_X emissions may be further reduced using selective catalytic reduction (SCR) technology.

5. Beyond the emergency

Once an emergency power generation system is built using a solution that is neither legally nor technically restricted from operating beyond emergencies, there are two essential ways of using this capability:

- Self-generation
- Merchant operation

In either case, the power plant could be owned and operated by the data center owner or a third party, which would then conclude a long-term agreement with the data center owner. Let us take a closer look at those options.

5.1. SELF-GENERATION MODEL

Essentially an obvious concept – if the data center has a power-generation facility that can be operated continuously, runs on an inexpensive fuel, and has very low emission footprint, then it may be very well used as a primary source of power. Because of the way emergency power supply systems are normally designed – with capacity redundancy and concurrent maintainability[1] that ensures that capacity sufficient to cover the data center's critical load is always available – such a plant would be able to provide power supply without any interruptions, with the maintenance of individual pieces of equipment not interrupting operation. This approach would practically reverse the traditional way of operating a data center – now the local power plant would become the primary source of electricity, while grid would only be a backup.

This approach protects the data center operator against unforeseen changes in the electricity market, as well as the high volatility of electricity prices. At the same time in most power systems, it would considerably reduce the carbon footprint of the facility, as in most countries high-efficiency on-site power generation based on natural gas generates less CO_2 than the average value for grid electricity.

And this is not the end of the benefits. By its very nature, the power plant would have some redundant capacity, with at least one or two generating sets, and then some spare capacity, as normally data centers are not operated at full design load. Of course the most important function of the redundant capacity is to ensure that the components of the plant may be maintained without disrupting power supply to the served facility, however the maintenance procedures are relatively short, so most of the time redundant capacity will not be needed by the data center. During that time this capacity can be used to generate extra electricity and sell it to the electricity market, for example on the intra-day or real time market at exactly those moments when electricity is very expensive. This would create an additional flow of revenue to the plant operator.

While this plant would be able to provide the power supply to the data center literally around the clock, it would not have to be the case all the time. One of possible models of operation would be supporting power supply from intermittent renewable sources. This would allow the data center operator to conclude a contract for power supply from wind or solar sources; then the local gas-fired plant would fill the inevitable gap between the demand and supply at any given time, automatically following the difference between the data center demand and actual renewable power supply. This is exactly how some "wind chasing" gas engine power plants – such as the Plains End Station shown in Fig. 1 – have been operating in power systems for many years. It would be equally possible

[1] Concurrent maintainability is an ability to maintain each and every component of a system without affecting its ability to serve the critical load.

1. IPP or data center operator builds a gas engine power plant at the data center site
2. Power plant operates as the primary source of power, at the same time providing required redundancy.
3. Extra electrical capacity needed for redundancy is used to generate extra electricity sold to the market.
4. Optional heat recovery systems are used to generate cooling power for data center or heat for local consumers

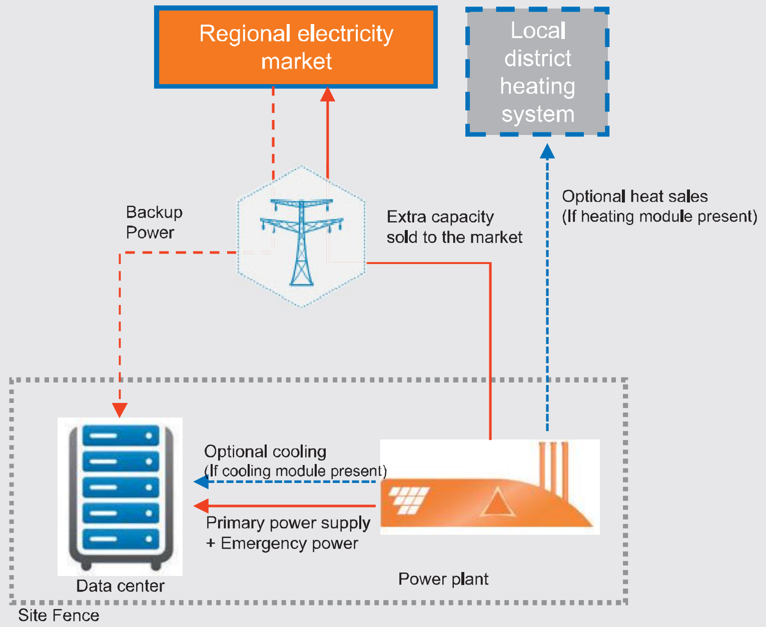

Fig. 6. The self-generation model for a gas-fired data center power plant.

to use the plant as a backup for high electricity prices in the local market, where the plant startup would be triggered by high procurement prices, with the grid supply being preferred when the prices are low.

Finally, there is the heat recovery option. When operating, an engine-generator set generates a lot of heat which, instead of being discharged into the environment, may very well be recovered for some practical application without any effect whatsoever on electricity production. Generally, there are two key possibilities:

- Hot water: a system of heat exchangers may be installed to generate hot water, used for heating buildings or industrial facilities. If there are heat consumers nearby, hot water can be sold for an additional revenue flow.
- Cold water: heat recovered from engine cooling and exhaust gases may be directed to absorption chillers, which use this energy to generate cooling power. This solution can be used to generate cooling for the data center itself, replacing traditional electricity-driven chillers and thus reducing the demand for electricity. It needs to be noted though that the absorption chillers are relatively expensive, so this solution is preferred for those facilities that really need forced cooling most of the time, such as in hot climates. Generated chilled water could be sold to external users as well.

In both of those cases, all additional equipment is built as engine-wise systems, which means that they do not affect the concurrent maintainability of the plant. They also may be freely bypassed so that potential failures would not inhibit plant's ability to generate electricity.

5.2. MERCHANT PLANT CONCEPT

1. IPP or data center operator builds a gas engine power plant at the data center site
2. Data center owner and IPP sign an emergency supply contract
3. Data center purchases electricity for data center from the electricity market
4. IPP operates the power plant on a merchant basis, selling electricity and system services to the market

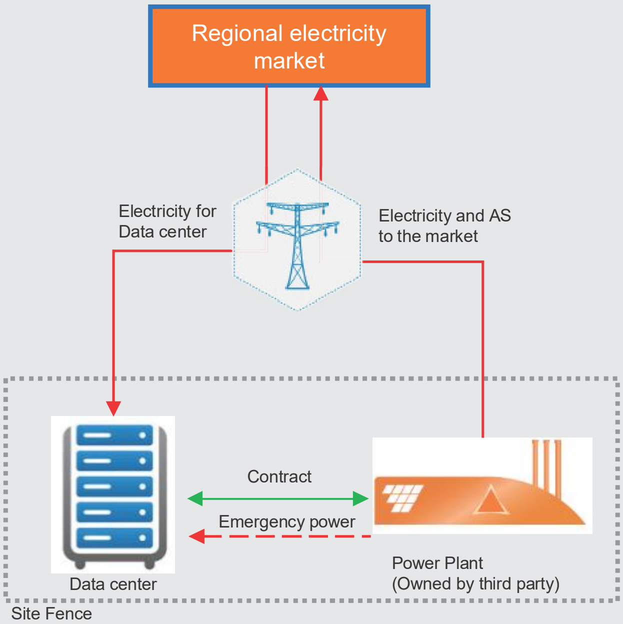

Fig. 7. Merchant plant model for the gas-fired data center power plant.

Alternatively, the gas-fired power plant can be used only as an emergency backup power source for the data center, while most of the time it would operate independently as a normal merchant generating station, selling its production to external customers. Thus, for most of the time it would act just like a normal gas-engine power plant, simply co-located with a data center. But in the event of any disruptions in the grid power supply, it would automatically switch to the emergency power supply mode. If the plant was not running, this would involve an immediate startup and feed the electricity directly to the data center. If the plant was generating, it would automatically disconnect from the grid and adjust its output to cover the data center needs, using its excellent loading and unloading characteristics. This solution is therefore primarily about getting additional flow of revenues using the new backup power equipment, while keeping the data center on grid supply. This might be a preferred approach for markets where wholesale prices of electricity are very volatile, enabling the profitable operation of peaking power plants, as the engine solution excels at this kind of application.

From the technical point of view, a self-generation plant described earlier and a merchant plant are absolutely identical, so the way of operating could be freely changed at any point of the facility's lifetime, according to changing market conditions.

5.3. SINGLE AND SPLIT OWNERSHIP

Regardless of operating model, the plant could be owned either by the data center operator or by a third party, who would then conclude a relevant long-term agreement with the data center operator. The latter option would allow data center operator to focus on the core business without the necessity to create a division specialized in power plant operations or electricity sales. Additionally, the cost of backup power facility would no longer be an overnight cost for the data center owner, but would rather be distributed over the years of data center operation. The incentive for the third parties would always lie in the long-term agreement. Even in the case of a plant operated most of the time as a merchant power plant, only providing backup power to the data center, the long-term backup power contract could make a big difference in project bankability. Thus, regardless of market conditions and prices – often seen as a big unknown and therefore a risk by financing institutions – the plant operator will always have a certain stable flow of revenues, sufficient to at least serve the debt. As a result, the risk of serious liquidity problems would be severely reduced. At the end of the day, it is a win-win scenario.

All the benefits for the parties involved for different operating models are listed in the table below.

SELF-GENERATION MODEL	MERCHANT MODEL
Single ownership – benefits for data center operator	
• Stable cost of electricity generation • Lower environmental footprint • Ability to combine the plant operation with power purchase from renewables • Additional revenues from selling extra electricity to the grid (using redundant capacity) • Ultimately, a lower cost of power supply (including backup)	• Cost of emergency power source replaced by revenue from electricity sales • Ability to sell electricity when wholesale market prices are the highest • Retained possibility to self-generate if power procurement cost gets too high • Ultimately, an offsetting cost of emergency power generation capability
Third-party ownership – benefits for data center operator	
• Outsourcing procurement and maintenance of all power generation equipment – ability to focus on core business • Emergency power generation sources removed from the investment cost • Procurement of power under a long-term power purchase agreement • Possibility to buy gas-and-renewable reliable power package, if the plant operator also owns wind power	• Outsourcing procurement and maintenance of all power generation equipment – ability to focus on core business • Emergency power generation sources removed from the investment cost • Ability to obtain lower lifecycle cost of backup power than owning dedicated generators, as the plant operator may use same equipment to generate revenues
Third-party ownership – benefits for the power plant operator	
• Power purchase agreement with the energy user – safe business instead of uncertainty • Good project bankability • Ability to offer a "renewable & gas" package to the data center operator in the event that the plant owner also owns renewable capacity	• Stable flow of revenues from the emergency power contract on top of normal power plant revenues • Reduction of business risk attributable to the long-term unpredictability of energy markets • Improved project bankability compared to a "normal" power plant project

6. Technology

Gas engine power plants operate according to the same general principle as emergency diesel facilities. Fuel energy is converted to mechanical energy of a rotating shaft in a reciprocating engine. The shaft drives a synchronous alternating current generator, and then generated electricity is distributed to the consumers. Functionally, a multi-engine power plant is essentially a set of individual single-engine power plants, with all of the equipment necessary for continuous operation being built as engine-wise. The special features of the gas engine technology and power plants dedicated for data center applications are discussed in more detail in following sections.

6.1. ENGINES

A gas engine is the heart of the solution discussed in this paper. Generally two types of gas engines are used in modern power engineering: high-speed and medium-speed. High-speed technology (where high speed means more than 1000 rpm, typical values are 1500 rpm for 50 Hz systems and 1800 rpm for 60 Hz systems) is used in smaller scale engines, up to some 4 MW per unit. Medium-speed technology (typically 750 rpm for 50 Hz and 720 rpm for 60 Hz) is used from some 4 MW and higher. There are following differences between those technologies:

- Medium-speed engines are somewhat larger and sturdier – they need larger volumes to achieve the same power output. This makes them also somewhat more expensive to construct and install.
- Medium-speed engines are much less expensive in maintenance. Also maintenance procedures are considerably less frequent due to slower wear of components.
- High-speed engines typically feature single-point gas admission system. Gas is fed into an air inlet duct before the turbocharger. This system, while simple and cheap, also has significant disadvantages: it does not permit individual cylinder control, and also causes delay in engine control system, making the engine less agile. In medium-speed engines, gas is typically supplied individually to every cylinder's inlet. While this requires somewhat higher gas supply pressure (around 6-7 bar or 85-100 psi), it brings significant benefits. Most importantly, this allows the optimization of the gas dose for the conditions of every single cylinder and every single cycle. This enables operation closer to the knocking and misfiring limits, and ultimately an increase in engine efficiency. Another important result is much better control response – the fuel dose may be adjusted practically without any delay, which makes such engines much better at taking rapid load steps. They also react better to variable gas conditions.

Therefore, the medium-speed solution, more efficient and cheaper to maintain, which leads to lower lifecycle costs, is preferred in all applications larger than a few megawatts, where engines are actually expected to run, not just sit idly as an emergency power source (this also applies to diesels, and that is exactly why for emergency-only applications high-speed models are used). A medium-speed solution is also more agile – faster to start and accept loads, making it a better – or even the only –solution for gas-fired data center plants.

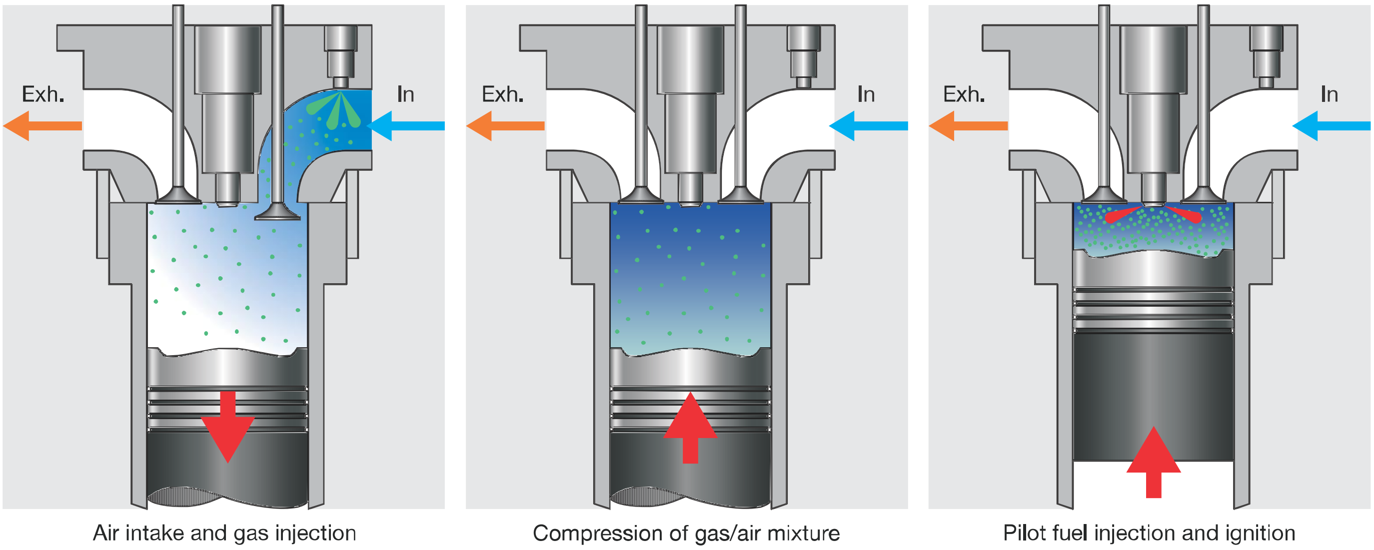

Fig. 8. The operation of a modern medium-speed gas engine. Most fuel gas is injected into the inlet duct of each cylinder during the intake stroke; the dose is individually adjusted for every cylinder to match its temperature. Some small amount of fuel gas is also injected into the so-called pre-chamber, a cavity in cylinder head, where a richer mixture forms. The source of ignition is provided at the end of compression stroke by a spark plug installed in the pre-chamber; then flame propagates into the main part of the cylinder.

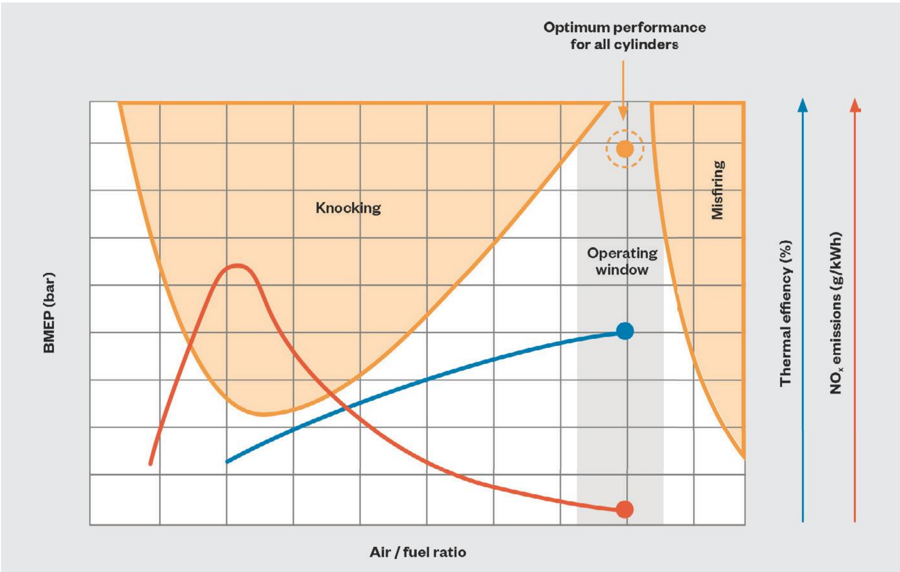

Fig. 9. The control system of a gas engine must control the air/fuel ratio (AFR) to ensure, that neither knocking nor misfiring occurs. Increasing the brake mean effective pressure, which is a way of improving engine efficiency, makes the safe operating window narrower, thus requiring more precision from the control system. Smaller engines, with single point of fuel injection, cannot control every cylinder separately. Because of that, their AFR in different cylinders will be slightly different, therefore they cannot operate in an operating window that is too narrow – this limits their BMEP and efficiency. Medium-speed lean-burn engines have individual and very agile control of AFR for every single cylinder, which means that they can be made more efficient without a risk of unstable operation.

Modern medium-speed gas engines have some other design features that differentiate them from emergency diesels popularly used in data centers. Most importantly, they are started up by the direct injection of compressed air into cylinders. This means that almost no electricity is needed to start the plant; the necessary air is generated in advance and stored in on-site bottles. Moreover, all the pumps necessary for engine operation (i.e. lubricating oil and cooling water pumps) are driven mechanically. This improves reliability and increases the net efficiency of the power plant.

Relatively high outputs of suitable gas engines mean that gas engine data center power plants should be built with N+R generating sets (i.e., N engines serving the critical load plus R redundant engines, where R would typically be 1 or 2), not 2N systems (where the entire plant is doubled).

6.2. GENERATORS

Due to their relatively high outputs, medium-speed engines typically come with medium voltage synchronous generators. Generators are directly coupled to the engine without any reduction gears. Typical voltage levels are 6, 10 or 15 kV for 50 Hz systems or 13.8 kV for 60 Hz systems. Generators are mounted on the same base frame as the engine, and in most cases are transported together with the engine.

One optional solution involves using generators as synchronous condensers. In this case, a generator can be uncoupled from the engine and kept rotating, synchronized with the grid, when the engine is stopped. This enables control of reactive power even when no active power is being generated, thus reducing the negative impact of a data center on the grid. This could also reduce starting time for the engine, as most of the mass is already rotating; the engine would be started up and then clutch would be closed.

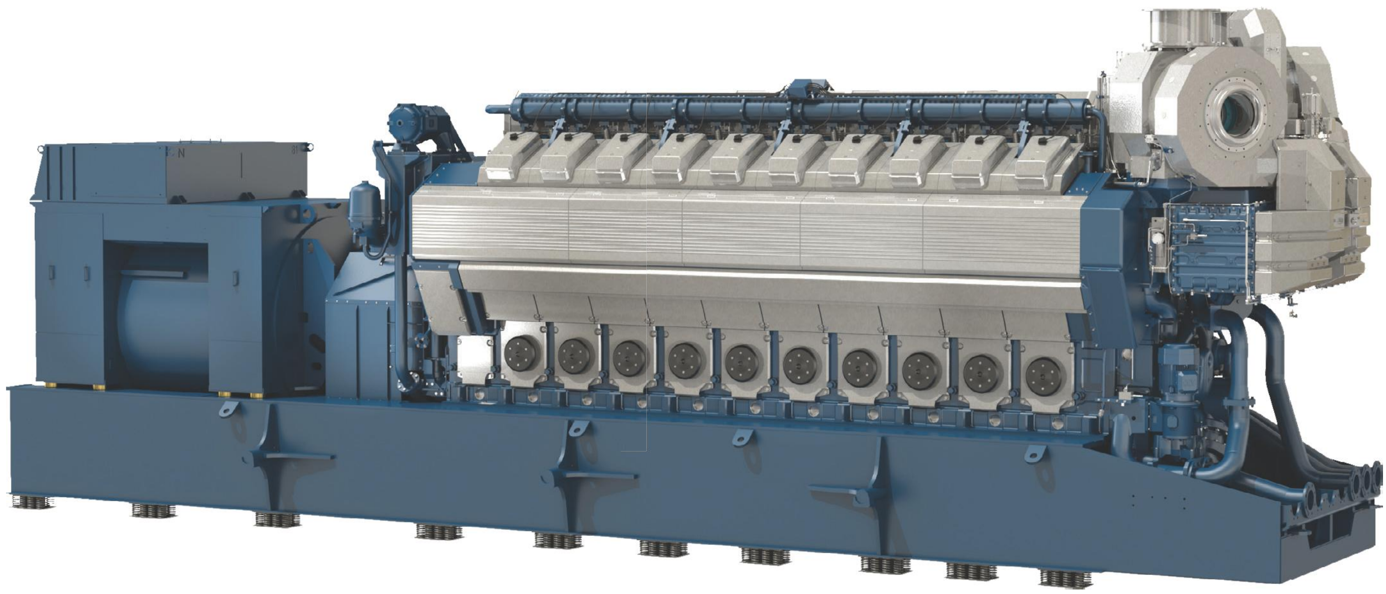

Fig. 10. A modern 10 MW-class gas-fired engine-generator set. The engine and generator are installed on a common base frame.

6.3. POWER OFF-TAKE SYSTEM

In a typical gas engine power plant, the power from several engines is taken off using a common medium voltage switchgear, then connected to the grid. However, this solution does not meet the concurrent maintainability requirement applicable for most data centers. Therefore, in case of a data center power plant, each engine-generator set is provided with its own medium voltage switchgear that then can supply the power into one of two paralleling buses. Each paralleling bus is capable of carrying the load from the entire power plant, ensuring the redundancy and concurrent maintainability of the power distribution path. Each of the paralleling buses can also be connected to the public grid via step-up transformers. The schematic diagram of such a system is shown in Fig. 11.

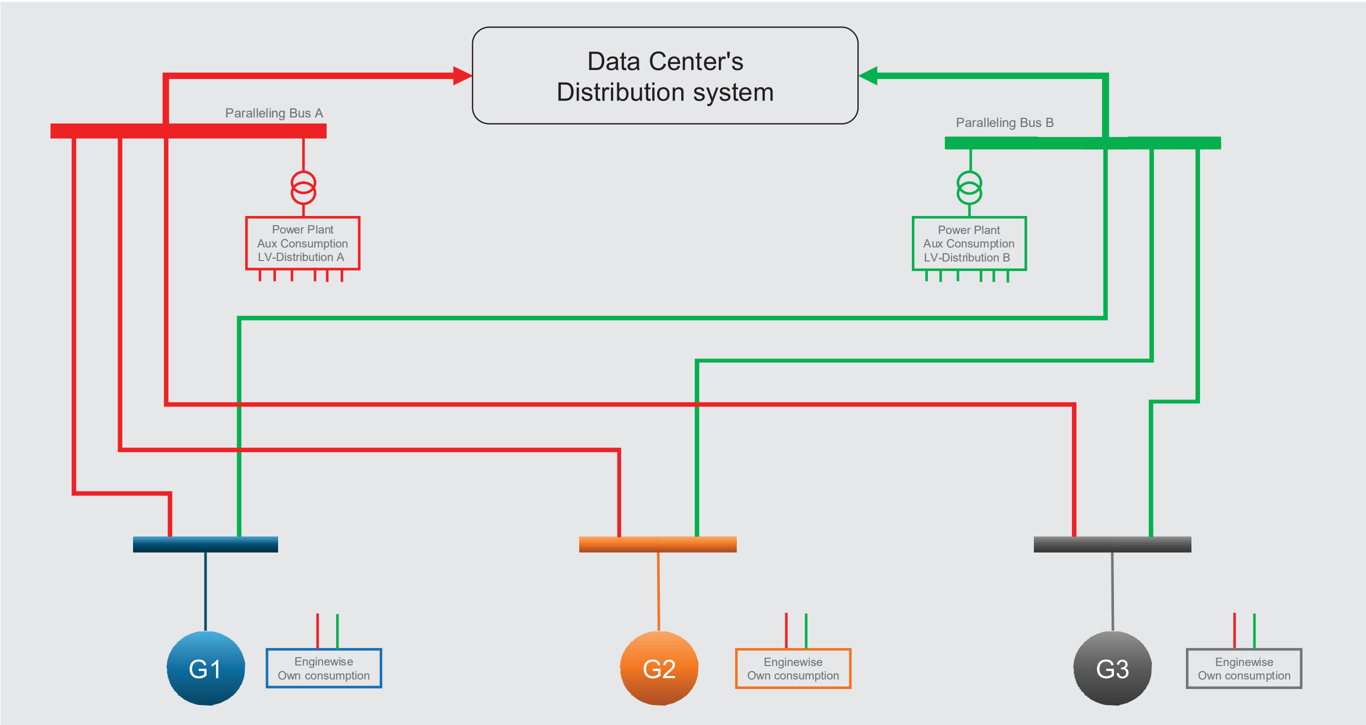

Fig. 11. Schematic diagram of a concurrently maintainable power off-take system of a concurrently maintainable gas engine data center power plant with three generating sets. Each engine may supply its power to either distribution path A or B. Also, the auxiliaries of every engine can be powered from either A or B distribution system. This ensures that either of distribution paths may be taken into maintenance without restricting capability to deliver full power to the data center or grid.

6.4. FUEL SUPPLY SYSTEM

Just like in case of the power off-take system, the fuel supply system of a data center power plant must be properly designed to ensure concurrent maintainability. A proper solution thus involves a loop pipeline, with doubled valves between each engine pair. This ensures that in order to maintain any pipeline section or any valve, no more than one engine needs to be stopped. A schematic diagram of such a system is shown in Fig. 12.

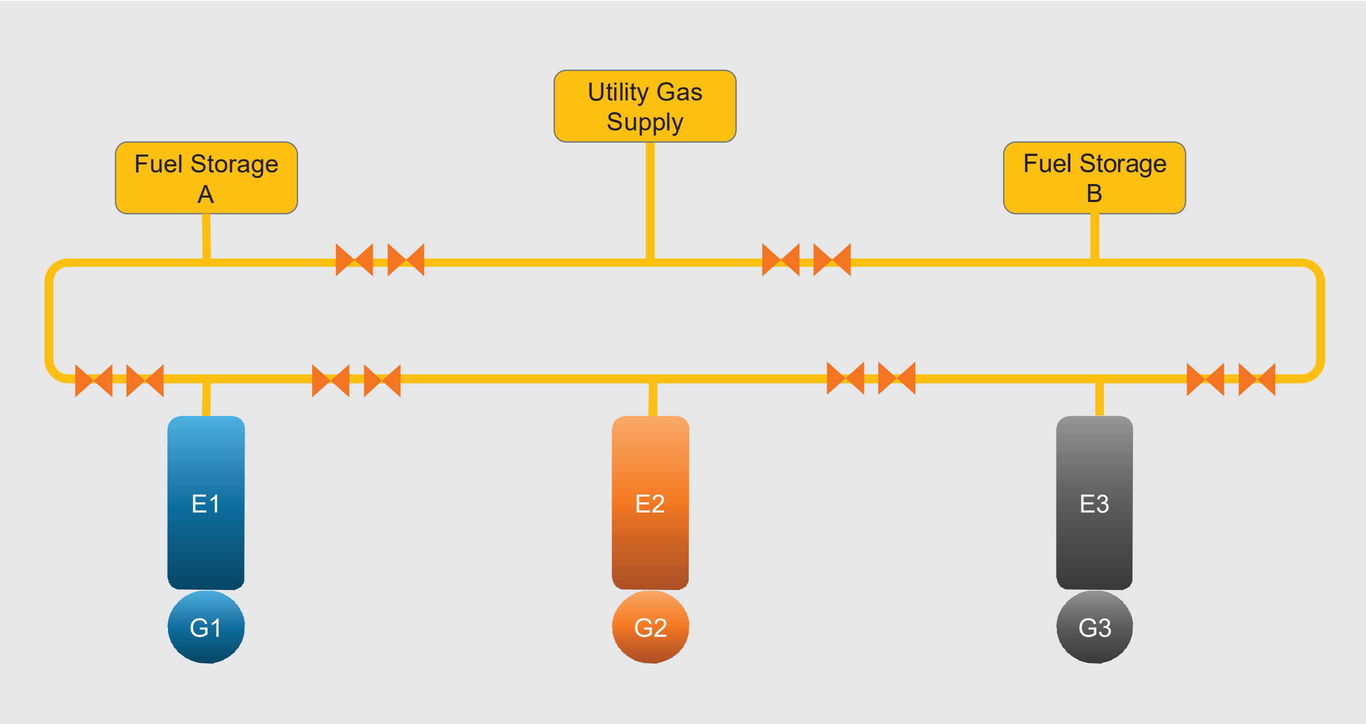

Fig. 12. Schematic diagram of the fuel gas system of a concurrently maintainable gas engine data center power plant. Each valve and pipeline section can be maintained without creating the necessity to stop more than one generating set.

6.5. FUEL STORAGE

Fuel storage capacity for a gas engine data center power plant may be provided in form of liquefied natural gas tanks. Storing natural gas in liquefied form enables the achievement of very high storage density with a small required storage volume. For example, in order to secure 12 hours of operation of a state-of-the-art 10 MW engine, volume of less than 50 m^3 (~1700 ft^3) would be sufficient. Due to the physical constraints, in order to stay in liquid phase, the fuel needs to be kept at low temperatures, below -162 °C (-260 °F). This is ensured by using well-insulated cryogenic tanks. As already mentioned in the introduction, tanks of this type are now becoming common in the ship industry and are delivered as modular structures. A view of a typical solution for such a storage facility is shown in Fig. 13.

As for fuel supply, liquefied gas is now a widely available commodity that can be freely purchased in most developed countries. For a facility of this scale, it is typically transported by road (sometimes also by barge). An alternative solution could be provided by the on-site liquefaction of pipeline gas or locally generated biogas.

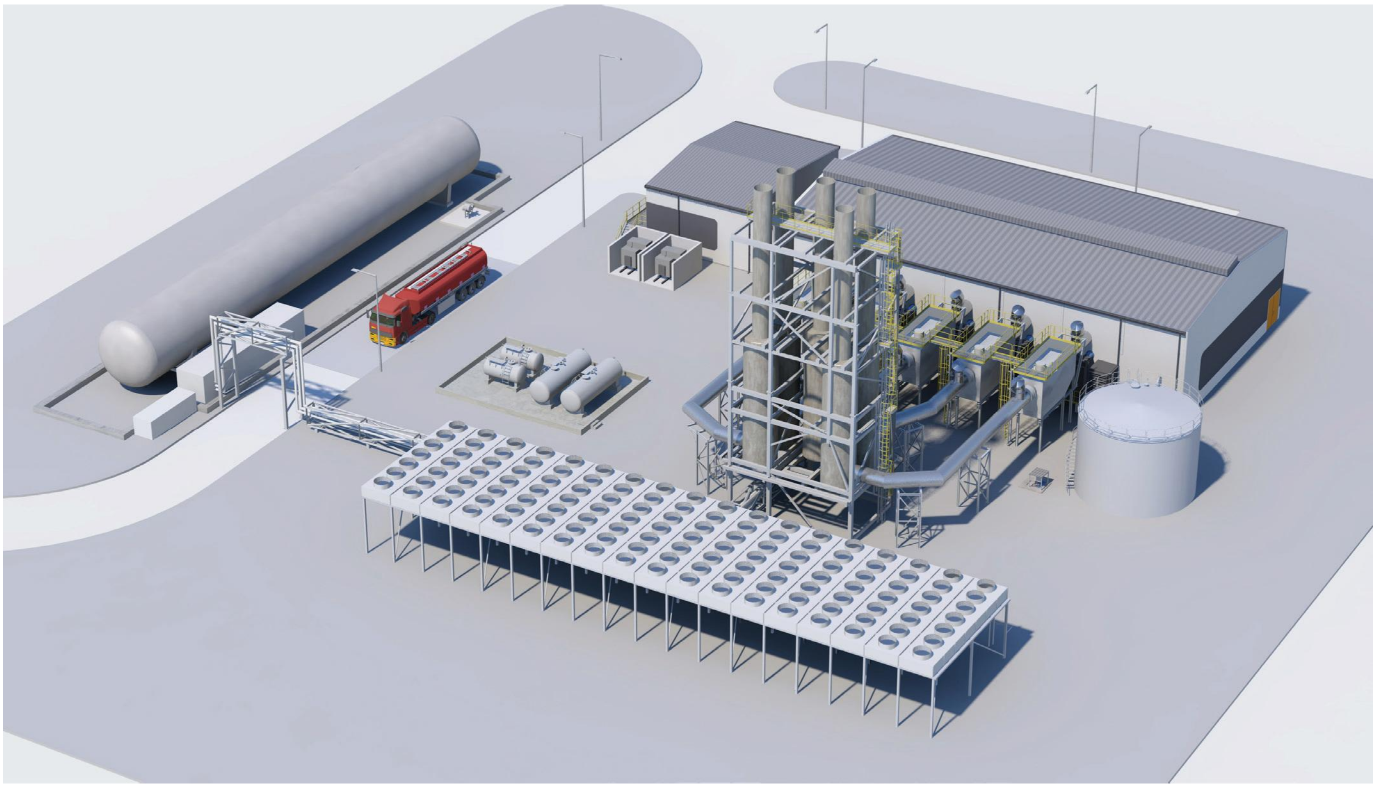

Fig. 13. Visualization of a 50 MW gas engine power plant with a 500 m³ (17,700 ft³) LNG storage system visible on the left-hand side. This tank would be sufficient for 24 hours of continuous plant operation at full load. The gas may be supplied in liquefied form by trucks, ships or railroad, depending on the local infrastructure.

If liquefied natural gas solution is, for some reason, not desirable for a particular location, there is also the possibility of using so-called dual-fuel engines. Such engines may operate either on liquid fuel – as normal diesels – or in gas mode. When running on gas, they still need a small (~1%) dose of light fuel oil used as a source of ignition (they do not have spark plugs). Gas for such engines is injected to the inlet channels of cylinders, just like the main dose of gas in spark-ignited engines. Of course in case of dual-fuel engines, fuel storage would involve the storage of light fuel oil like in a standard diesel plant. However, the dual- fuel engines have certain disadvantages compared to "pure" gas engines, most importantly they have somewhat lower efficiencies. Also their constant demand for fuel oil will have an impact on economy. Finally their NO_X emissions are higher, requiring more efficient exhaust gas cleaning systems. It also needs to be remembered that the storage of light fuel oil does carry its own share of challenges as well, as oil needs to be maintained in good condition by circulating and filtering it. There is also a risk of spillage, which does not exist in the case of natural gas (in which case the leak will just evaporate).

6.6. EMISSION CONTROL

As discussed in the earlier sections, natural gas engines are characterized by very low emissions. They do not emit any sulfur oxides or particulate matter due to the characteristics of the fuel. Pollutants that still need control are nitrogen oxides (NO_X) and carbon monoxide (CO). Nitrogen oxide may be controlled by optimizing the combustion process. Adjusting the temperature of the air fed into the cylinders (effected by controlling operation of charge air coolers) allows minimizing the NO_X formation, which ensures compatibility with many legal standards – notably current European Union regulations

– without a need to use any exhaust gas cleaning devices. If primary methods are not sufficient (like in some areas of the United States), selective catalytic reduction (SCR) process is used to reduce the NO_X content in the exhaust gas. The SCR process involves a reactor installed in the exhaust gas duct. The reactor needs to be supplied with a reagent in the form of a water solution of urea or, in rare cases, ammonia. Layers of catalytic material installed inside the reactor accelerate the reaction that breaks down the NO_X particles into oxygen and nitrogen. SCR reactors are always supplied as engine-wise. To ensure concurrent maintainability, the reagent supply would be provided by a looped system, just like the fuel gas.

The reduction of carbon monoxide, except for efficient combustion control, is accomplished with an oxidation catalyst, which causes the further oxidation of CO into CO_2. This kind of catalytic converter is also installed in the exhaust gas duct and does not require any reagent supply.

6.7. MAINTENANCE

Unlike small high-speed emergency diesel generators, medium-speed gas engines used in commercial power industry are very robust and sturdy, which makes them also relatively bulky and heavy. Therefore, once installed on-site, they are not moved for maintenance. Instead all of the components that might need refurbishment, such as cylinder heads, cylinder liners, pistons, connecting rods, etc., may be removed using an on-site overhead crane and transported individually to refurbishment workshops, while the heaviest components – the engine block, generator and crankshaft – stay at the site for the entire lifetime of the plant, which may easily exceed 25 years of baseload operation.

Individual engine-generator sets are maintained one at a time, along with engine-wise auxiliaries, so the overhaul of one engine does not require outage of any other generating set. While traditionally maintenance was performed according to predetermined schedule, most modern plants use so-called condition-based maintenance (CBM). In this solution, similar to what is used in modern commercial aviation, the condition of each engine is continuously monitored by a service center, which then issues recommendations concerning all scheduled and preventive maintenance procedures. Thanks to this process, maintenance procedures are performed in certain “time windows” instead of fixed moments of time, which improves operational flexibility.

Gas engine power plants with medium-speed engines are designed for minimum operator intervention, can be remotely controlled and dispatched, if desired, and do not require the presence of a permanent on-site crew. The most frequent maintenance procedures, such as checks and spark plug replacements, are fast procedures carried out in a matter of hours. Larger engine overhauls occur after no less than 16,000 running hours, and, in the case of the most advanced engines, the most extensive overhaul is scheduled only at 96,000 running hours, i.e. twelve years of continuous operation. This means that for peaking power plants, the largest overhaul may not ever happen during the project’s economic lifetime.

It needs to be noted that number of starts and stops of an engine has no impact on its maintenance schedule, unlike in some other power generation technologies where a single start may be counted as the equivalent to multiple running hours due to the extra thermal stresses. This is inherent feature of the engine technology designed for cyclic operation.

6.8. OPTIONAL HEAT RECOVERY

Just like any other fuel-driven machine, a gas-fired reciprocating engine inevitably converts a considerable portion of fuel energy into heat, which is then discharged to the environment. In order to improve efficiency of fuel utilization, this heat may be recovered and put into use.

A modern medium-speed gas engine discharges heat in following ways:

- With exhaust gas. Exhaust gas discharged from the engine has a temperature of approximately 380°C (715°F), and carries around 25-30% of fuel input energy. If no heat recovery is used, hot exhaust gas is released to the atmosphere.
- Through water used for cooling the engine block. This water has an outlet temperature of approximately 90°C (195°F), and carries around 5% of fuel input energy. If no heat recovery is used, this water is cooled down in outdoor radiators.
- Through lubricating oil. Oil has an outlet temperature of 70-80°C (160-175°F) and carries around 5% of fuel input energy. If no heat recovery is used, oil is cooled by a water circuit, which is itself cooled in outdoor radiators.
- Through charge air cooling. Intake air is compressed in a turbocharger and then cooled in water coolers. Typically two stage of coolers are used: high temperature at around 90°C (195°F) which discharges around 5% of fuel energy, and low temperature at around 40°C (105°C), which discharges around 2.5% of fuel energy. If no heat recovery is used, water used to cool the air is then cooled in outdoor radiators.

All of this heat may be recovered and put into practical use without any impact on electricity production. In the most optimal cases this may increase the total efficiency of the plant from 45-50% obtained when only electricity is generated to values exceeding 90%.

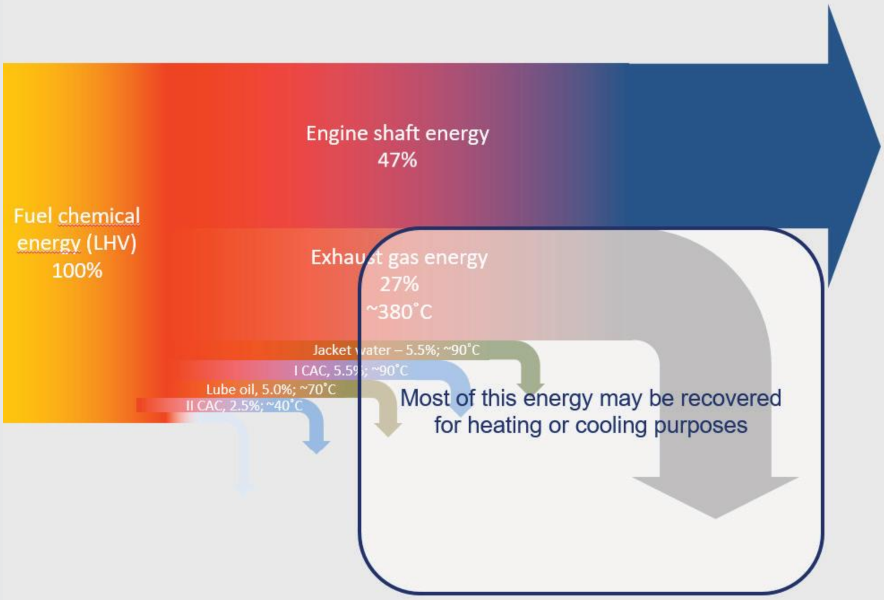

Fig. 14. Energy balance of a typical medium-speed gas engine. CAC stands for charge air cooler.

The simplest way of using this energy involves producing hot water in appropriate heat exchangers, including exhaust gas boilers. Such water may then be supplied to some local consumers, for example, the district heating system, office complexes, warehouses, etc. In the event that no heat is needed, all of the heat exchangers may be safely bypassed, so disruptions in the heat recovery and utilization process do not affect engine operation and power generation. It might be noted that this method of combined heat and power generation is among the most popular methods of heat generation used in modern energy systems, for example, in Northern and Central Europe.

It is also possible to use recovered thermal energy to generate cooling power. This is done using absorption chillers, i.e. devices that produce chilled water using heat as their energy source. Absorption chillers may be powered directly by exhaust gas, hot water or both. The most efficient solution is a chiller supplied with both exhaust gas and hot water generated from engine cooling circuits. This kind of system is shown in Fig. 15. A chiller powered only by hot water is less efficient, but also less expensive, and might also be a useful solution, depending on project economy.

Generated chilled water may be used directly by the data center or by some other nearby facilities.

It is possible to build a full tri-generation system, which can produce both hot and chilled water in adjustable proportions, depending on current demand (or season). Such an arrangement is schematically presented in Fig. 16.

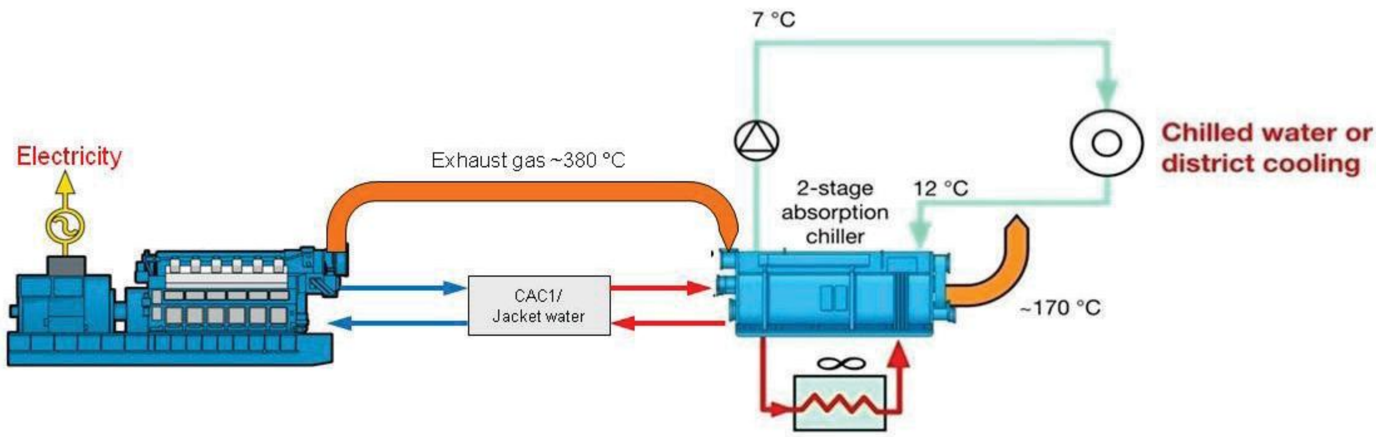

Fig. 15. A combined power and cooling module with a highly efficient chiller driven by both exhaust gases and hot water. Chilled water temperature values are exemplary only, they are properly adjusted to a specific application.

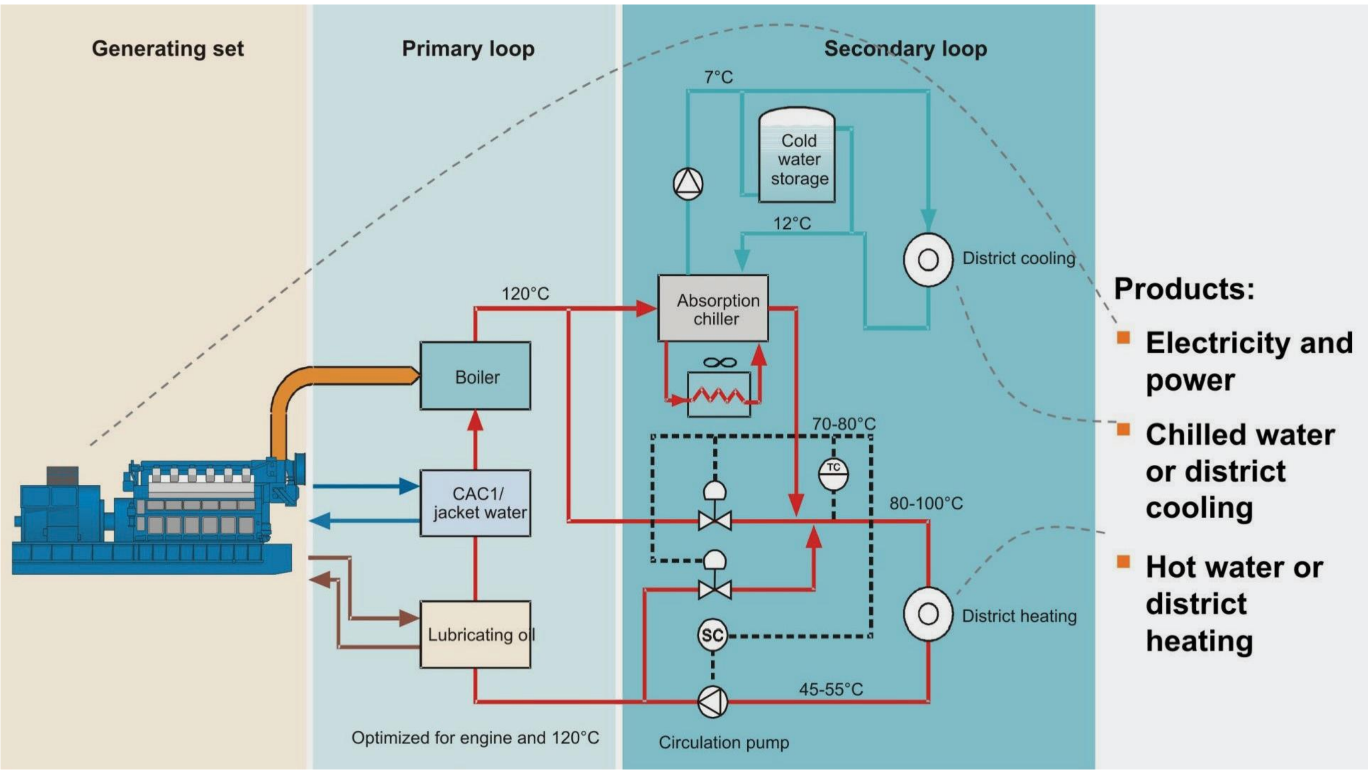

Fig. 16. A schematic diagram of a trigeneration system with an absorption chiller driven by hot water. This kind of plant may deliver more cooling power in the hot season and more heating power in the cold season – the proportion between heating and cooling may be freely adjusted.

Fig. 17. Trigeneration plant at Adolfo Suárez Madrid–Barajas Airport. The plant is based on reciprocating engines fueled mainly with natural gas and has been ensuring the reliable supply of electricity, heat and cooling for the largest airport of Spain since 2005.

7. Conclusions

Recent developments in gas engine technology, combined with advent of liquefied natural gas solutions, make gas engines a viable option for the emergency power supply of data centers. At the same time, the robustness of this technology, low emissions, high efficiency and affordable fuel prices make such a solution suitable for much more than just providing backup for rare cases of grid failure. The solution described in this paper allows data center operators to replace the necessary cost of technical insurance against grid failures into a profitable component of their business. At the same time, it will reduce the environmental footprint of their facility, both on global (carbon emissions) and local (particulate matter, nitrogen oxides) levels.

WÄRTSILÄ ENERGY SOLUTIONS
IN BRIEF

Wärtsilä Energy Solutions is a leading global system integrator offering a broad range of environmentally sound solutions. The company supplies ultra-flexible internal combustion engine based power plants and utility-scale solar PV power plants, as well as LNG terminals and distribution systems. The flexible and efficient Wärtsilä solutions provide customers with superior value and enable a transition to a more sustainable and modern energy system. As of 2017, Wärtsilä has 63 GW of installed power plant capacity in 176 countries around the world.

CONTACT:
Adam Rajewski, Manager, Data Center Technology,
Wärtsilä Energy Solutions
adam.rajewski@wartsila.com
+48 604 137 511 (CET time zone)

03.2016 / Bock's Office

www.smartpowergeneration.com
www.wartsila.com/energy

WÄRTSILÄ