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COVER STORY

MAXIMISING PROFITS
Efficient pulse load operation

24 page

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THE EFFICIENCY ECONOMY

Efficiency is about making the best use of scarce resources. By improving efficiency, maximising outputs with available inputs, businesses can reduce their costs and boost their competitiveness.

In the last decade, digitalisation has taken efficiency to a totally new level. We can tackle problems we may not have even recognised before. To make our efforts more efficient, we need to know where the inefficiencies lie. For that, we need data. But collecting and analysing this data manually is incredibly slow, especially if we are not even sure what information will be most useful.

Through digitalisation, we can automate more products and processes than ever before and collect all sorts of data quickly and in real-time. With more sophisticated analytics to combine data from increasingly varied sources, this connectivity allows us to see things we could not see before and to react faster. We can create operational efficiencies, whether internally or on behalf of our customers, to eliminate waste and non-value-added elements, and we can develop innovative products and new ways of working that provide even more value.

In this issue, you can read about how Wärtsilä's new Genius Service products are doing just that – using data to optimise assets, improve predictability and solve problems through digital solutions. Also read about our exciting Marine Mastermind competition and its winner, who envisions greater efficiency by automating routine marina and port bureaucracies.

Digital monitoring makes it easy to track the variability of renewable energy sources, but we need fast-reacting components to efficiently integrate larger shares of wind and solar energy in power generation. Wärtsilä's flexible internal combustion engine technology enables efficiency on many levels, such as maximising profits with more efficient pulse load operation.

On the marine side, the drastic boost in efficiency in the adoption of DFDE (dual-fuel diesel electric) on LNG carriers has made steam turbines obsolete, and shaft generator systems are an additional option to help ship owners and operators increase efficiency.

To hear more "in detail" about where the industry and Wärtsilä are heading, join us at CIMAC, which we are proud to host in Helsinki this June. As a main sponsor, Wärtsilä will be giving more than 20 presentations. So you will get the latest information about our offerings and will be able to talk directly with our technical experts. In the exhibition, you can get up close and personal with the technologies and their creators.

We also want to hear from you, our dear readers, whether you are a customer, supplier or stakeholder. How are our products working in the field? Based on how your business is developing, what are the future requirements? Hopefully we can connect many dots that will lead to new innovations and greater efficiency. Looking forward to meeting you in Helsinki!

Ilari Kallio
Vice President of R & D,
Marine Solutions 4-Stroke
Editor-in-Chief of In Detail

MARINE MASTERMIND

Wärtsilä announces the winning start-up partner from its Marine Mastermind competition.

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Back to the future: steam turbine to DFDE conversion

The boost of efficiency of DFDE on LNG carriers makes steam turbines obsolete.

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Plains End power plant, Colorado, U.S.

Unlocking optimum CHP performance in future power systems

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The Combined Heat and Power (CHP) power plant portfolio requires modernisation so it can continue profitable operations alongside intermittent wind and solar sources. This article outlines why Smart Power Generation (SPG) is the optimal technology solution for the next generation of CHP plants.

The strong growth in intermittent renewable power is driving change in Europe's energy market. With intermittent wind and solar power given feed-in priority, in support of global decarbonisation aspirations and national carbon reduction targets, an increasing portion of the thermal fleet must switch from baseload operations to delivering a more flexible and intermittent output that provides power only when lower emission sources are not available.

Despite the considerable challenges brought by the paradigm shift towards renewables, including increased price volatility and reduced running hours, significant opportunities remain for CHP plants. If supported by the right technology, such facilities will not only continue to operate profitably in partnership with renewables, they can also take advantage of additional income generation opportunities.

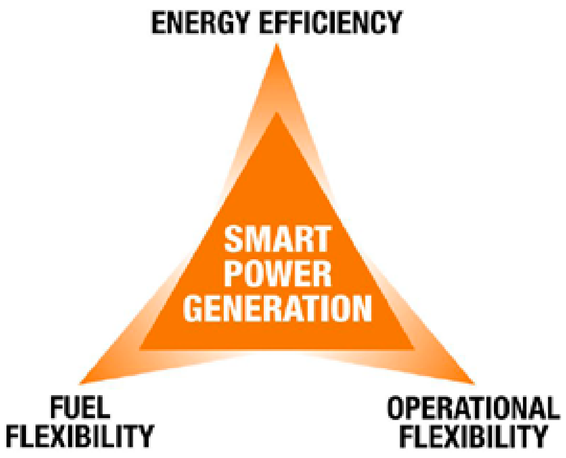

Fig. 1 - The three pillars of SPG: operational flexibility, energy efficiency and fuel flexibility.

CHP in the generation mix

Generating power and heat via CHP is already desirable in today's energy mix, due to the potential for optimally designed systems to achieve energy efficiency of up to 90%. Indeed, as a result of this high efficiency, CHP is commonly ranked second, behind wind and solar power, in terms of grid feed-in priority.

However, much like the power sector, CHP has been affected by increasing price volatility and by the generation variability of renewable energy. For example, when wind generation peaks, there will be excess power on the market and consequently lower power prices, resulting in reduced opportunities for CHP plants to generate earnings through power markets.

Today, CHP plants typically operate seasonally according to peaks in demand. In winter, when heat is in high demand, CHP plants generate heat while simultaneously generating power as a by-product to be sold to the grid. While in summer, plants cease operation because heat load is typically below the minimum load of the plant, and power prices are lower than in the winter, making operation less economically viable.

Redefining CHP operating patterns with SPG

However, this operating pattern is set to change due to the 'dynamic' capabilities of Smart Power Generation (SPG), a technology pioneered by Wärtsilä. SPG enables an existing power system (either CHP or power only) to operate at its maximum efficiency, absorbing current and future system load variations and providing dramatic savings. In the context of CHP plants, an SPG application would involve replacing the system's prime mover, typically a combined cycle gas turbine (CCGT), with agile, internal combustion engine (ICE) power plants. The key benefit this SPG capability brings is ultra-fast ramping, which would enable the CHP plant to start in less than one minute and reach full load in less than five minutes. When considered as part of a generation mix increasingly dominated by renewables, this means a CHP plant equipped with SPG could turn on almost instantaneously to provide power in the summer, when profitable, and cease operations when prices are reduced.

Fast ramp times – an in depth analysis

Wärtsilä maintains that SPG offers the only feasible route to a reliable and economically viable future power system with a high penetration of renewables. This solution is supported principally by the fast start up times associated with SPG (applicable to a CHP or power only facility), which are demonstrated in Figure 2.

The main benefit of fast ramp-up times is the removal of the costs associated with 'equivalent operating hours': the need to operate an engine with a slow ramp-up time for significantly longer than its power is required, to account for start up and shut down times. For example, in a previous system, where power plants generate a steady load, maintenance shutdowns would take place only every 10,000 hours. In a new system with a high integration of renewable energy, this is not possible, as plants are required to ramp up and down on a regular basis to balance wind and solar power. In an anecdotal example, this means that it may take ten hours to start a plant in order for it to operate for five hours, meaning 15 hours are placed on the 'lifetime clock' of the power plant. These hours are further extended if power prices dip within the five-hour operating period, meaning the plant may stop after one hour of operating and then be restarted again after two hours. This would equate to ten hours for the first start, one hour running, ten hours for start two and then another four hours of running. Collectively, this means 25 hours on the lifetime clock of a plant for each five hours of operation. This is an extremely uneconomical way to balance renewables and highlights why an ICE– as well as a CHP, should an owner look to provide renewables balancing in the summer– would be far more advantageous in power applications. With two-minute start times,

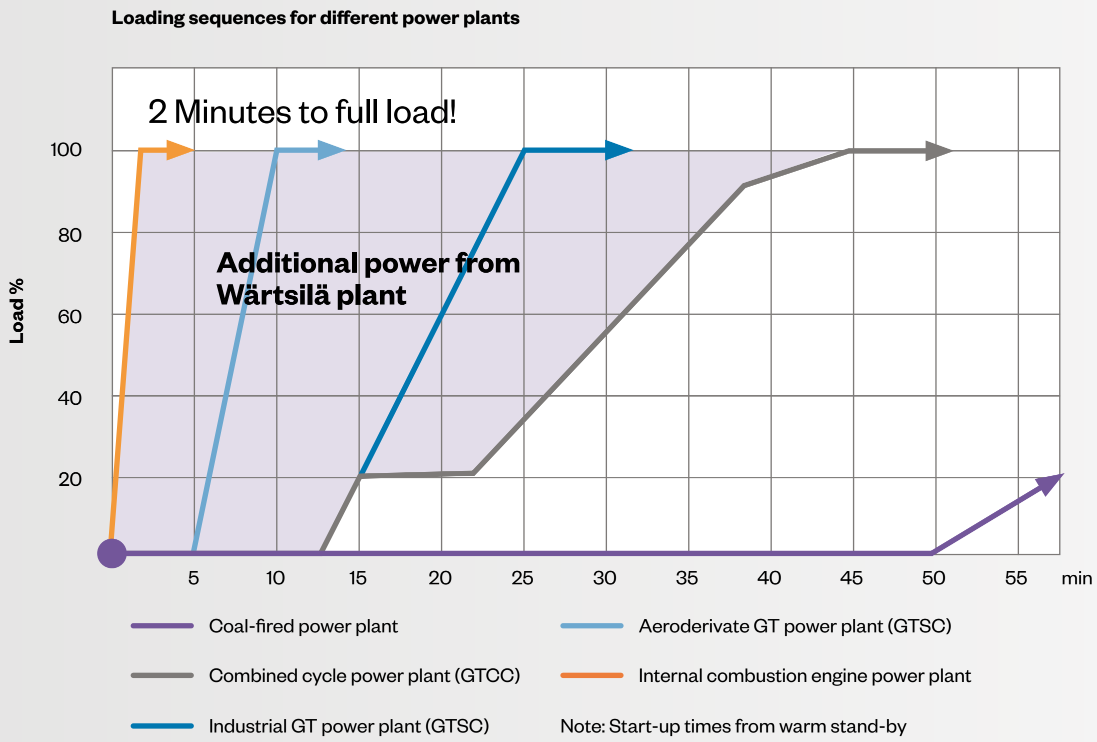

Fig. 2 – A comparison of power plant ramp-up times for Smart Power Generation technology versus aero gas turbines, industrial gas turbines, combined cycle gas turbines and coal-fired power plants.

SPG eliminates the need for equivalent starting hours, meaning maintenance on the plant is only required for the actual hours that the plant runs.

Another key benefit of SPG is modularity. In the past, utilities picked larger facilities in order to realise economies of scale in terms of efficiencies and cost, but this approach is losing favour. As the requirement to balance renewables increases, so do the instances where the plant is required to operate at partial load, which increases the maintenance burden and results in less power being sold to the market. In contrast, it is possible to 'decouple' each turbine in an SPG power plant. For example, in a 200 MW unit, there could be 10 to 20 smaller engines in a row, each capable of performing at high efficiency in isolation. This means the power plant owner can go to the power market and offer, for example, only 10 MW as one 'slice' and operate at high efficiency.

Cost-benefit modelling

While the examples above offer a strong case for investing in SPG, investment barriers remain. Namely, the upfront investment in an ICE for a power or CHP plant can be around 10–20% more than a conventional CCGT system. Therefore, the case for investment in SPG relies heavily on demonstrating lifecycle benefits. While the anecdotal benefits mentioned above provide a strong case in support of SPG, Wärtsilä brings added conviction through its latest power market modelling. In a study prepared by Energy Exemplar, Wärtsilä examined the benefits of SPG within the capacity extension plan and 10-year dispatch of the California energy system.

Remarkably, the results showed that SPG could save USD 870 million throughout a 10-year dispatch period from 2013 to 2022. Such savings are achieved when the entire existing fleet of aero gas turbines, and a large portion of industrial gas turbines, are replaced by SPG. With SPG balancing renewables, the fleet of CCGT can remain and operate in its most efficient baseload capacity.

These savings come from a number of areas. First, by portfolio optimisation, in which the zero start costs and high operational ramp rates of SPG allow CCGT to focus on generating a more stable dispatch, thus avoiding costs associated with equivalent operating hours. Secondly, further savings are achieved by increasing overall efficiency of the generation fleet, through the replacement of aero and

NPV values ($ BUSD)	BASE	FLEX	Delta
Operation cost	53.54	52.96	**- 0.58**
Capital cost	4.67	4.68	0.02
Export (revenue)	**- 3.94**	**- 4.30**	**- 0.36**
NPV total cost	54.28	53.41	**- 0.87**

Fig. 3 – A comparison of the savings possible between 2013 and 2022 when the entire existing fleet of aero gas turbines, and a large portion of industrial gas turbines, are replaced by gas-fired internal combustion engines.

industrial gas turbines, which are less efficient compared to SPG. Thirdly, SPG promotes lower marginal power costs, which reduces the need for costly imports and increases trade from exports. Finally, in terms of capacity, with SPG's fast start-ups and modular design enabling the replacement of part-loading with precise load following, less overall capacity is needed to balance renewables. An added bonus is reduced CO_2 emissions of 1.5%, which is made possible through heightened efficiency.

SPG in practice

While some utility professionals remain comfortable with the practice of part-loading to achieve flexibility, due to the widespread use of the technology in traditional power systems, the most forward thinking are already waking up to the benefits of SPG.

Colorado is home to Plains End I & II, the largest natural gas-fuelled ICE power plant in the USA, which delivers 231 MW of power through 34 gas engines from Wärtsilä. The site is located in Colorado, an area with a high proportion of intermittent wind-driven generating capacity, which demands Plains End to cope with sudden load swings. In fact, the plant's local utility, Xcel Energy, expects Plains End's grid-balancing capacity to routinely exceed changes of 20 MW per minute, which the plant is able to compensate for by ramping from minimum load to full load and back again in record time.

Additional opportunities for CHP

CHP owners may recognise the opportunity that SPG can provide, in terms of bringing their facilities online in the summer to dispatch power when profitable. However, questions still remain regarding how associated heat generated during the process could be used. The solution to this is adding an accumulator that enables more effective and flexible operation. Accumulators perform best in systems with a high penetration of intermittent renewables generation. They enable the plant to run on full power in the summer, when power prices are high, while simultaneously storing heat. The heat is then discharged when lower power prices make operation of the CHP plant unattractive.

SPG characteristics also open up an additional revenue stream for CHP plant owners, who can utilise its fast starting and ramping capabilities on the ancillary services markets. For example, in a period of low heat demand, a 100 MW CHP plant with ICEs can operate with one unit running and nine units at a standstill. These standstill units can be made available to provide fast grid reserve to power markets, where necessary. Together with heat storage, the gas engine power plant can optimize and then also decouple the CHP.

Transferring theory to working examples

While CHP plants are already one of the most efficient means of producing heat and power, the power plant portfolio will become increasingly exposed to price volatility in the power markets and to the variable generation created by increasing shares of intermittent renewable power generation. If the same technology continues to be utilised in CHP prime movers, CHP plants lose out in the power markets, if they are not agile enough to respond to peaks and troughs in pricing. However, with the right technology selection, CHP plants can not only remain competitive, they also can continue running year-round, unlocking significant new revenue streams through summer power production and the provision of services to the ancillary services markets. All the while, heat loss can be prevented through the use of heat storages. Power market modelling by Wärtsilä lends support to the investment case for SPG. In order to cement decisions, Wärtsilä is calling on CHP owners to explore how SPG could deliver cost and environmental benefits to their unique facilities. By applying the theoretical market modelling and anecdotal evidence already collected by Wärtsilä to real case examples, the CHP industry will increasingly realise the benefits of SPG.

Fig. 1 - Plains End power plant.

Investment in flexible generation makes sense in North America

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Time flies. It already has been several years since Wärtsilä started to talk about the need for flexible power generation. That was back in 2002, when Wärtsilä sold the Plains End (Figure 1) Power Station, which started to operate with flexible capacity. The dispatcher called that plant Wind Chaser as well as Dispatcher's Dream.

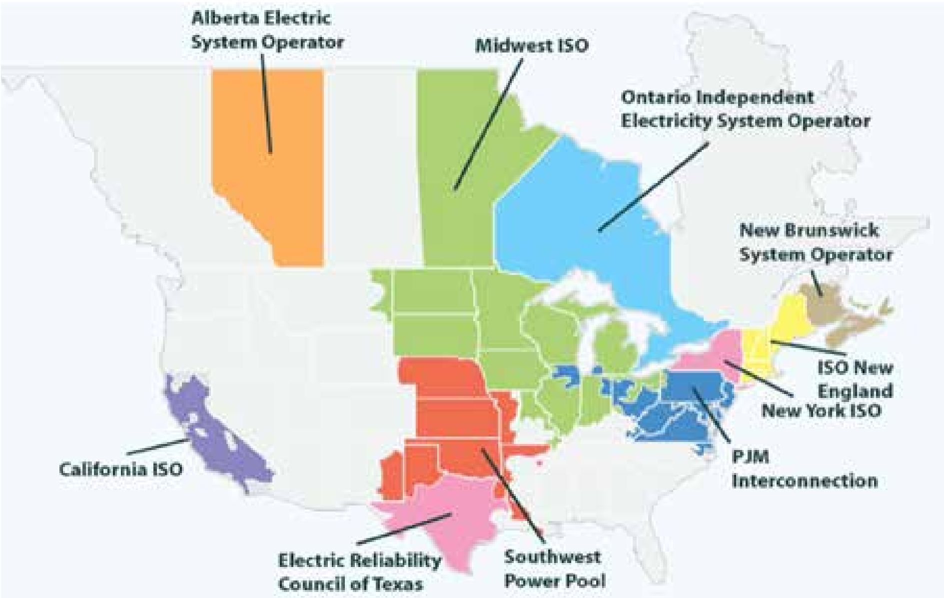


Fig. 2 - Organized electricity markets in North America.

In 2016, it is widely accepted that flexibility is needed in current power systems, but it will be increasingly necessary in the future due to the growth of renewable power generation. However, it still seems to be the case that, in general, investors do not see the value of flexible power generation in the USA because, they argue, the market is not rewarding the fast starting and fast ramping technology. Of course, market rules can be enhanced, but the organized electricity markets in the USA and Canada already reward flexible generation today. It is just the mindset and the traditional approach to analysing power plant investments that does not reward flexibility.

But there are always the first adopters in a fast-changing environment who see opportunities and are willing to capture those opportunities. Since 2014, Wärtsilä has worked closely with investors in North America to build a case for flexible power generation. Now, in early 2016, the first investment cases have started to materialize. This paper describes why and how progress is being made.

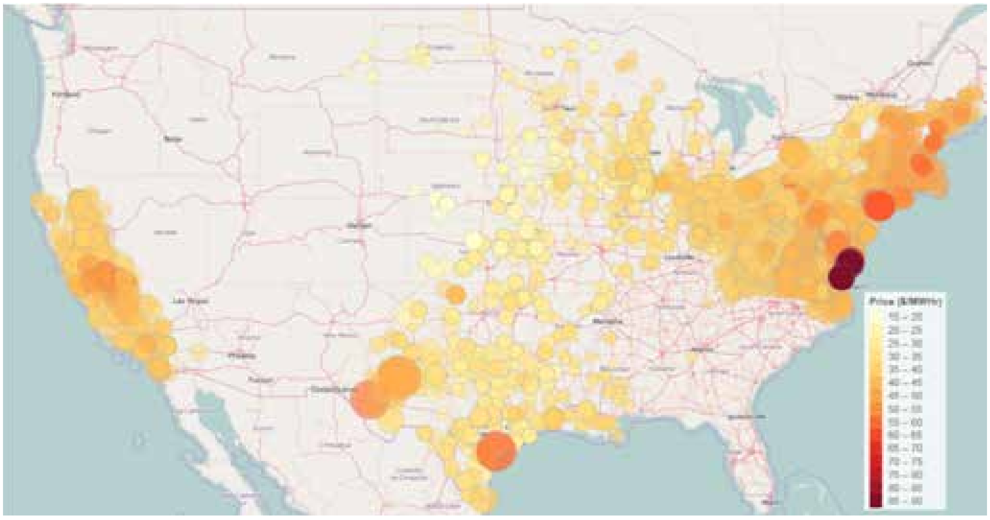
Favourable market environment

The prevailing mindset is that flexible power generation can be profitable if there are a lot of renewable resources in the market. This definitely helps the business case, but the main source of value is price volatility. The increasing amount of renewable generation helps to increase volatility, but in the end, the market rules define the level of volatility that we see. In other words, if the market rules are not reflecting the value of flexibility, the additional renewable generation will not help. On the other hand, if the market rules reward flexibility, then every additional MW of renewable generation makes a more compelling case for flexible generation.

Let's look first at the market setup in North America. There are nine organized electricity markets on the continent (Figure 2), typically called ISO markets (Independent System Operator market). These ISO markets represent around 66% of generation capacity in the USA and are expanding their service territory constantly. The ISO markets provide a solid model to analyze the competitiveness of different generation technologies, since there is price information on the energy and various system services.

All ISO markets are centrally dispatched. Typical dispatch granularity is 5 minutes so there is a price for electricity in every 5-minute period. However, in many markets, the price paid for generation is not set every 5 minutes, but instead the settlement is based on longer periods of time, e.g. 1 hour. This will change in the near future, as the Federal Energy Regulatory Commission (FERC) has said that market operators need to move to finer granularity in their price setting and that all costs that occur in a dispatch period should be reflected in the market prices. This means that ISO markets are moving to 5-minute settlement periods and that the price volatility will increase due to better cost allocation. This is the first market element that makes the business case more attractive and transparent for truly flexible generation.

The second element that makes the market environment more favourable is the increasing amount of renewables. Already two-thirds of new power capacity in the USA comes from renewables, and the decreasing price of renewables will boost this development even further. So why are we, as a flexible power source, interested in increasing the amount of renewables? We hear comments like, "You can balance the wind," or "You guys can help the system." These are valid points, but they do not really serve the interests of investors. An →



■ Fig. 3 - Volatility heat map.

■ Fig. 4 - Day-ahead price and dispatch.

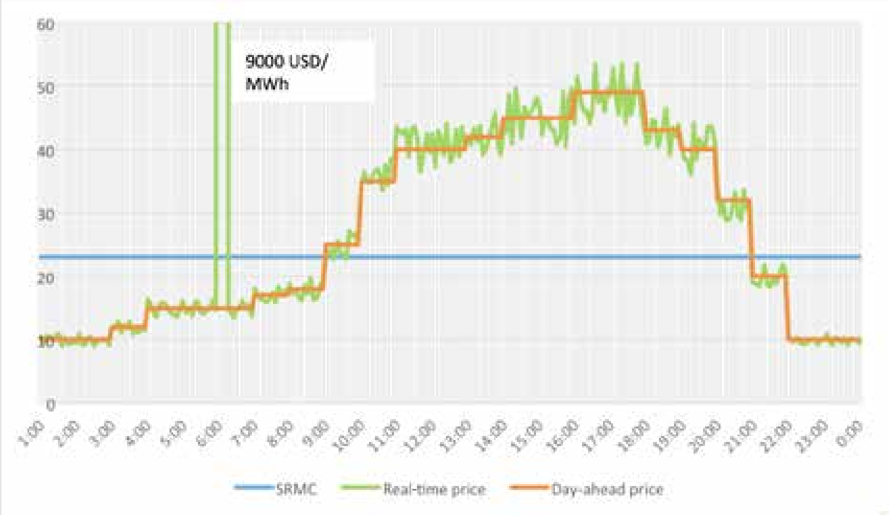


Fig. 5 - Real-time market example with a price spike.

investor or utility wants either to lower their cost to serve load or make more money in the market. The return on investment is made through more volatile market prices.

Volatility describes the variation in prices. The higher the volatility, the greater the variation in prices. Renewables increase volatility in two ways. First, when the wind is blowing or the sun is shining, the market price for power drops. Second, when renewables stop providing energy, thermal capacity like gas generation needs to kick in and balance the power load in the system. The first element lowers the price, and the second increases the price. So both elements increase the volatility (just in opposite directions).

Figure 3 shows the average prices and volatility for different price nodes in the USA. The bigger the bubble, the greater the volatility, and the darker the colour, the higher the average price. For instance, in northwest Texas, there is a lot of volatility driven by the massive amount of wind generation in the area. Also, the Pennsylvania-New Jersey-Maryland (PJM) market area shows some volatility and quite a high average price for energy. We forecast that the sizes of the bubbles will get larger in the future, making the case for flexible gas generation even more attractive to North American markets.

Value of flexible operation mode

So far, we have talked about increasing market price volatility, why this is important for flexible gas generation, and how the volatility helps justify an investment case. There are two main elements in the American ISO markets: day-ahead market and real-time market. The first one sets the price for each hour the day before, while the latter one sets the price for every 5 minutes, just 5 to 10 minutes in advance.

The next couple of examples demonstrate how flexible gas generation is able to exploit market opportunities in different market situations.

Flexible gas plant description

- Capacity = 200 MW
- Efficiency = 50%
- Gas price = USD 10/MWh
- Variable O&M = USD 3.0/MWh
- Short run marginal cost (SRMC) = (USD 10/MWh / 50% + USD 3.0/MWh) = USD 23/MWh
- The flexible gas plant will run if the market price is above USD 23/MWh
- Start-up time to full load = 5 min, no minimum up time
- No start-up penalty

Case 1: Traditional day-ahead dispatch

Figure 4 shows a traditional day-ahead dispatch where the price has been set for each hour. The day-ahead price is between the hours ending at 9:00 and 20:00. So the plant will be started at 8:00 and stopped at 20:00, operating 12 hours during the day. We are able to calculate profit for the plant by subtracting the SRMC from the market price during the hours when the plant is operating. The profit for this 200 MW plant over the 12-hour period is USD 44,000.

Case 2: Price spikes in the real-time market

On average, the real-time price is very close to the day-ahead price over a longer period, e.g. a year. But in the short term, there can be large deviations from the day-ahead price. Figure 5 shows an example from the Texas market (ERCOT), where the price can hit a price cap of USD 9000/MWh in a scarcity situation. In Figure 5, this type of event happens at 6:00 and lasts only 15 minutes. This type of situation can be caused by a large plant failure or a problem in the transmission line.

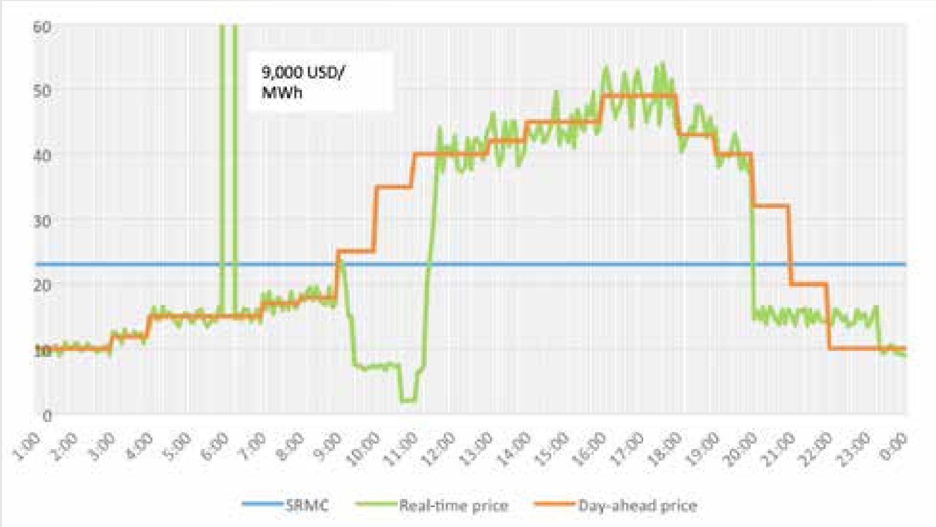


Fig. 6 - Real-time market example with low prices.

As this kind of event comes "out of the blue," the traditional generation that is not online is not able to react. Fast-starting gas generation, however, is able to exploit this opportunity by starting fast and catching the price spike. The plant will come online and run only 15 minutes. The price is USD 9,000/MWh and the plant runs 15 minutes with the SRMC of USD 23/MWh, when the margin from this 15 minutes is USD 448,850 ((9000 USD/MWh – 23 USD/MWh)*200 MW/4) = USD 448,850.

The flexible gas unit that was able to react to the price signal was able to make 10 times higher margin during 15 minutes in the real-time market than running for 12 hours in the day-ahead market.

Case 3: Price below the short run marginal cost in the real-time market

The real-time price can be also below the day-ahead price – for instance, if there is more wind generation available than was predicted 24 hours before. This type of situation has been illustrated in Figure 6. The real-time prices start to deviate from the day-ahead price at 9:00, and the same happens in the evening around 20:00. This could happen, for instance, if the wind starts to blow earlier than predicted and calms down earlier than predicted.

A flexible gas power plant can also exploit this situation. It has the day-ahead commitment, but it can fulfil its commitment by buying the electricity from the real-time market. This makes sense, if the electricity price in the real-time market is below SRMC. In our example, the plant would have been started at 9:00, and shut down at 9:10 when the real-time market prices go below SRMC. The plant comes online again at 11:25 when the real-time price is above SRMC. By shutting down the plant and fulfilling the commitment from market-based resources, the plant makes USD 6916 additional margin. The same kind of situation takes place in the evening, when the plant is able to generate USD 1582 additional margin. In total, the plant makes USD 8498 additional margin during the lower real-time market price periods.

By exploiting the opportunities, the flexible gas plant is able to make a profit of USD 501,348 during the day, which is more than 11 times the profit when compared to day-ahead dispatch only. Of course, the operational profile looks different than the day-ahead dispatch (Figure 7). Now the plant will start three times during the day, with an aggressive ramping. On the other hand, this is not a big deal since the flexible plant is designed for this type of operation with unlimited starts and stops.

Case studies from the North American market

Illustrative examples are good to demonstrate the basis of a value proposition, but the real life situation is a different story. To demonstrate the value of Wärtsilä's flexible gas power plants, we have carried out several market-based analyses where the power plants are dispatched against historical and future prices. The following case studies talk about the value and business case of a Wärtsilä flexible gas power plant in the PJM and Southwest Power Pool (SPP) markets in the USA.

Load-serving entity looks for "cheap" capacity in Southwest Power Pool

SPP launched a so-called Integrated Marketplace in March 2014. The Integrated Marketplace introduced market-wide system balancing through the real-time market, which totally changed the operational profile of existing Wärtsilä assets in the market. The Antelope Station owned by Golden Spread Electric Cooperative experienced around 10 starts per engine in the month prior to the market change. Since

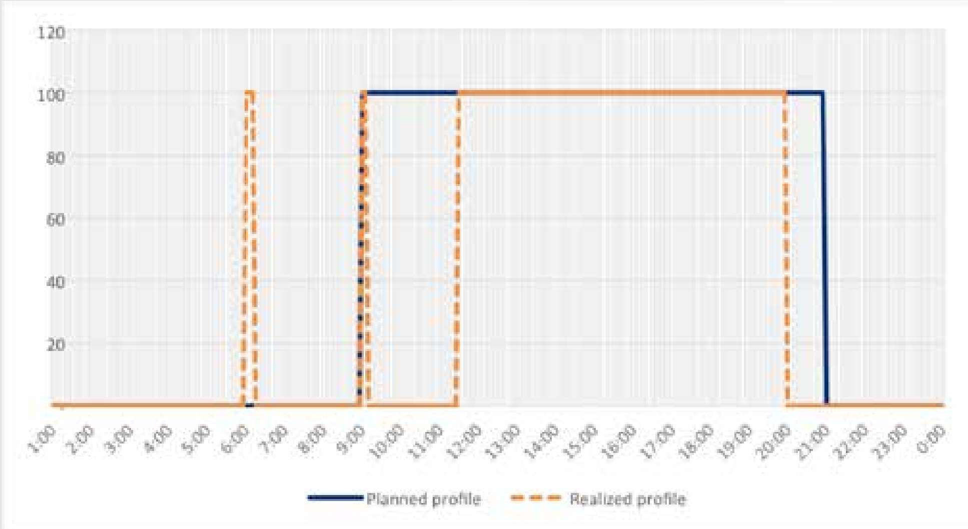


Fig. 7 - Planned and realized operational profile.

March 2014, the Antelope station has started each engine on average 80 times per month and 3 times on average daily.

Wärtsilä wanted to understand the value of this type of operation from a cooperative perspective that tries to minimize the cost to serve load for its customers. Wärtsilä analysed the first 12 months of operations of the SPP market and replicated the market dispatch with its analysis tool.

In the analysis, Wärtsilä compared three potential alternatives for a typical load-serving entity in the SPP. The load-serving entity has to serve a load of 200 MW, and it is looking for 200 MW of generation capacity to serve that load. The generation alternatives are Wärtsilä 18V50SG, Industrial Gas Turbine and Aeroderivate gas turbine (Table 1).

The analysis tool dispatched all generation alternatives against the market prices based on their variable costs (SRMC) and technical capabilities. The dispatch analysis was first done only for the day-ahead market, and then for day-ahead, real-time and ancillary services markets. The results of these dispatch simulations are shown in Figure 8.

The full optimization case takes into account the real-time market opportunity as well as the ancillary services market. Due to its better heat rate as well as flexibility, Wärtsilä's solution will operate a lot more than the gas turbines. The plant will operate more than 4000 hours and start about 1550 times per year.

Load-serving entities use "net cost to serve load" as the metric to estimate the most affordable generation option to meet their load. This approach assumes that

	18V50SG	Industrial GT	Aeroderivate
Output (ISO)	18.4 MW	227 MW	102 MW
Output (Site, ISO temp)	200 MW	200 MW	200 MW
Overnight EPC cost	700 USD/kW	500 USD/kW	700 USD/kW
Heat rate (HHV)	8,266 Btu/kWh	9,838 Btu/kWh	9,105 Btu/kWh
Minimum stable load	20%	40%	40%
Heat rate minimum stable load	10,845 Btu/kWh	13,899 Btu/kWh	12,190 Btu/kWh
Start-up time to full load	5 min	15 min	10 min
Start-up cost	0 USD/start	15,000 USD/start	0 USD/start
Variable O&M and major overhaul	5.5 USD/MWh	0.9 USD/MWh	3.0 USD/MWh
Fixed O&M	15 USD/kW/y	15 USD/kW/y	15 USD/kW/y

Table 1 - Generation alternatives.

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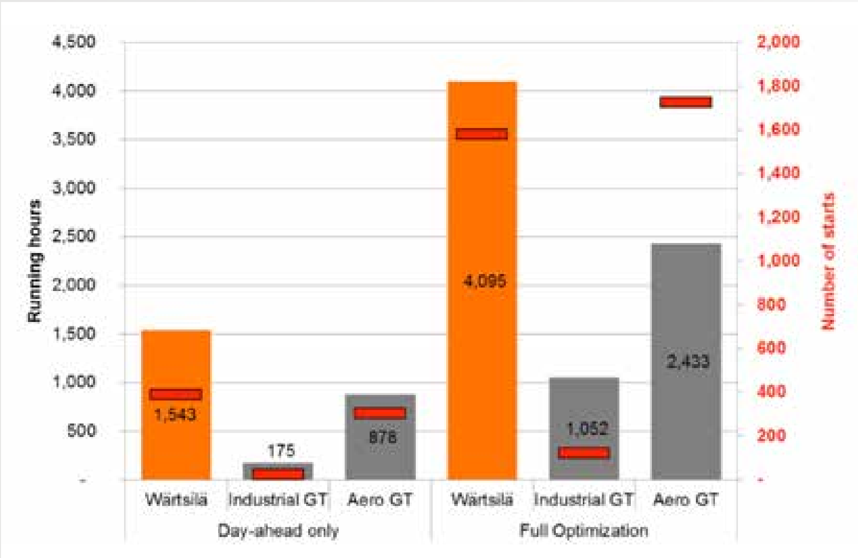

Fig. 8 - SPP market based dispatch analysis.

COST TO SERVE LOAD FROM MARKET BASED RESOURCES	-	REVENUE FROM ENERGY AND A/S MARKET	+	FUEL COST + VOM	+	CAPITAL CARRYING CHARGE	+	FIXED OPERATION AND MAINTENANCE	=	NET COST TO SERVE LOAD
Cost of procuring electricity from the market or from contracts		Revenue that is received when selling the electricity from generation (or contract) to market		Cost of fuel and variable O&M operating the power plant or utilization fee of a contract		Annualized capital cost of generation investment or availability payment of contract		Fixed operation and maintenance cost of power generation		Total net cost of serving the load

Fig. 9 - Net Cost to Serve Load formula.

	Wärtsilä	Industrial GT	Aeroderivate GT
COST TO SERVE LOAD FROM MARKET BASED RESOURCES	62 MUSD	62 MUSD	62 MUSD
- REVENUE FROM ENERGY AND A/S MARKET	- 63.6 MUSD	- 12.4 MUSD	- 32.4 MUSD
+ FUEL COST + VOM	41.5 MUSD	11.1 MUSD	22.3 MUSD
+ CAPITAL CARRYING CHARGE	11.7 MUSD	8.4 MUSD	11.7 MUSD
+ FIXED OPERATION AND MAINTENACE	3.0 MUSD	3.0 MUSD	3.0 MUSD
= NET COST TO SERVE LOAD	55 MUSD	72 MUSD	67 MUSD

Fig. 10 - Results of Net Cost to Serve Load analysis.

all electricity needed to serve its load is bought from the market, and all generated electricity is sold to the market. The formula and explanations are shown in Figure 9.

In our analysis, we used the dispatch results from the first 12 months of the SPP Integrated Marketplace, and filled in the other cost elements of the net cost to serve load calculation (Figure 10).

The net cost to serve load analysis clearly shows that the 200 MW Wärtsilä option provides the lowest cost to serve load. Annualized cost with the Wärtsilä solution is USD 55 million, while the lowest capital cost product, the industrial gas turbine, ends up at USD 72 million. Traditionally, load-serving entities have been looking for only the lowest capital cost products, but in today's market environment, that option does not provide the lowest cost to serve load. Wärtsilä's 200 MW option is able to provide USD 17.5 million savings on an annual basis compared to the industrial gas turbine. The higher capital cost of Wärtsilä's solution is compensated by the higher utilization of the asset in the market, providing additional revenues and gross margin from the market.

Independent Power Producer looking for the best rate of return

Another interesting investor group in the USA, Independent Power Producers (IPP), is trying to maximize the return on investment. The utilization of the asset is the same as with the load-serving entity case (maximize utilization), but the financial perspective is a bit different. An IPP will put its own money (equity) into a project and try to maximize the return on this investment. The typical metrics used in the industry is internal rate of return (IRR) for leveraged project, or equity IRR.

Wärtsilä did a market analysis from an IPP perspective for the PJM market in the USA, which is the biggest electricity market in the world. The IPP was looking for an investment between the most efficient Combined Cycle Gas Turbine (CCGT) and Wärtsilä 18V50SG simple cycle configuration (Table 2).

	Wärtsilä	CCGT
Output (Site, ISO temp)	18.4 x 25 = 460 MW	452 MW
Heat rate (HHV)	8,261 Btu/kWh	6,530 Btu/kWh
VOM	5.5 USD/MWh	3.5 USD/MWh
FOM	5.7 USD/kW/y	8.7 USD/kW/y
Overnight EPC cost	750 USD/kW	950 USD/kW
Owner's cost	15% of EPC cost	15% of EPC cost
Construction time	18 months	30 months
Equity/Dept	30%/70%	30%/70%

Table 2 - Input parameters in the PJM analysis.

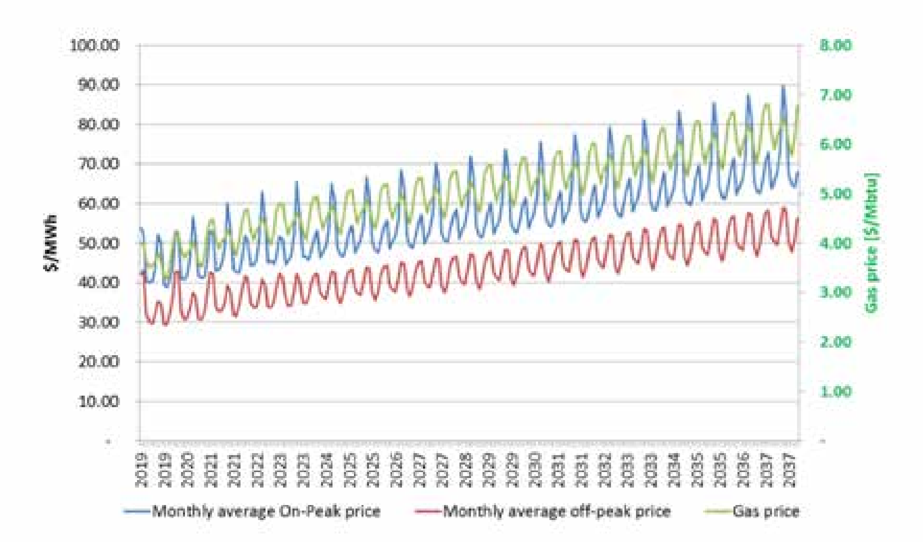

Fig. 11 - PJM forward price curves.

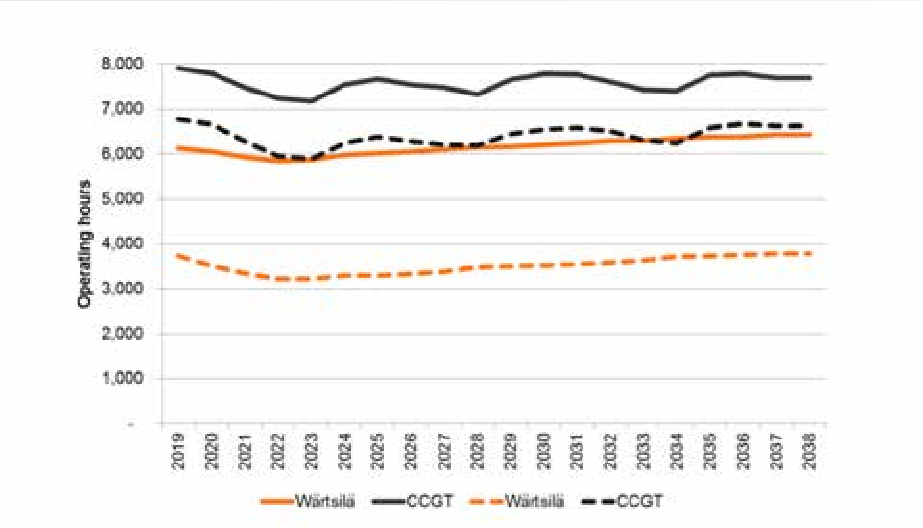

Fig. 12 - Operational profiles of Wärtsilä and CCGT in the PJM future analysis.

The IPP was interested in analysing the performance of both alternatives against the future price curves (Figure 11). Wärtsilä ran the market dispatch tool against the future price curves, while assuming the same historical volatility levels for day-ahead, real-time and ancillary services prices. The results of the dispatch analysis are shown in Figure 12.

When the comparison is made against the high efficiency CCGT, Wärtsilä's solution runs less. Once again, there is a big difference if we include only the day-ahead market (dotted line), or in addition the real-time and ancillary service market opportunities. For a flexible gas plant, the real-time market and ancillary service market are essential. Taking them into account almost doubles the economical running hours. These markets also have significant impact on the IRR numbers, which can be seen in Figure 13.

The day-ahead only analysis shows that the CCGT option is slightly better than the Wärtsilä solution. The full optimization case, which also contains the real-time market and ancillary services market, gives totally different results. Return on equity more than doubles to 30%, and now Wärtsilä's solution is clearly a better investment case than CCGT. The traditional day-ahead analysis does not add value for flexibility. Rather, it looks only at the heat rate and capital expenditure, while the full optimization is able to demonstrate the value of flexibility on top of the day-ahead analysis. The PJM analysis has been an eye-opener in the market, as this is the first time that Wärtsilä is able to show better return on investment with a large-scale reciprocating engine solution than the state-of-the-art CCGT.

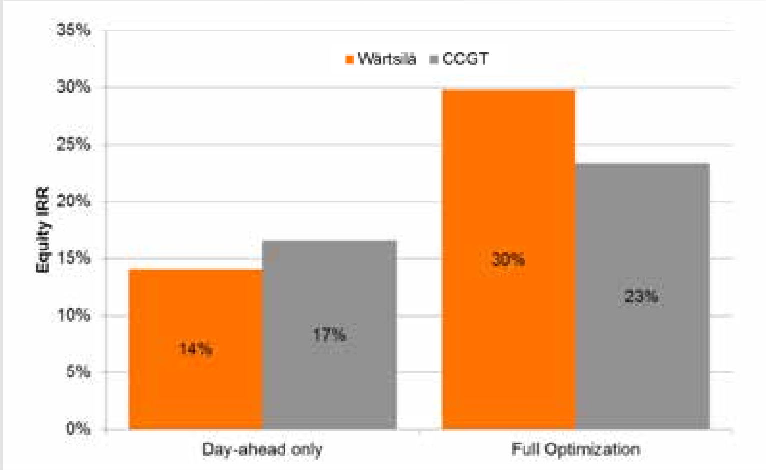

Fig. 13 - Equity IRR (leveraged IRR) in PJM.

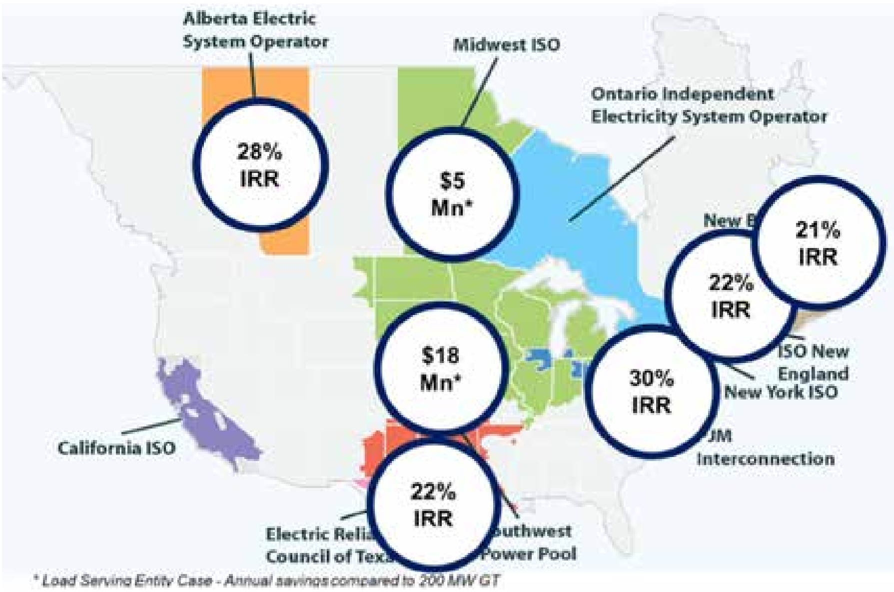

Fig. 14 - Results of the ISO market analysis - Leveraged IRRs and Savings for load serving entities (SPP and MISO).

Conclusions

The electricity market environment in North America is becoming more favourable for flexible gas. The increasing renewables, together with enhanced market rules, are increasing price volatility across the markets, making the investment case for flexible gas power very attractive.

Wärtsilä's existing plants in the USA are already experiencing this change, and their operational profiles are very flexible: for instance, starting and stopping the engines 1400 times per year, and ramping up and down constantly, in order to balance the system more economically. The mindset among investors to date has been, "This is great, but we're not able to quantify the value." But Wärtsilä has done extensive modelling to quantify the value of flexibility across the North American ISO markets, and the results are impressive.

Figure 14 summarizes the notable results of the analyses done so far. Across the ISO markets, Wärtsilä's solution is able to provide either lower cost to serve load or higher return on investment than gas turbines. If you want to learn more about the analysis, please visit www.smartpowergeneration.com.

Smart Power Generation can help China stop curtailing its wind power

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China's inflexible power system, which can't respond well to changes in supply and demand, forces it to curtail more of its wind energy every year, despite the country's renewable-energy ambitions. With wind farms in the north feeding power to the population-dense south, China's new focus on gas-fuelled generation is welcome, but it needs to be the right gas technology, argues a recent white paper from Wärtsilä.

China is focusing strongly on the deployment of wind and solar energy to support global emission reduction targets. However, to fully optimise the output from wind and solar parks into a legacy system dominated by baseload coal plants, the country needs to fundamentally change its power system. With a high proportion of China's wind power located in the north and the northeast, and load centres situated in the south and the southeast, the country recognises the need to transmit clean power across the country. To bridge the geographical divide, the Chinese government has plans to invest at least CNY 2 trillion (USD 315 bn) in its power grid (Reuters 2015).

Relocating power, however, is only part of the solution. When energy arrives in the south, China's power system must be able to balance variable renewable energy. Thermal generators must therefore switch from typical baseload operations and instead deliver flexible and intermittent output that produces power only when wind and solar are not available. To that end, China needs generators with ultra-fast start-up times to provide accurate load following.

While the penetration of wind and solar energy is expected to increase from 6% to 20% by 2030 (Bloomberg New Energy Finance 2015a), China's nuclear- and coal-dominated generation mix makes load following unworkable. Today, the only option has thus been to curtail variable renewable energy, a practice that comes at great environmental and financial cost. During the first half of 2015, 15% of China's wind power was curtailed, at a cost of CNY 8.9 bn (USD 1.4 bn) (Bloomberg New Energy Finance 2015b). If nothing is done, that percentage will keep going up as more renewable energy comes online.

In a recent white paper, Wärtsilä crunched numbers to propose a solution in the shape of its Smart Power Generation (SPG): an agile generation technology based on multiple fast-reacting internal combustion engines. Due to the inherent operational flexibility of the engines, SPG power plants

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can follow precisely the output of wind and solar power. If placed in southern China, SPG installations would help to absorb the variable wind energy from the north. The increased flexibility would in turn make it possible for China to integrate larger shares of wind and solar energy.

In a CHP (combined heat and power) configuration, SPG power stations can also produce heat for district heating, potentially replacing combined cycle gas turbines (CCGT) or coal-based generation.

Wind curtailment in China

While variable renewable energy accounts for around 6% of total generation in China, yet wind curtailment is already a significant issue. The country curtailed 15.2% of its potential wind energy in the first half of 2015, a dramatic increase from the previous year when the rate was 8.5% (Bloomberg New Energy Finance 2015b). There are a number of reasons why, but most importantly the wind farms' location triggers curtailment. As demonstrated in Figure 1, there is a stark divide between levels in the north and the south – most notably, the map shows curtailment of 43% in Jilin, a northern province.

The high levels of wind curtailment in the north are intrinsically linked to the load centres in the south. With China's major load centres, including Beijing, Shanghai and Guangzhou, located in the south, much of the wind energy has to be transmitted to these regions of great demand, both from private and industry consumers.

In addition to the transmission challenge, China's two main grid companies, the state-owned Grid Company of China and China Southern Power Grid Company, prefer to keep all power plants operating at a lower load level rather than shutting down some plants when there's a supply surplus. This becomes problematic when renewable energy generation peaks, since thermal power plants running at low load do not have any downward flexibility. That's when the grid companies prefer to curtail the extra renewable output rather than force baseload thermal plants to shut down beyond their already low utilisation rates.

Although China acknowledges its wind curtailment as a problem, the situation has not stopped the country from keeping the rollout of renewables going. Figure 2 shows that solar and wind generation penetration in China is expected to increase from 6% in 2015 to 20% in 2030.

Solutions to wind curtailment

First step: expanding transmission network

To avoid wind curtailment, due to the geographical divide between renewable generation and load centres, the Chinese government has plans to invest at least CNY 2 trillion (USD 315 bn) in its power grid (Reuters 2015). This is certainly a desirable development, because expanding the grid is an important step towards an efficient power system with a high penetration of variable renewable generation. A strengthened grid does not, however, solve balancing challenges, because it contains virtually no energy storage capacity. Therefore, when variable renewable energy arrives at China's load centres, a highly flexible thermal power fleet must balance the power.

A solution can be found with technology that can ramp up in an instant at minimal cost to provide power when variable renewable energy is not available, and ramp down again at the same speed when wind and solar power come back online. An everyday example is early evenings, when the sun goes down but demand spikes as consumers return home from work.

Avoiding inflexible gas-fired generation

While coal and nuclear power plants dominate China's thermal fleet, the country's generation mix also includes some gas-fired power plants, and plans are in place to increase their total generation from 2% to 3% by 2030. These operate mainly in China's cities, including Beijing, where new policies support the closure of coal power plants and the installation of new gas power plants that typically use CCGT technology.

Traditionally, CCGT plants have provided a degree of flexibility by ramping up over a number of hours and then quickly flexing their output to provide system balance through a process known as 'part-loading'. While this solution may have been adequate in the past when a small amount of renewable energy was integrated into electricity systems, it is not an efficient way to provide the increased amount of flexibility needed in China as renewables increase. Part-loading entails extra costs, including increased carbon costs, reduced fuel efficiency, more generators on the grid and the cost of curtailment. So while China's gas-fired capacity increase is welcome, close consideration must be given to installing the right type of gas technology. Otherwise China could miss out on introducing flexibility that enables a high penetration of renewables.

Introducing Smart Power Generation

SPG could bring significant benefits to China's power system. The technology that underpins SPG is modular power based on internal combustion engines (ICE), capable of balancing variable renewable energy by starting in less than one minute and

Fig. 1 - China must find ways to reduce wind energy curtailment, as high as 43% in some areas, due to its monetary and environmental impact. Source: Bloomberg New Energy Finance.

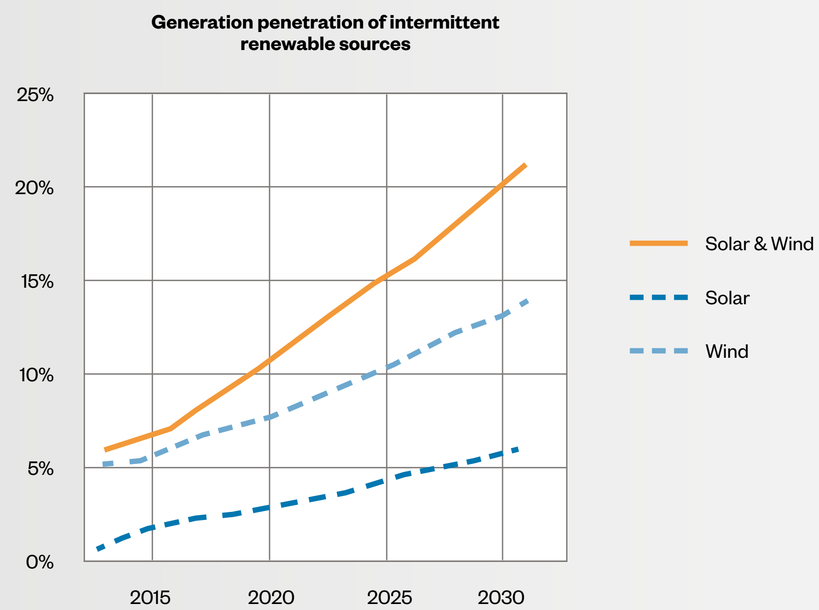

Fig. 2 - As China continues to deploy variable renewable energy, the country needs to absorb new generators into the power system to avoid an increase in wind curtailment costs. Source: Bloomberg New Energy Finance, New Energy Outlook 2015.

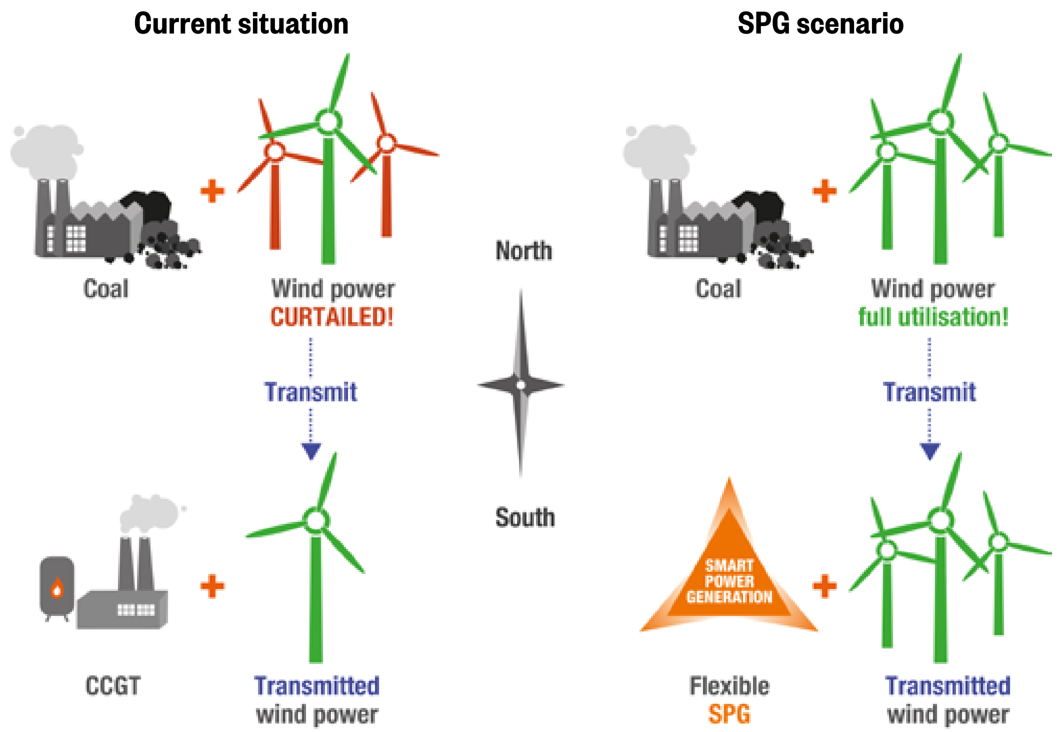

Fig. 3 - Inflexible CCGT plants in the south cannot balance wind power from the north. Instead, wind power is partly curtailed and CCGTs are forced into inefficient part-loading. By contrast, SPG power plants can follow the variable output of renewables in real time and maintain top efficiency also in part-load mode. If placed in the load centres of southern China, SPG plants would help to minimise wind curtailment, hence cutting costs and pollution.

reaching full load in less than five minutes. Used in partnership with traditional coal and gas power plants, operated with their highest efficiency at baseload, SPG is not only proven to balance electricity systems with a high penetration of renewables with great reliability, but also at a cost that will save money for the consumers.

In Figure 3 the "Current situation" shows business-as-usual in China, including wind, coal-fired power plants and CCGT plants. In this scenario, coal-fired power plants must continue to run in the colder north in winter to supply the district heating that keeps households and industries warm. As the coal plants keep running, excess wind energy is transmitted to the south, but on arrival at the load centres CCGT plants can't ramp up and down quickly enough to balance the variable output. Essentially, power transmission does not add any flexibility to the system. At the load centres in the south, CCGT plants have to run to provide heat, but can only operate within a loading range of 50% to 100% because of the considerable time and cost associated with stops and starts. There's no flexible thermal generation and, as a result, the only option is to get flexibility from windmills by curtailing their generation, which results in costs, loss of free energy, and reduced opportunities to limit emissions.

In contrast, the "SPG scenario" proposes the replacement of CCGT plants in China's load centres with SPG, which can stop and start almost instantly to follow the load from wind farms in the north. This means the SPG plants could provide fast and flexible power when the wind is not blowing, and cease operations again when wind becomes available once more. Additionally, SPG in a CHP (combined heat and power) configuration can replace the heat production of CCGT plants, and in doing so deliver heat more efficiently and flexibly. This is possible through the use of an accumulator, which is a hot water storage tank dimensioned to the size and needs of the district heating network. Accumulators perform best in systems with a high penetration of variable renewable energy, enabling the SPG plant to run on full power when wind power is not available, while simultaneously storing heat. This heat is discharged when wind power becomes available again, promoting the balancing of intermittent generation while also supporting the heat requirements of district heating. The combination of SPG and heat storage enables plants in load centres to operate a load of between 0–100% based on demand, which means the thermal fleet can provide enough flexibility to optimise wind power.

In power systems with a high penetration of variable renewable energy, the 0–100% load range provided by SPG can make a significant difference to the power system balance. This is demonstrated in Figure 4, which compares China's typical daily dispatch with either CCGT or SPG. The graph on the left demonstrates the resulting wind curtailment, when only coal and CCGT generation are used, where these inflexible sources already run at their

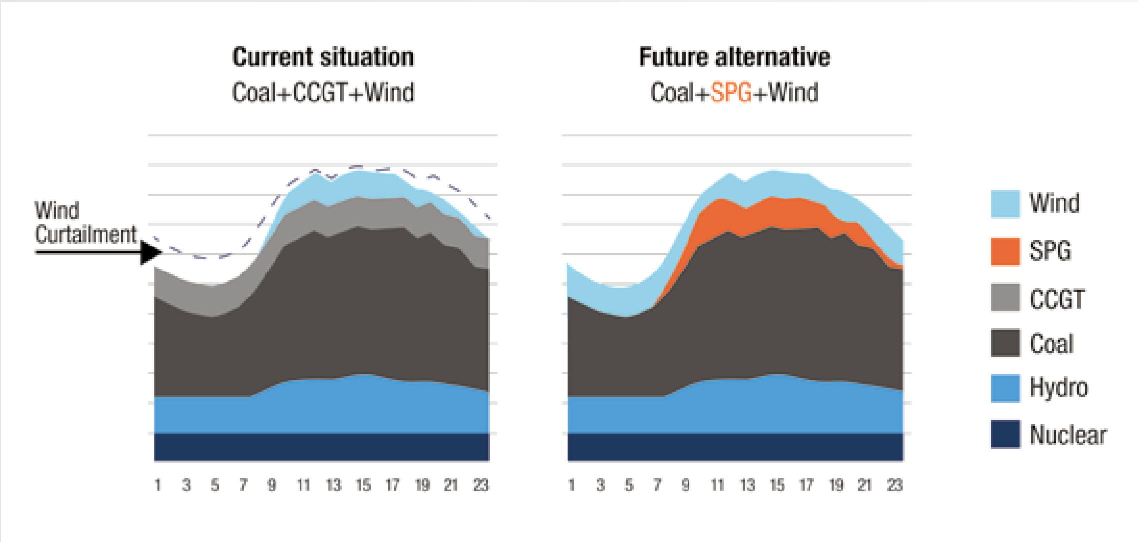

Fig. 4 - An illustration of the impact of CCGT and SPG load ranges on wind energy curtailment. Through its ability to ramp up from zero to 100% almost instantly, SPG can eliminate wind curtailment by following the output of wind energy in real time.

minimum stable loads of 50% at night and are unable to reduce output any further to integrate wind power.

As demonstrated in the left graph, when CCGT plants are replaced with SPG, all available wind generation can be accommodated at night by shutting down SPG. During the day when wind generation cannot meet peak demand, SPG is started up to provide power.

Conclusion: How to enable SPG for integrating wind power

While there are no doubts about SPG's ability to balance the grid and prevent wind curtailment, questions remain over its economic viability on project level. Specifically, the lack of market-based pricing means that China, unlike Europe, US and Australia, does not price electricity by the hour or even five-minute intervals that reflect demand and variable renewable generation. Instead, for those wishing to develop a power plant in China, the price of the electricity is constant and fixed when they apply for planning permission. This means that there is only one price for the entire lifecycle of the plant. Furthermore, grid companies dedicate running hours more or less equally to all power plants without taking into account the age, efficiency or emissions. That is not the case in the countries that have introduced electricity markets where power plants are dispatched reflecting their real generation cost.

China recognises how serious an issue wind curtailment is. The National People's Congress has indicated that it will pursue a market-based pricing structure to support the country's emerging decarbonised energy system (Chinese Communist Party's Central Committee and the State Council 2015). In order to support technologies such as SPG, the electricity market must be designed to cause sufficient price volatility that offers incentives to invest in thermal generation that can balance variable renewable generation.

The Wärtsilä white paper argues that policies that support agile thermal generation would cement the case for investing in new, flexible capacity. Although China has made significant progress in decarbonising its power supply, the country cannot afford to continue curtailing its wind assets and should proceed to optimising its current and future power system.

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Maximising profits through efficient pulse load operation

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Over the past few years, the share of wind and solar power in many grids has increased rapidly all over the globe. Nowadays, a sizeable proportion of all installed capacity is made up of intermittent renewable energy sources, a fact that introduces a previously unheard of degree of uncertainty into the power systems. This makes it increasingly difficult to ensure the essential balance between supply and demand in the power systems of the 21st century. It is clear that, in order to secure system stability, flexibility will be needed more than ever. Since intermittent renewable power sources are incapable of providing said flexibility in the form of on-demand power, future thermal generation will need to bear the burden and be as flexible as possible. One key characteristic of a flexible plant is the ability to ramp up and down quickly, fitting a demanded production time bracket that we refer to as a pulse.

This article is based on the award-winning paper (Highly Commended 2015 in the track "Power Plant Technologies"): "Maximising profits through efficient pulse load operation" presented at the Power-Gen Asia 2015 conference.

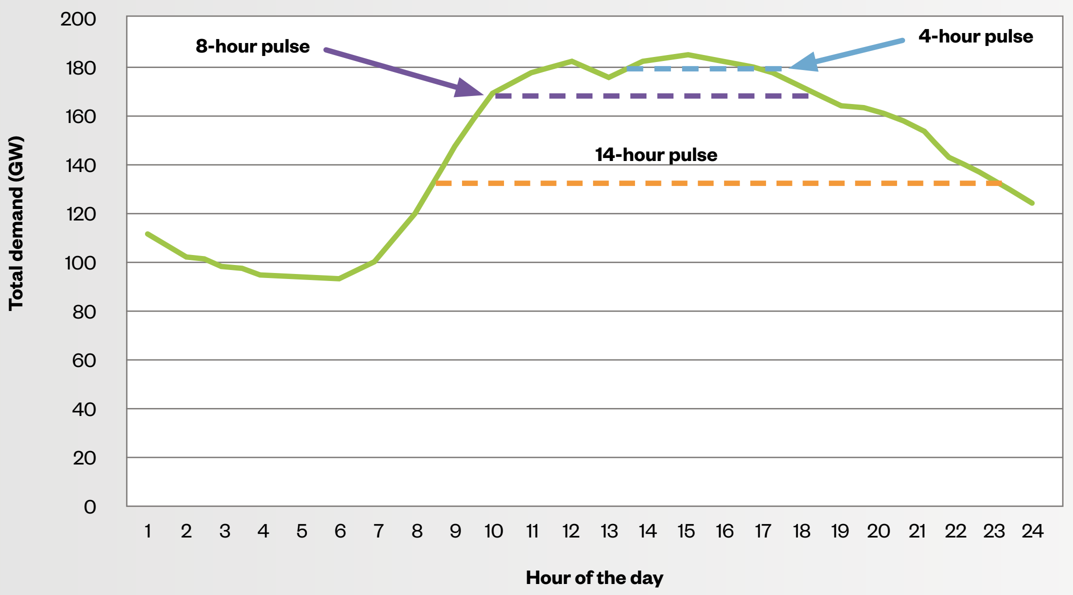

Fig. 1 - Examples of different pulse loads in a typical daily demand curve.

Dealing with pulses

These pulses require the power generation fleet to adapt to them, by raising output for a set period of time and returning to the previous level after the pulse is over. The backbone of most modern power systems is made of so-called baseload technologies: those that cannot easily adapt their output in a short time span or that suffer high efficiency losses if they do so. For example, nuclear power plants and coal power plants, as part of the baseload fleet, are ill-suited to provide on-demand flexible generation so they are not considered in this study.

Gas-fired power, due to its superior ramping capabilities compared to baseload technology, is generally used to supply the needed power for these pulses. However, combined cycle gas turbines (CCGTs) are the most widespread solution of that kind. Although able to ramp up and down in relatively short periods of time, they are still better suited for dealing with stable loads due to their heavy derating under variable load conditions. Since CCGTs are currently the state-of-the-art technology used to deal with load pulses, they constitute the benchmark for the solution we propose in this paper.

Next, a number of different cases of pulse load operation will be reviewed. The considered time frames for the pulses are four hours, eight hours and 14 hours. The plant sizes taken into consideration are 100 MW and 400 MW, representing two of the most usual classes in current power systems.

Case study: 100 MW power plants

Introduction

The reasoning behind the choice of these concrete examples is their real-life relevance. As it can be seen in Figure 1, the 4-, 8- and 14-hour pulses can be found as recurring patterns in daily demand curves of highly industrialised power systems. Although this concrete figure corresponds to the Japanese daily demand, similar patterns are commonplace in most US power systems.

Assumptions

The operational costs considered include the total fuel costs, as well as the total variable operations and maintenance costs (VOM). Both are calculated for the duration of the startup process, the actual, required period of generation, as well as the shutdown time. Additionally, the cost impact on maintenance from the start-up, i.e. the equivalent operating hours (EOH), is also taken into consideration.

The considered technologies are all gas-fired combined cycle power plants, equipped with air-cooled condensers. The comparison is made between state-of-the-art technology based on internal combustion engines (CC ICE) and gas turbines (CCGT). The former technology is represented by Wärtsilä's Flexicycle solution, whereas the latter is based on a Frame 6 solution (100 MW case) and on a Frame 7 solution (400 MW case). The performance data has been obtained from the latest available versions of engineering calculation software, namely GT Pro for the combined cycle gas turbines and PerfPro for the internal combustion engines.

The fuel price taken into consideration is the harshest in the region, signifying the most favourable condition for CCGTs, due to their higher nominal baseload efficiency. For that matter, we have chosen the Japan LNG import spot price as of May 2015, averaging at approximately 12.13 USD/MMBTU (41.39 USD/MWh).

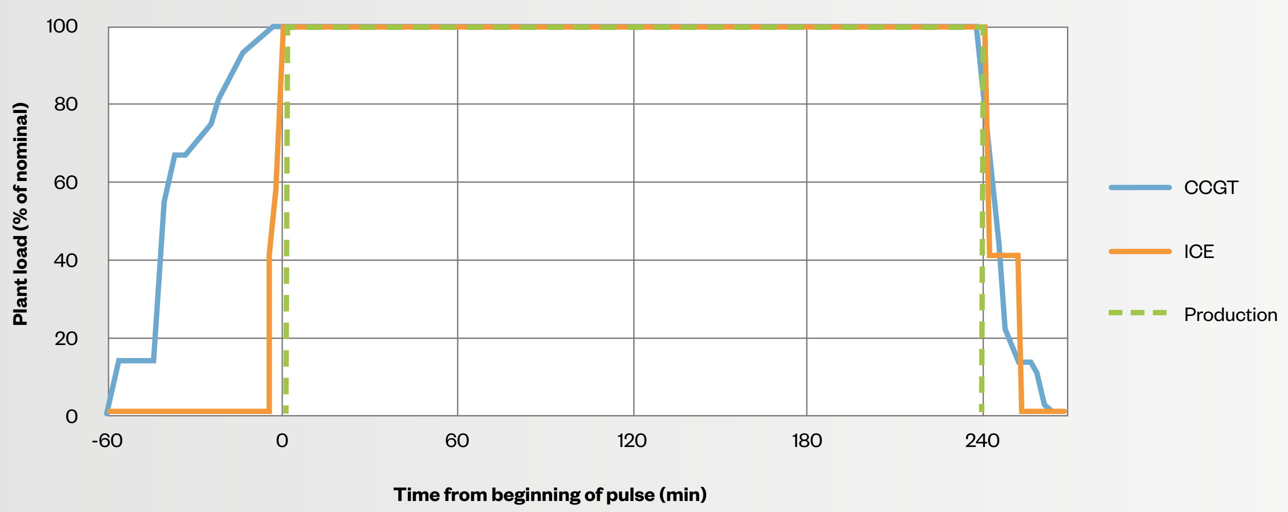

Fig. 2 - 4-hour pulse, ramp-up and -down required by gas-fired technologies under analysis.

4-hour pulse

A typical CCGT power plant has a start-up time of approximately 60 minutes. Hence, the CCGT plant needs to receive the start command one hour before the actual pulse takes place, a situation that in many cases may prove difficult. Moreover, the energy produced during this start-up hour is typically not reimbursed. The same applies for the shut-down time, which is typically 30 minutes.

On the other hand, a typical ICE in single cycle (SC) mode can be started in only 5 minutes. As soon as the combined cycle equipment is ready, typically in approximately 50 min, the loop can be closed, all while the plant is operating continuously. When it comes to shut-down, the combined cycle ICE plant is able to unload in 20 minutes (1 min when in SC mode).

Hence, the amount of time the ICE plant is run outside the required settlement periods, as defined by the electricity markets, can be minimised efficiently. In other words, the amount of consumed fuel and accumulated running hours can be kept to a minimum.

Next, the total operating costs of 100 MW power plants during a four-hour pulse will be analysed. As seen in Figure 3, at first, the impact of the start-up costs of the CCGT is considerable. Second, when adding the fuel and VOM costs for the one-hour start-up period, the accumulated costs already exceed USD 13,000 at the time when the settlement period begins. Over the four-hour pulse, the higher nominal efficiency of the CCGT only marginally compensates for these initial costs, compared to the CC ICE. When also considering the costs associated with the shut-down time, the total difference over the full pulse is over USD 10,200, in favour of the CC ICE.

When looking at the four-hour pulse in terms of efficiency, the energy produced during the start-up and shut-down periods must not be taken into account since it is not reimbursable. This energy production is only a by-product of the pulse operation and is not of commercial use. Hence, we will define the overall pulse efficiency as:

$$\eta_p^T = \frac{\int_{t=0}^{t=t_p} P(t)\,dt - \int_{-\infty}^{t=0} P(t)\,dt - \int_{t=t_p}^{t=\infty} P(t)\,dt}{m_f \cdot LHV_f}$$

Magnitude	Units	CC ICE	Frame 6 CCGT
Full-load efficiency	%	49.2	51.4
Start-up time	minutes	5 (SC) / 50 (CC)	60
Shutdown time	minutes	1 (SC) / 20 (CC)	30
O&M costs	EUR/MWh	5	3
Start-up costs	EUR/MW	0	64.5

Table 1 - Performance comparison of 100 MW power plants.

Where we have defined t_p = (4, 8, 14) h, depending on the length of the pulse under analysis in each case. Each of the integrals account for the energy produced in one of three periods of time: before the actual delivery of the energy pulse (t<0), during the pulse (0<t<tp) and after the pulse is over (t>tp). Since the early start-up and the delayed shut-down are needed, yet do not provide any monetary value being outside of the contracted load pulse, we will discount the energy produced during said periods by subtracting the integrals that quantify out-of-pulse energy delivery. Predictably, the closer the generation technology is able

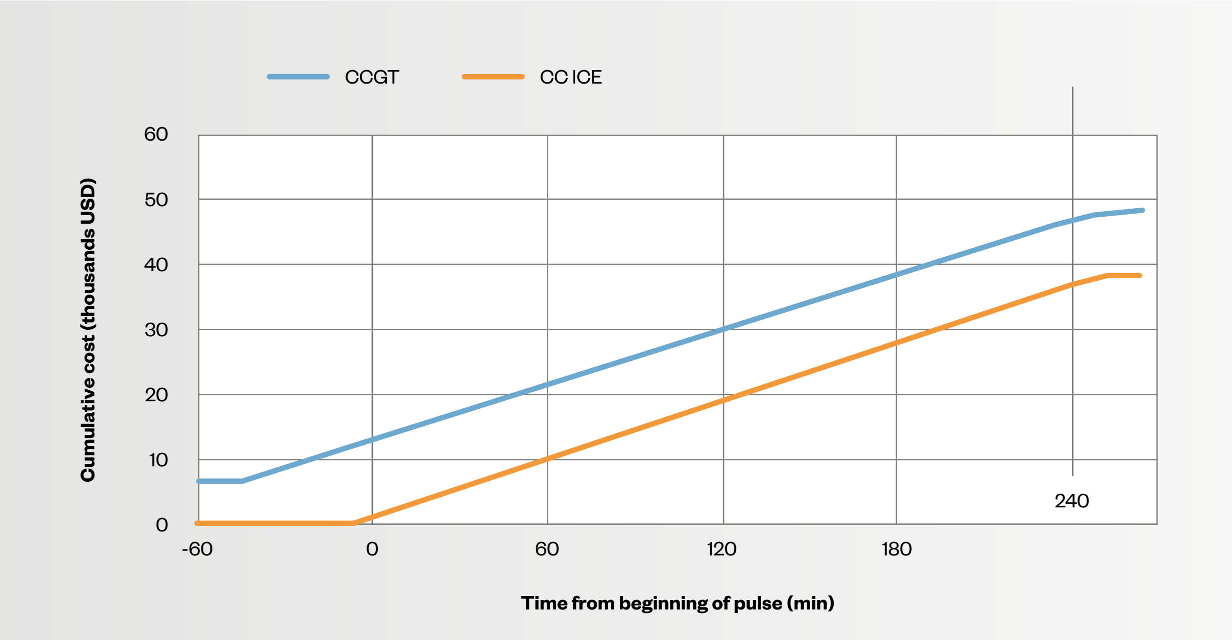

Fig. 3 - 4-hour pulse production – fuel, O&M and start-up costs (100 MW power plants).

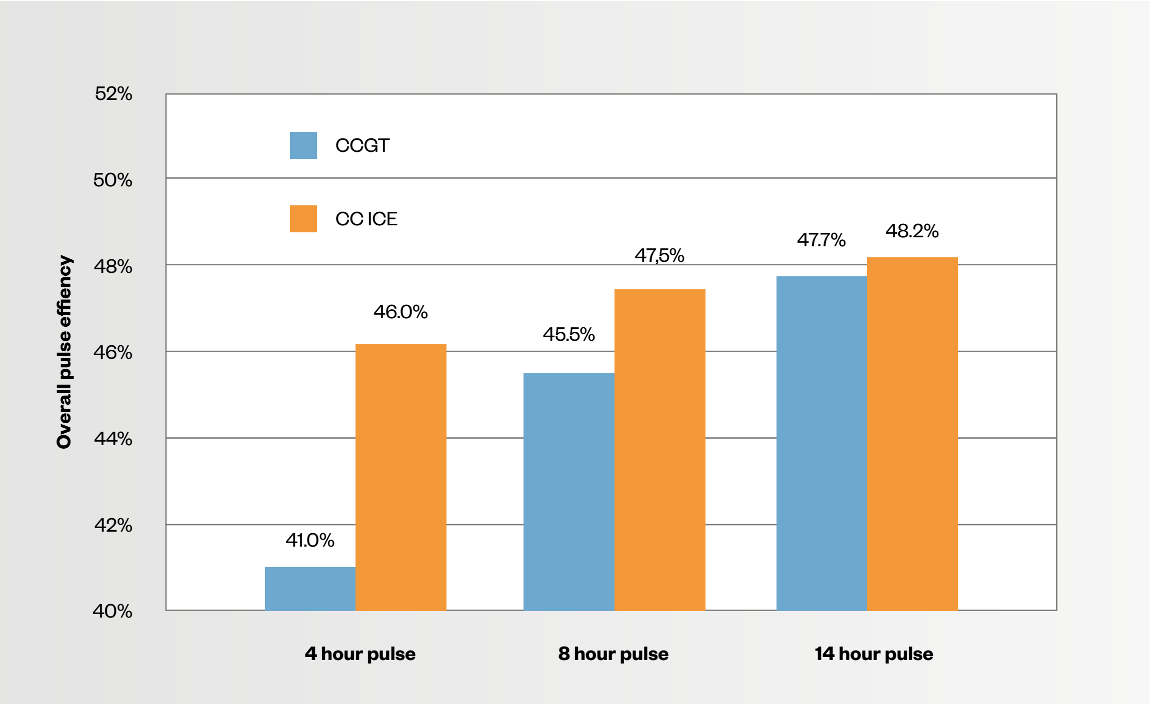

Fig. 4 - Pulse efficiencies (including fuel, O&M and start-up costs) for 100 MW power plants.

[ENERGY / IN DETAIL]

Magnitude	Units	CC ICE	Frame 7 CCGT
Full-load efficiency	%	49.2	54.0
Start-up time	minutes	5 (SC) / 50 (CC)	60
Shutdown time	minutes	1 (SC) / 20 (CC)	30
O&M costs	EUR/MWh	5	3
Start-up costs	EUR/MW	0	64.5

Table 2 - Performance comparison of 400 MW power plants.

to match the shape of the demand pulse, the less the energy waste. This equates to an interesting balance between baseload efficiency and operational flexibility, which our overall pulse efficiency (η_P^T) quantifies.

Based on this calculation and the previous assumptions, we find that the overall pulse efficiency of the CCGT is 41.0% vs. 46.0% for the CC ICE. We can conclude that, in the case of a 4-hour pulse, the far superior operational flexibility of the internal combustion engines outweighs the higher baseload efficiency of the CCGT.

The second part of our analysis focuses on the economic side of the issue. For energy production in current-day competitive markets to be profitable for asset owners, ensuring that the most efficient solution 'on paper' also makes economic sense, is a must.

As we can see in Table 1, the CCGT solution incurs hefty start-up costs, due to the use of start-up fuel and the greatly increased wear and tear of the machinery during the start-up phase, accounted for in the so-called equivalent operating hours (EOH) calculation. This start-up cost puts the CCGT at a disadvantage compared to the combustion engines, which do not suffer any increased wear and tear nor require extra fuel for starting up. Also, being internal combustion engines capable of starting just five minutes before the beginning of the pulse, the amount of fuel spent in generating non-productive (i.e. out-of-pulse) energy is negligible compared to that of the CCGT solution.

The results of the economic analysis are summed up in Figure 3. We can see that for the case of a 4-hour pulse, the steep start-up cost of the CCGT and its need for one hour of out-of-pulse production cannot be compensated by means of its superior baseload efficiency. Hence, for the typical pulse length of four hours, which covers most morning and evening peaks in developed countries, we conclude that the CC ICE solution is not only technically superior (i.e. it yields a higher overall pulse efficiency), but it is also economically superior by means of a reduced operation cost compared to that of a CCGT.

8-hour and 14-hour pulse

Similarly, eight- and 14-hour pulses have been analysed for the 100 MW power plants. A summary of the overall pulse efficiencies for these periods is presented in Figure 4. Hence, not even during a 14-hour pulse is the higher nominal efficiency of the CCGT sufficient to compensate for the energy waste resulting from a slower start-up and shut-down; the CC ICE solution is still a more efficient option.

Case study: 400 MW power plants

In a similar fashion to that used for analysing 100 MW power plant solutions in the previous chapter, we now present a comparison of the pulse load efficiencies of a Frame 7-based CCGT solution and a scaled-up version of the CC ICE solution based on Wärtsilä's Flexicycle technology. Table 2 provides a comparison of the technical performance of these solutions.

4-hour, 8-hour and 14-hour pulses

An overview of the calculated pulse efficiencies for the 400 MW CCGT and CC ICE solutions is presented in Figure 5.

It is in this case, where larger power plants are evaluated, that the results turn out most interestingly. During the 4-hour pulse, the overall efficiency is almost three percentage points higher for the CC ICE solution. However, we can observe a near break-even of the efficiencies occurring briefly before 8 hours.

For lengthier pulses, the CCGT becomes the more efficient option, surpassing the CC ICE by a slim margin. However, it is important to notice that even though the pulse efficiency of the CCGT is slightly higher than that of the CC ICE, the total operational costs are still higher.

In the 8-hour case, although the overall pulse efficiency of the 400 MW CCGT is 0.3 percentage points higher than that of the CC ICE, the overall cost generated by the CCGT is still 8.1% higher, which is a very remarkable difference. Even in the 14-hour case, where the CCGT, best suited for baseload operation, clearly wins in terms of overall pulse efficiency, the CC ICE retains a 1% cost advantage.

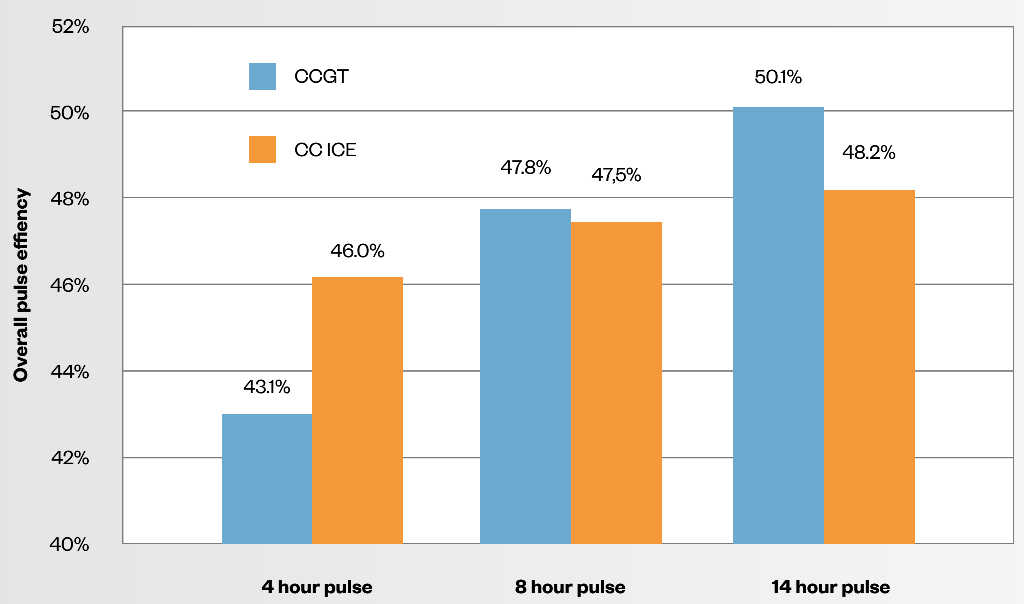

Fig. 5 - Pulse efficiencies (including fuel, O&M and start-up costs) for 400 MW power plants.

Conclusions

As a result of our technical and economic analysis, we can conclude that the shorter a single pulse of power generation is, the greater the importance of reaching full load quickly. This emphasis on flexibility easily outweighs a higher baseload efficiency, and, therefore, the evaluation criteria in power plant projects must be rethought. In summary, we conclude the following:

- For short and medium pulses, 4 and 8 hours, an internal combustion engine-fired combined cycle (such as Wärtsilä´s Flexicycle solution) is a more competitive option than both small-scale (100 MW) and large-scale (400 MW) CCGTs.
- Even though the 400 MW CCGT has a higher average efficiency than Flexicycle during an 8-hour pulse, its total operational costs are higher (due to the start-up costs and increased maintenance needs).
- For long pulses, 14 hours, CC ICE is a more competitive option than small-scale (100 MW) CCGTs.
- Even though the 400 MW CCGT has considerably higher average efficiency than CC ICE during a 14-hour pulse, its total operational costs are still higher than that of the internal combustion engine-based solution.

Table 3 serves as a summary of the completed modelling and presents the best solution in both technical (overall pulse efficiency) and financial (overall cost) terms, for each of the scenarios under analysis.

	100 MW plant		400 MW plant	
Length of pulse	Better overall pulse efficiency	Better overall cost	Better overall pulse efficiency	Better overall cost
4 hours	CC ICE	CC ICE	CC ICE	CC ICE
8 hours	CC ICE	CC ICE	CCGT	CC ICE
14 hours	CC ICE	CC ICE	CCGT	CC ICE

Table 3 - Summary of the completed modelling.

Wärtsilä delivers the first propane-fired power plant

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The Wärtsilä 34SG is the first and largest medium-speed engine running on propane on the market.

In September 2014, Wärtsilä was awarded a contract for a pair of Wärtsilä 20V34SG-LPG GasCubes to be installed for an industrial customer in Central America. These are the first Wärtsilä 20V34SG-LPG GasCubes to use propane gas as their main fuel.

Jyrki Anturaniemi, Proposal Manager, Americas, Sales Proposals, Wärtsilä Energy Solutions, believes the Wärtsilä 34SG-LPG is well suited for this application. Not only is the Wärtsilä 34SG-LPG engine the right size for the job, it meets the customer's requirements for a package that enables liquefied petroleum gas (LPG) fuel usage and can be delivered quickly. Furthermore, it also satisfies the customer's need for a compact, space-saving and fully engineered solution. This project, with an extended-EEQ (Engineered Equipment Delivery) scope basis from Wärtsilä, allows the customer to save money, by assuming the responsibility for purchasing and installing its own supplied boiler system alongside the GasCube solution.

In brief, the scope of the order includes standard supporting auxiliaries for the gas fuel system (natural gas/liquefied petroleum gas), such as a lube oil system, starting air system, cooling system, charge air system, exhaust gas silencer, automation & control system, low-voltage and medium-voltage switchgear, basic engineering, civil material for the Cubes and a reasonable number of days for installation and commissioning supervision and training.

The key driver was the existing LPG at the site. This facility needed 14 MW of electricity generation supplied with LPG fuel, consisting of a minimum 97% propane and maximum 3% butane.

When operating on natural gas at the generator terminals, the normal output of the Wärtsilä 20V34SG unit is 9341 kWe. For LPG operation, the output is 6995 kWe, but the same engine can run on natural gas (NG) and achieve the full output of 9341 kWe per unit. This solution gives the customer the fuel flexibility to switch from LPG to NG fuel operation in the future, when they anticipate availability of natural gas from an LNG terminal project in the area. This would give the plant a total generating capacity of 18.6 MW when fuelled by natural gas.

The Wärtsilä engines will generate energy for the customer's industrial facility processes with the LPG fuel. This underlines and demonstrates the confidence in and reliability of the provided solution.

This project opened up a new alternative fuel usage for Wärtsilä technology to improve the competitiveness of the Wärtsilä 34SG engine. One of the particular benefits was the GasCube concept, which seemed to be the only configuration that would fit in the customer's plant area, thereby bringing significant demonstrable value to the customer.

PROPANE FACTS

1. Propane is the main component in liquefied petroleum gas (LPG), which is commonly used in cooking appliances and vehicles and is increasingly offered for power production. LPG is a by-product of natural gas processing and crude oil refining. By replacing heavy fuel oil with propane, carbon dioxide and other emissions from a power plant can be significantly reduced.

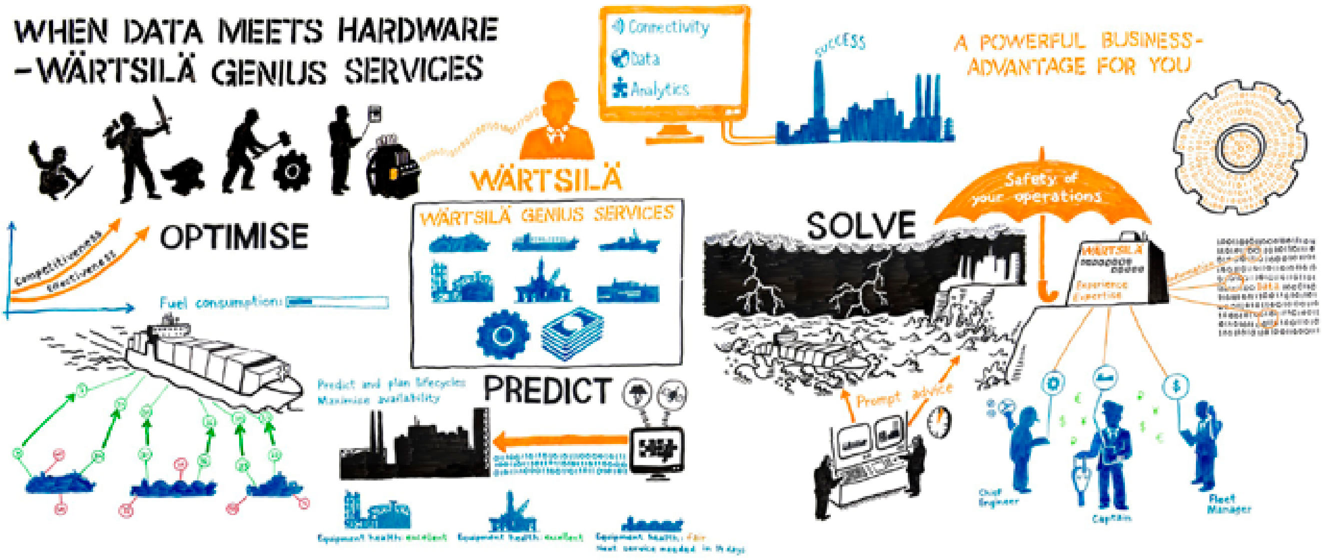
2. The Wärtsilä 34SG is the first medium-speed engine capable of running on propane. It is also the largest engine running on propane on the market.

3. The propane engine is not a new engine type, but the Wärtsilä 34SG is optimized for using propane. The same engine can be used with propane, natural gas and also ethane, making it, in fact, a tri-fuel engine. Fuels can be changed on the fly without stopping the engine. We see this new development as a natural extension of the fuel flexibility of Smart Power Generation power plants. Fuel security is important, and customers have the capability of always choosing the cleanest and the most affordable fuels – or simply the fuels that are readily available.

4. Customers are interested in propane especially in areas where natural gas is not available and in areas where it will be available in the future – for example, LNG plans on islands. Propane can serve as a temporary solution since the same power plant can run on both fuels.

5. In March 2016 Wärtsilä received an order to supply a 28 MW propane power plant to Honduras.

[MARINE / IN DETAIL]



Big data: a Genius engine for efficiency

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"Legacy" industries such as shipping are rarely thought to be at the vanguard of the digital transformation trend sweeping across all areas of business. But Wärtsilä, with its Internet of Things-based Genius Services, is not only challenging this view but also offering its maritime customers new ways to become more efficient and profitable.

Digital transformation is forcing businesses of all stripes to rethink what their customers value and how to meet those needs.

Until recently, the maritime industry has been left largely untouched by digital transformation, a term which refers to the changes associated with the application of digital technology to all areas of commerce.

The real-time analysis of "big data" (the huge amount of raw information generated by all sorts of machines and systems that can be analysed to reveal trends, spot opportunities, etc.) is a technological innovation, as it can provide new ways of thinking about issues and identifying opportunities. The maritime industry is generating massive amounts of data from vessel operations and other sources, and much of it has not been used efficiently.

"The retrieval of data from equipment is not new – ship owners and operators have been collecting it for years," says **Timo E. Lehtinen**, Product Manager of Wärtsilä Genius Services.

"What is new is the availability of analysis tools. These can make use of the data that is collected to give operators an accurate insight into whether their equipment is operating at its optimum level. A cargo ship typically generates a huge amount of data per day. So it is just a matter of making sense of the data to make educated decisions. It's a huge step forward for asset performance optimization."

Wärtsilä's new suite of Genius Service digital products not only makes sense of the chaos of 'big data,' but it also transforms data into an asset performance optimization tool to help customers.

"With these new tools, we're actually using this huge mass of data more intelligently," Lehtinen says. "We're fetching the data, analysing it and then offering something valuable back to the customer so they can make decisions in the field to improve efficiency and save money. Data is used to make real, tangible improvements to the services we offer our clients."

The three Wärtsilä Genius product families – *Optimise, Predict and Solve* – apply the data towards optimising customers' assets in real-time, improving predictability and helping to solve problems through digital solutions.

Using real-time and historical equipment data, Wärtsilä Genius Services are designed to optimise everything from a single installation's energy efficiency right up to the management of an entire fleet. The latter is achieved by integrating advanced dynamic voyage planning, ship efficiency advisory services and energy analysis, as well as extensive condition monitoring of the main equipment, into one consolidated solution.

Solutions and services within *Optimise* are designed to increase the competitiveness and efficiency of a customer's operations. Optimise solutions will enable, for example, tracking of fuel consumption in real-time and fine tuning the ship's efficiency to optimal with the help of trim adjustments.

Predict will improve the customer's asset availability and predictability through lifecycle maintenance. For the customer, this means a clearer picture of a coming maintenance need, meaning that maintenance can be performed based on actual condition and not according to a predefined schedule.

Solve by Wärtsilä Genius Services will ensure the safety of the customer's operations and allow them to access instant support whenever and wherever they need it. As part of Solve services, the customer can share their computer screen with Wärtsilä experts on shore.

"The Genius set of services are essentially a new, all-encompassing brand for pre-existing services," says Lehtinen. "We have been involved in condition-based maintenance (CBM) since 2002. However, we are now at a point where the user interface and usability of data have reached a stage that makes it much more effective."

The principle of CBM is that, through the use of real-time data analysis, it becomes possible to perform maintenance when it is needed, rather than at regular intervals when it may not be necessary and might even be detrimental to the effective running of a vessel and its equipment. The Predict and Solve product families of Genius are focused on this aspect.

However, the Optimise products work on increasing efficiency in real-time.

The Wärtsilä engine efficiency monitoring service (EEMS) works with any four-stroke engine. The service monitors an engine's efficiency in a standardised (ISO specified fuel oil consumption) way, and supports overhaul and operational decisions.

"When an engine is running," explains Lehtinen, "many aspects are constantly changing. The ambient air temperature, the humidity, the barometric pressure, the fuel mass, the power and the fuel quality amongst other attributes. The EEMS monitors all of this. These factors all affect fuel consumption, and, if we monitor them, we can drill right down into the engine's efficiency. If you have an efficiency deterioration because of worn components or poor fuel quality or dirt somewhere, we can detect this and make minute calibrations that can increase engine efficiency by up to 10%."The other product in the Optimise range is the Wärtsilä propulsive efficiency monitoring service (PEMS), which is a comprehensive high-quality service for any ship with conventional shaft lines. It measures shaft power, thrust and various craft conditions such as different trim, fouling and ambient conditions. It is a self-learning system for all operating conditions that optimises the management of a vessel through continuous validation.

"PEMS is remarkable," says Lehtinen. "For example, trim is one of the major contributors to a ship's efficiency or inefficiency. Your propulsive efficiency can be improved up to 10% by adjusting the trim. PEMS constantly monitors the trim efficiency. The dynamic trim advisory gathers your vessel and ambient-condition data and continuously presents this via the advisory monitor on board. PEMS also helps detect any hull and propeller fouling early on by taking into account the contributory factors. PEMS also indicates if increased propulsion power or thrust needs to originate from the propeller or from the hull and defines the optimal cleaning time based on added resistance, cleaning work expenses, potential savings and known ship-relevant off-hire losses. It's a comprehensive asset performance optimization tool."

And it doesn't just monitor the ship.

"We also gather data from external stakeholders," says Lehtinen.

"For example, we monitor the weather. What is the weather like in the area where the ship is sailing? How high are the waves? What is the wind like? What is the sea salinity or temperature? This gives us external information that our expert analysts can combine to inform the customer."

Lehtinen adds, "Of course, if you have an integrated Wärtsilä NACOS Platinum bridge in place, you can also see the constant stream of advice that EEMS or PEMS offers, although I think EEMS is more for onsite engine staff, and PEMS is more for technical staff or officers on the bridge."

With Wärtsilä already a leading contributor to the digital transformation of the maritime industry, where does Lehtinen see the next technological advances for asset performance optimization?

"I think we will see further integration of products and services that will provide ship owners and operators with even better information with which to make decisions. Our aim is to always improve efficiency, increase revenue and use less fuel."

Shaft Generators: propelling vessels toward leaner, greener power generation

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Energy efficiency is the name of the shipping game these days. In addition to lowering operational costs, increased efficiency often translates to fewer emissions and can mean better compliance with environmental legislation. Over the last few decades, shaft generator systems have become a more common option to help ship owners and operators achieve profitability in a sea of fierce competition and keep those waters cleaner for future generations.

A vessel generates power for both the ship's operational equipment as well as crew accommodation, such as the galley and cabin lighting. To achieve this, a standard generator burns a large volume of marine diesel fuel, which increases the operational cost, requires more frequent maintenance of the generator and contributes to air pollution. Merchant vessels typically spend most of their operational life sail long distances and fuel economy is the most important factor after safety and reliability.

As an alternative, a shaft generator (SG) is driven by the ship's main engines which, when compared to auxiliary diesel generators, generally have lower fuel consumption and can run on less expensive heavy fuel oil or liquefied natural gas (LNG). However, saving money on fuel is only part of the equation as tightening regulations on ship emissions means that reduced fuel burnt not only increases efficiency and reduces cost but also lowers overall emissions.

Traditionally, the downside of this arrangement was that the propulsion machinery could only be run at constant speed to maintain the network frequency to within limits when operating with a Shaft Generator arrangement. This is because the ships network frequency is tied tightly to propeller rotational speed and any change in speed has a direct impact on network frequency which was traditionally overcome by controlling propulsion thrust and ship speed by changing the propeller pitch, which can lead to decreased efficiency and increased CO_2 emissions.

The ideal operational scenario is to enable efficient and reliable power generation when the ships propulsion system operates at varying speeds needed to maintain optimal propulsion efficiency. Adding a frequency converter to the shaft generator makes this possibility a reality.

The frequency converter, designed using the most modern pulse-width modulation (PWM) technology and power switches, enables the option of taking power from the main engine whilst maintaining a stable frequency and voltage while the main engine speed is changing, such as at reduced speed, manoeuvring, or due to heavy sea conditions. Such Power Take Off (PTO) systems are available in a power range of 500 kW to 3000 KW in low voltage (450 V) technology and above 3000 kW up to 7000 kW in medium voltage (6600 V) technology. Direct connection to the ship mains without requiring a step-up transformer ensures an efficiency factor above 91%.

These systems are available in slow speed technology with the shaft generator directly mounted in the main propulsion shaft line or driven by a gearbox, resulting in a higher speed range. Due to the simple design, installation in the propeller shaft line accounts for 90% of shaft generator applications. PTO shaft generators are offered with a variety of generator technologies but the most common design is made using a synchronous machine with top mounted rectifier and water cooler for an efficient, compact, low cost and light weight package. These systems are also available in the same power and system voltage range as PTO/PTI (booster motor) drives and as PTO/PTH (Power Take Home) drives.

Once fitted as part of the shaft generator system the frequency converter can also be used to adapt various shore supply voltages and frequencies, with no need for additional panels in the main switchboard. Connection to a shore based power supply is possible using the existing synchronizing equipment having the advantage of not using the auxiliary diesel engines in harbour, an additional environmental benefit. The arrangement is often used to supply the thruster motors via the shaft generator system with split busbars during manoeuvring, further improving efficiency and system flexibility.

As an option for vessels with a Waste Heat Recovery Turbine System, Wärtsilä Electrical & Automation also offers a PTO/PTI system. A higher efficiency of the Waste Heat Recovery Turbine System can be achieved by integrating the turbo-alternator system using the same technology.

Due to the numerous advantages of shaft generator systems, more and more vessels are equipped with them. In summary, some of the greatest benefits include the following:

- Lowering of fuel and lubrication costs
- Reduction of maintenance costs and personnel on board
- Return on investment in 3 to 4 years
- Increased safety for ship and crew
- Low noise power generation
- Smaller or fewer diesel generator sets
- Continuous parallel operation together (two SG systems) or combined with diesel generator sets

The more than 450 systems delivered indicate that shaft generator systems are a valuable technical solution for ship owners who are looking for economical and cleaner electrical power generation during their sea voyage. In addition, the number of installations underlines Wärtsilä Electrical & Automation's position as the world leader in this market segment.

Boil-Off Gas handling onboard LNG fuelled ships

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Clean burning natural gas has emerged as an important fuel for ships as the marine industry seeks ways of complying with increasingly stringent environmental regulations. These restrictions limit emissions of sulphur oxides (SOx), nitrogen oxides (NOx) and particulates. The options for compliance are to employ after-treatment systems when using conventional marine fuels, or to use cleaner fuel having fewer harmful emissions, such as natural gas.

One drawback of natural gas is that it has very low energy density compared to traditional fuels. In order to serve as a convenient energy source, the density needs to be increased. This is done by cooling the gas to cryogenic temperatures, creating liquefied natural gas (LNG). The liquefied gas can be stored in insulated tanks, keeping it in a liquid state for longer periods. However, heat flux from the surroundings will increase the temperature inside the tank, thus causing the liquid to evaporate. The generated gas from this is known as boil-off gas (BOG).

The larger volume of gaseous natural gas created by this BOG will increase the tank pressure. To manage this, pressure vessels are utilised to contain the pressure. For longer storage periods, however, the pressure increases might be too high, which will require alternative solutions to handle the gas pressure.

Wärtsilä, a leading developer of gas and dual-fuel marine engine technologies, has extensively studied the handling of BOG onboard LNG fuelled ships. This article is based on these studies.

Pressure build-up

Pressure build-up depends on several parameters, including the ambient temperature and the amount of LNG in the tank. Another aspect to consider is stratification, which may cause a faster

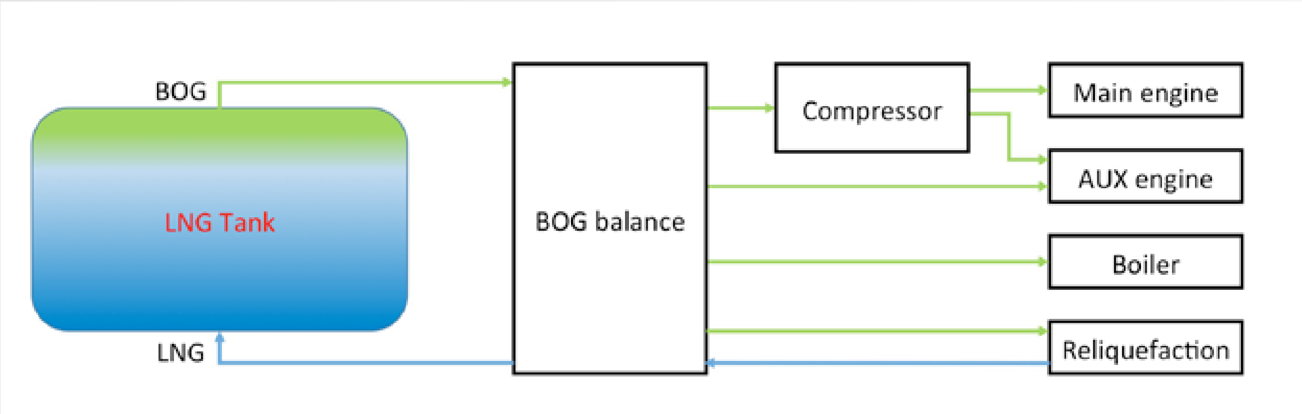


Fig. 1 - Simplified system layout for BOG handling, when using two-stroke main engines and four-stroke auxiliary engines. Ideally consumption should match BOR, resulting in a BOG balance of zero.

pressure rise. Stratification means that the LNG is divided into layers with the higher density liquid at the bottom and the lower density liquid on top. When the lower layer is heated, it cannot evaporate because of the cover. The densities of the layers are eventually equalised due to boil-off from the top layer and heat transfer. The warmer LNG from the bottom rises to the top and evaporates. This is called rollover and causes a rapid increase in the BOR (boil-off rate), which is difficult to predict.

Thermal stratification can be eliminated by agitating the tank, which occurs naturally on gas-fuelled ships due to the motion of the waves. Agitation of the tank may cause an opposite reaction when warm LNG is mixed with colder LNG, since the temperature at the surface will then decrease and condensate the BOG. The result is a collapse of pressure, which is followed by saturation at a lower pressure.

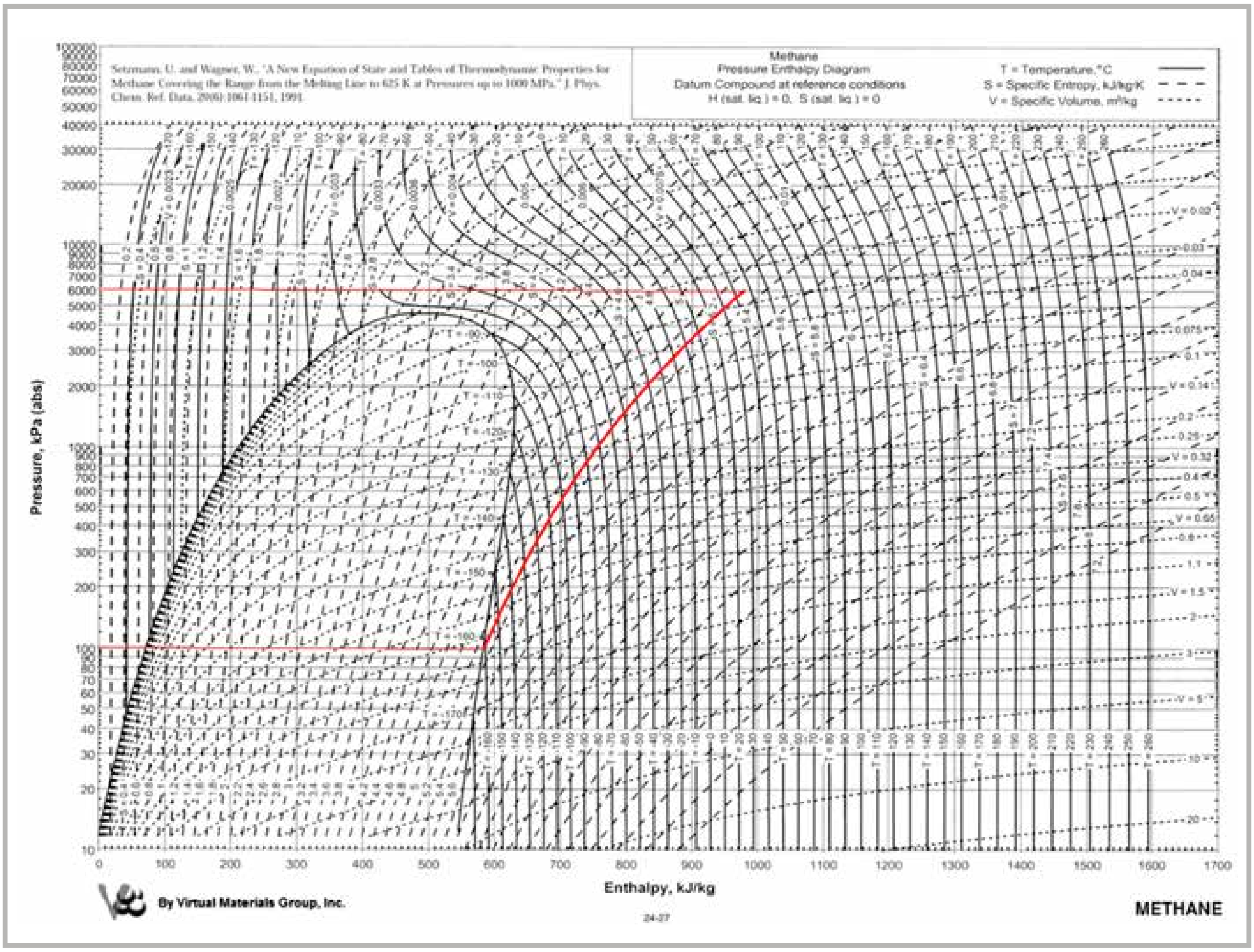
BOG handling requirements

There are various means of handling the pressure build-up in LNG tanks. One is to contain the pressure for the ambient temperature of the fuel. Other methods include reliquefaction, thermal oxidation, and pressure accumulation. The IGF code – the international safety code for ships using gases or other low flashpoint fuels – also accepts cooling of the fuel in a liquid state. For reliquefaction, a direct system, where the evaporated gas is compressed and condensed before being returned to the tank, is one solution. The other alternative is an indirect system, where the gas is condensed or cooled with an external refrigerant, without being compressed.

Apart from handling the maximal BOR in the tank, the selected method also needs to cope with zero or low BOR's. In the case of failure, the system must provide a redundant system that can maintain the tank pressure. Venting gas to the atmosphere is not an alternative for pressure control, and is only allowed in emergency situations.

Reliquefaction

Liquefaction is the process where, using a



■ Fig. 2 - Illustration of an isochoric temperature increase of methane from -162°C at atmospheric pressure to 45°C (upper design temperature for worldwide service). The result is a pressure of around 60 bar.

refrigerant cycle, warm gas is cooled and condensed into a liquid. Reliquefaction indicates the process whereby evaporated LNG is cooled and reverted to a liquid state.

Several licensed refrigeration processes are available for the liquefaction of natural gas. These processes use one or more cycles in order to imitate the cooling curve of natural gas. A good match of the curve will give the process high efficiency and thus, low energy consumption. Conversely, a low temperature difference between the refrigerant and the gas will demand a larger heat exchange area. Refrigeration process design is about optimising the number of cycles, the refrigerant composition, and the heat exchange area. The result depends on whether simplicity, efficiency, a compact footprint, or low cost is the key boundary condition. Depending on which refrigeration cycle is used, liquefaction processes can be divided into three categories; cascade cycle, mixed refrigerant and expander cycle.

Cascade cycle

The cascade process is defined by several cascaded refrigeration cycles, based on the reversed Rankine cycle, using pure two-phase refrigerants. The idea is to reduce entropy production by using several refrigeration cycles for each liquefaction stage. By evaporating the liquid refrigerants, a very high thermodynamic efficiency can be achieved. Conversely the process is complicated and requires a large number of components, meaning the size requirement is large and the capital cost is high. The high efficiency and high investment cost makes it suitable for large land based liquefaction plants.

Mixed refrigerant

Mixed refrigerant liquefaction is also based on the Rankine cycle. However, contrary to cascade cycles, a blend of refrigerants is used to obtain a close following of the natural gas cooling curve. By mixing refrigerants a temperature glide can be attained, which means the temperature at phase change will not be constant. This is because the components in the mixture evaporate at different temperatures, causing a change of concentration, which can be adapted to the process gas cooling curve. In reality, the mixed refrigerant will cause a curved temperature profile, which will lower the thermodynamic efficiency, compared to the cascade cycle. The mixed refrigerant process is suitable for small-scale liquefaction plants where the low equipment count and simplicity can be a substitute for high efficiency.

Expander cycle

The expander cycle differs from the other liquefaction cycles by using an expander instead of a J-T valve. The expander is connected to the compressor, and extracts useful power from the compressed gas. The refrigerant used is a pure gas, and is only in gaseous phase, making it insensitive to motion. This also eliminates issues relating to the distribution of liquid refrigerants in the heat exchangers, thereby allowing rapid start-up. A gaseous phase refrigerant, however, has a limited enthalpy difference, and requires a higher refrigerant flow than two-phase refrigerants, which limits the capacity. The process does not follow the cooling curve of the process gas very well, which results in lower efficiency than with other technologies. This, on the other hand, makes the process more forgiving to variations in the gas composition.

Most expander processes utilise the reversed Brayton cycle, either closed or open loop, to generate cooling. This is done either in a single or dual stage or with pre-cooling. By using an open-loop expander cycle, a fraction of the process gas is utilised as a refrigerant. This eliminates the need for excess refrigerants.

The reversed Stirling cycle is another type of expander process used for liquefaction. The Stirling cycle is a modified Carnot-cycle, where heat from the compression stage is utilised in the expansion stage, making it a regenerative cycle.

Offshore reliquefaction

The selection of liquefaction technology for offshore applications differs from the onshore equivalents. Space on marine vessels is limited, which increases the need for a compact solution.

The use of hazardous hydrocarbons has to be limited for safety reasons.

Small-scale offshore reliquefaction is, from a capacity perspective, quite similar to onshore peak-shaving plants. The expander cycle is a proven technology for these small-scale plants and is a viable choice for offshore reliquefaction.

Thermal oxidation

Another method for handling BOG is by thermal oxidation, i.e. combustion. This is primarily done by feeding the excess gas to the consumers, i.e. the ship's engines. Two- and four-stroke internal combustion engines are normally used for propulsion and power generation, while two-stroke engines usually have a high power output and are used for direct propulsion. Four-stroke engines can be used both as main and auxiliary engines, the latter being used while in port as well as when at sea. Additionally, auxiliary boilers can be used to produce steam or hot water. If the amount of BOG does not correspond to the rate of consumption, the gas can be fed to a gas combustion unit (GCU). The GCU is a burner which combusts the BOG in a controlled manner without the risk of releasing unburned natural gas to the atmosphere. Although a possible solution for BOG handling, no useful energy can be recovered from a GCU, which is why it should primarily be recovered by other means.

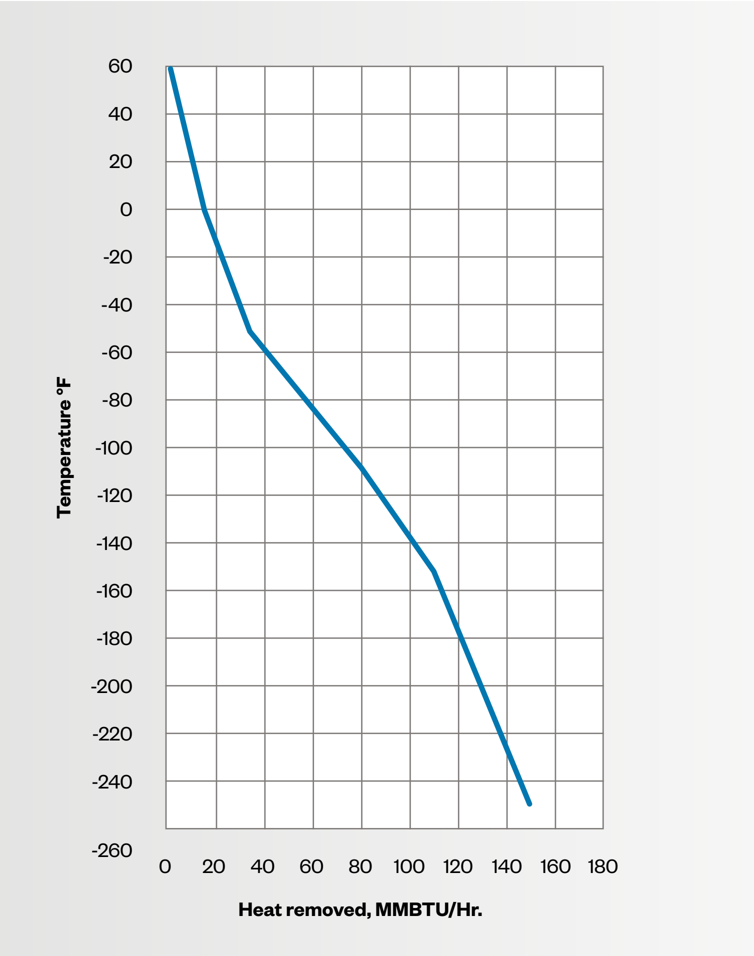


Fig. 3 - The three-stage cooling curve of natural gas (15–-161°C), with pre-cooling, liquefaction and sub-cooling.

Fig. 4 - The Wärtsilä LNGPac system allows the safe and convenient utilisation of gas fuel.

Compression

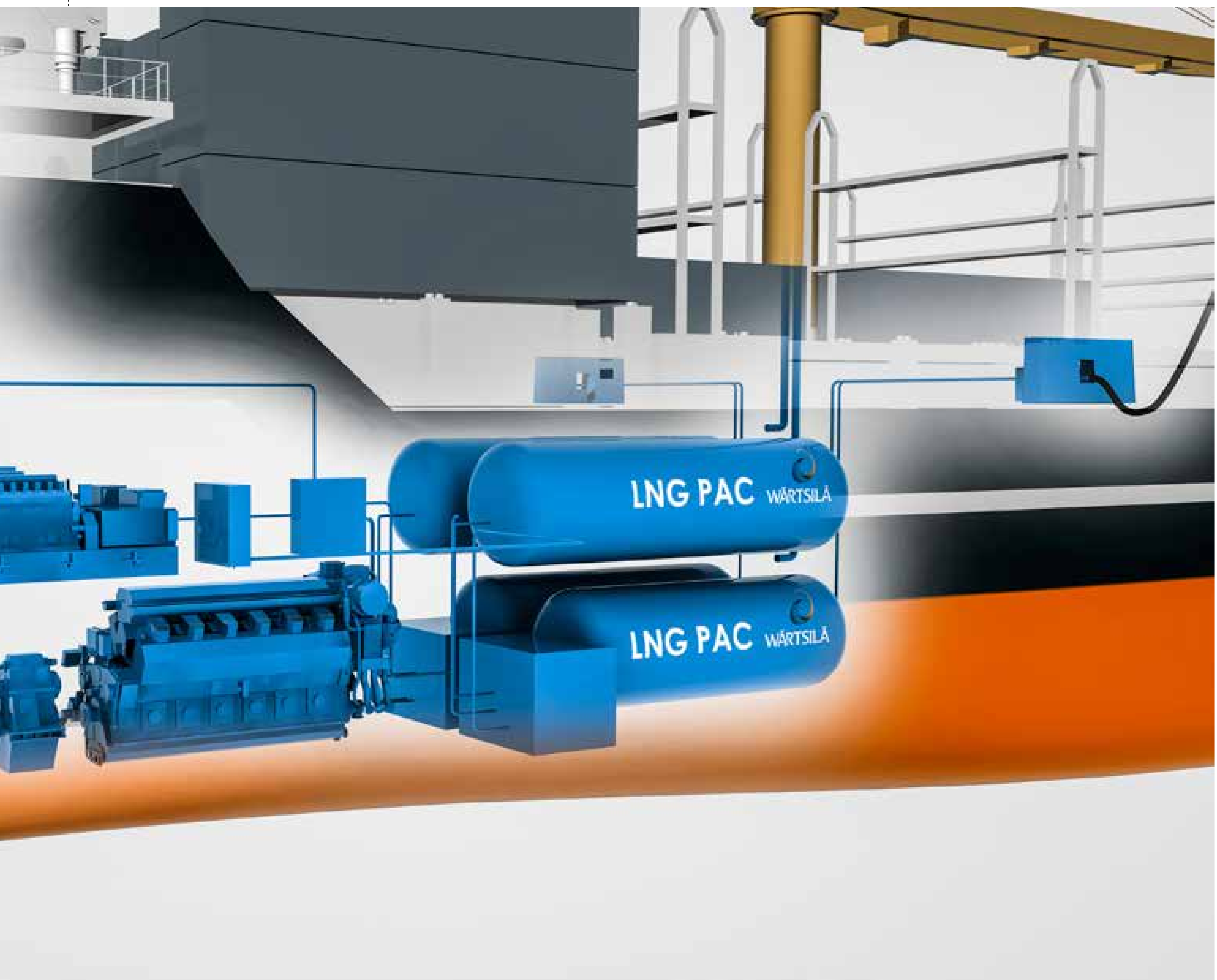
Feeding gas to the engines is one way of handling BOG in the tanks. Four-stroke engines usually have a suitable fuel pressure need for type C tanks and can consume the gas at tank pressure. Two-stroke engines, however, demand a higher pressure. Therefore, in order to consume the BOG, the pressure must be increased to that required by the engines.

When choosing the compressor type, pressure ratio and gas flow are the most important aspects that need to be evaluated. For safety reasons when using LNG as feed gas, contamination from lubricants and the risk of gas leaks need to be considered. Either a piston or a rotary screw compressor should be used for gas flows below 1000 m3/h. Piston compressors have a compression ratio suitable for high pressure engines. Screw compressors, with their lower compression ratio, are suitable for low pressure engines.

In oil-free piston compressors, non-contact seals are usually used between the piston and cylinder. To minimise leakage, the contact surfaces are lined with sharp edges, called labyrinth seals. Rotary screw compressors can also be designed to operate without lubricants. These compressors are driven by synchronised gears, making small clearances possible without rotor contact.

Fuel sharing

In order to match BOG generation with engine consumption for a desired load, fuel sharing can be utilised. Dual-fuel engines are capable of running on both diesel and gas, which can be used to even out variations



in gas supply or quality. With normal gas operation, around 1—5% of the pilot fuel is needed to ignite the gas. With fuel sharing, the amount of gas can be varied between around 15% and 85%, with the rest being diesel.

Summary

There are basically three suitable BOG handling methods which should be considered, namely boilers, auxiliary engines or reliquefaction units. Auxiliary engines are more suited to gas consumption than main engines. Additionally, the power generated is usually needed - even in port. Reliquefaction units using an expander cycle have rather low efficiency, which means they should be avoided for large BOR. For such cases, thermal oxidation in either a boiler or an auxiliary engine is a better solution.

By comparing the different BOG handling methods, it is clear that there is no universal solution that works for all systems. On the contrary the solution is rather sensitive to tank size and consumer types. This means that the BOG handling solution has to be evaluated on a case by case basis.

Hybrid technology for new emerging markets – inductive charging

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The double ended car ferry 'Folgefonn,' as a part of the pre-commercial activities within hybrid systems introduction, has been converted from a diesel electric ferry to a complete plug-in hybrid and plug-in electrical ferry. This technology demonstration has undergone successful testing during normal operation for about one year. This stage of the demonstration project has given the 'Folgefonn' energy storage capability in the form of a battery pack, hybrid control system, power transfer system and onshore energy storage system. Wärtsilä's contribution to the 'Folgefonn' project is the concept development, including the inverter systems, the hybrid control, battery package and systems, power transfer and land-based energy storage system as well as the integration of the onboard systems. As a part of the project, renewable energy from shore is used to reduce the environmental impact and to make the ferry operation more efficient.

The transfer of power is critical for a ferry dependent on "external fuel," and a high-power, fast-charging concept is one of the critical issues for this type of operation. The search for reliable and safe systems that can be connected and disconnected quickly initiated the research and development of wireless high-power technology.

Hybrid Energy Storage Systems (ESS)

Hybrid power systems combine different power sources with energy storage devices.

The introduction of the hybrid power system, and its integration with conventional diesel or dual- fuel engine generating sets, offers a significant improvement in efficiency by running the engines on optimal load and absorbing many of the load fluctuations through batteries.

For plug-in hybrid systems, parts of the energy will be harvested from shore. As such, a higher degree of energy utilization is possible, due to the improved efficiency in the energy conversion.

A further step is a complete plug-in electrical system where the total energy demand is taken from external land-based energy sources, preferably renewable sources. The total efficiency from power supplied locally onshore to propeller will be more than 85%.

The key element in these types of power systems is how to store the energy safely and efficiently. The most available technology at present is batteries.

Currently, battery technology is improving in cost and performance, and as such this is a logical choice for energy storage.

Another possible technology may be double-layer capacitors, especially for power-demanding applications.

Discussions about how to design the capacity of an energy storage system will depend on how the system is to be used. Knowledge about the actual vessel operation is therefore important.

Batteries can deliver large power peaks, normally in the 3-6 C area (times nominal capacity), but they are limited by the investment in power electronics to deal with such high power peaks.

For full operation, there may be a demand for both high power and energy.

Many influencing factors have to be considered, such as charging strategies including renewable and onshore power limitations, the battery life, investment costs, and the configurations of other engine driven generating sets onboard.

Inductive charging

Inductive charging (wireless charging) uses an electromagnetic field to transfer energy between two coils. A sending induction coil is used to create an alternating electromagnetic field and a second induction coil takes the power from the electromagnetic field and converts it back into electric energy. To manage longer distances between sender and receiver coils the inductive charging system uses resonant inductive coupling.

Successful application of battery storage systems for plug-in hybrid vessels will require fast, safe and reliable power transfer from the onshore power system while the ship is docked.

Coastal transportation systems, and especially ferries, are operating on a fixed schedule with short docking times.

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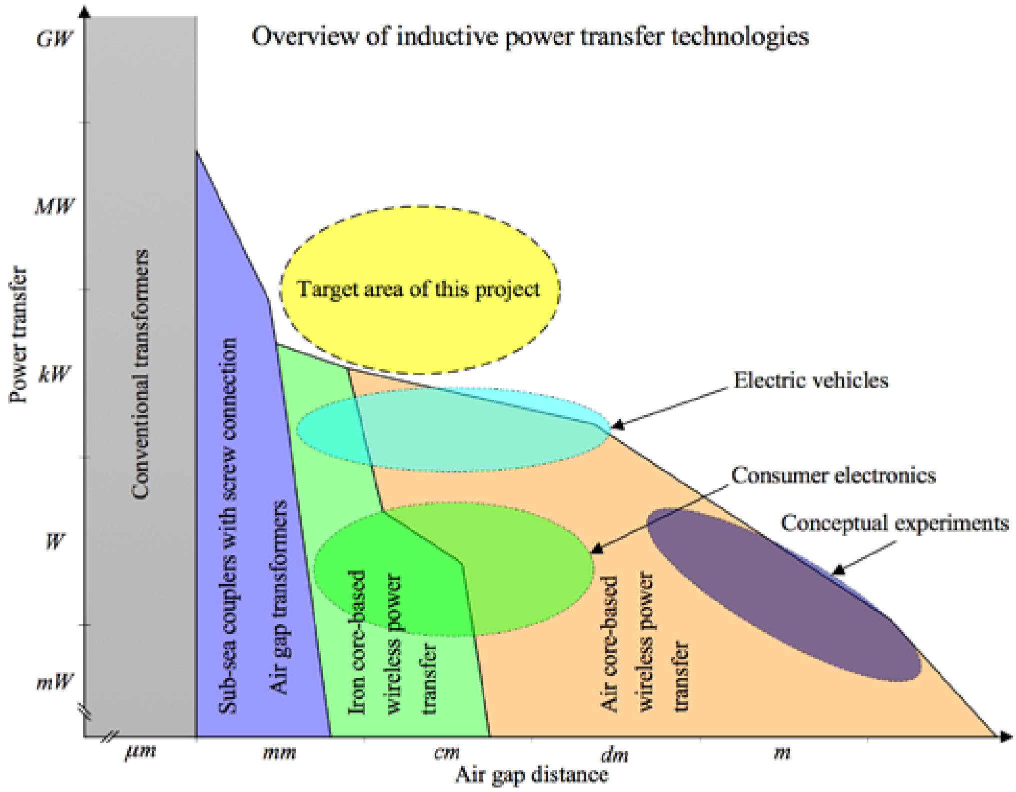


Fig. 1 - Overview of existing capabilities within commercially available inductive charging technology. The yellow area has been the target for maritime applications.

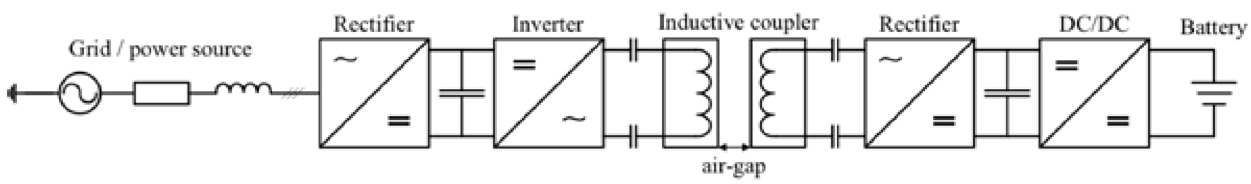


Fig. 2 - Typical inductive charging system.

Therefore, maximum utilization of the time available for charging will be important for effective utilization of the energy storage capacity. In this context, existing solutions for high power electrical connections, with flexible cables and mechanical contacts in the docking area, impose time and availability limitations. The time required for connecting and disconnecting the power supply for on-board battery charging will limit the energy transfer during docking. Direct electrical connection also causes challenges related to safety and reliability in harsh environments.

A possible approach for overcoming the drawbacks of conventional electrical connections for high-power battery charging, would be to apply technology for wireless, inductive power transfer. Such technology has been undergoing rapid scientific and commercial development during the last years, especially for battery charging of electric vehicles, including private cars as well as public transportation systems like busses, trams and trains. However, the power level and transfer distance achievable with commercially available solutions for inductive power transfer is limited to a few hundreds of kWs across distances up to 20-30 cm, while large scale commercial ship applications require power transfer capability in the MW power range across distances of up to about 50 cm.

Developing dedicated technology and practical solutions that enable high-power, wireless, inductive battery charging will allow integration of the technology into the ship and harbour-side structures. Thus, it will be possible to design systems that can allow for fully automated charging operations that will start immediately when the ship is docking.

With this background, Wärtsilä and its partners conducted research in this field and created a lab prototype as the final proof of use of the technology.

This can become an enabling technology for utilizing battery storage in various coastal transportation systems. Additionally, this solution should have the potential to serve as one of the enablers for complete automated charging systems and as a part of future autonomous operation.

Technology development

The feasibility of high-power, wireless inductive charging systems was first investigated by theoretical studies, based on analytical evaluation of various mechanical designs operating at different transfer distances and with different electrical frequencies. These analyses included the evaluation of electrical resonance circuits, required for achieving high power transfer capability in inductive charging systems, and of the power electronic converters required to control the system. From the analysis, the feasibility of power transfer capabilities exceeding 1 MW was confirmed for the range of transfer distances and within the space requirements expected for ship applications. Furthermore, it was demonstrated that this can be achieved by using our own standard inverter systems.

Results from the analyses were used to study the operation of the power electronic converters and to design control systems that will allow for seamless dynamic operation, including the controlled transfer of required power even with wide variations in the mechanical positioning of the transmitting and receiving coils. The system has been designed to transfer rated power of 1 MW within a range of 15-50 cm between the coils. This is a significantly larger variation in relative magnetic coupling conditions than encountered in battery charging systems for electric vehicles.

The onboard batteries will normally be dimensioned for the full charging capacity of the transfer system, but utilization is depending on the type of chemistry, charging intervals and the lifetime prediction of the batteries. Charging rates of about 2-3 times nominal its battery capacity are usual with the present battery technologies, but with high power battery chemistry the charging rates can be in the area of 6 times the battery capacity.

The resulting system can be controlled so that the power converter operation during charging will automatically compensate for dynamic variations in the mechanical positions while required power flow is maintained.

FEM-based simulation models developed during the project have been used to assess the practical construction of the full-scale prototype and to assess the need for the electromagnetic shielding required to comply with international standards for electromagnetic exposure. This analysis has revealed information about how the physical structure of the coil should be constructed to avoid additional losses.

The main technical inventions developed within the project have been included in a patent application to secure relevant intellectual property rights (IPR).

The specially constructed coils, the associated resonance circuits and the power electronic conversion systems have already been undergoing tests in Wärtsilä's high-power laboratory facilities in Stord, Norway. The preliminary results are promising, and transfer of 1 MW at a distance up to 50 cm has already been demonstrated. Efficiency figures are for the moment >95%. These tests verified the developed concept, which is to be considered ready for further industrial product design and full scale testing in a vessel.

Market concepts

The inductive charging technology is very flexible to integrate and can be introduced in new market areas and applications.

Since the introduction of the technology, there has been interest from many market areas and industries such as road vehicles (trucks), military applications and demanding transfer applications where time restrictions and safety aspects are dominant.

The focus area at the time was coastal ferries, where new contract demands require strict targets for use of energy and release of climate gases. This is a new trend in this market segment and is driven by regulatory demands, political visions and incentives and a more sustainable way of running this business.

A close co-operation between Electrical & Automation and Ship Design has led to a complete new ferry design with an integrated Wärtsilä hybrid system and inductive charging.

The primary goal when designing plug-in power systems is to reduce the power demand to a minimum for the operation. The hull design and the utility system have been carefully evaluated and computational fluid dynamics (CFD) analyses have been performed to quantify the best hull for the actual number of cars and speed of the ferry.

The present charging systems available and used for this kind of application have been traditional plug connection or pantograph systems with necessary redundancy to secure availability of electrical energy. These have been used together with vacuum mooring.

Mooring systems are an advantage as they keep the ferry in a steady position, and the main propeller can be stopped during the docking time to reduce the total energy use during the day.

As a spin-off of the ferry design, Wärtsilä has made an agreement with Cavotec to combine the use of their vacuum mooring unit and the inductive charging technology.

Cavotec has a strong brand and a strong market position within vacuum mooring systems and in general power transfer systems.

→

Fig. 3 - The new ferry design from Wärtsilä Ship Design.

For the vessel owner, the combined solution will give the following benefits:

- Automatic mooring
- Automatic charging
- Maximum utilization of the charging time available while docking
- High degree of availability of energy
- High reliability
- Minimum maintenance needs due to limited wear and tear
- Optimisation of the onboard ESS investment due to high energy transfer rate
- Galvanic isolation between shore and vessel
- Increased safety during operation

Compared with a traditional plug-connection system, the losses during transfer will be somewhat higher with the inductive system. However, due to reduced maintenance costs, reduced operation costs and attractive cost for renewable energy, the total operation cost will be favourable.

The investment cost for the inductive charging depends on how the integration is done both onshore and onboard. Compared with a redundant plug-based system with auto-mooring the combined inductive charging and mooring unit will have about the same cost.

Many influencing factors like the onshore infrastructure, the need for onshore energy storage and the operational conditions will decide the total cost.

Some of the ferry routes have more than 20,000 short dockings per year so maintenance and reliability issues are important.

Full-scale demonstration

To ensure a fast market introduction and a full-scale validation of the developed concept, it is important to verify the integrated design in a full-scale demonstration. The partners in the Folgefonn project succeeded in getting governmental funding to integrate a full-scale 1 MW unit in the 'Folgefonn' ferry to provide such verification and to demonstrate reliable, real-life operation of the technology. The estimated time for installation of the system is late 2016 and the first part of 2017, with a test program during regular operation completed within 2017. A commercial introduction of the technology will start this year, in parallel with the first full-scale pilot installation.

Electrical onboard DC distribution

DC bus is a natural common point of coupling in a modern hybrid system, as DC is the basic source for most of the modern power inverters. Energy sources and loads connected to the same DC source will reduce the number of conversion steps onboard.

The bi-directional DC/DC converter controls the battery and steps up the voltage on the DC bus to the desired voltage level.

A bi-directional active front-end inverter (AFE) is connected between the DC bus and the AC network.

The inductive charging is connected to the DC grid through a DC/DC converter and is stabilizing the power from the induction receiving coil.

Electrical onshore system

The inductive sending coil is connected to a bi-directional active front-end inverter (AFE) that is connected to the on-shore grid supply. Alternatively the input can be from a DC supply from an onshore ESS if this is necessary for stabilizing the grid or to overcome tariff regimes that can be costly with large power peaks drawn from the grid.

The batteries and the power electronics can also be used as grid voltage support and as such be attractive for the power utility provider to improve the grid capacity.

System control

The main objective of the control system is to keep a stable power transfer flow to the batteries with variable overlapping of the induction coils, a variable air gap and variable tilting. This is achievable by using our own inverter control and reconfiguring the hardware, firmware and software to

Fig. 4 - Illustration of the combined vacuum mooring and induction charging system.

stabilize and control the power flow. The advanced diagnostic system embedded in the inverter control secures remote on-line services for the operation.

Not only is the high power transfer wireless, but the control from the vessel to the shore system is controlled by a wireless Wi-Fi link.

Conclusion

The introduction of new Hybrid Power Systems with energy storage is a new and attractive way of reducing both fuel and exhaust emissions.

With the new inductive charging technology, Wärtsilä can offer total electrical plug-in solutions as a part of their portfolio and complete integrated vessel design concepts.

The expected results from a full-scale operation will improve the availability and safety of these kinds of operations, and the concept will be the first fast-charging wireless technology in the ferry industry. The technology will act as an enabler for efficient use of electrical plug-in solutions in this industry.

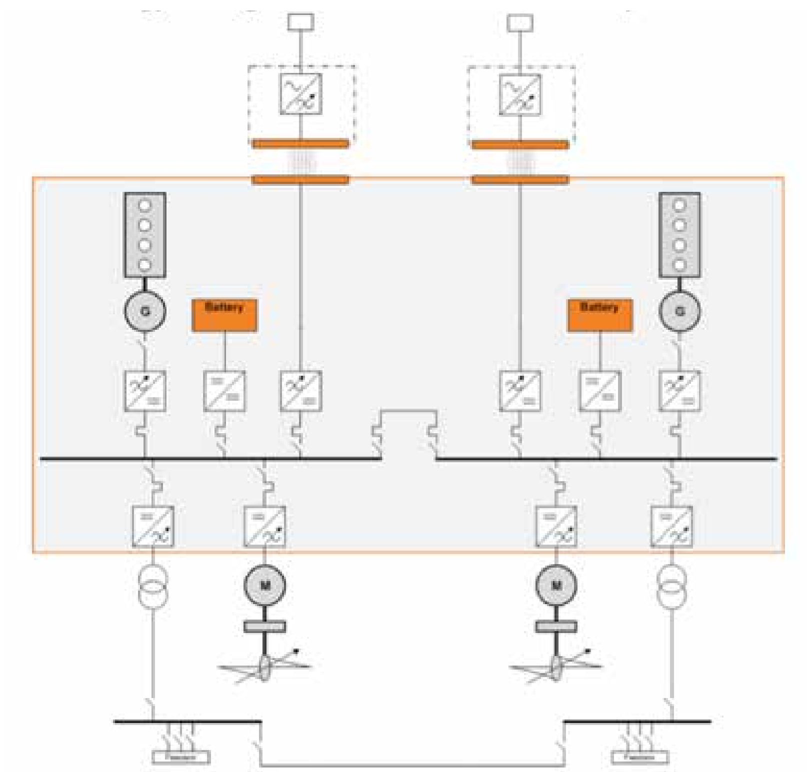
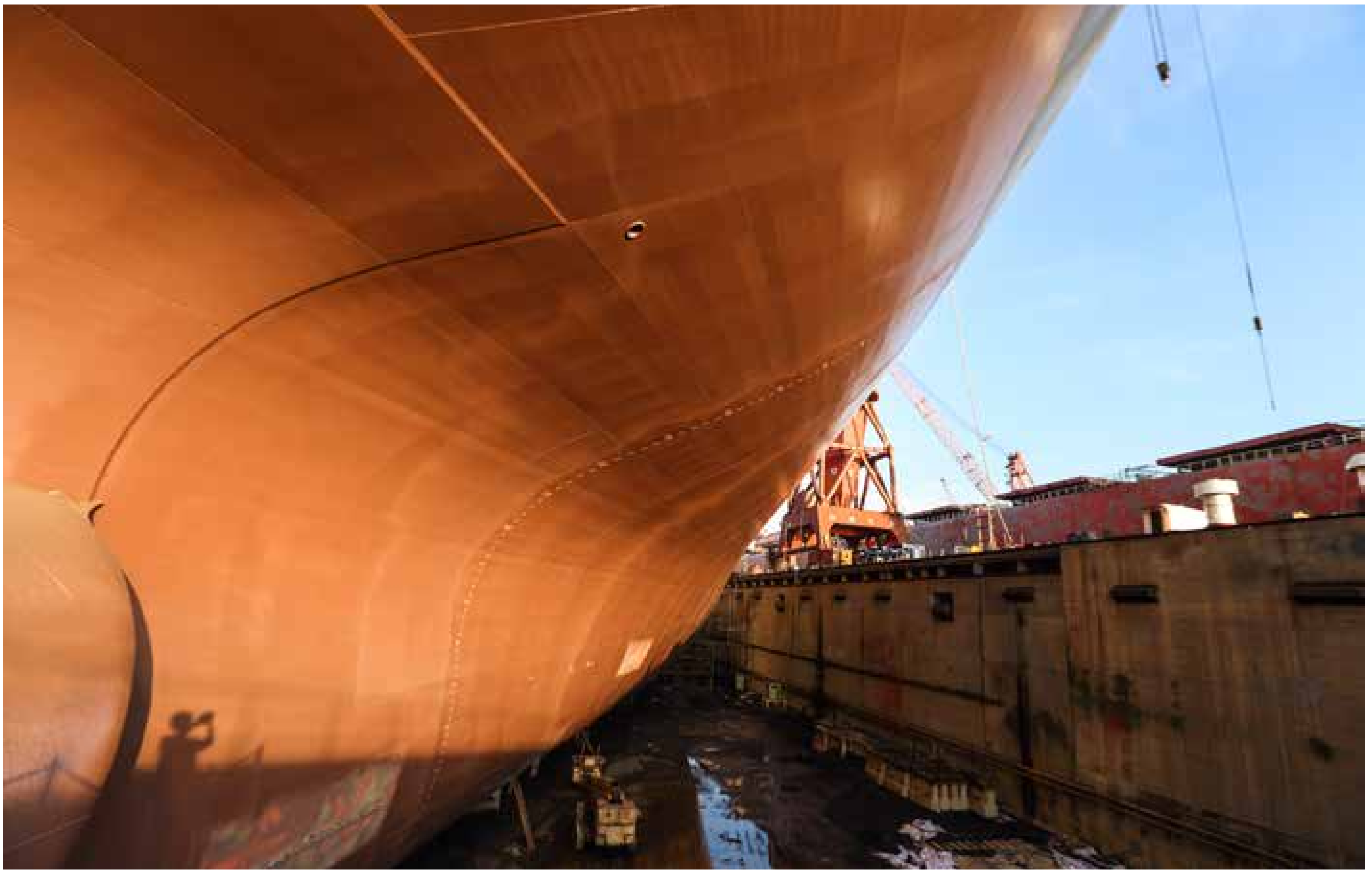


Fig 5 - Typical DC distribution and plug-in hybrid solution with induction charging.



Back to the future: steam turbine to DFDE conversion for LNG carriers

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As per maritime common practice, the fuel bill is not included in the charter daily rate and the gas consumption directly affects the charterer's business. For this reason, steam turbines became obsolete on LNG carriers in early 2000s, when the adoption of DFDE (dual-fuel diesel electric) brought a drastic boost in ship efficiency. Existing steam turbine vessels are still accounting for about 60% of the active fleet and are losing competitiveness against more modern technologies. If a charter contract is close to expiring, charterers will simply move to a more efficient propulsion system, while those bound to a several-year residual agreement face a strong challenge. To enable this transition with a limited investment of funds and time, Wärtsilä has developed an integrated, total solution package to convert old, steam turbine LNG carriers into modern DFDEs.

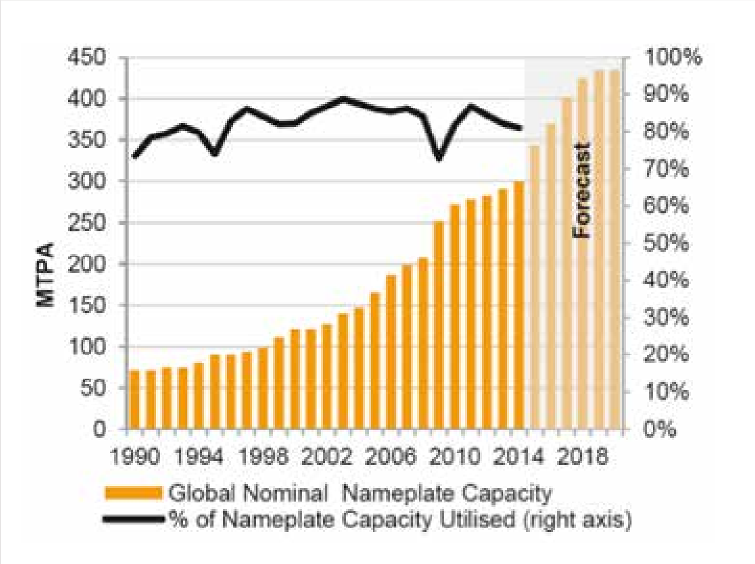


Fig. 1 - Global liquefaction capacity build-out, 1990–2020. Sources IHS, Company announcements.

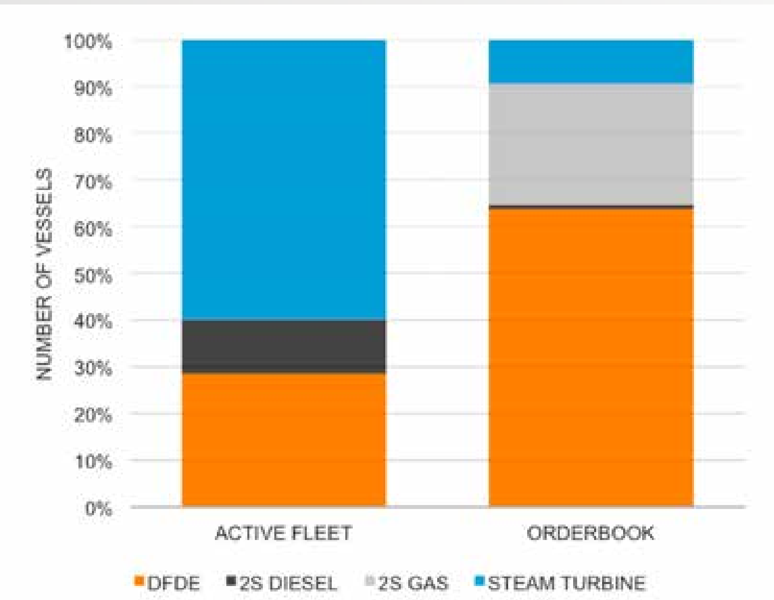


Fig. 2 - Existing and on order LNG fleet (>100,000 cbm) by propulsion type. Source Clarksons, 2015.

LNG market

World LNG trade volumes have more than tripled over the last 20 years, growing from 70 MTPA (million tons per annum) in 1995 to 250 MTPA in 2015 (Figure 1). Despite slowing down in the last few years, due to the longer-than-expected European economic crisis, it will resume its expansion over the long term. Recently discovered technology will extend the accessible reserves, and new terminals will boost the liquefaction capacity. On the demand side, the growth will be driven by a steadily raising hunger for energy as well as an increasingly stronger focus on reducing emissions.

The LNG carrier building market has evolved accordingly. The newbuilds orderbook amounts to around 170 units (compared to an active fleet of about 450), regardless of the momentary tonnage oversupply. The fact that as much as 20% of the newbuilds consists of vessels commissioned on speculation further highlights a strong and widespread confidence in a steep market ramp-up.

Propulsion systems

The major driver for LNG carrier machinery selection is the need to burn natural boil-off-gas, which shaped a totally diverging trend from the traditional merchant vessel design. Until the early 2000s, as boilers were the only means for consuming natural boil-off-gas, steam turbines were the broadly preferred propulsion system. In 2001, GDF Suez ordered the first two LNG carriers powered by Wärtsilä dual-fuel, medium-speed engines in a diesel electric configuration. The new propulsion system brought major enhancements in terms of operating flexibility and, above all, efficiency, enabling up to 40% fuel savings over the traditional steam turbines.

Wärtsilä DFDE quickly became the new standard for LNG carriers, equipping 90% of newbuilds in 2014 and boasting almost 200 references. A variety of other new

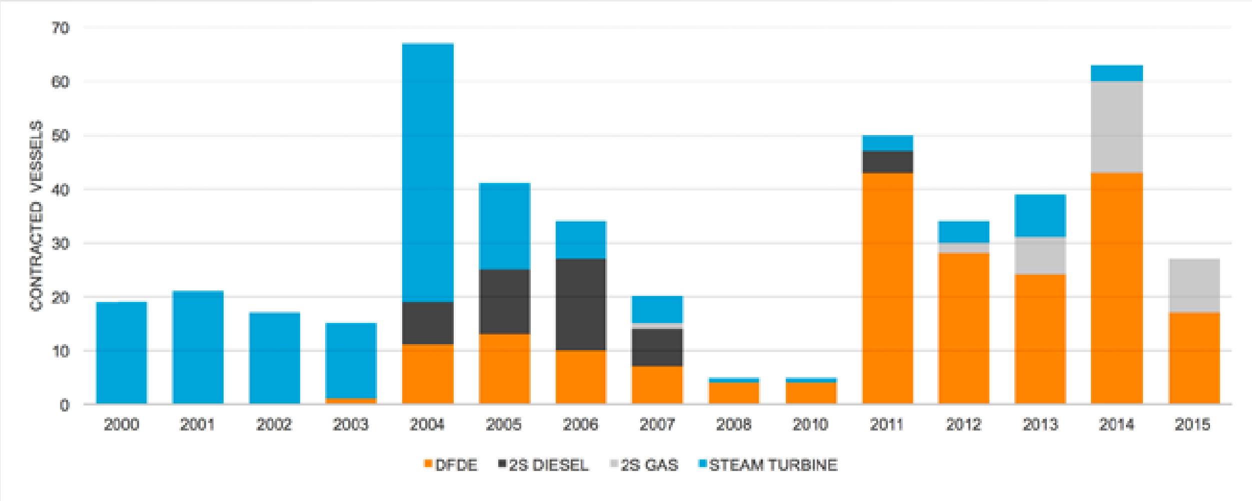


Fig. 3 - LNG Fleet (> 100,000 cbm) by propulsion type. Source Clarksons, 2015.

technologies, such as the low pressure slow-speed dual-fuel or the high pressure slow-speed gas-diesel, have recently entered this market claiming a further trimming of operating expenditures. (Figures 2 and 3)

Conversion business potential

Wärtsilä realized the opportunity to offer an integrated solution to convert an obsolete steam turbine system into a modern and business-competitive DFDE. When assessing the relevant market, over 150 vessels were identified as potential targets.

Different business scenarios arose (Figure 4), depending on the contract situation between owner and charterer.

The conversion proved to be particularly attractive when the residual chartering time is long enough to generate buy-in by the charterers and make it convenient for them to contribute to the initial investment. Thanks to the improvement in ship efficiency, some charterers calculated an impressively low payback time, even if they would have to take on the whole conversion cost.

A high level study was presented at GasTech in Singapore in October 2015 and triggered extraordinary interest – to the

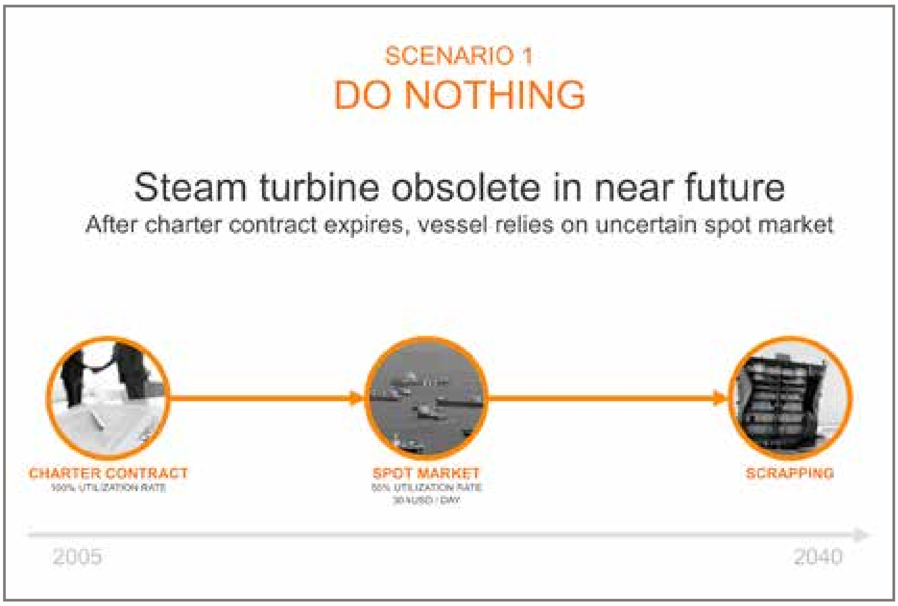
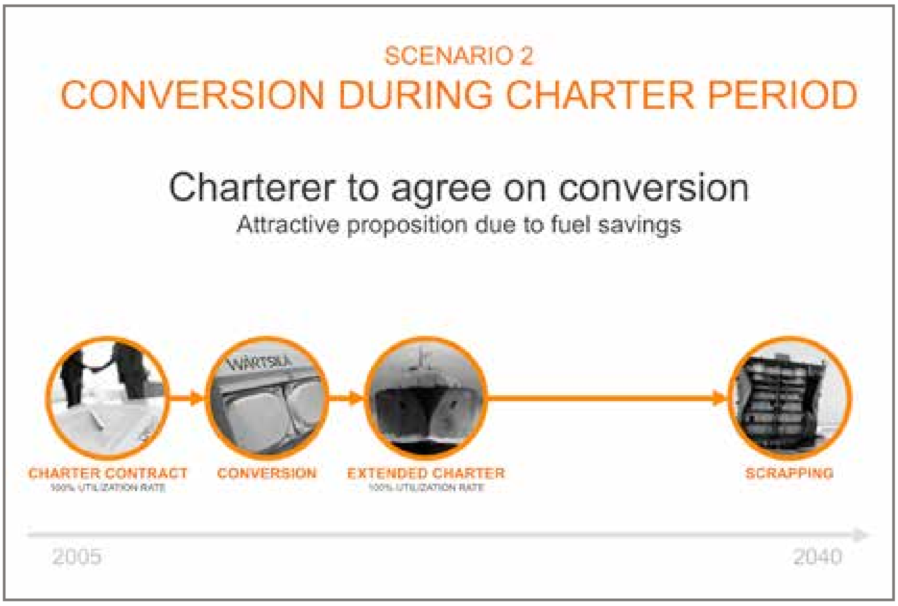
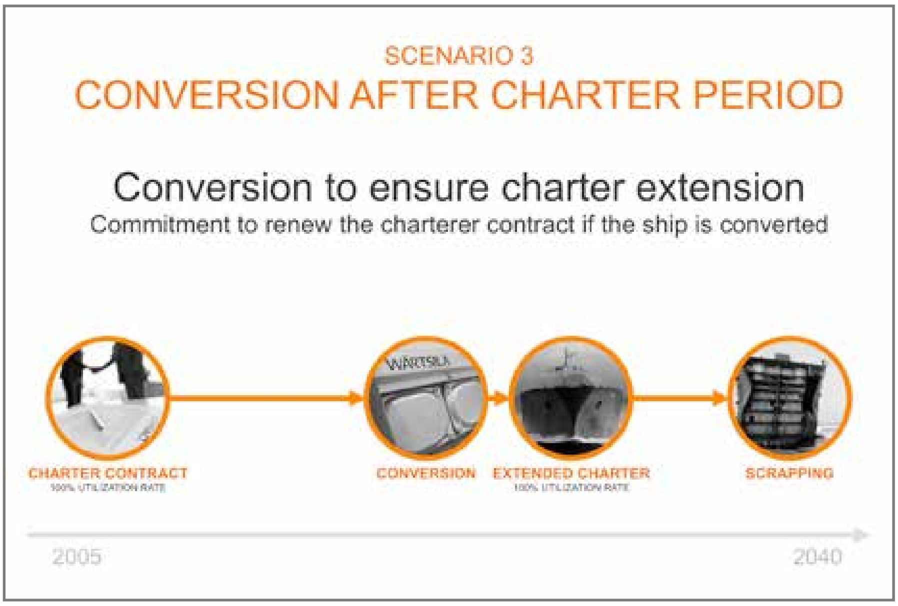
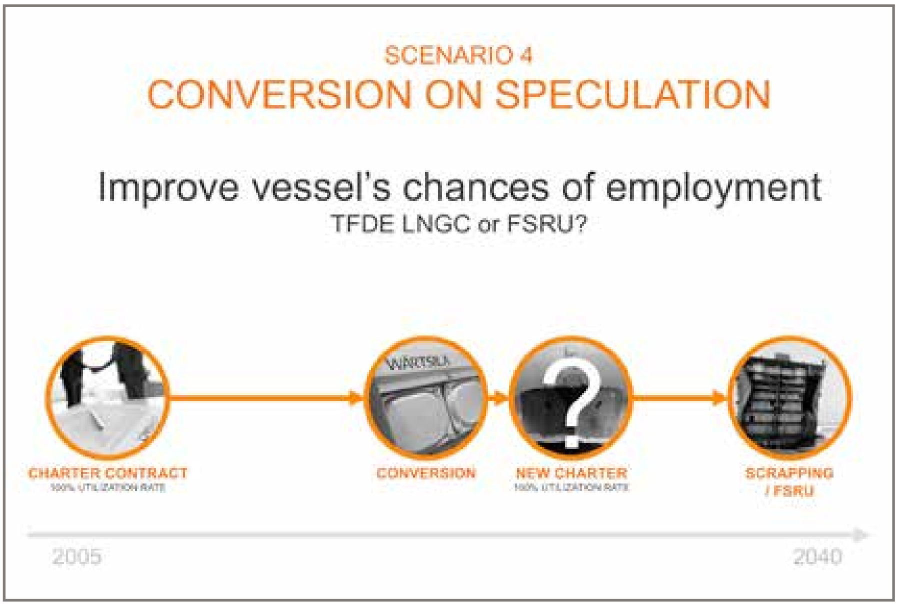


Fig. 4 - Conversion business scenarios.


SCENARIO 2
CONVERSION DURING CHARTER PERIOD
Charterer to agree on conversion
Attractive proposition due to fuel savings
CHARTER CONTRACT
100% UTILIZATION RATE
CONVERSION
EXTENDED CHARTER
100% UTILIZATION RATE
SCRAPPING
2005
2040


SCENARIO 3
CONVERSION AFTER CHARTER PERIOD
Conversion to ensure charter extension
Commitment to renew the charterer contract if the ship is converted
CHARTER CONTRACT
100% UTILIZATION RATE
CONVERSION
EXTENDED CHARTER
100% UTILIZATION RATE
SCRAPPING
2005
2040


SCENARIO 4
CONVERSION ON SPECULATION
Improve vessel's chances of employment
TFDE LNGC or FSRU?
CHARTER CONTRACT
100% UTILIZATION RATE
CONVERSION
NEW CHARTER
100% UTILIZATION RATE
SCRAPPING / FSRU
2005
2040

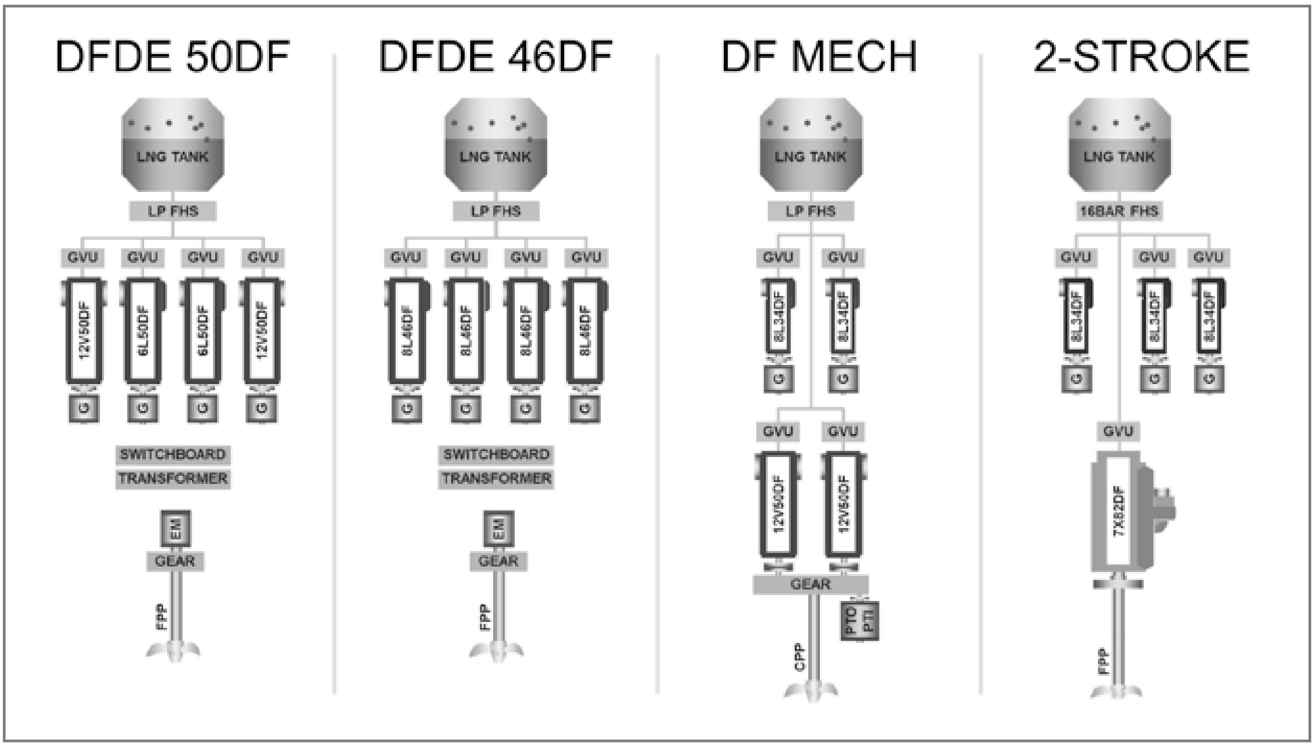


Fig. 5 - Conversion options.

extent that a conversion specification was commissioned for Wärtsilä.

Conversion in practice

The specification basically consists of a detailed picture of what the conversion entails, with respect to equipment components, structural impact and system modifications.

Three propulsion system conversion alternatives have been considered: DFDE (2 x Wärtsilä 12V50DF + 2 x Wärtsilä 6L50DF or 4 x Wärtsilä 8L46DF), dual-fuel four-stroke mechanic (2 x Wärtsilä 12V50DF + 2 x PTO + 2 x Wärtsilä 8L34DF) and dual-fuel two-stroke (1 x Wärtsilä 7X82DF + 3 x Wärtsilä 8L34DF). (Figure 5)

In all cases, the existing steam turbine plant has to be removed through openings in the decks. The dual-fuel four-stroke mechanic and the dual-fuel two-stroke alternatives require drastic structural modifications, including hull cropping to fit the main engines. Moreover, for the two-stroke alternative, it is not always viable to keep the existing shaftline, resulting in a possible re-design of the whole vessel aft. In comparison, the impact of a DFDE installation is more limited; the equipment can be fit through the openings created to remove the steam turbine system, and the existing propeller and shaftline potentially can be maintained. (Figure 6)

Available natural boil-off-gas is sufficient for a DFDE system to sail at any vessel speed. So benefits from further paring down gas consumption materialise only in ballast conditions. Therefore, those benefits are too limited to justify a bigger impact conversion than what a mechanical solution entails.

In cooperation with one of the major ship owners in the LNG market, strategically-located yards were identified worldwide, based on their relevant experience, and asked to provide both a quotation and a time schedule. Some of them proved to have the right skills and expertise to perform the conversion, and their offers matched the budget and time-span upper limits defined in the owner business cases.

Charterer business case: number crunching

Wärtsilä estimated the potential fuel savings that a DFDE system would enable on a 145,000 cbm steam-turbine-powered LNG carrier built in early 2000s.

Given a standard operating profile, a DFDE vessel can sail exclusively on natural boil-off-gas in laden conditions. On the other hand, with a steam turbine, it is necessary to force a remarkable quantity of boil-off (e.g. at 17.5 knots the usual forced boil-off-gas demand is in the range of 50 tons per day).

The calculated savings for reducing the fuel by more than 15,000 tons per year is USD 5.5 million, assuming an average LNG price of USD 350 per ton over the forthcoming period. Financial evaluations based on today's gas prices are quite limiting, as the conversion benefits materialise over the longer term. (Figure 7)

In the current market situation, charterers have to pay a USD 2.5 million premium on their yearly rate, if they choose a DFDE over a steam turbine vessel. However, the extra fee does not fully apply if the charterer invests in the conversion: the premium is limited to the maintenance costs coverage, about USD 500,000 per year.

For the DFDE alternative, the conversion implies an initial investment that ranges between USD 30–40 million and requires about 3 months' conversion time, depending

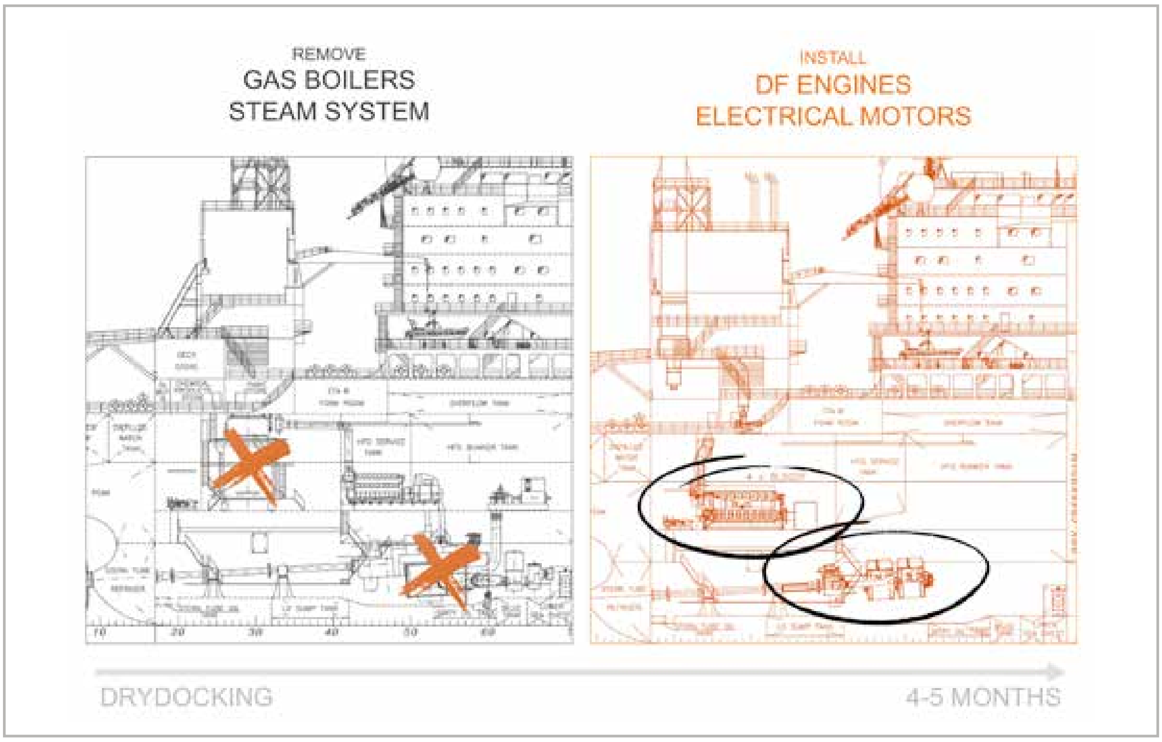


Fig. 6 - Conversion in brief.

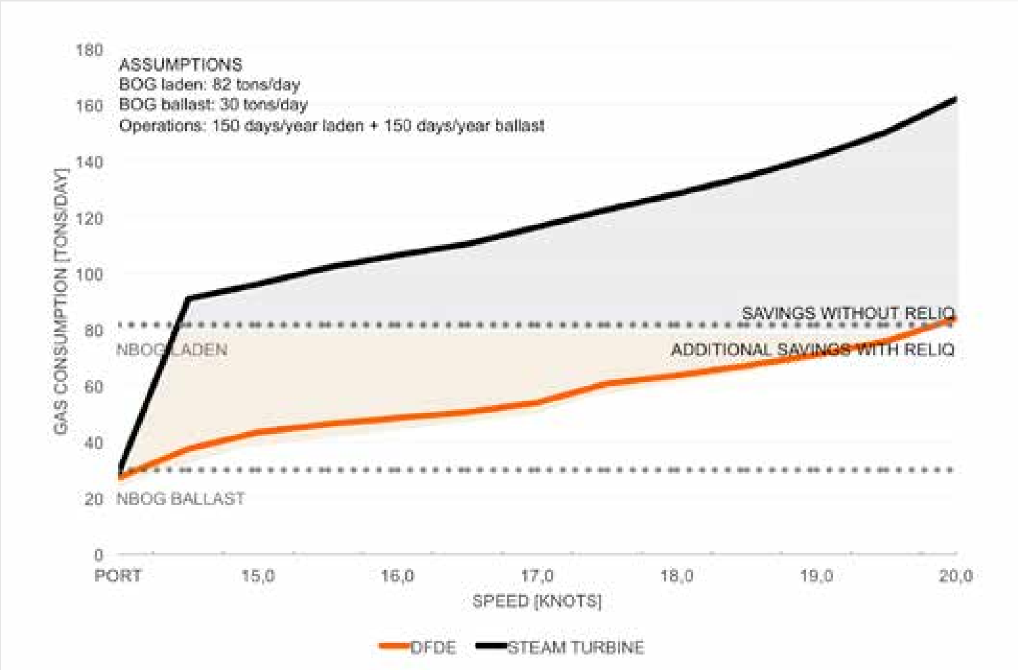


Fig. 7 - No forced boil-off required with DFDE in laden.

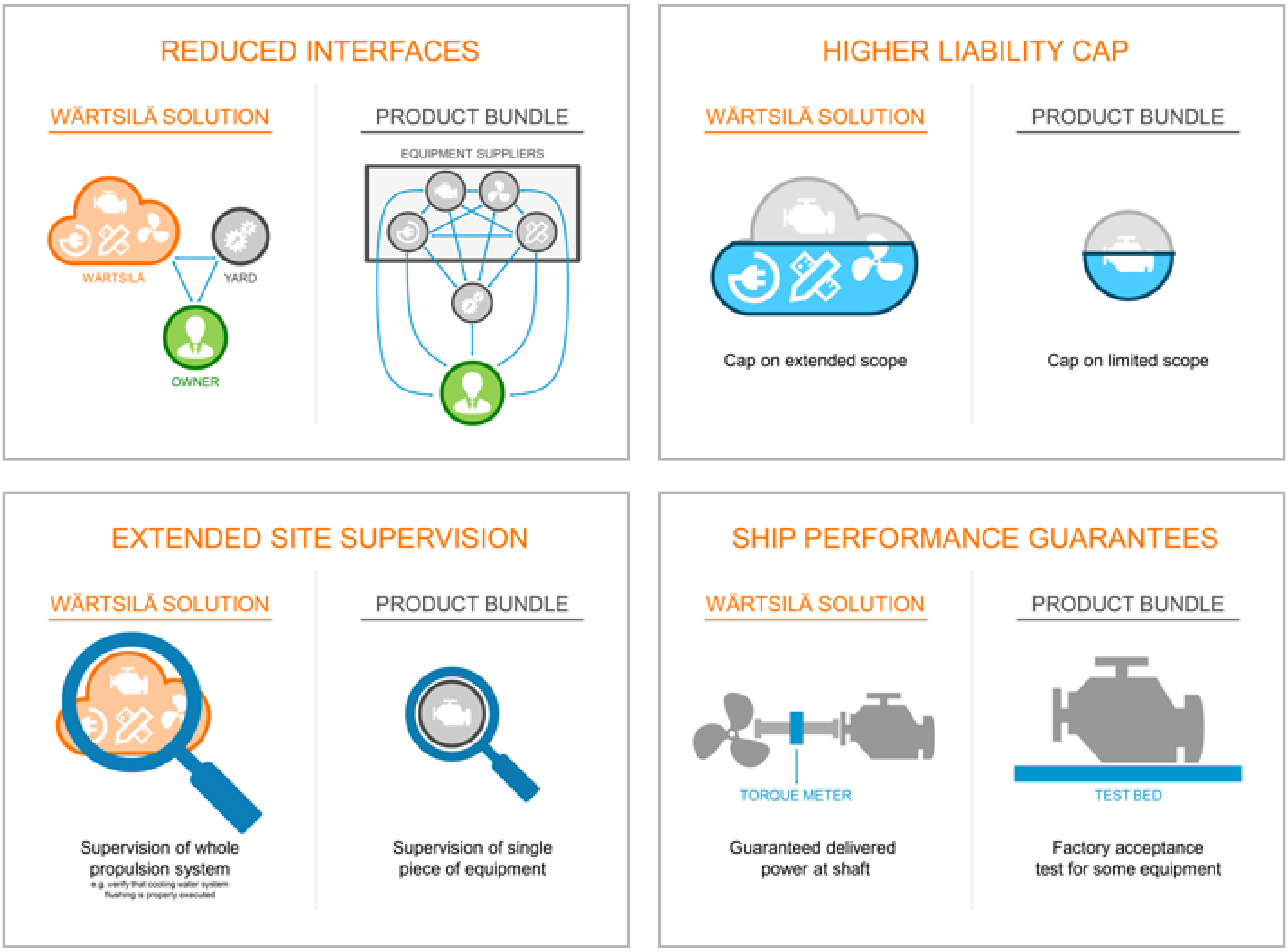


Fig. 8 - Comparison between a total integrated solution and a product bundle.

on the shipyard capabilities and vessel specification.

Time, in particular, turned out to be a key factor, not only due to the direct costs at the yard, but also because of the need to hire a replacement vessel. Even taking advantage of pre-assembled modules and combined with the extended dry-docking, the vessel off-hire translates into USD 2.5 million additional expenditure.

All in all, considering direct and indirect initial costs, as well as net operational savings, the payback time does not exceed 7 years. Although very conservative, as based on the assumption that the owner does not contribute to the conversion, the financial outcome suggests an exciting business opportunity for the charterer.

Indeed, the market response has been extremely enthusiastic: Wärtsilä is receiving queries from owners and charterers on a daily basis, and the on-going discussions are becoming more and more concrete.

DFDE technology

Besides high efficiency, DFDE offers several advantages in terms of ease of installation, reliability, redundancy, performance, flexibility and emissions.

- Ease of installation: the conversion to a DFDE has no major impacts on the vessel structure, unlike mechanical configurations.
- Reliability: DFDE configuration has by far the most extensive references in the LNG marine business, with more than 1400 engines sold and over 13 million running hours.
- Redundancy: DFDE is able to sail 24/7/365, even during a sea-going maintenance.
- Performance: Electrical motors can provide maximum torque at zero speed with any propeller design.
- Flexibility: The fuel-sharing mode can maximize the use of boil-off gas and reach the highest output with lower gas quality.
- Emissions: Dual-fuel engines work according to the Otto cycle, which means IMO Tier III compliance in gas mode without any after-treatment, while diesel cycle engines require either EGR (exhaust gas recirculation) or SCR (selective catalytic reduction).

Wärtsilä turnkey total solution

Thanks to its broad product portfolio, the most comprehensive in the marine market, Wärtsilä aims to promote the conversion as a turnkey total solution. All of the needed equipment and engineering can be included in the project scope, ranging from fuel gas system, engines, electrical package, gearbox, IAS (integrated automation system) upgrade, boilers, economizers, and GCU (gas combustion unit) to the class-approved drawings. Opting for a total integrated solution rather than a product bundle can be highly beneficial for the customer from many different perspectives. (Figure 8)

Communication is a good example. The interfaces are drastically simplified and reduced to three main stakeholders: owner, shipyard and Wärtsilä, the one single equipment supplier.

Project risk mitigation is another important added value. This is guaranteed, for instance, by state-of-the-art integration engineering and is reached thanks to information availability, geared internal synergies and deep knowledge about Wärtsilä's own product portfolio.

On top of that, Wärtsilä is able to provide support prior, during and post installation, i.e. by estimating the expected overall efficiency of the system, supervising the building phase (including installation and integration of equipment and auxiliary systems), and training the crew regarding the management of the entire engine room.

Furthermore, a liability cap covering an extended scope, rather than a single product, further limits the customer's exposure to risks.

A glimpse ahead

In an increasingly tough market, owners are facing the need to boost their fleet competitiveness. Improving efficiency by 40% makes vessels remarkably more attractive and ensures fleet employment, also in case of tonnage oversupply, whereas steam turbines are doomed to remain the very last choice. Moreover, the asset lifetime gets longer and can be even further extended through via an FSRU (Floating Storage and Regasification Unit) through the installation of a regasification plant.

Nevertheless, charterers are those who can benefit the most from the conversion, thanks to a terrific abatement of operational expenditures.

An investment cost-sharing between owner and charterer is therefore a fair compromise, where both parties can significantly enhance their respective business with a limited investment.

Getting the first project to materialize successfully could pave the way for a new course of action in the LNG shipping industry. Thanks to its unmatched track record as technology pioneer and its unique capacity to provide turnkey solutions for the whole engine room, Wärtsilä is the ideal partner for a successful conversion.

Hannes Koppel, founder of Marina Ahoy, lives on the Estonian island Saaremaa, where sailing is popular. "I like to sail, as do most of my friends. And my son has just started to sail on his own, too."

The self-service harbour

AUTHOR: Lena Barner-Rasmussen **PHOTO:** Karl Vilhjálmsson

Marina Ahoy is looking into automatising harbours. With the help of Wärtsilä, this vision might come true even faster.

Think of how automation has changed airports. Most of us can check in without any help from airport staff. Now, take that thought a bit further to imagine an automated flight tower but for boats and ships, turning marinas into easy-to-manage businesses and making harbour operations smooth.

Thanks to Marina Ahoy, winner of Wärtsilä's Marine Mastermind competition, this might be a reality in the not-so-distant future.

Marina Ahoy, founded in Estonia less than a year ago, is looking into changing the marina business all at once with a solution

that would make it possible to manage a harbour automatically around the clock.

"In a yacht marina, 15 minutes of man hours are spent on each visitor, and the load of paperwork accounts for about 30% of the harbour management's time. Simple tasks like check-in and -out, together with booking and billing, requires a lot of attention from the visitors. And every harbour has their own way of working, making it even more difficult as you need to find out how things work," says **Hannes Koppel**, CEO and one of the founders of Marina Ahoy.

There has got to be a simpler way to do this, thought Marina Ahoy's founders when they gathered together in the Estonian harbour town, Kuressaare island, for a harbour seminar last summer. One of the co-founders **Relika Metsallik-Koppel** immediately started sketching the first model of the e-services design. And a month later, Marina Ahoy was born during a Hackathon event in Tallinn, where the idea got great feedback. That's fast action even in the start-up world.

So what does Marina Ahoy do?

"Sailors can check in by themselves through our system that gives a real-time overview of available berth, along with booking and mobile payment for all types of marina services," explains Koppel.

So, basically, Marine Ahoy connects vessels in real-time to a marina or harbour in order to automate routine bureaucracy. For marinas, that translates into keeping open 24/7. But in commercial shipping, it could disrupt how harbours are run today, just like booking.com did for hotels. Having a big port automate its services would lead to a win-win situation for shipping companies, sailors and ports. Just think how many man-hours the world's busiest port in Shanghai, handling more than 32 million containers annually, would save. This could completely disrupt the marina business.

"All the finalists were very impressive, but Marina Ahoy is the company with the biggest chances of having a truly disrupting impact," says Tero Hottinen, responsible for organising the Marine Mastermind contest and one of the jury members.

As the winners of the Wärtsilä Marine Mastermind contest, Marina Ahoy can look forward to a 30-day Lean Innovation Lab, supported by Wärtsilä. Koppel has high hopes for the sprint.

"We're a step away from entering the marine service business, and the Marine Mastermind competition has been a good opportunity to evaluate our idea in front of a jury and get some feedback from experts. During the sprint, we are looking for an outcome that interests us as well as Wärtsilä. I can't wait to play through this," says Koppel, who has been an entrepreneur most of his professional life. He loves it.

"It's a way to test your fantasies in a real business environment. You can't be afraid of failure."

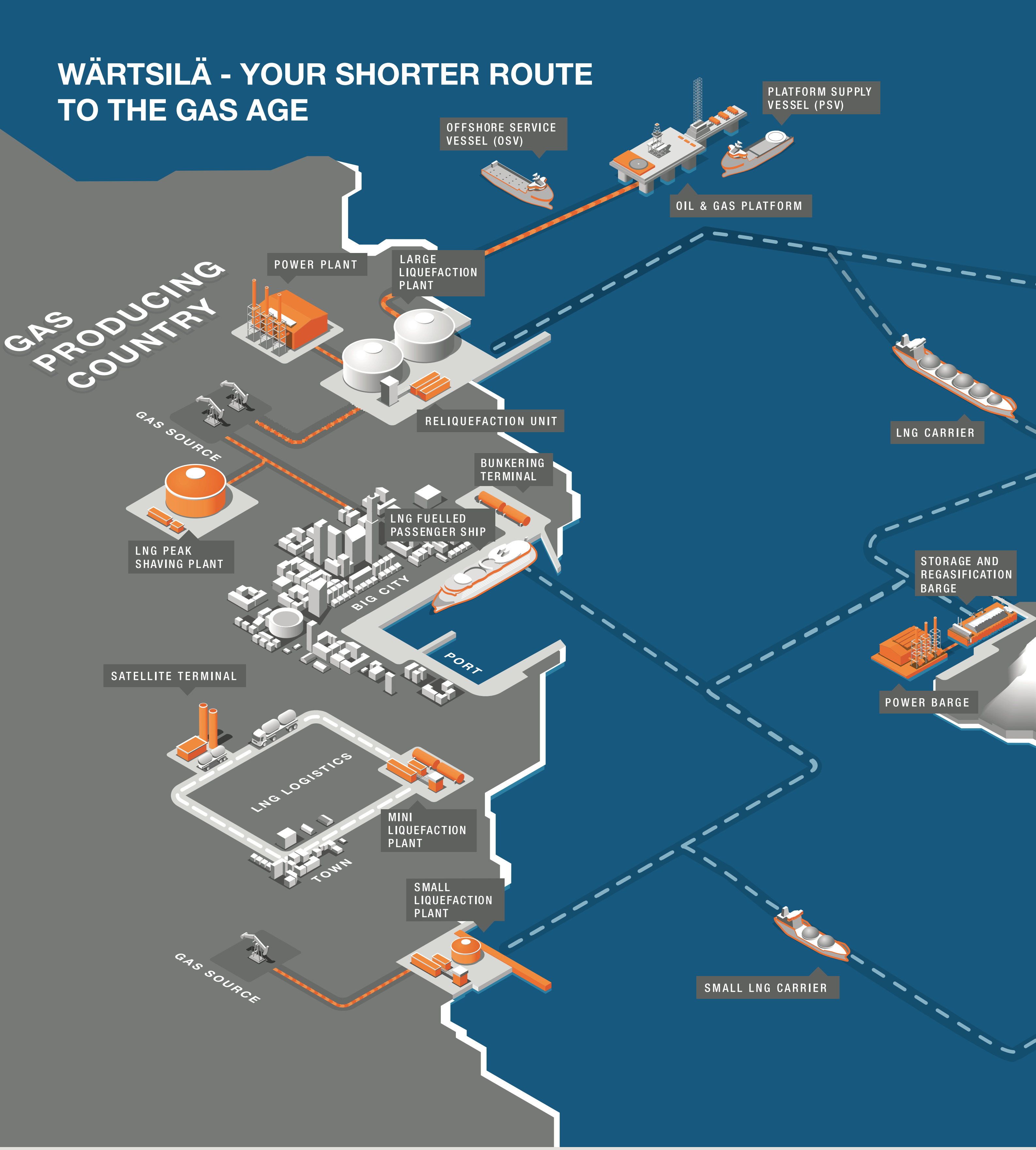
OPEN TO NEW IDEAS

The Wärtsilä Marine Mastermind contest was launched in November 2015 with the aim of finding interesting partners in the start-up world who could help further propel Wärtsilä's digitalisation efforts.

"We got 47 applications from 17 different countries. The jury had a positive problem because it was difficult to choose just five finalists," says Tero Hottinen. The finalists were then invited to Helsinki to pitch their ideas in person to a jury, and, during Digital Ship in Copenhagen in the beginning of April, the winner was announced. Hottinen says the Marine Mastermind contest is just the beginning for Wärtsilä in teaming up with start-ups.

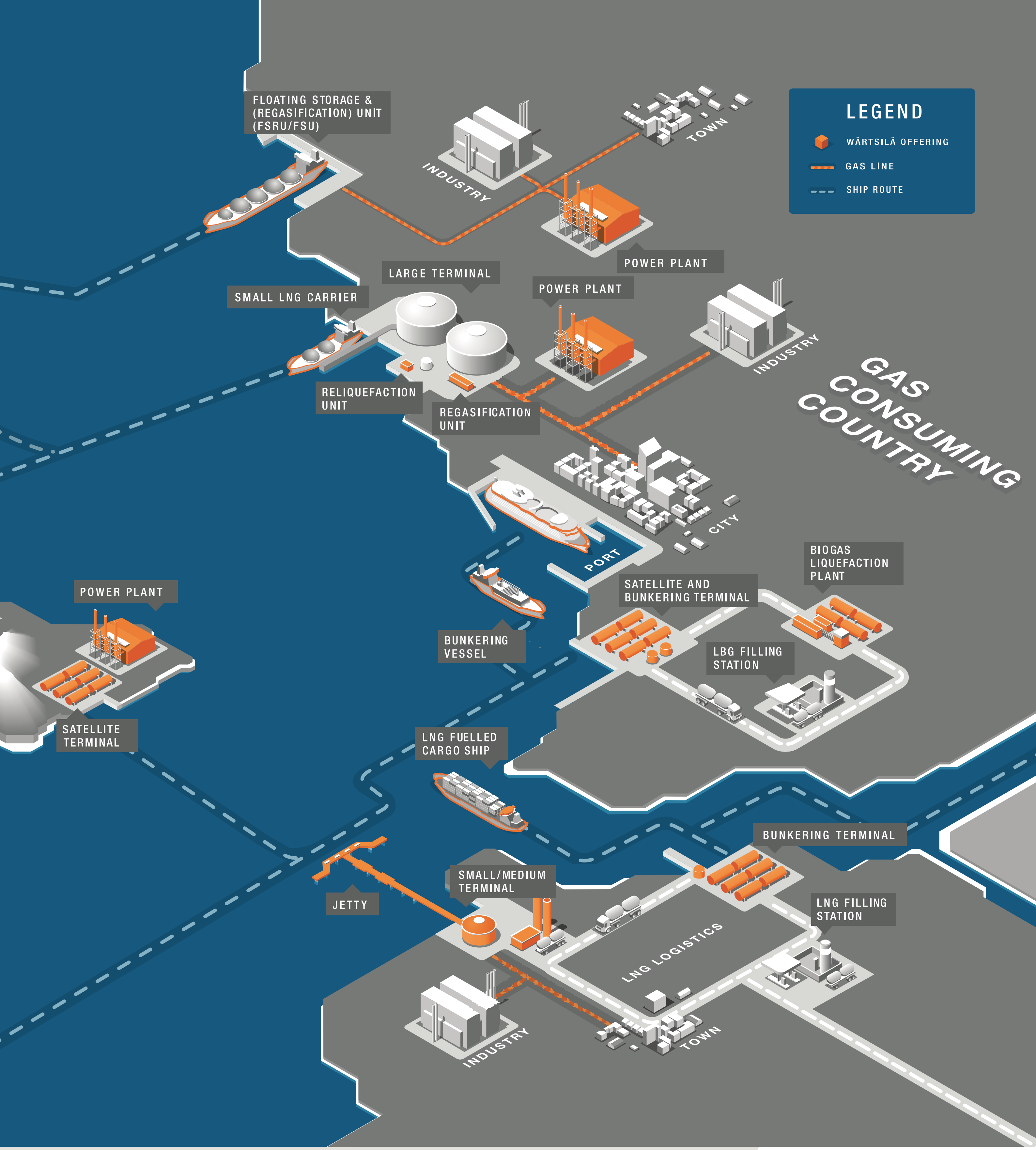
"We are now tapping into a new area when it comes to start-up collaboration, and we might be looking at transforming entire business models with the help of open innovation."

WÄRTSILÄ - YOUR SHORTER ROUTE TO THE GAS AGE



WÄRTSILÄ CONNECTS THE DOTS

Wärtsilä has the expertise, experience and offering you need. Our offering covers integrated solutions, EPC turnkey delivery, services and products for all phases of the LNG lifecycle. Read more about what we have to offer your business at **www.wartsila.com**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POWER PLANT
INDUSTRY
GAS CONSUMING COUNTRY
RELIQUEFACTION UNIT
REGASIFICATION UNIT
CITY
PORT
BIOGAS LIQUEFACTION PLANT
SATELLITE AND BUNKERING TERMINAL
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BUNKERING VESSEL
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SMALL/MEDIUM TERMINAL
JETTY
LNG FILLING STATION
LNG LOGISTICS
INDUSTRY
TOWN

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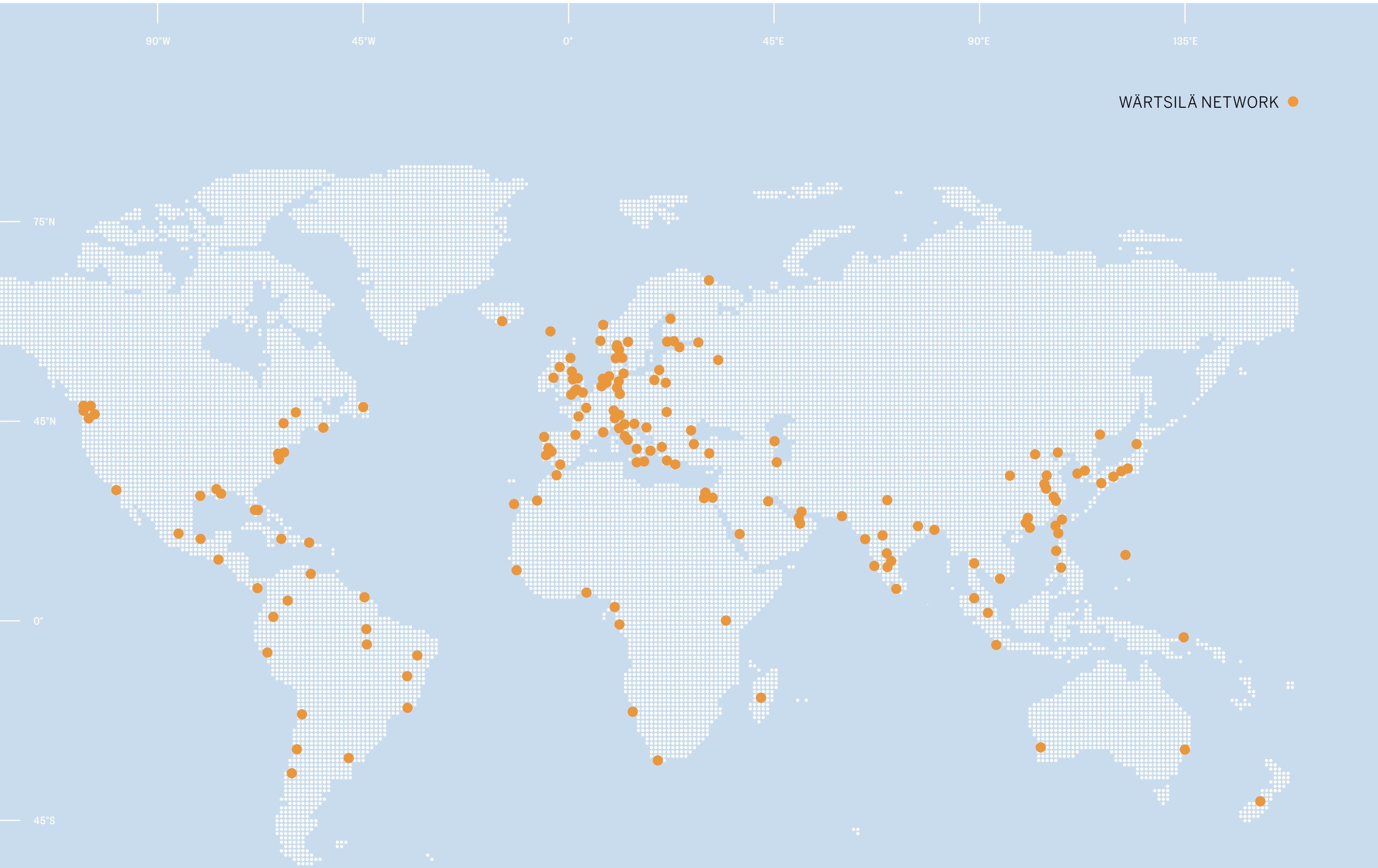

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in**detail**