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COVER STORY

MARKET REFORM IMPACTS INVESTMENTS
Case examples from EU, USA & Australia
4 page

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GOOD IDEAS ARE MEANT TO BE SHARED

An idea without implementation is not yet an innovation; it is just an idea. Fast and efficient implementation of ideas needs validation with customers, suppliers or other stakeholders. Startups are good at this, as their survival is dependent on it. But if potentially useful ideas remain too long in the heads of those who think of them, their potential for actualisation or application diminishes. So, by enabling networking, the exchange of ideas and co-creation in partnerships, even large companies can turn their ideas into valuable business faster.

Many of the articles in this issue of In Detail magazine have been adapted from award-winning papers presented at conferences, like the CIMAC Congress and Power-Gen. What all these papers have in common is that they are examples of Wärtsilä's best experts putting forth their innovative and forward-thinking work and sharing the outcomes with customers and other technical experts.

Since not everyone can attend every technical conference, we believe it is a value to our readers to get a glimpse of the solutions being developed. No matter which articles you choose to read, you will learn more about what is behind our products and their applications and their value to our customers, and you will see Wärtsilä's thought leadership in action. If something sparks your interest, we invite you to contact the individual authors for further disucssion.

With this issue, we also welcome Eniram to the Wärtsilä family. Its complementary offering provides a leading opportunity in the industry. Read more about it on page 58.

Then, in the Future article at the end of the magazine, learn how our new Chief Digital Officer, Marco Ryan, is leading Wärtsilä's digital transformation – one of the biggest transformations our company has seen – with five 'digital promises.' Digitalisation will enable new ideas to be implemented into new business model innovations, value-added services or products and great results for our customers and our company.

However, rather than replacing our work to date, our digital transformation will help us build on everything we have done so far. It provides a whole other platform for new ideas and innovative solutions to maximise the environmental and economic performance of our customers' vessels and power plants. We trust it expands our opportunities to co-innovate with you for decades to come.

Ilari Kallio
Vice President, Technology
Wärtsilä Engines
Editor-in-Chief of In Detail

KEEPING PACE

The third industrial revolution blurs lines between manufacturing and digital services.

REFERENCES

The optimal logistics chain

Modelling distances, gas consumption and the sizes of available ships shows how the LNG value chain can be optimised.

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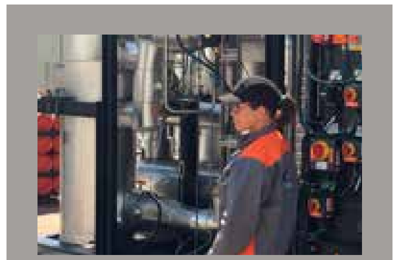

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Looking for new opportunities with the 1 MW pilot Wärtsilä Gas Reformer in Bermeo, Spain.

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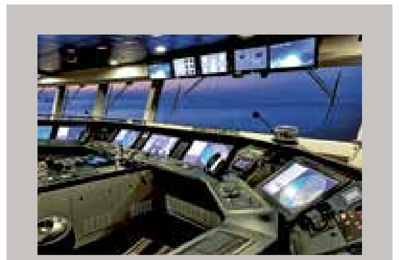

Navigating into the future

Wärtsilä Nacos Platinum responds to tighter regulatory demands for maritime navigation system performance and safety.

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Status and impact of market reform policy on investments: Case examples EU, USA & Australia

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Reform policy options and market mechanisms can incentivise investments in flexible generation for renewable integration, and the right combination of capabilities in a power system can create total system optimisation. Examining different electricity market structures in the EU (specific member states) and the USA (specific markets), while not an exhaustive description of all markets and mechanisms, provides context for some essential developments contributing to the increased focus on flexible generation investments and their value.

This article is based on the award-winning paper “Market reform policy – Case examples EU, USA and Australia: status and impact on investments” presented at the Power-Gen Europe 2016 conference.

Major drivers in US and EU energy markets

Renewable Energy

Over the last decade, many countries and regions of the world have shown strong commitment to decarbonising their economy. For example, in 2012, the earlier EU decarbonisation commitment was extended to 2030, and in October of that year it was further strengthened when the European Council adopted the following targets:

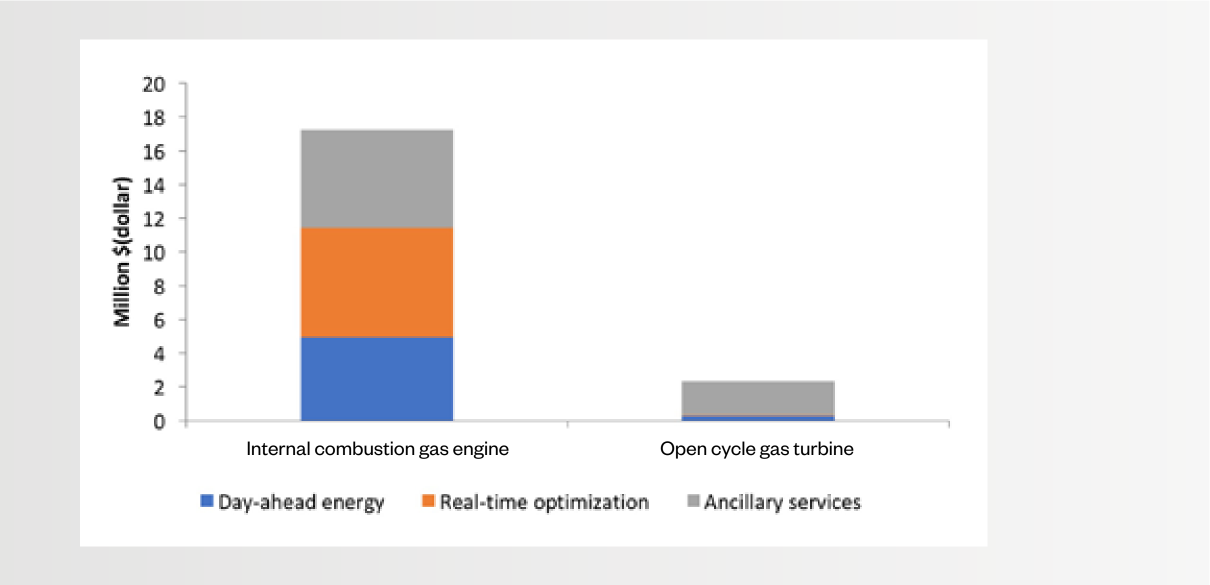

Fig. 1 - Annualised gross margin profit by market product for internal combustion gas engines and an open cycle gas turbine.

- At least 40% emissions reduction in EU greenhouse gas emission from 1990 levels
- Raising the share of EU energy consumption produced from renewable resources to 27%
- A 27% improvement in the EU’s energy efficiency [1]

The energy sector is one of the main enablers of these objectives, and thus electricity production from renewable energy sources (RES) has increased strongly in the EU. Consequently, energy produced from conventional sources declined.

Although the energy produced from RES in the US is not as high – about 13% of the domestically produced electricity in 2015 – specific regions have had dramatic growth in installed wind and solar capacity over the last decade, which presents new challenges in integrating these variable sources. New utility-scale solar installations were expected to reach 9.5 GW in 2016 alone, which is more than the total from 2013 to 2015 combined (9.4 GW). New wind plants in 2016 were expected to reach 6.8 GW, a slight decline from the 8.1 GW in 2015.

The changing nature of electricity demand

Total electricity demand in the US and EU in recent years has been flat or even negative, due to several underlying factors. For one, higher demand growth is strongly linked to industrial output, but growth in the population’s wealth is no longer closely linked with industrial output. Instead, as consumers get wealthier, they move towards greater energy efficiency and the economy moves away from an energy-intensive industry focus to a more service-based focus. Another driver is the increased focus on energy efficiency and demand response by utilities and their regulators. This does not mean that no new generation investments are needed but rather that new generation resources going forward should provide a different value proposition than before.

Weather conditions ultimately determine when and how much energy can be produced by RES. Although forecast technologies improve, the resulting intermittent production is difficult to predict, especially for time periods long before actual delivery. Thus, dispatchable capacity is required to balance the fluctuating production from RES and maintain security of supply in the system.

Fluctuations can be over longer periods of time (when the wind stops blowing for several days) and very short intervals (when several GW of firm power is required within an hour). Therefore, the typical thermal investments of the past, CCGT plants for energy and low-cost gas turbines for peaking (capacity reserve), are being challenged by smaller, faster, yet still very efficient generators that can balance minute-by-minute the higher-volatility Net Load (demand minus variable output of renewable sources).

In addition to the total electricity demand, peak demand – defined as the highest instantaneous load on the grid – is a significant determinant of the shape and the size of the power system. In developed countries, growth in peak demand over the last decade has outpaced annual electricity demand. Our demand profiles are becoming “peakier” as relatively stable industrial demand is replaced by more variable commercial and residential demand. Adding to this the non-dispatchable renewable energy gives a much more volatile Net Load that must be balanced with much more flexible resources, both on the production side (flexible power generation) as well as on the demand side (Demand Side Response [DSR]).

Though solutions are available, investments in flexibility solutions are not materialising. In past years, policymakers have considered how electricity market design can be adjusted to provide market-based incentives for these technologies. By examining markets where an updated, Energy-only Market set-up was implemented and markets where a Capacity Mechanism (CM) was implemented, we

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evaluate whether these market arrangements lead to the desired outcome.

Review of electricity market set-ups

United Kingdom Capacity Market

Market design

In the context of wider decarbonisation goals, EU member states are rolling out renewable technologies rapidly. The UK must achieve 15% renewables share of energy by 2020, which translates to around 30% share of electricity from RES. As nuclear options face huge political and cost challenges after Fukushima, and the technical and commercial potential of Carbon Capture and Storage (CCS) remains to be proven, most new plants in the UK use wind (given the UK's plentiful wind resources).

However, just as flexibility needs to grow with increasing volumes of RES, much of the UK's existing fleet of dispatchable flexible resources is set to close (due to age and emissions regulations). This has raised concerns of capacity adequacy, which forms the basis for the Electricity Market Reform (EMR) capacity mechanism.

As part of its EMR process, the Department of Energy and Climate Change (DECC) has decided to implement a 'market-wide' capacity mechanism in the UK, in the form of a forward capacity auction with availability incentives and penalties. The rationale is to deal with the 'missing money' problem brought about by increasingly uncertain market-based revenues for thermal plants. The capacity mechanism will be technology-neutral (subject to technical availability requirements) and focused on ensuring overall capacity adequacy rather than on securing certain types of capacity. While this form of capacity mechanism may increase the UK capacity margin and reduce risks to supply security, it may not deliver the right mix of flexible capacity at the lowest cost to consumers.

Outcome

At the first CM auction held at the end of 2014, almost 50 GW of capacity won contracts at GBP 19.4/kW, of which the majority was for one-year contracts for existing generation.[2] A total of 2.6 GW of new capacity won 15-year contracts. Of this new capacity, 1.8 GW was accounted for by the Trafford CCGT project and 900 kW by smaller-scale, high-speed diesel reciprocating engines. The Trafford plant was bid into the capacity auction without financing and without a long-term tolling agreement to back it, and the company is struggling to secure an offtake contract and financing and may not be able to deliver against its 2018/19 capacity agreement.

The second auction at the end of 2015, aimed at securing capacity for 2019/20, saw just over 46 GW cleared at GBP 18/kW. Again, the majority was for one-year contracts for existing generation. The share of high-speed diesel reciprocating engines clearing the auction for new capacity was even higher compared to the 2014 auction.

The outcome of the two CM auctions clearly shows that this specific market design is not incentivising investments in new capacity, even though 5-10 GW of coal and CCGT plants will close over the next 18 months. Additionally, the CM does not provide any signal to the market to invest in flexibility. Only the technology with the lowest CAPEX is rewarded with CM contracts, and system-level benefits (such as integrating and enabling the use of more RES) are not taken into consideration. This leads to the strange situation where the UK is now subsidising diesel-fired generation, at a time when decarbonisation of the power system is high on the agenda.

Germany's Strommarkt 2.0

Market design

After a broad consultation process regarding the electricity market design, the German Federal Ministry for Economic Affairs and Energy (FMEAE) decided in 2015 to develop the existing market into an electricity market 2.0 (EOM2.0).[3]

The EOM2.0 is meant to strengthen the confidence of market players in competition-based price formation. The FMEAE will enshrine in law that pricing will take place based on competition. This means that high price peaks can occur, and the investment incentives of the market mechanisms can take full effect. Also, companies can offer prices that are higher than their marginal costs ("mark-up"). The incentives to uphold balancing group commitments will be strengthened by introducing marginal pay-as-cleared balancing energy prices based on cost-reflective imbalance charges. The balancing energy system provides the incentives for responsible parties to ensure they have contracted enough electricity to uphold their commitments.

In addition to strengthening the market, the FMEAE included an additional "security" component: to backup the electricity market 2.0 with capacity reserve. Unlike the capacity mechanism, the capacity reserve consists solely of power stations that do not participate in the electricity market and do not distort competition and pricing. These power stations will be used only if, despite free price formation on the wholesale market and contrary to expectations, supply does not cover demand at a given time.

Outcome

To understand and gain insights into the effects of the proposed EOM2.0, Wärtsilä commissioned Baringa Partners LLP (an energy advisory consultancy based in the UK and Germany) in 2014 to model the German market over the period 2020 to 2035 with the EOM 2.0 criteria.[4]

The modelling work concluded that the EOM 2.0 creates strong incentives for flexibility as it targets financial incentives on flexible operation itself (instead of remunerating all types of capacity with the same level of payment as would be case in CM). Although the analysis is conservatively based on historic intra-day and ancillary service prices, Baringa observed an increase in the profitability of flexible resources relative to inflexible resources.

The profitability analysis also shows that flexible forms of capacity, such as gas engine power plants, are exposed to stronger incentives to invest. This is driven by superior operational capabilities, allowing them to collect additional revenues from operating flexibly in the intra-day and ancillary service markets.

These results highlight that market design choice can have significant impact on technology choice for investors. This analysis suggests that the EOM 2.0 is more likely to deliver more flexible capacity, which aligns with the future needs of the German system.

In December 2016 Wärtsilä won a contract to supply a flexible 100 MW combined heat and power (CHP) plant to Kraftwerke Mainz-Wiesbaden AG in Germany. This new highly efficient CHP power plant will enable the customer to operate profitably in the increasingly volatile power market and provide climate-friendly district heating to the community.

Southwest Power Pool (SPP), US

Market design

The market design in SPP consists of a two-phase settlement. Plant commitment, market clearing and ancillary service procurements take place in the day-ahead market settlement. Market players are not allowed to withhold capacity from the day-ahead market, and available capacity, including wind generation, must be offered. The second settlement takes place in the real-time market, which is a five-minute marketplace. All deviations from the day-ahead market clearing are covered through the real-time market.

The SPP market has 75,000 MW of installed generation capacity with a reserve margin of 47%. Compared against standard planning reserves of 15%, SPP has the largest reserve margin in the US. In terms of market dynamics, generators are in an extremely weak position to exercise market power and collect scarcity rents during high demand periods. The substantial amount of excess capacity usually creates poor fundamental conditions for peaking units to realise adequate returns to justify their entry on a merchant basis. However, SPP also has a rapidly growing fleet of wind generators that constitute over 10% of energy production, with wind providing 15% of energy by 2015. The combination of variable wind and over 25,000 MW of relatively inflexible coal generation creates conditions of high-variability real-time prices.

How can such a market provide opportunities for a new generation? The flexibility of supply resources in SPP responds to changes in load and addresses congestion problems. Generation responds dynamically to the changes in load to maintain proper balance between demand and supply. If ramp rates are too low, the market cannot respond quickly enough to manage system changes, and ramp deficiencies occur. Deficiencies result in price spikes and increase overall price volatility. From 2012 to 2013, ramp deficiencies increased by about 10% to approximately 100 events per year because of the added variability of increased wind generation and the decrease in ramp capabilities from online capacity. The deficiency in ramp capabilities manifests itself through higher, more volatile market prices for regulation services and energy. While these events are short-lived, they can create extreme changes in real-time prices. For example, real-time power prices are 300% more volatile than day-ahead prices.

Outcome

Ascend Analytics performed an independent market assessment valuing 200 MW equivalent of Wärtsilä 50SG engines and an open cycle gas turbine (OCGT) (a General Electric 7FA turbine was used) for the SPP Lubbock price node from 1 March to 1 September 2014.[5] The purpose was to assess the economic value of each asset under observed SPP market conditions. While both assets are flexible generators, they differ in their efficiency and responsiveness. The SPP market places a substantial economic premium on flexibility to react to the five-minute, real-time market.

The results confer the economic value of generation flexibility inherent in the gas engine relative to the OCGT. (Figure 1) Generation that can rapidly and efficiently respond to the SPP market price signals has substantial value over less flexible generation.

For 200 MW of equivalent gas engine and OCGT generation capacity, the engines realise 740% more value.

Electricity Reliability Council of Texas (ERCOT), US

Market design

The Electric Reliability Council of Texas (ERCOT), which operates the electric grid for most of the state of Texas, has experienced steadily growing demand over the last several years. From 2011 onwards, rising demand, generating unit retirements and the cancellation or postponement of several capacity projects presented challenges in maintaining adequate planning reserve margins. ERCOT carefully monitored its system resource adequacy, recognising a threat of declining reserve margin in upcoming years. These concerns spurred consideration of a capacity mechanism in ERCOT to attract new investment. However, in 2014, the Public Utility Commission of Texas decided to continue with the energy-only market design. ERCOT worked on market enhancements to provide adequate scarcity price signals together with enhancements in Real-Time Market design. The price cap was increased USD 9000 per megawatt-hour (MWh) to reflect the value of flexibility.

Outcome

Adjustments to scarcity pricing of the market, together with declining reserve margin, have boosted investment activity in ERCOT. Currently, there is more than 8000 MW of new peaking gas capacity in the development pipeline, and a couple hundred megawatts of capacity is under construction.

Wärtsilä has analysed historical ERCOT market pricing and the performance of open cycle gas turbines (a General Electric Frame 7FA.05) compared with Wärtsilä's internal combustion engine gas technology (Wärtsilä 18V50SG engine) under various market participation cases.[6]

To examine project feasibility and internal rate of return (IRR), detailed dispatch and financial modelling for both the OCGT and gas engine power plant in the ERCOT Day-Ahead (DA), Real-Time (RT) and Ancillary Services (AS) Markets for 2011–2014 was conducted. The gas engine power plant financially outperforms the OCGT due to the higher flexibility. The ability of the gas engine to start up within five minutes, reduce load to 20% of full capacity, and incur no maintenance penalties from frequent starts and stops allows the plant to participate in ERCOT's Ancillary Services Market, offering variety of ancillary service products as shown in. (Figure 2)

Because of the longer start-up time of the OCGT and increased maintenance costs associated with frequent starts, the OCGT project could only offer limited ancillary services.

As market conditions predict, there will be higher price spikes in ERCOT in coming years and increasing demand for hedging products, which will drive up the hedge prices. The more valuable call option and ability to earn revenue from several markets further improves the business case for more flexible power plants.

Wärtsilä signed in September 2016

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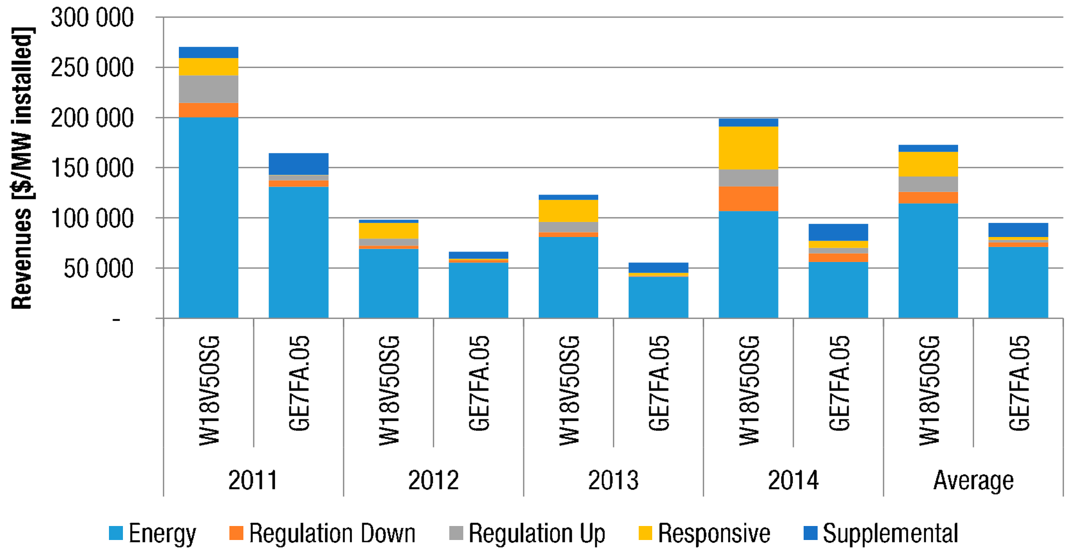
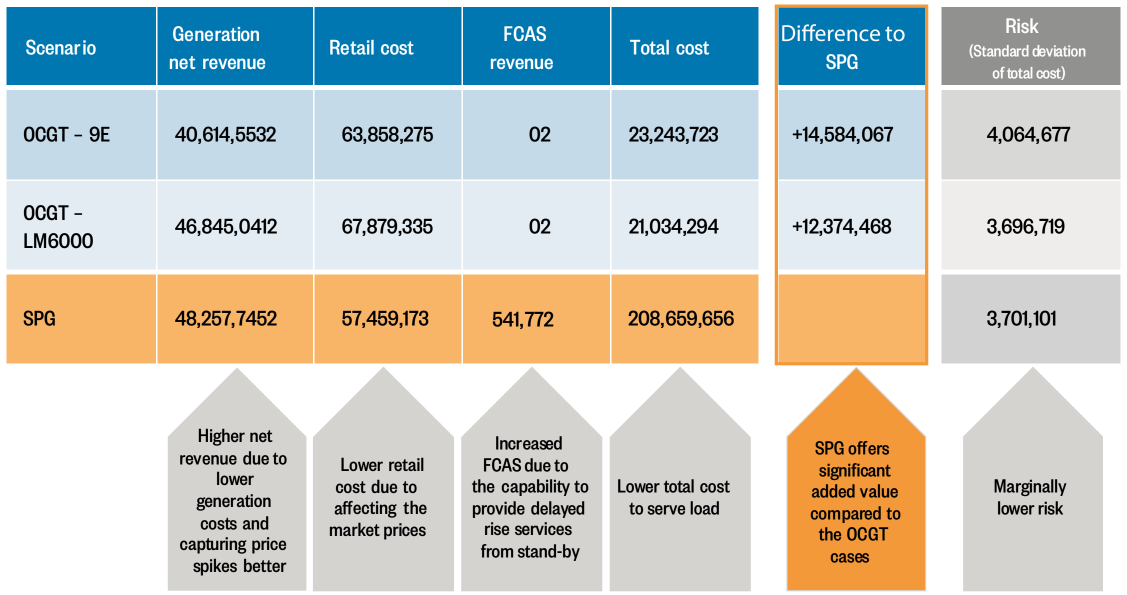


Fig. 2 - The Wärtsilä 18V50SG generates more revenue than the GE 7FA.05 due to greater dispatch ability in markets.



Scenario	Generation net revenue	Retail cost	FCAS revenue	Total cost	Difference to SPG	Risk (Standard deviation of total cost)
OCGT – 9E	40,614,5532	63,858,275	02	23,243,723	+14,584,067	4,064,677
OCGT – LM6000	46,845,0412	67,879,335	02	21,034,294	+12,374,468	3,696,719
SPG	48,257,7452	57,459,173	541,772	208,659,656		3,701,101

Fig. 3 - Compared to the OCGT 9E and OCGT LM6000 cases, SPG enables significant added value due to the higher generation net revenue, lower retail cost and superior revenue in frequency control ancillary services.

a major contract to supply a 225 MW Smart Power Generation plant to Denton Municipal Electric, the locally-owned utility for the City of Denton, Texas. The plant will provide balancing power to the community, which is moving towards a green, low emissions power system, aiming to have 70 % of its energy produced from renewables by early 2019.

National Electricity Market (NEM), Australia

Market design

The market design of the National Electricity Market (NEM) is a gross mandatory pool, where all generators are obligated to sell all produced electricity to the market. Correspondingly, electricity is bought by retailers from the pool. The market aggregates all generation and simultaneously schedules generators to meet the demand. This is managed through a central dispatch process, operated by the Australian Energy Market Operator (AEMO). Based on generation offers and demand bids, AEMO defines the most cost-efficient dispatch for every five minutes. The first indicative dispatch is computed a day before delivery. Redispatching, based on the adjusted bids, continues until five minutes before the actual five-minute dispatch interval. At the gate closure, the final dispatch and the dispatch interval prices are defined for the five NEM regions across Australia. Six consecutive five-minute dispatch interval prices are averaged every half-hour to determine spot prices for each 30-minute trading period.

Market rules define the market cap and floor price, which are currently 13,500 AUD/MWh and -1000 AUD/MWh respectively. A negative market floor price makes generators pay to stay online. This can occur when the cost of staying online is lower than the cost of shutting down and restarting a plant. A high market price cap serves as an incentive for new power plant investments. Most of the utilities in NEM are so-called gentailers (generator retailers). They have generation assets and load to serve. One important task for gentailers is to balance their own thermal generation according to their expected retail load and intermittent renewable output. This causes active rebidding just prior to the gate closure, occasionally creating significant price spikes.

Spot prices are highly volatile in the NEM, and market participants should manage their exposure to risks created by the price volatility. Generators and retailers manage their market price risk by using long- and short-term financial contracts, which ensure a firm price for electricity. These contracts are called Contracts for Differences and include swaps, caps, options and futures.

Outcome

In the NEM, OCGT plants have traditionally been used as peaking plants. Gentailers have used these plants as a physical hedge to protect their retail arm against market price volatility. However, superior flexibility of highly flexible power plants could enable more efficient market price risk mitigation, as well as significantly higher generation revenues.

Wärtsilä engaged ROAM Consulting to carry out a study of the potential for internal combustion engine Smart Power Generation (SPG) power plants within a large utility portfolio in South Australia, operating in the NEM. A state-of-the-art modelling framework shows that an SPG peaking power plant can provide significant gross margin to the utility, compared to OCGT alternatives. At the same time, SPG decreases the risk exposure of the utility by reducing the volatility of annual returns. The benefits are based on the inherent operational flexibility of internal combustion engine (ICE) technology, especially the capability to reach full load in less than five minutes. Such agile operation enables a superior position in the five-minute market, compared to slower peaking plant technologies. The analysis shows that, in comparison with the aero derivative OCGT case, a 200 MW SPG power plant generates an additional gross margin of AUD 12.4 million for the selected utility in 2020. The gross margin is AUD 14.6 million compared to the heavy-duty OCGT case. (Figure 3)

In a year-long operation regime, the SPG plant is started 1054 times with 933 running hours, while the heavy duty OCGT is started 434 times with 395 running hours. The difference is due to the SPG plant's operational capability to capture more market opportunities. Besides, the study results also show interesting system-level benefits. With 200 MW of SPG capacity as part of the portfolio, the average wholesale electricity price in the NEM is reduced by 4% compared to the heavy-duty OCGT case, with market prices of 41.3 AUD/MWh and 42.9 AUD/MWh, respectively. The price drop is result of the SPG plant being used to prevent disadvantageous price spikes for the utility.

Conclusions

Flexibility is required to integrate the increasing amounts of intermittent RES into a power system. The electricity markets described here clearly demonstrate the influence market design has on the type of future investments.

In several markets, flexibility provides value to stakeholders by rewarding dynamic capabilities. The mechanisms discussed in the German, SPP, ERCOT and NEM markets are essential to attract such investments and serve as examples for any market moving towards an optimal power system that is reliable, sustainable and affordable.

The examples also show that no specific government incentives or subsidies are needed to attract new investments in flexibility. A functioning electricity market that rewards performance in terms of flexibility, with close to real-time energy markets, price volatility and visibility, can provide the required incentives and guide investment decisions.

The UK example clearly shows the risks associated with capacity mechanism. Even though the capacity adequacy can be fulfilled through such a mechanism, it does not attract investments in flexibility and, therefore, does not support the transition towards a sustainable and affordable power system.

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1 Conclusions European Council, 23 and 24 October, www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/145397.pdf

2 National Grid, Provisional Auction Results, T-4 Capacity Market Auction 2014, December 2014

3 Federal Ministry for Economic Affairs, An electricity market for Germany's energy transition, White paper by the Federal Ministry for Economic Affairs, July 2015

4 Wärtsilä Stellungnahme zu der Grünbuch-Konsultation, Januar 2015, http://www.bmwi.de/DE/Themen/Energie/Strommarkt-der-Zukunft/Strommarkt-2-0/stellungnahmen-gruenbuch.html

5 Independent market assessment on Southwest Power Pool market, USA, http://www.smartpowergeneration.com/spp

6 http://www.smartpowergeneration.com/ercot

Optimising the South African power system with ultra-flexible LNG power plants

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In accordance with the IRP2010 and Ministerial Determinations, South Africa (SA) will soon embark on a large, new-build gas independent power producer (IPP) programme for 3126 MW, most of which will likely be supplied initially with imported liquefied natural gas (LNG). However, SA has not yet defined the plant performance criteria that will ensure the maximum system benefit. Modelling can determine the true operational requirements for SA's future gas to power opportunities.

This article is based on the award-winning paper (Highly Commended): "Optimising the South African power system with ultra-flexible LNG power plants" presented at the Power-Gen Africa 2016 conference.

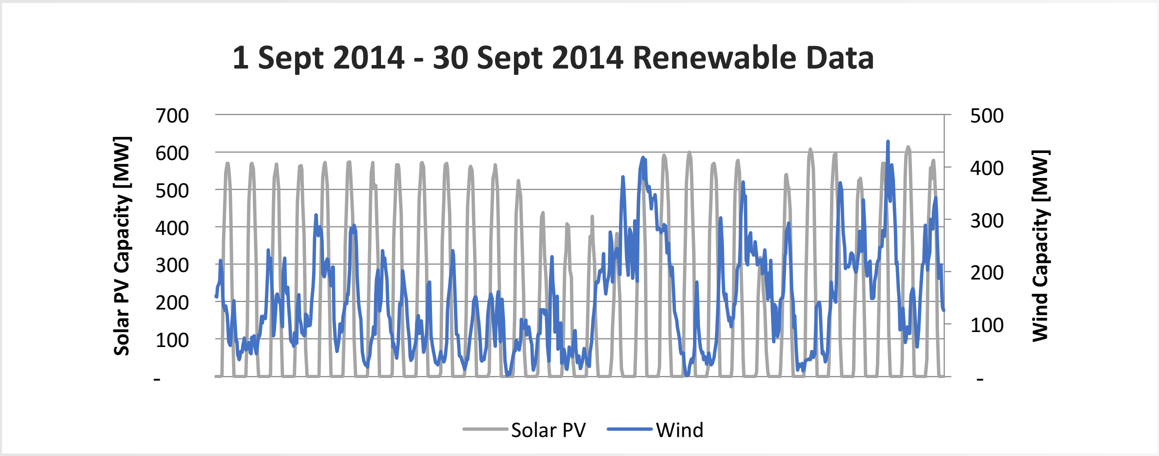

Fig. 1 - Renewables are highly intermittent in South Africa, as can be seen from aggregated energy production of solar and wind over one month from the REIPPP.

The regulatory context for new gas capacity

For many years, SA has obtained most of its energy needs from large-scale, coal-fired power stations, but this capacity mix is changing rapidly, due to increasing environmental pressures and the need for a diversified energy mix, as discussed within the Integrated Energy Plan (IEP) and the Integrated Resource Plan (IRP).

In 2012, the Minister of Energy released determinations for the construction of 3126 MW to be procured through the establishment of IPPs and, in May 2015, sought a wide range of gas-related energy projects with a focus on LNG-supplied projects (The Republic of South Africa - Department of Energy, 2015). Key features included the following:

- 3 GW of capacity would have a 35% load factor for the years 2020, 2025, 2030.
- Power plants would require "intra-day flexibility with lower-load factors during night and higher-load factors during the day and evening peak hours."

In this context, we examined the gas flexibility requirements for the SA power system and linked them to the complexities of the LNG supply. First, we highlight some of the variables that influence what the system will require from future gas capacity.

Future system variables

A few events contribute to both the long- and short-term uncertainty and variability of the power system and have a significant impact on the role of gas in the power system. These events include the following:

- Increasing renewable energy
- Increasing coal plant unavailability/ decommissioning
- Varying country demand

Through the successful Renewable Energy Independent Power Producer Programme (REIPPP), SA has a total of 6.3 GW already procured, with a total allocation of 13,225 MW to be built predominantly through wind and solar energy (Creamer Media, 2015). The drawbacks, however, arise from the intermittent nature of these sources. (Figure 1)

Because of this intermittency, increasing the relative share of renewables in the power system creates system imbalances for which flexible measures must be introduced. If South Africa follows the planned capacity increases per the IRP, it can anticipate an 11% penetration by 2020 and 26% by 2030. According to the International Energy Agency, a power system starts to experience the effects of variability from renewable sources after only reaching 5% penetration levels (International Energy Agency, 2014). Thus, there is a clear need to start planning today for this increasing intermittency or risk decreasing the reliability of the grid.

In parallel to the increase in renewables, the system will lose coal baseload capacity, due to lower availabilities and decommissioning taking place from 2019 (Republic of South Africa, 2011). Eskom's coal stations have been rapidly decreasing their availabilities, from 90% in the early 1990s down to 75% in 2015 (NERSA, 2015) (Moneyweb, 2015). In addition, most of the existing coal fleet is planned for decommissioning between 2025 – 2030 (Republic of South Africa, 2011).

Perhaps the biggest factors in the future health of the power system are the country's growth and demand for electricity. The years 2012 to 2017 illustrate the level of unpredictability – from the country's demand with rolling blackouts ensuing in 2015 to a surplus of capacity in 2017. And whilst South Africa is not currently under an energy constraint, history has shown that the country's demand is erratic and unpredictable, which will likely remain true going forward.

Clearly, the power system is subject to a multitude of variables that continuously alter the balance of energy supply and

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	Conditions	Wärtsilä Flexicycle [14-1-1]	CCGT [1-1-1]
Output		250 MW	250 MW
Efficiency (Net, LHV)	100% (25 °C)	50%	55%
	50% (25 °C)	50%	47.8%
Startup times	Hot Standby	10 min (90%) / 1:20 min (10%)	20 min (40–60%) / 1:30 min (100%)
Startup costs	EUR/MW/start	5	60
Plant availability/reliability	minimum 90% capacity	99/99.99	92/98
Water consumption (Dry cooled)		0.04m³/MWh	~1.2m³/MWh
Plant construction time	Months	12–24	18–36

Table 1 - Key parameter comparisons between a Wärtsilä Flexicycle power plant and a CCGT power plant.

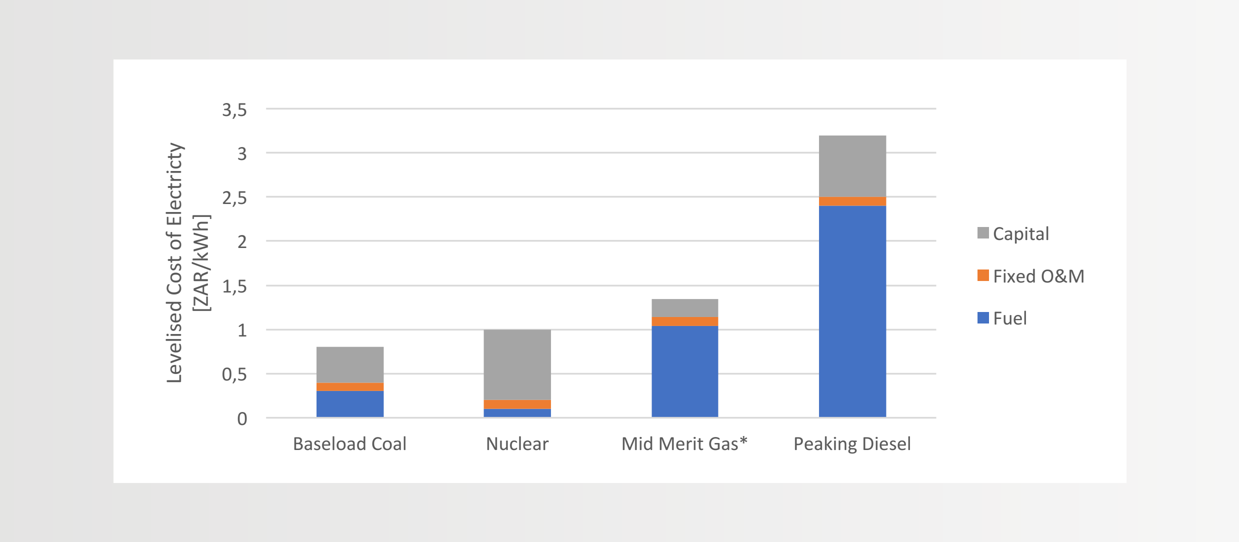

Fig. 2 - As long as LNG is used as a feedstock, it is unlikely that gas tariffs will be lower than coal or nuclear tariffs.

demand. It is exactly in this ongoing balancing act that gas power can play a pivotal role in ensuring the long-term reliability of the South African power system.

Gas technology review

Two available options for prime movers to convert gas into electricity are internal combustion engines (ICE) and gas turbines (GT). Due to the higher efficiencies that combined cycle configurations offer, we limit our analysis to the following configurations: Wärtsilä Flexicycle technology (combined cycle technology in reciprocating engines) and CCGTs (combined cycle gas turbines). We will, however, learn from this analysis that efficiency is not a priority factor and that flexibility is an important consideration when looking to create an optimal power system.

The Wärtsilä Flexicycle solution is based on a gas, multi-fuel, or liquid-fuel power plant combined with a heat recovery steam generator (HRSG) and steam turbine. Wärtsilä Flexicycle power plants can operate both in highly efficient, combined cycle mode and in dynamic, fast simple cycle mode.

The combination of flexibility and efficiency makes Wärtsilä Flexicycle power plants ideally suited to load-following in a power system whilst also being competitive at near baseload dispatch profiles. Wärtsilä's Flexicycle plants are composed of standardised modular units, allowing for fast construction times and easy expansions. Dry-cooling technologies, which use approximately 96% less water than a conventional CCGT plant, may also be considered. The table above compares the key features of the two plant types included in the power-system modelling analysis.

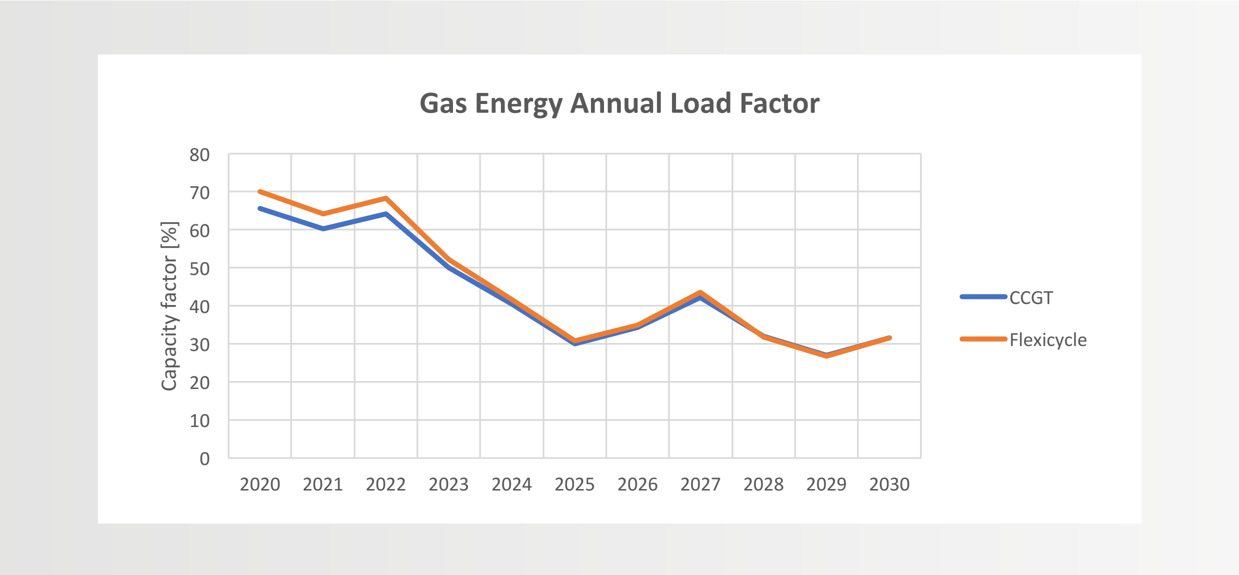

Fig. 3 - Engines and turbines play a similar role in providing the constantly varying energy requirements of the power system. Note: Assumptions: 3126 MW available from 2020; 'moderate growth' path for demand used; old coal plant availability is 73%.

SA's energy and reserve requirements

To understand the role of gas in South Africa, the discussion is divided into two main areas where gas power traditionally plays a role, namely, electrical energy and operating reserves:

- Electrical energy requirements are the forecasted energy requirements of the grid, based on a predicted demand/supply balance. Generators used to supply energy to the system will have a pre-defined dispatch profile that varies depending on the cost of providing energy versus the demand for that energy. The most familiar, simplified profiles are that of baseload, mid-merit and peaking.
- Operating reserve requirements refer to the capacity made available to the power system within a short interval of time in the event of an imbalance between supply and demand.

Compared to the electrical energy requirements of a system, the role of the reserves is somewhat less obvious but equally important in maintaining the reliability and quality of the supply. This fact becomes even more apparent as the level of renewable energy increases in the system.

Globally, gas generation capacity often is used to meet one or both these requirements. We now discuss if and how gas satisfies these roles in the South African power system context.

Energy requirements

To understand the energy requirements of gas, it is important to distinguish where it 'fits in' with the available alternatives, based on the cost of producing energy. For this, we take guidance from work done by the Council for Scientific and Industrial Research (CSIR), which has performed calculations to compare the new-build tariffs for various technologies, as depicted in Figure 2.

As shown, gas capacity (from engines or turbines) sits between coal and diesel capacity, due to the high fuel component that has been assumed to be R150/GJ. Even considering gas prices of R100/GJ or R200/GJ, it still will not change the relative merit order for gas.

But as gas is situated after the large amount of coal on the system's dispatch merit order, it is far more susceptible to any system supply/demand variations, resulting in a continuously variable annual energy load factor.

Figure 3 shows this varying load factor for either 3 GW of CCGTs or 3 GW of Wärtsilä Flexicycle capacity, in an IRP2010 'base case' scenario with a 'moderate growth' path and 73% coal availability from the ageing coal fleet.

Note that, every year, the energy load factor requirements change, due to changes in baseload capacity with new capacity coming online (i.e. nuclear in 2022) or old capacity going offline (i.e. old coal stations in 2027). As a result, gas projects should not be designed according to a fixed average load factor but should be capable of effectively providing a wide range of load factors that could be anticipated for gas. Indications from the latest IRP reveal that gas is typically used in load factors of 20–40%.

Operating reserve requirements

To date, Eskom largely relies on its newest coal fleet to meet the system's reserve requirements, with diesel turbines used as a backup. These are the only plants of sufficient capacity that are technically capable of meeting the short-term demand and supply variations. However, continuously providing varying energy escalates the degradation experienced by these coal units, thus leading to increased

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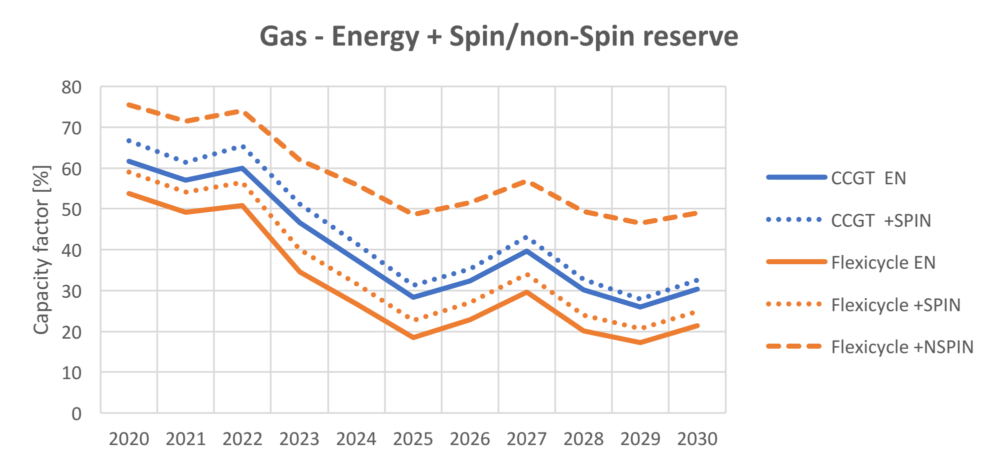
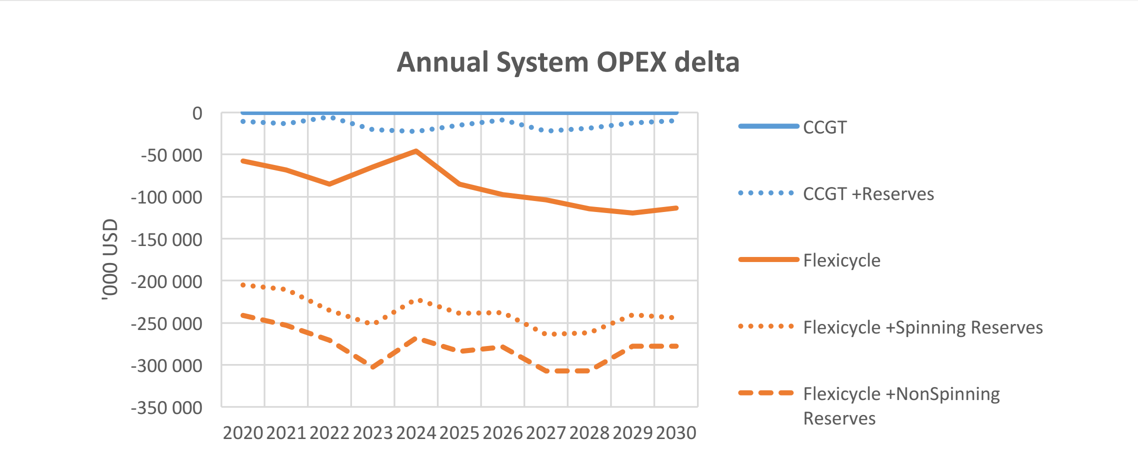


■ Fig. 4 - The ability of engines to provide reserves from a non-spinning state increases their total effective load factor by 20-30%.



■ Fig. 5 - ICE technology creates savings as both an energy and reserves provider to the power system.

operational costs and reduced reliability levels. But, with the introduction of gas as an option, there are now opportunities for flexible gas power plants to undertake some of these reserve requirements.

The system has three types of operating reserves: regulation, instantaneous and 10-minute reserves. Each reserve type serves a different function and is largely characterised by the required response time. Of particular interest to us is the 10-minute reserve category, as it is likely that gas will be utilised best in fulfilling these requirements, due to the relatively high cost of energy from LNG-sourced gas. This reserve type is used to restore the regulating and instantaneous reserves and must be fully activated within 10 minutes from either a spinning or non-spinning state. This allowance to provide these reserves from a non-spinning state is an important one and is elaborated further in the section below.

Per Eskom (Eskom, 2015), the system will require 1100 MW of 10-minute reserves by 2019. This value will likely increase significantly as the contribution of intermittent renewable energy increases. However, for this study, we have assumed a conservative annual increase of 50 MW.

Spinning vs. non-spinning

A plant operates in spinning mode when the prime mover (either an engine or turbine) is physically rotating and in non-spinning mode when not rotating. This simple distinction has significant economic relevance as plants operating in spinning mode require ongoing variable maintenance and have reduced part load efficiencies, resulting in a higher net tariff. Thus, to reduce expenditures incurred by the spinning plant, it is preferable to use technologies that provide non-spinning reserves.

The key distinction between engines and turbines is that engines can fully satisfy the regulating reserve requirements from both a spinning and non-spinning state, whereas turbines can only do so partially from a spinning state. Based on this, the power system can achieve overall efficiency improvements by replacing existing spinning reserves, operating at suboptimal output efficiencies, with fast-starting, non-spinning reserves that operate at maximum efficiency. Operating costs can be lowered further by replacing ill-suited capacity (such as coal), with high technical degradation from cycling, with engines that incur negligible start-up and cycling costs.

System effects from gas energy

To show how the two primary, gas-based, power generation options satisfy the respective reserve and energy requirements, we introduce 3126 MWs of either turbine or engine technology into the system and allow the software to determine how this capacity is best used. The parameters observed include the following:

- Energy load factor (EN)
- Spinning reserves load factor (SPIN)
- Non-spinning reserves load factor (NSPIN)

Figure 4 indicates the cumulative turbine and engine load factors for energy (EN) and reserve (+SPIN and +NSPIN) provisions over a 10-year period.

In the earlier years, only 5% of the installed CCGT turbine capacity is allocated to providing reserves from a spinning state, and energy requirements in 2020 are 62%. Whilst we see a lower demand for energy supply (55%), there is significantly more demand from the system for the engines to provide reserves from both a spinning and non-spinning state. This high-reserve utilisation effectively pushes the total engine plant load factor to over 75% in 2020, which is 15–20% higher than the total turbine load factor throughout the 10-year period.

Interestingly, the 'engines only' scenario selects only engines to provide the entire amount of reserves required by the system, whereas coal capacity is still the preferred reserves provider in the turbine case. These findings are perfectly aligned with the technical differences between the technologies and highlight the benefits of having ultra-fast starting capabilities.

As the model dispatches plants with the lowest total system cost, we can extract the total system savings attributable to having both Flexicycle and CCGTs providing reserves to the system. Figure 5 shows the annual savings achieved by both Flexicycle and CCGT plants providing spinning and non-spinning reserves and CCGTs providing the baseline (with cumulative savings derived from the spinning and non-spinning reserves).

Not only do the engines provide system savings as an energy provider, but when allowed to provide non-spinning reserves, the savings can exceed US 250 million per year. But how? To illustrate, we compare the total generation cost of each technology and identify the cost variations for each of the scenarios. What we see is that the

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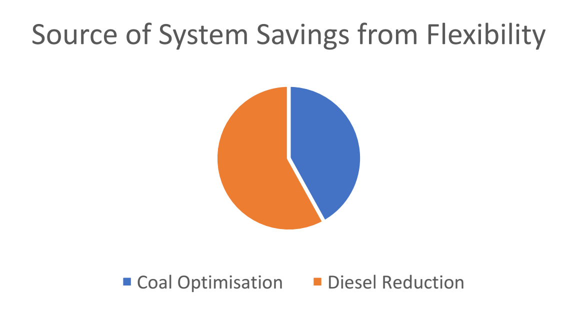


Fig. 6 - The system savings generated by flexible capacity from optimising the coal fleet and reducing diesel consumption.

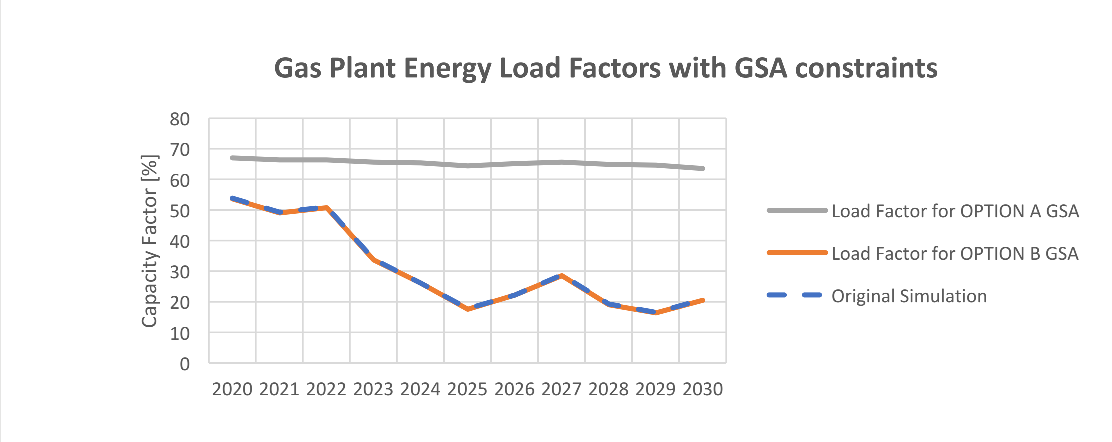


Fig. 7 - Imposing the take-or-pay constraints causes the plant to be dispatched at a constant load factor, but a premium placed on a flexible LNG supply will have no effect on the plant dispatch.

cost variations mainly occur in two areas, diesel replacement and coal optimisation. (Figure 6)

Due to the extremely high cost of diesel, diesel replacement is an obvious use of gas. But when we consider how savings are created from the coal optimisation, we discover two sources of savings in the following areas:

- Reducing the costs incurred by starting and stopping the coal units
- Reducing the part-load operational requirements, thereby allowing the coal fleet to operate at maximum output efficiency, without incurring additional ramping costs

These findings once again prove that gas is best used as a flexible energy source, as this is how the system realises the most benefit.

Considerations for LNG supply

The next step to consider is how this flexibility can extend into the LNG Gas Supply Agreement (GSA). The convergence of these two distinct industries presents certain challenges, as the LNG value chain traditionally favours stable energy supplies whilst the power value chain clearly favours (as proven above) flexible energy supplies.

In this section, we give an overview of key market-, technical-, and contractual-related aspects that have an influence on the ability to provide LNG flexibly.

Trends in LNG supplies

LNG trade is rapidly evolving as new gas discoveries and new consumers enter the market. Trends and predictions reveal higher growth in LNG production than in consumption, thereby supporting a 'buyers' market' that allows new consumers to negotiate better terms.

In the GSA negotiations, purchasers are pushing suppliers for greater volume flexibility to better suit their energy demand requirements, but even so, buyers are not exempt from requesting or discarding LNG cargoes at very short notice. Buyers still must present their requests in advance to allow for LNGCs to be identified and travel to the port of delivery. This is a feat not easily achieved when needing to predict the energy requirements, which literally change like the wind.

Naturally, as flexibility increases, the price of LNG also increases, as LNG suppliers will have greater financial risk exposure. But this price increase needs to be evaluated against the benefits of having flexibility downstream, which in our case is the system savings from having flexibility on the grid. Next we review exactly how these gas contract limitations and costs were considered in the integrated power system modelling.

Modelling the LNG supply

Here we present two approaches that favour either a cost-optimised LNG GSA (Option A) or the power system requirements (Option B).

OPTION A: optimal cost LNG GSA approach
In considering the entire LNG value chain, gas must pass through several distinct stages before reaching the power plant in a usable form:

Production – Liquefaction – Maritime transport – Storage/regasification – Pipeline – Power station

Whilst our intention here is not to discuss the complexities of each, we can highlight some broad principles that help achieve the lowest cost for gas delivered to the power plant.

The principles of high fixed volumes of supply hold when attempting to minimise LNG costs. By using infrastructure investments sized to take advantage of the economies of scale at each stage, one can reduce the per unit cost for each molecule delivered. Pressure to maximise and stabilise the volumes is seen at the liquefaction plants, which represent massive investments requiring long-term certainty of throughput to finance them. Pressure is also found at the storage and regasification facilities, which in South Africa's case, may potentially be an FSRU solution (Reuters, 2015). Depending on various ocean conditions and jetty and FSRU designs, maximum LNG throughputs typically range from 3–4 Mtpa, which is enough to supply 3 GW of Flexicycle capacity at a load factor of 75%.

In addition, requiring a 100% take-or-pay obligation from the buyer over a long-term contract (i.e. 20 years) give the supplier financial security, in exchange for which the buyer can get the lowest molecule price, estimated in this study to be 10 USD/GJ.

OPTION B: optimal power system approach
As in Figure 4, the 3 GW of gas capacity may experience annual load factors between 80% (with reserves) and 20% (without reserves). This equates to potential LNG volume supply variations of approximately 1-3.5 Mtpa! Requesting this degree of flexibility will result in LNG suppliers imposing a premium for cargoes that potentially would be cancelled by the power plant dispatcher. The exact increase would be largely determined by the project specifics, but for our analysis, we have adopted an ultra-conservative premium value of 5 USD/MMBtu making for a total gas price of 15 USD/MMBtu.

Based on the above options, we have proposed the following two GSA model structures:

– OPTION A – Inflexible: 3 Mtpa of 100% take-or-pay at 10USD/MMBtu

– OPTION B – Flexible: Unrestricted volume with no take-or-pay obligations at 15USD/MMBtu

Integrating the LNG and power perspectives

We now assess the impact of integrating an inflexible (Option A) and flexible (Option B) LNG supply, by varying the delivered LNG price and imposing specific contractual obligations on the LNG supply. We then review the system impact to see whether this 'cost of LNG supply flexibility' has an impact on how the gas plants are operated.

Gas power load factors

After imposing LNG GSA constraints, how the gas plant is dispatched may differ from the calculations in Figure 4. Figure 7 compares plant load factors with GSA Options A and B and the initial calculation (which assumes flexible LNG priced at 12USD/GJ).

With Option A, there is a fairly constant load factor of 64–67%. However, as this is

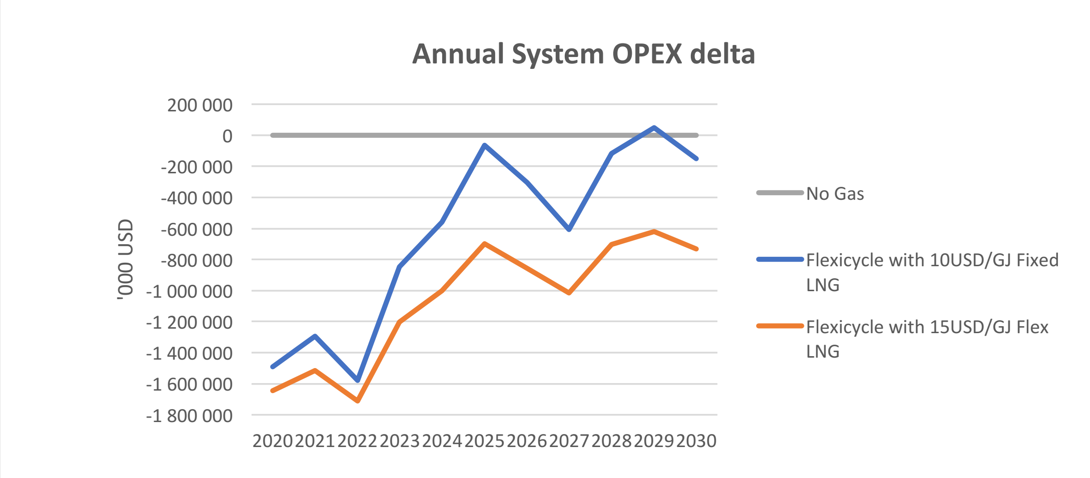


Fig. 8 - Even with a 50% flexibility premium on LNG price, the system always experiences cost savings from providing flexible power as the system requires.

lower than the 3 Mtpa capacity to supply a 75% load factor, 15% of the LNG delivered would be paid for (due to take-or-pay obligations) but not consumed. So if the gas power is not required by the system, it is optimal not to dispatch the power plant and incur the take-or-pay penalty.

If we now compare Option B to our original simulation, the only difference is the gas prices (12 vs. 15 USD/GJ). This finding reflects the fact that the merit order of gas power will not change, even with large variations in the LNG price. This is no surprise considering the widely spaced merit order between coal, gas and diesel.

Total system cost impact

Now we examine how the system cost varies between Options A and B, when compared to the option of having no gas at all in the power system. (Figure 8)

As shown, even after applying a heavy premium for flexibility on the gas supply, providing flexible power still generates overall system savings every year. During 2020-2022, when the plant load factors are relatively closely aligned (67% and 62%), a small system savings is incurred. However, as the system demands a lower load factor from the gas plants, we see large system cost differences from paying for gas energy that is not needed. Note that, for the years 2025 and 2029, there is no benefit in having the inflexible gas solution in place at all!

Over the 10-year period, the total savings incurred by having a flexible GSA over an inflexible GSA amounts to USD 4.7 billion.

Based on this result, unless the delivered gas price is less than 7 USD/GJ, a fixed LNG supply does not make sense. Obviously, this simplistic answer does not consider indices and exchange rate risks, which are major considerations in LNG supply contracting.

Conclusion

Using rigorous analysis and complex power system modelling software, one can determine the true operational requirements for SA's future gas to power opportunities. A 3 GW LNG power plant would generate high system cost savings, in excess of 250 MUSD per year, if allowed to provide a variable annual energy load factor and reserves.

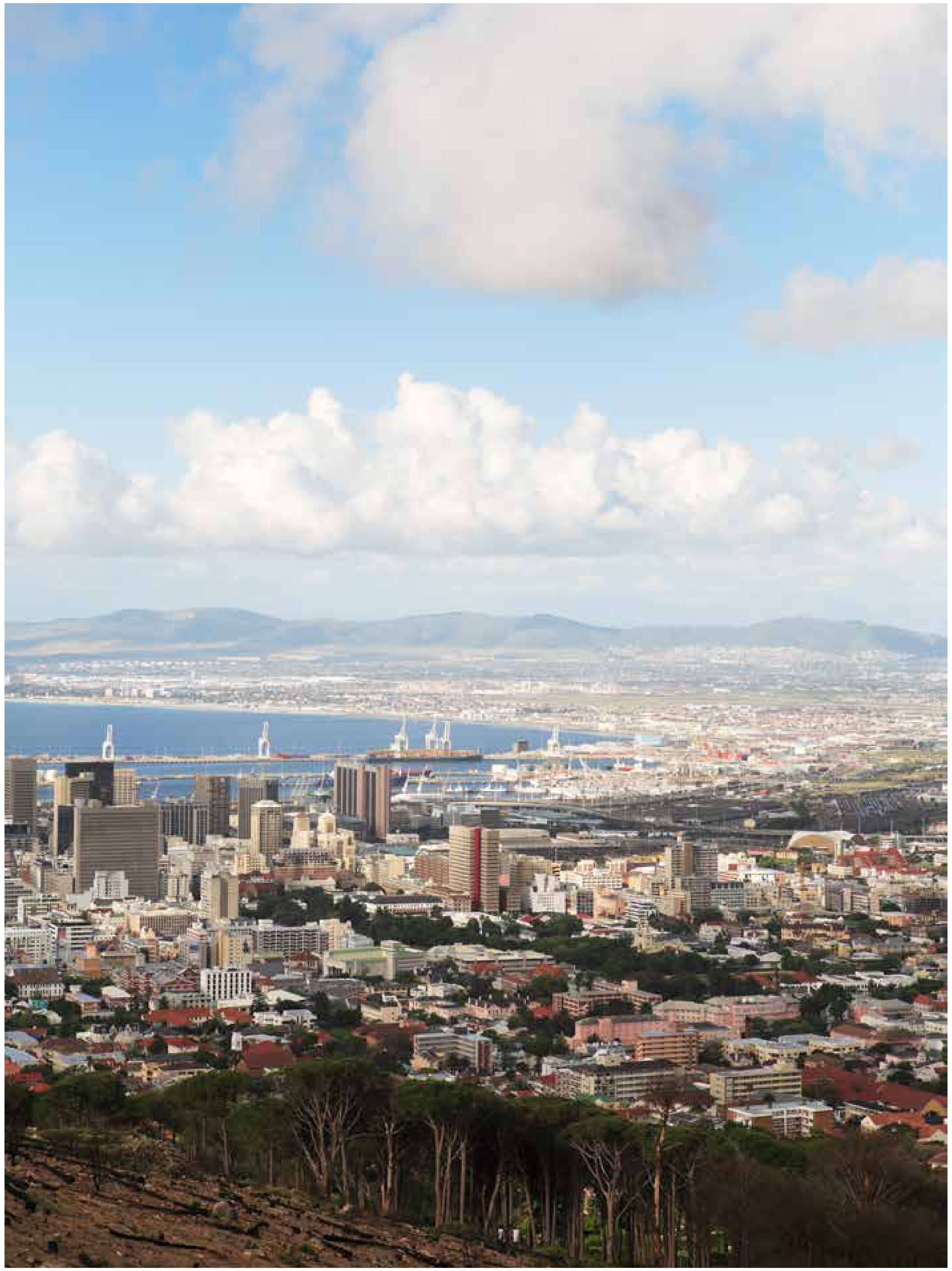
Wärtsilä Flexicycle is ideally suited to satisfy these requirements due to its high efficiency and fast operational capability, enabling non-spinning regulating reserves that result in significant savings. By reducing the operating burden in a flexible manner, savings are achieved through displaced diesel generation and optimised coal-based capacity.

Two possible GSA structures, flexible or inflexible, were proposed in the model to test the LNG GSA limitations. Despite the addition of a conservative GSA flexibility premium, the system-level benefits of having a flexible solution still far outweigh the project-level cost savings with a cost-optimised GSA, and savings amount to USD 4.7 billion over a 10-year period.

Given that it is difficult to predict what future system demand/supply requirements will be, it is even more critical to adopt flexible solutions that accommodate any uncertainty, even if it means accepting flexibility premiums. As the LNG power project is there to support the power system, the systems' requirements must take precedence over project considerations.

Recommendations for future gas-to-power IPP programmes are the following:

- Power plant flexibility should form part of the evaluation criteria.
- Flexible LNG contracting options should be recognised and appropriately valued.



ICE power plants by Wärtsilä comprise several independent 10-20 MW engine units. The modular design ensures high reliability: if one engine is under maintenance, the others are fully operational. Modularity also enables high part-load efficiency, key in balancing renewables.

Optimising the power grid in Baja California Sur

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In a modelling study, comparing state-of-the-art gas turbine power plants and internal combustion engine (ICE) power plants as alternatives for required new-build capacity, ICE can generate significant savings, especially in the case of uncertainties.

Introduction

The isolated power grid of Baja California Sur is facing severe challenges. Currently, the price of electricity is by far the highest in Mexico. The population also demands cleaner power with less emissions and more integration of renewable energy. Significant amounts of intermittent wind and solar power will come online, but several old thermal power plants must be mothballed. Due to the booming tourist industry, the electricity demand will almost double by 2030. (Figure 1)

According to SENER, the Secretary of Energy of Mexico, as much as 584 MW – roughly half of the planned total capacity of 1250 MW – of new thermal generation capacity will be needed in the Baja California Sur grid. Decision-makers must determine which technology for this new thermal capacity will create a power system that functions optimally, in terms of affordability, reliability and sustainability.

Based on data from SENER and Energy Exemplar, Wärtsilä conducted a modelling study where state-of-the-art gas turbine power plants and internal combustion engine (ICE) power plants were compared as alternatives for the new-build capacity. The focus of the in-depth PLEXOS analysis is on system-level cost savings (OPEX+CAPEX), which will have a direct impact on the electricity price in Baja California Sur.

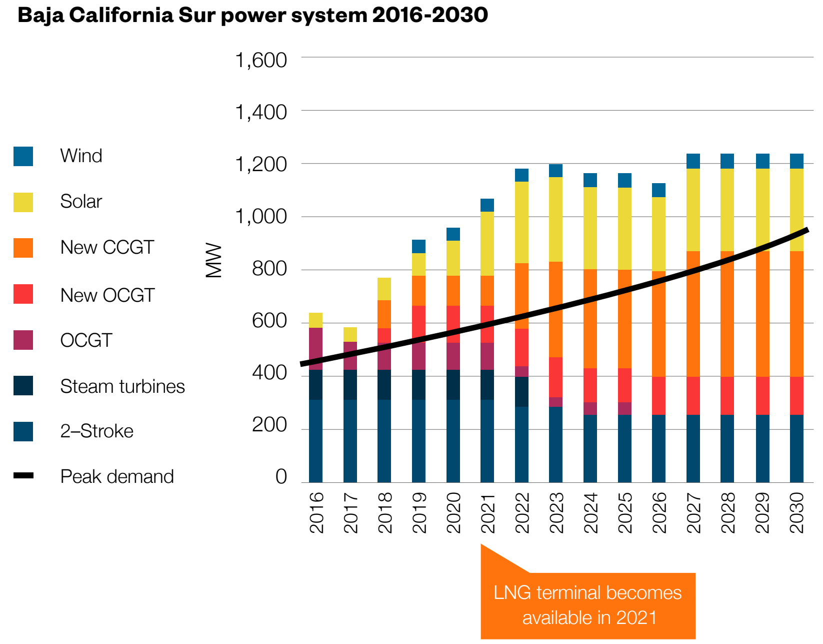

Fig. 1 - In the next 15 years in Baja California Sur, the generation capacity, as well as the peak demand, will roughly double. The focus of analysis is on a 584 MW new-build thermal fleet ("New CCGT" and "New OCGT"). Source: SENER and Energy Exemplar.

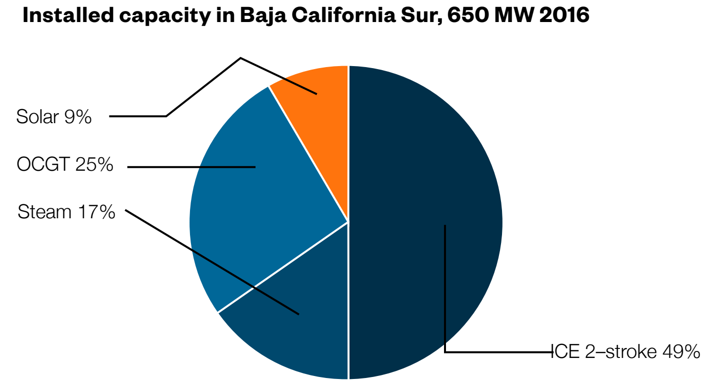

Fig. 2 - The share of renewables will grow by many times in Baja California Sur by 2030.

Scenarios

BASE CASE – THE VALUE OF FLEXIBLE GENERATION

This base scenario includes all the planned capacity in Baja California Sur from 2016-2030 and compares gas turbine assets against ICE power plants in fulfilling the thermal new-build target of 584 MW by 2030. According to SENER guidelines, this target is further split into combined cycle (CCGT) and open cycle (OCGT) technology, 480 MW and 94 MW respectively[1].

Liquefied natural gas (LNG) is forecast to be available in 2021, which is optimistic for completing the new LNG import terminal in Baja California Sur. According to default goals published by SENER, the combined share of wind and solar energy by 2030 will be 16%. (Figure 2)

Figure 3 shows the results of the Base Case. Compared to the frame gas turbine option, the ICE assets produce cumulative savings of USD 372.7 million by 2030. In other words, choosing ICE technology for the new thermal fleet would lower the total operating costs of the grid by 9.1%.

Compared to the aeroderivative gas turbine option, the ICE alternative saves USD 232.4 million by 2030, or 5.7%. The savings derive from three factors:

Fuel flexibility. Wärtsilä ICE plants can use any liquid or gaseous fuels. In this scenario, they run on inexpensive heavy fuel oil (HFO) until 2021 and then switch to LNG-based natural gas. The gas turbines, by contrast, have to rely on the relatively expensive light fuel oil (LFO) until LNG becomes available.

Flexible operation. Due to the high penetration of renewable energy, especially solar power, the baseload plants in the system must be extremely flexible and follow the variable output of the renewables. Thanks to the ultra-fast starts and stops, quick ramping capability, and high part load operation efficiency, Wärtsilä ICE plants outperform gas turbines in this task. This capability also reduces the consumption of fossil fuels overall.

Reduced spinning reserve costs. To ensure system reliability, the required spinning reserve capacity in the model is 11% of the peak demand or the size of the largest single generation unit – whichever is greater. Therefore, the large unit size of the gas turbine assets, 60–120 MW, would significantly increase the need for spinning reserves from other power stations in the grid. Due to its small unit size, the ICE case would not increase the requirement[2].

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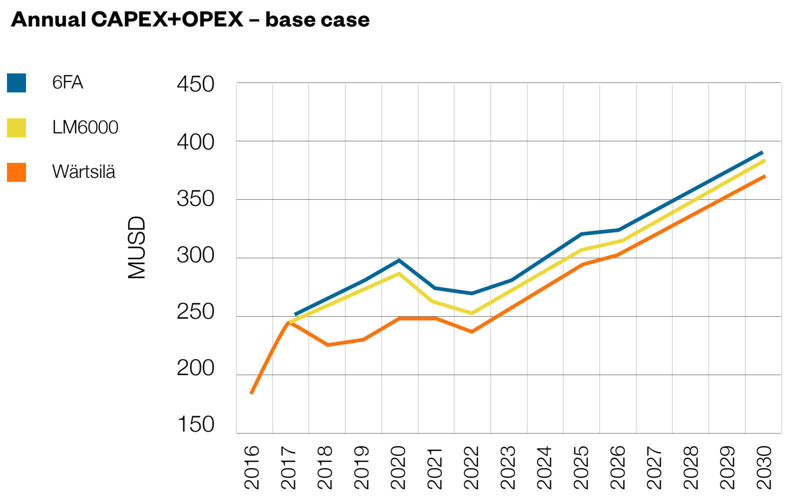


Annual savings (USD million)		
	Wärtsilä vs. 6FA	Wärtsilä vs. LM6000
TOTAL	–372.7	–232.4
	–9.1%	–5.7%

Fig. 3 - In the Base Case, ICE technology, if chosen for the new 584 MW thermal fleet, would produce significant savings in total electricity generation costs in the power system compared to the gas turbine options. The savings come from fuel flexibility, operational flexibility and the reduced need for spinning reserves. The Base Case assumes LNG availability in 2021.

SENSITIVITY CASE A:
DELAY IN LNG TERMINAL

The timing of construction of the new LNG terminal in Baja California Sur is crucial to the costs of generating electricity. In the model, natural gas will replace HFO in the Wärtsilä assets and LFO in gas turbines whenever it becomes available. The optimistic estimate is 2021, but the real risk of delay was modelled to show the consequences.

Compared to the Base Case, a five-year delay in LNG availability from 2021 to 2026 causes a dramatic rise in gas turbine systems costs (Figure 5). However, it causes an equally drastic increase in the relative savings achieved by the ICE option, which would continue to use inexpensive HFO until 2026 while gas turbines rely on costly LFO.

If the LNG imports begin in 2026, the ICE option brings total cumulative savings of USD 739.1 million (17.8%), compared to the frame gas turbine, and USD 576.2 million (13.9%), compared to the aeroderivative gas turbine option, by 2030. If there is a delay of 10 years or more, meaning that LNG is not available in 2030, the ICE choice produces savings of USD 1475.5 million (33.4%) and USD 1270.1 million (28.8%), respectively[3].

SENSITIVITY CASE B:
HIGH RENEWABLES

In the Base Case, the combined share of wind and solar energy is based on default SENER targets: 19% in 2024 and 16% in 2030[4]. However, in August 2016, new and more ambitious targets for Mexico were published by SENER: 35% in 2024 and 37.7% in 2030[5].

High shares of renewable energy are needed to reduce significantly the carbon dioxide emissions from electricity production. In addition, the price of wind and solar energy is competitive. However, due to their natural variability, wind and solar power cause stress in the power system – especially in an isolated one. Sudden changes in their output have to be compensated by thermal power plants that are flexible enough to absorb the changes[6]. In the High Renewables scenario, all thermal assets are forced to cycle daily.

Compared to the Base Case, the High Renewables scenario shows more savings for the ICE option: USD 408.8. million (10.3%) against the frame gas turbine, and USD 255.6 million (6.5%) compared to the aeroderivative gas turbine alternative. (Figure 6)

Due to their ultra-flexible operation capabilities, Wärtsilä ICE plants efficiently integrate variable renewables[7]. Continuously throughout the day and without penalty in maintenance costs, the ICE plants can start up to full power in less than two minutes and shut down in less than one. Their efficiency in part-load is very high, which is essential in backing up renewables. These are factors behind the savings.

It is worth noting that, on the system level, the High Renewables ICE case is 3.1% cheaper than the ICE Base Case. The same does not apply to the gas turbine options. This means that introducing ambitious shares of wind and solar energy quickly will result in a power grid that is both sustainable and affordable, if the thermal assets are flexible enough to support the integration of the renewables.

Conclusions

The Baja California Sur power system is a good example of a contemporary grid with challenges in increasing electricity demand, ensuring fuel availability and addressing ambitious goals to include intermittent renewables. The fact that the grid is isolated only reinforces these challenges. This PLEXOS modelling shows that new thermal assets in Baja California Sur should be planned from the system-level perspective. Only this kind of helicopter view provides

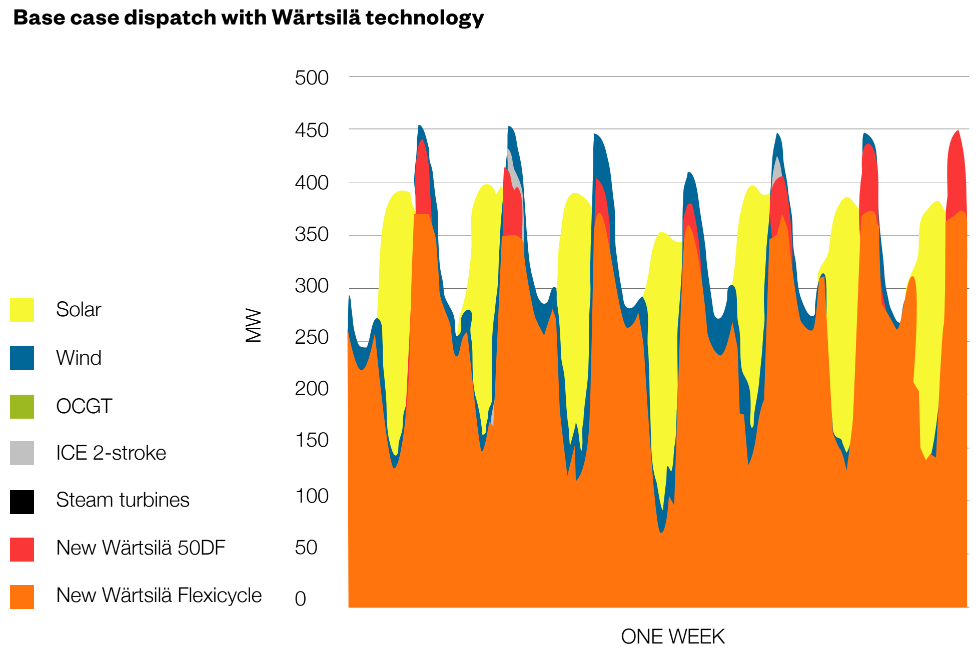
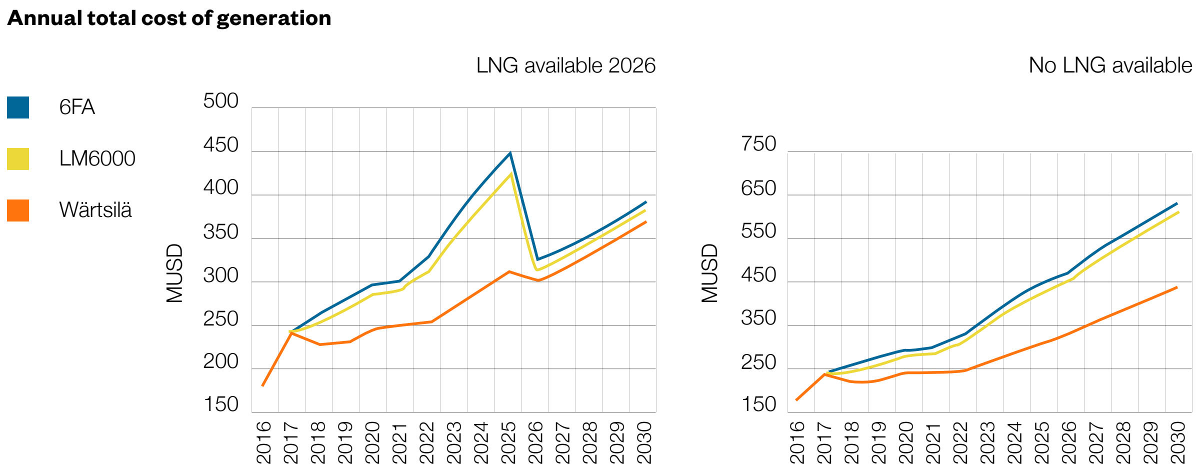


Fig. 4 - This one-week dispatch graph for the year 2025 shows how dramatic the effect of renewables is to the dispatch pattern. Solar PV will peak at noon daily, and thermal power plants must ramp down. In the afternoon, thermal power needs to ramp up hundreds of megawatts in a very short time. The system savings of the ICE option derive largely from the capability of such ultra-flexible operation.



Savings when LNG available in 2026 (USD million)		
	Wärtsilä vs. 6FA	Wärtsilä vs. LM6000
TOTAL Savings	–739.1	–576.2
	–17.8%	–13.9%

Savings when no LNG available (USD million)		
	Wärtsilä vs. 6FA	Wärtsilä vs. LM6000
TOTAL Savings	–1,475.5	–1,270.1
	–33.4%	–28.8%

Fig. 5 - Natural gas will be the cheapest and cleanest fossil fuel in Baja California Sur. Thus, as this figure demonstrates, delays in completion of the new LNG terminal impact the electricity production costs of the system.

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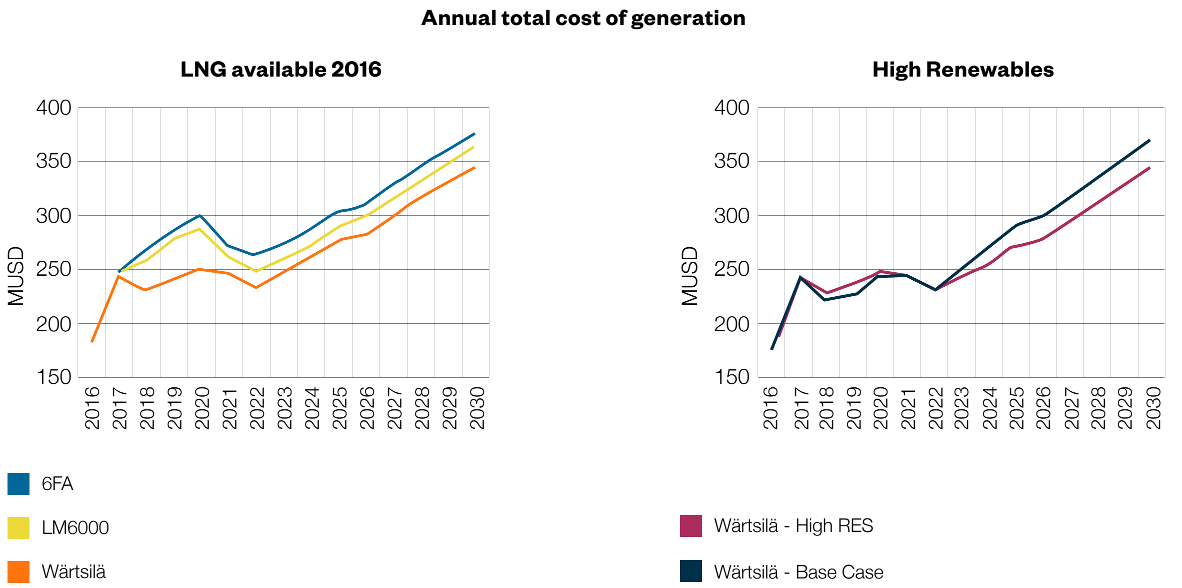

Savings in high RES case (USD million)		
	Wärtsilä vs. 6FA	Wärtsilä vs. LM6000
TOTAL Savings	–408.8	–255.6
	–10.3%	–6.5%

Savings in high RES case (USD million)	
	Wärtsilä base case vs. Wärtsilä high RES case
TOTAL Savings	–126.0
	–3.1%

Fig. 6 - If the amount of wind and solar in Baja California Sur increases according to the latest national targets by SENER, extreme flexibility is needed from the thermal fleet. ICE technology is superior in such agile operation, producing significant system-level savings compared to the gas turbine options.

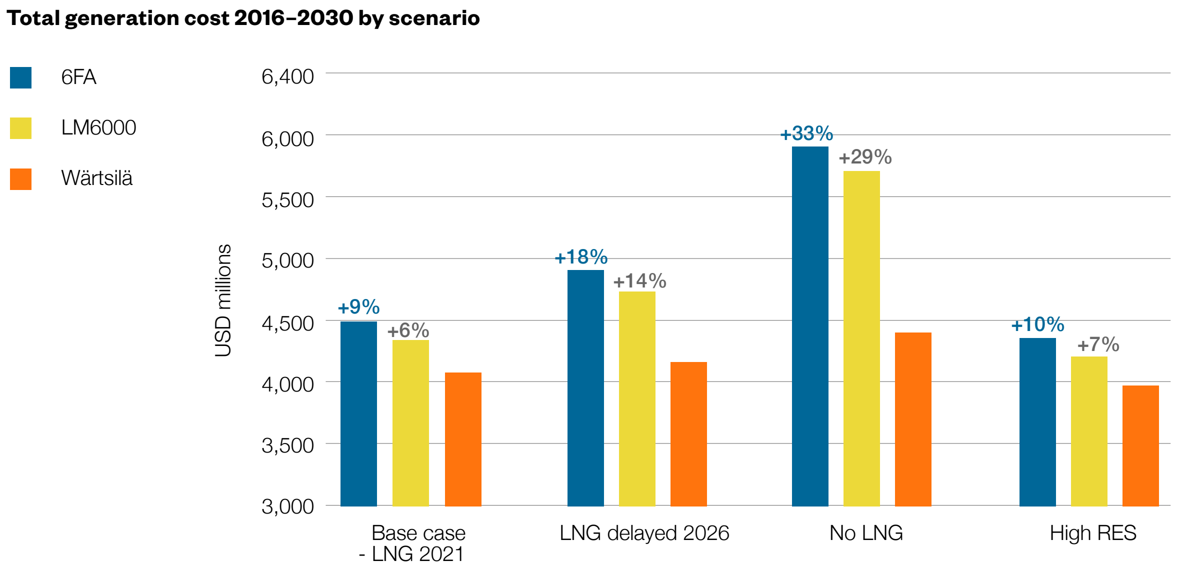

Fig. 7 - Wärtsilä ICE technology enables significant, system-level savings in the Base Case and in all uncertainty scenarios. The flexibility of the ICE plants provides resilience, a guarantee against unpredictable future changes, such as a delay in LNG availability.

the full picture of how the grid can be developed into a more reliable, affordable and sustainable power system.

Modelling of the total system costs of a 584 MW new-build thermal generation fleet by 2030 used two alternative technologies, ICE power plants and gas turbine power plants. The Base Case results show that the ICE option enables USD 232.4-372.7 million (5.7-9.1%) cumulative savings, compared to the gas turbine alternatives, by 2030.

In addition, two uncertainty scenarios were modelled, demonstrating a delay in LNG availability, and a very high renewables penetration. The ICE option provides up to USD 1475,5 million (33.4) savings by 2030, compared to the gas turbine options.

The ICE option is superior in all uncertainty scenarios and is cleaner, more reliable and more economical. This means that flexible generation future-proofs the power system against future changes. The operational and fuel flexibility makes the power system more resilient and helps to manage risks better. Therefore, it is a safe investment even when there are major uncertainties. In fact, installing new thermal capacity in Baja California Sur is an opportunity to optimise the power grid.

The challenges are similar to the rest of Mexico: rising demand, high penetration of renewables, ageing thermal plants and varying availability of cleaner natural gas. These results may predict the right path for the national grid as well, but more research is needed. ●

THE CASE FOR AN INTERCONNECTED SYSTEM

Yet another possible development in the Baja California Sur power system is connecting it to the national electricity grid with a DC-link of 650–850 MW capacity. This plan, initiated by the Mexican government, includes 1800 km of bipolar DC cables to the mainland, five substations and two capacitator banks. The connecting cables would put an end to the isolation of the power grid of Baja California Sur and provide a substantial continuous capacity of affordable imported electricity[8].

The DC-link plan was included in the PLEXOS modelling as an alternative scenario. Obviously, one conclusion is that less than 584 MW new thermal capacity will be needed if the connection is built. This is because the 650–850 MW connection would cover most of the electricity demand in 2030. However, it is unclear whether the full capacity of the connection could be used continuously. There may be technical challenges, such as reduced inertia in the Baja California Sur System. Another conclusion is that the DC-link would lower total system-level costs significantly, due to a new source of low-cost electricity, and a delay in building the connection would increase them.

Most importantly, the results show that the ultra-flexibility of ICE power plants provides notable savings in all the three modelled DC-link scenarios. If the connection is available in 2022, ICE plants provide 6–7% percent savings, compared to the two gas turbine options, and if delayed to 2026 or beyond, the savings provided by the ICE case increase to 16–33% by 2030.

The results show a similar hedging mechanism as in the Sensitivity Case A: Delay in LNG Terminal. The ICE option is not only the most affordable scenario from the system cost point of view but also as a tool for risk management. Building the connection to the mainland is a complex project so delays are possible. By choosing the ICE option for the local new-build thermal generation fleet, additional costs of such delays are minimised.

References

1 For the OCGT requirement, Wärtsilä Flexicycle technology was used. Wärtsilä Flexicycle consists of ICE gensets and a combined cycle heat recovery system. For the OCGT target, Wärtsilä 50DF open cycle power stations were used.

2 ICE plants are modular, consisting of several gensets that can be operated independently. The largest engine power plant in the world, the 623 MW IPP3 in Jordan, comprises 38 Wärtsilä 50DF engines.

3 An average price of 8 USD/MMBtu is used for LNG. This includes the base mainland price of USD 5 for natural gas, and an additional USD 3 premium for transporting the gas to Baja California Sur in the form of LNG.

4 Renewables grow aggressively in the first modelling years but remain steady after 2023.

5 http://www.gob.mx/sener/prensa/mexico-a-la-vanguardia-en-eficienciaenergetica?idiom=es energetica?idiom=es

6 The four sources of flexibility include flexible generation, energy storage, interconnectivity and demand response. Generally, only flexible generation is economically and technically feasible in grid scale.

7 In the US, Wärtsilä has supplied several 200 MW dedicated wind-balancing ICE plants. The engines in these plants typically start and stop several times per day.

8 It is assumed here that the price for imported electricity would be 40 USD/MWh on average.

LNG value chain optimisation – Case Myanmar

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An optimal logistics chain is the key to making liquefied natural gas (LNG) affordable for the end users and profitable for the LNG solution providers. Due to the number of unknowns in the equation, planning and optimisation can be challenging. However, a case study can help estimate the cost prices of gas for project configuration options and examine the resulting effects.

Fig. 1 - The LNG value chain.

Introduction

The key to making liquefied natural gas (LNG) affordable for end users and still allow some profit for LNG solution providers is to design an optimal logistics chain. Due to the increasing complexity of handling -163°C LNG as compared to +25°C diesel and heavy fuel oil (HFO), the LNG logistics chain needs a lot more consideration. Furthermore, the solutions and configurations for a small-scale logistics chain are still being developed. This makes the planning and optimisation challenging, as the equation includes a lot of unknowns.

In parts of the world, we already see brave companies that recently got their LNG logistics up and running and are now busy looking for additional consumers – to increase their volumes and get full utilisation of their infrastructure investments. Moreover, there will be a lot more first movers continuing to shape the industry in still-developing parts of the world. By being first in a new market, thereby signing up new customers before anyone else, these first movers and entrepreneurs can build the necessary volumes to make their investments profitable. Being the first in a region and capturing the base load (or base flow) of LNG makes it hard for competitors to enter. But this is not without risk.

As so many variables can change, there will also be first movers whose investments, for various reasons, may not be able to attract the necessary volumes and, therefore, will remain unprofitable. To reduce this risk and ensure successful projects, the team or consortium setting out to develop the project ideally should include experts from all segments, starting from the molecule providers, shipping, permitting and local community knowledge, engineering, procurement and construction (EPC) and operations & maintenance. Besides the coordination of these diverse teams, Wärtsilä's LNG solution team can also provide the complete EPC, operations & maintenance of LNG terminals.

In the previous *In Detail* (02/2016), we discussed the LNG logistics chain main parameters that determine the landed cost of LNG. Therefore, we will not discuss this again but rather will use these details in a practical case study.

In that former *In Detail* article, we also used a case study, where we created a fictive receiving terminal in Aruba (in the southern Caribbean) and linked it to four potential regional LNG suppliers at various distances from the terminal. We compared the landed LNG cost based on various ship sizes, chartering rates and receiving terminal storage capacities. By increasing ship size and the receiving terminal's storage capacity, shipping and refilling frequency can be reduced. The objective of the case was to find the optimal ship and storage capacity, in relation to the shipping and refilling frequency, from each of the four supply points. Finally, we compared the four supply locations to each other.

In this case, we will study the opposite situation – where we have decided on one supplier with three potential receiving consumers. The fictive case is based on transport from the Singapore LNG terminal to various sites in Myanmar.

→

Fig. 2 - LNG floating storage & regasification barge (FSRB). Ideal for: locations with shallow protected water, difficult site conditions and expensive local infrastructure. Advantage: a mobile and modularised asset (in sizes from 7500 m^3 to 30,000 m^3) that, therefore, can be multiplied or relocated if demands change

Fig. 3 - Medium-size LNG terminal based on a flat-bottom concrete tank. Ideal for: terminals where a storage capacity over 15,000 m^3 is required and where local labour and construction equipment are available. Advantage: a well-insulated tank and terminal that can withstand any type of weather.

Fig. 4 - Small-size LNG terminal based on insulated bullet tanks. Ideal for: smaller-size terminals where a storage capacity up to 15,000 m^3 is required or where there is not sufficient availability of local labour and construction equipment. Advantage: a solution that needs minimal site work, as most of the work is shifted to factories.

Fig. 5 - Floating storage & regasification unit (FSRU). Ideal for: large-size storage (from 125,000 m^3 and up), where there is at least 600 MW offtake. Advantage: a flexible solution that can be moved whenever demand changes.

LNG terminal solutions

The receiving and redistribution terminal can take many forms. The choice of terminal depends on the site locations and the volumes required.

For large onshore terminals, flat-bottom concrete tanks are the most commonly used. For small sizes, the pressurised steel tanks are becoming popular.

For large-scale terminals, there are possibilities to employ an offshore solution with an FSRU (floating storage & regasification unit) or an FSU (floating storage unit) with a regasification unit mounted on the jetty. Projects have also been planned using outdated LNG carriers as FSUs. These LNG carriers can be purchased at a low price because they are no longer economical to use as carriers, due to their usually old and inefficient steam engines.

In locations where an onshore location is not suitable, and the gas amounts are too small to make an FSU or FSRU feasible, Wärtsilä's LNG floating storage & regasification barge (FSRB) can be the best alternative.

Fig. 6 - The map showing three different sites in Myanmar.

Case

Background

Now we illustrate the LNG to power solutions discussed so far through a fictive case, loosely based on a few sites in Myanmar and assumptions about these sites and the logistic chain. We estimate the cost price of gas for two alternative project configurations and examine the effects of our preferences:

- In Alternative 1, we choose a **preference for low CAPEX.**
- In Alternative 2, we choose a **preference for low OPEX**.

As per the map in Figure 6, we have selected three different sites in Myanmar. The main parameters of the locations are described below.

Nga Yoke Kaung:
Located near the city of Pathein (350,000 habitants) with basic industry, universities and some tourism.
LNG consumers:
50 MW power plant running at power factor (PF) = 80% (average load 40 MW)
Will provide power for local population and industry.
Site quality:
No existing marine infrastructure.
Otherwise suitable for an onshore terminal.
Marine data:
Deep water (10 m) near shore, location fairly sheltered for winds except from the south.
Risk for cyclones, flooding and earthquakes.
No tugs and no local port authority.
Other infrastructure:
Pathein offers little industry and relatively low-skill workforce.

Yangon:
Major city with a population of six million. It is the country's centre for industry, trade, tourism, etc. Chronic power shortages currently limit the factories' operating hours.
LNG consumers:
125 MW power plant running at PF = 80% (average load 100 MW).
Site quality:
Slightly sloped waterfront, soft soil, low environmental and social impact. Suitable for an onshore terminal.
Marine data:
Close to river mouth, water depth 8 m, considerable traffic. The tide is quite strong. Fairly well protected from wind in normal conditions. Risk for cyclones, flooding and earthquakes.
Pilotage required.
Other infrastructure:
Workforce capable of civil infrastructure works.

Dawei:
Dawei has approximately 150,000 inhabitants. Dawei is the proposed site for a Special Economic Zone (SEZ) with a deep-sea port (which, in this case study, we assume has been built already).
LNG consumers:
75 MW power plant running at PF = 66% (average load 50 MW) providing electricity for industry during the day and for the inhabitants of Dawei primarily in the morning and evening.
Site quality:
Deepwater port, good soil conditions, industrial zoning. There are plans for a large onshore LNG terminal or an FSRU, but an intermediate solution is needed in order to enable industry to start producing in the SEZ. Therefore the investors have envisioned a floating storage and regasification barge (FSRB).
Marine data:
14 m sea depth, existing breakwater, sheltered quay where LNGC and FSRB can be positioned alongside the quay. Extreme monsoons may cause flooding, but cyclones and earthquakes are less likely in this part of Myanmar.
Other infrastructure:
Good availability of heavy lifting equipment.

→

Site	NgaYoke Kaung	Yangon	Dawei
Power need	50 MW at PF 80%	125 MW at PF 80%	75 MW at PF 66%
Total LNG consumption	57,400 TPA (10,400 m^3/month)	144,000 TPA (26,000 m^3/month)	71,700 TPA (13,000 m^3/month)
Average daily LNG consumption	342 m^3	854 m^3	427 m^3

Table 1 - Calculation of total LNG consumption at each site.

Singapore - Dawei

Round Trip Duration (hours)	Loading	Unloading	Total
Loading (hours)	6.9	13.8	20.7
Port Arrival (hours)	36.0	12.0	48.0
Transportation time incl. Sea margin			134.5
Total Hours Round Trip			203.2
Total Days Round Trip			8.5
Total days in operation			365
Number of trips per year			43.1

Dawei - Yangon - Nga Yoke Kaung

Round Trip Duration (hours)	Loading	Unloading	Total
Loading (hours)	4.8	4.8	9.6
Port Arrival (hours)	12.0	24.0	36.0
Transportation time incl. Sea margin			49.1
Total Hours Round Trip			94.7
Total Days Round Trip			3.9
Total days in operation			365
Number of trips per year			92.5

Singapore - Dawei

Round Trip Duration (hours)	Loading	Unloading	Total
Loading (hours)	13.5	20.3	33.8
Port Arrival (hours)	36.0	12.0	48.0
Transportation time incl. Sea margin			130.2
Total Hours Round Trip			212.0
Total Days Round Trip			8.8
Total days in operation			132
Number of trips per year			14.9

The total combined offtake is 272,500 tonnes per annum (TPA). We assume that the LNG price "free on board" (FOB) Singapore is oil-linked, according to the following formula: Brent price x 14.5% slope, which with an oil price of USD 55 per barrel would result in an LNG price of USD 7.98 per million British Thermal Units (MMBtu). This price is not based on information from the supplier, but as small-scale LNG pricing seldom is transparent, we have chosen a simplified formula.

When examining the sites and planning the logistics chain, we encounter a challenge. The size of carrier that would be needed to make possible a "milk run" delivery to all the sites cannot, according to our (fictive) site description, reach the Yangon site due to draught limitations. The solution is to create a hub terminal in Dawei and distribute the LNG from there in a smaller vessel to the other sites.

For Alternative 1, where we prefer low CAPEX, we need to keep the terminals as small as possible. We calculate that we can make do with an intermediate terminal with 22,500 m^3 capacity that would be serviced by a 15,600 m^3 LNGC going back and forth to Singapore. For this size of terminal, the FSRB envisioned by the investors will be possible. There will be approximately 8.5 days between filling the tank in Dawei. Moreover, a 5500 m^3 LNGC would do a milk run on the route Dawei – Yangon – Nga Yoke Kaung. Such a vessel has a design draught that would enable it to travel to the Yangon site. The terminals in Yangon and Nga Yoke Kaung can make do with fairly little reserve capacity since the milk run is short and the power plant owners have opted for dual-fuel power plants which, if needed, can run on liquid fuels.

For Alternative 2, where we prefer low OPEX, we focus on finding a less expensive way of delivering LNG. Hypothetically, we could look for a ship owner who can offer a larger LNG carrier. This would, of course, come at a higher day rate than the 15,600 m^3 LNGC in Alternative 1, but this time we manage to sign a flexible agreement that allows us to charter the vessel only for the period when we need it. With a 45,000 m^3 LNGC, we can extend the time between filling the tank in Dawei from 8.5 days to 25 days.

Fig. 7 - Example of a 45,000 m^3 LNG carrier currently being built for Saga LNG Shipping. Wärtsilä has been contracted to supply the complete cargo handling system including the fuel system, as well as the main propulsion system.

		Dawei hub	Yangon	Nga Yoke Kuang
LNG FOB price. USD/MMBtu		7.98	9.61	9.61
CAPEX		0.62	0.64	1.31
OPEX (incl. Tolling fee)		0.07	0.32	0.32
LNG supply chain		1.04	0.59	1.30
Cost price of gas		**9.71**	**11.17**	**12.54**

		Dawei hub	Yangon	Nga Yoke Kuang
LNG demand/year	tonnes	272 502	143 387	57 422
Shrinkage	%	1.5%	0 %	0 %
LNG demand (incl. Shrinkage)	ton	276 589	143 387	57 422
	m^3	601 281	311 710	124 830
	MMBtu	11 718 231	6 074 847	2 432 784
	m^3/month	50 107	25 976	10 403
Average demand / day	m^3	1 623	854	342
Required minimum reserve	days	4	2	2
Minimum storage size net	m^3	20 288	5 124	2 052
Heel requirement	%	10 %	10 %	10 %
Minimum storage size gross	m^3	22 542	5 693	2 280
Financing assumptions				
Investment lifetime	Years	20	20	20
Required return on equity	%	15 %	15 %	15 %
Loan financing	%	75 %	75 %	75 %
Equity financing	%	25 %	25 %	25 %
Loan interest rate	%	5 %	5 %	5 %
Construction period	months	32	18	18
Construction period	Years	2.7	1.5	1.5
WACC	%	**7.50 %**	**7.50 %**	**7.50 %**
CAPEX (incl. Marine infrastructure & first fill)				
Total system investment	USD	**74 280 000**	**39 819 025**	**32 464 675**
Total system investment	**USD/MMBtu**	**0.62**	**0.64**	**1.31**
Annual opex (incl. Effects of tolling fee paid by satellites to hub terminal)				
Total OPEX	USD	781 378	2 003 525	802 114
Total OPEX	**USD/MMBtu**	**0.07**	**0.33**	**0.33**
Allocated transportation/infrastructure costs (incl. Pipelines)				
LNG transport/ supply chain	**USD/MMBtu**	**1.04**	**0.59**	**1.30**

Comparison: Alternative 1 (Low CAPEX)

	Alternative 1	Alternative 2
LNGC Dawei-Singapore	15,600 m^3	45,000 m^3
Dawei terminal	22,500 m^3 FSRB	60,000 m^3 onshore
LNGC Dawei-Yangon-Nga Yoke Kaung	5500 m^3	5500 m^3
Yangon terminal	7500 m^3 FSRB	7500 m^3 FSRB
Nga Yoke Kaung terminal	2500 m^3 onshore	2500 m^3 onshore

Table 2 - Project configurations

		Dawei hub	Yangon	Nga Yoke Kuang
LNG FOB price. USD/MMBtu		7.98	9.57	9.57
CAPEX		1.06	0.64	1.31
OPEX (incl. Tolling fee)		0.07	0.32	0.32
LNG supply chain		0.57	0.33	0.74
Cost price of gas		**9.67**	**10.86**	**11.94**

		Dawei hub	Yangon	Nga Yoke Kuang
LNG demand/year	tonnes	272 502	143 387	57 422
Shrinkage	%	1.5%	0 %	0 %
LNG demand (incl. Shrinkage)	ton	276 589	143 387	57 422
	m^3	601 281	311 710	124 830
	MMBtu	11 718 231	6 074 847	2 432 784
	m^3/month	50 107	25 976	10 403
Average demand / day	m^3	1 623	854	342
Required minimum reserve	days	8	2	2
Minimum storage size net	m^3	53 559	5 124	2 052
Heel requirement	%	5 %	10 %	10 %
Minimum storage size gross	m^3	56 378	5 693	2 280
Financing assumptions				
Investment lifetime	Years	20	20	20
Required return on equity	%	15 %	15 %	15 %
Loan financing	%	75 %	75 %	75 %
Equity financing	%	25 %	25 %	25 %
Loan interest rate	%	5 %	5 %	5 %
Construction period	months	36	18	18
Construction period	Years	3.0	1.5	1.5
WACC	%	**7.50 %**	**7.50 %**	**7.50 %**
CAPEX (incl. Marine infrastructure & first fill)				
Total system investment	USD	**126 094 325**	**39 763 225**	**32 446 075**
Total system investment	**USD/MMBtu**	**1.06**	**0.64**	**1.31**
Annual opex (incl. Effects of tolling fee paid by satellites to hub terminal)				
Total OPEX	USD	850 290	1 954 318	782 409
Total OPEX	**USD/MMBtu**	**0.07**	**0.32**	**0.32**
Allocated transportation/infrastructure costs (incl. Pipelines)				
LNG transport/ supply chain	**USD/MMBtu**	**0.57**	**0.33**	**0.74**

Comparison: Alternative 2 (Low OPEX)

The logistics for the Dawei – Yangon – Nga Yoke Kaung milk run remain unchanged.

With a longer supply interval, however, it would also make sense to have more reserve capacity at Dawei. Therefore, we increase it from four days in Alternative 1 to eight days in Alternative 2. This would require us to build a 60,000 m³ terminal in Dawei at considerably higher CAPEX. The larger LNG storage capacity available gives the power plant investors reassurance that gas will always be available, and they decide to prioritise efficiency over dual-fuel capabilities and choose to invest in a gas power plant rather than the dual-fuel power plant that they originally planned. The terminal investors also decide that, rather than having two 30,000 m³ FSRBs, it would be acceptable to build the terminal as a permanent onshore solution. Can this investment be recovered through the more flexible charter agreement?

Conclusions

The calculations show that the effects of the more flexible charter agreement were considerable. For Nga Yoke Kuang, we managed to reduce the cost price of gas by USD 0.60 per MMBtu, which might have a decisive impact on the financial feasibility of the entire project. For the other sites, we also managed to reduce the costs, despite the effects of a significantly higher CAPEX.

This case study shows that judging a project's feasibility simply by looking at the CAPEX can be extremely misleading. One can make significant improvements by designing a logistical chain with a good fit with regard to distances, gas consumption and the sizes of available ships. Such optimisation also should examine the effects of even the slightest reduction of charter rates or LNG prices on the final cost price of gas. This is something that we will expand on in upcoming articles.

Onsite LNG backup system: your guarantee against curtailment

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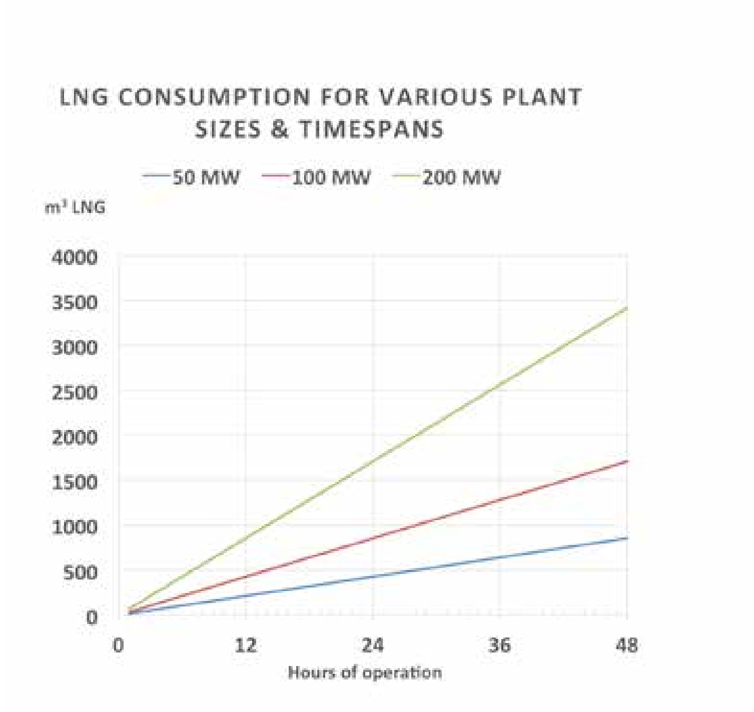
The loss of fuel supply at a power plant can have huge negative impacts – potentially resulting in a loss of electricity supply to the plant owner's customers and, consequently, millions of dollars.

For gas-fired plants, the use of liquefied natural gas (LNG) storage can be an effective and economical solution for providing a backup source of fuel in the event of a pipeline gas interruption.

Previously, the only means of doing this was for the gas utility to build LNG peak shaving plants and satellite terminals to increase the reliability of the gas grid.

One development with significant potential is the possibility to equip a gas engine-based power plant with its own onsite LNG terminal, to be refuelled by cryogenic tank trucks. The size of the terminal is a function of the power plant's capacity, projected length of gas interruptions and setup of the refuelling logistics. Typically, the tanks range from a few hundred to a couple thousand cubic metres.

This was an option adopted by a municipally owned electric utility in the US, when it asked Wärtsilä to build a gas-fired power plant with a backup LNG terminal under an EEQ (engineering and equipment delivery) contract. Wärtsilä also provided engineering for the LNG system.



Assumptions:
Wärtsilä gas power plant Heat rate: 7900 kJ/kWh
Gas: LHV (lower heating value):
37,000 kJ/m^3 Density: 0.737 kg/m^3
LNG: Density: 421 kg/m^3

Fig. 1 - LNG consumption for various plant sizes and timespans.

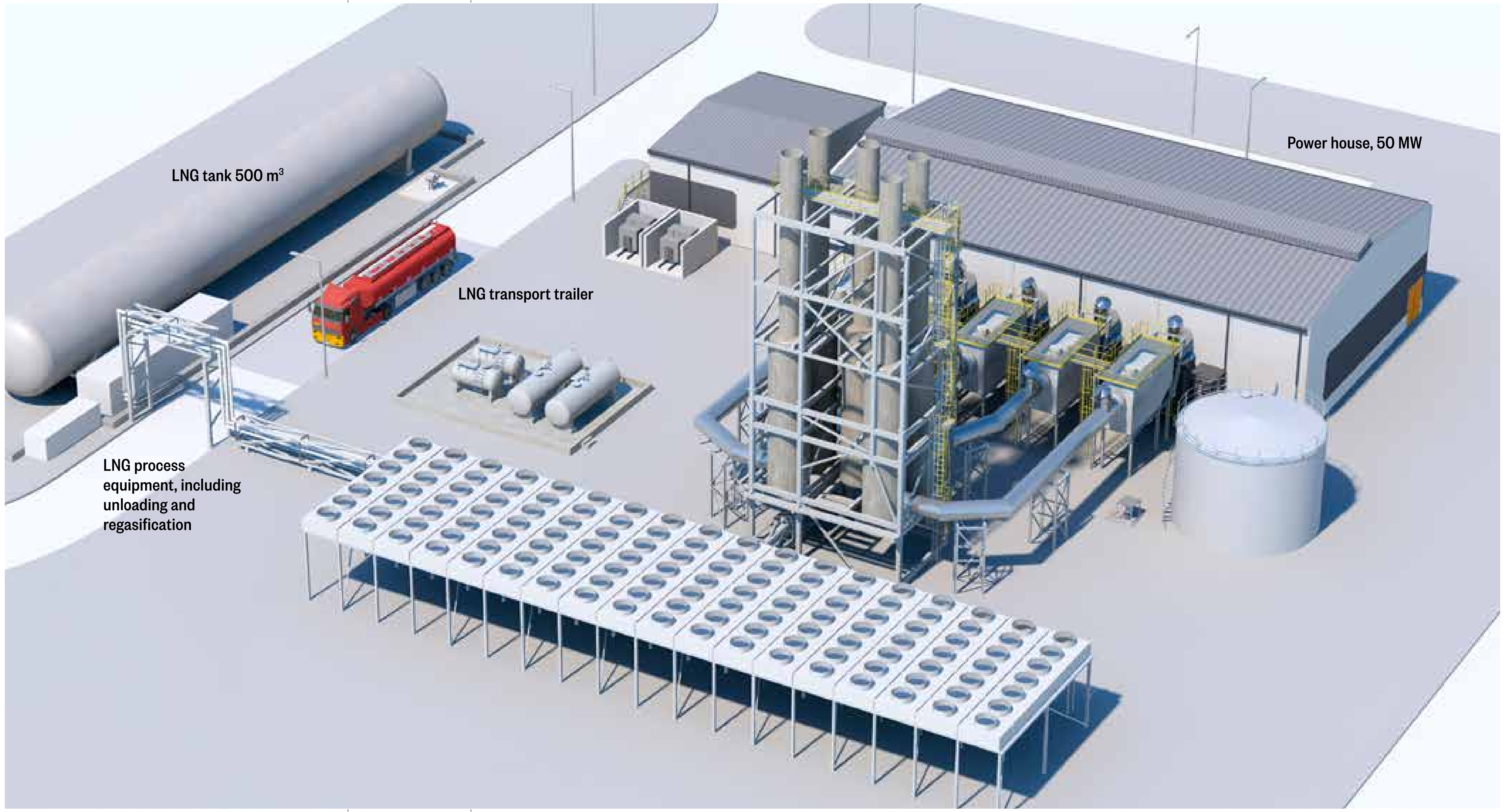


Fig. 2 - A Wärtsilä power plant combined with an LNG backup solution.

Integrated rationale

The US, with its upsurge of gas-fired power plants resulting from the shale gas revolution, is an ideal market for integrated power with LNG backup installations.

In addition to the rapid rise of gas-fired generation, the growth of the shale gas industry has resulted in increasing availability of LNG.

Wärtsilä is perfectly positioned to take advantage of current US gas market developments. We have been building power plants based on internal combustion engines – capable of running on liquid fuel, gas, or both – for many years. For the last couple of years, we also have developed expertise in providing LNG infrastructure.

With both power and LNG expertise, Wärtsilä is now able to supply and install a complete power and LNG backup solution for plant owners. Although the challenges for gas-fired generation vary from market to market, there are incentives to consider an LNG backup solution in almost all countries.

Integrated LNG – smart power solution

The utility in the US first began looking at building a new power plant a few years ago and focused on gas, as clean, reliable generation was the primary goal.

The use of multiple prime movers not only provides redundancy but also gives the plant excellent load following capability. The ability to run individual units at full load, to provide incremental 'blocks' of power, means there is never a need to derate output, thereby avoiding a reduction in efficiency at part load and any corresponding increase in emissions.

Wärtsilä will supply the LNG terminal with a truck unloading station, a 380 m^3 cryogenic tank capable of fuelling 20 hours of operation, and regasification systems.

The entire facility will be controlled from a single integrated control system, also supplied by Wärtsilä.

Value proposition

Having a backup gas supply can make sense to a plant owner for a number of reasons. It may be that the gas supply is subject to interruptions or varying pipeline pressure. Depending on the market in which the plant is operating, the owner could also be hit by severe financial penalties for failing to produce electricity during times of peak consumption. It could also provide a means of hedging fuel price since the price of LNG is not as volatile as for pipeline gas during peak periods.

In terms of operation, having an LNG backup can potentially provide savings in several areas.

In the US, the price a power plant owner pays for pipeline gas varies according to the hub price and the price of transporting gas along the pipeline. Further, if the power plant is at the end of the pipeline, gas availability is less reliable, and the plant owner will often have to pay a premium for a reliable supply. A firm gas contract to ensure gas is available 100% of the time could typically cost around USD 8 million/year in the Northwest for a 200 MW power plant.

If the plant is in the Northeast, north Midwest or Northwest of the US, where high gas demand in the winter can cause gas availability issues, a plant operator will either need to have a firm gas contract or a backup fuel.

The cost of failure to supply electricity for a minimum specified time due to lack of gas can be huge. In the PJM (Pennsylvania, New Jersey and Maryland) market, for example, the financial penalty is the loss of capacity payment for an entire year. For a 200 MW power plant operating in this market, this could amount to several millions of dollars for each incident.

With these considerations, a fuel backup solution, whether liquid fuel or LNG, makes good economic sense. The hours of backup needed vary according to market rules but, by way of example, building a fuel backup system for a 200 MW power plant in PJM with 48-hour storage capability will cost in the region of USD 20 million. This would result in a payback of less than three years for the backup option versus a firm gas contract.

As the capital cost of constructing a fuel oil backup versus an LNG backup is lower, the choice between the two is dictated by environmental restrictions.

Although fuel oil may at times be a little cheaper to buy, operators typically are not permitted to burn diesel for more than 200-300 hours/year. In some areas, it is difficult or sometimes impossible to obtain a permit for burning fuel oil.

Another advantage of an LNG backup over fuel oil is that a dual-fuel power plant owner can reduce maintenance costs by running the plant on clean-burning gas only.

An integrated power plant with LNG backup should be a consideration for power plant owners now and in the future.

Simulation based grid compliance

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Today, large diesel and gas engines face an abundance of different loading conditions, in both energy production and marine applications. Hence, the importance of being able to accurately analyse these loading conditions is constantly growing. The goal of this article is to introduce the possibilities of coupling electrical and automation system models with flexible multibody dynamics to enhance and optimise the engine design for varying loading conditions.

This article is based on the award-winning paper “Simulation Based Grid Compliance,” published at the CIMAC 2016 World Congress by J. Könnö, T. Frondelius, T. Resch and M. Santos-Descalzo. Please refer to that paper for further details on the methodology.

Introduction

In field operation, generating sets are often subject to highly fluctuating loading conditions and anomalous phenomena imposed on the generator by the electric grid. Examples of such events are unstable grids with possible short circuits, heavily varying loading in peaking power plants, or frequency fluctuations in small power grids. Typically, the performance of the generating set for unstable grids must be demonstrated by fulfilling certain grid compliance requirements. Such tests are typically dictated by legislation and aim to assure that the generating set stays connected to the grid in the case of a transient event, such as a short circuit or an unwanted breaker opening in the grid. A typical example is to show that the generating set stays in the grid during a short circuit of a few hundred milliseconds.

For the operator, this translates directly to increased uptime of the power plant and increased reliability in energy production. On the other hand, running through such heavy transients imposes elevated load levels on the engine and generator components. To guarantee that a given engine will perform under all possible loading conditions during the operational life, simulations are the only viable choice to assure that such elevated loading does not affect the component lifetime negatively. Similarly, understanding and being able to simulate such events helps us to better design the equipment for specific customer loading conditions and business demands.

Although grid compliance issues are typically related to power plant applications, one faces very similar challenges in marine applications as well. In the marine operating environment, the internal grid of the vessel is small, which also leads to highly fluctuating loading conditions, particularly in special applications with highly varying power output demands, such as dredgers. Adding to the complexity are installations where there is both mechanical propulsion and electricity generation coupled to a single engine. In such conditions, the generating sets should be able to respond to the load changes rapidly enough to avoid destabilising the vessel electrical system. In addition, hybrid applications are becoming more common, further underlining the need for modelling. Moreover, in marine applications, safety typically plays a key role. As well as providing the best possible economic output through increased efficiency to the vessel operator, tightly coupled mechanical and system simulation models help in assuring the safety at sea of the equipment – even under the most severe loading conditions.

Interplay of the electrical network, automation and multibody dynamics

In this test case, we take a closer look at the 20-cylinder Wärtsilä 32 engine. This is a typical engine used in power plant installations, usually comprising several such generating sets. When coupled to a small grid, such as on a stand alone island application, the interplay of the generating set and the control system becomes one of the determining factors of the genset performance. Consequently, understanding the coupled transient behaviour is of utmost importance when designing generating sets for such demanding conditions. Typically, a generating set, after reaching the target speed, runs at a constant speed to produce electricity of a constant frequency. It is essential for the frequency of the electricity to remain as close as possible to that of the grid to ensure it stays in synchronisation with the grid. As the generator rotor and crankshaft are directly connected by a flexible shaft system, any higher variation of the crankshaft speed induces a variation of the rotor speed and, consequently, of the induced magnetic field. Such variation can come, for example, from an unwanted variation in the cylinder pressure or from a non-constant electrical grid. Therefore, even for a demanded constant speed, the rotor speed needs to be controlled by manipulating the injection quantity and ignition timing.

To accurately simulate transients, such as whether the generating set will survive a short circuit without falling off the grid, one needs to consider the engine mechanical model as a coupled model with corresponding automation and electrical models. Consequently, this coupled model will not only serve the needs of mechanical simulations, but it can also act as a testbed for more refined control system development in a virtual environment, thus delivering better solutions to the customer in a shorter amount of time. In the daily operation of a generating set in a power plant or marine installation, such high transient effects play an important role and are demanded to be considered in the development of the engine control system.

To cover such effects as described above, a highly complex system, covering the correct signal flow and controls, is required. But, as the simulation targets are still component durability, bearing analysis and vibration control, the considered sub-systems, structures and their interactions must also stay on the complex 3D level. A simplification of the mechanical model, as used for pure signal-flow simulations, is simply not valid for this type of simulation. Therefore, the next step in virtual development and validation is a virtual model for multibody simulation coupled with control systems and an online load generation algorithm. The target is to simulate how the whole generating set responds to predefined network events, such as short circuits, to satisfy the needs and requirements discussed above.

The virtual model

The idea of the virtual model approach is to realise a simulation model that is as near as possible to real-life conditions. Thus, all important influences on the electro-mechanical system of the engine and generator are to be considered as an integral part of the complete generating set before any real parts are produced. During the product development process, the real-life conditions need to be verified to have confidence in the applied procedures and methods to assure the performance of the final product.

There are also obvious obstacles to implementing physical testing of all possible application cases throughout the complete system in the early development stage.

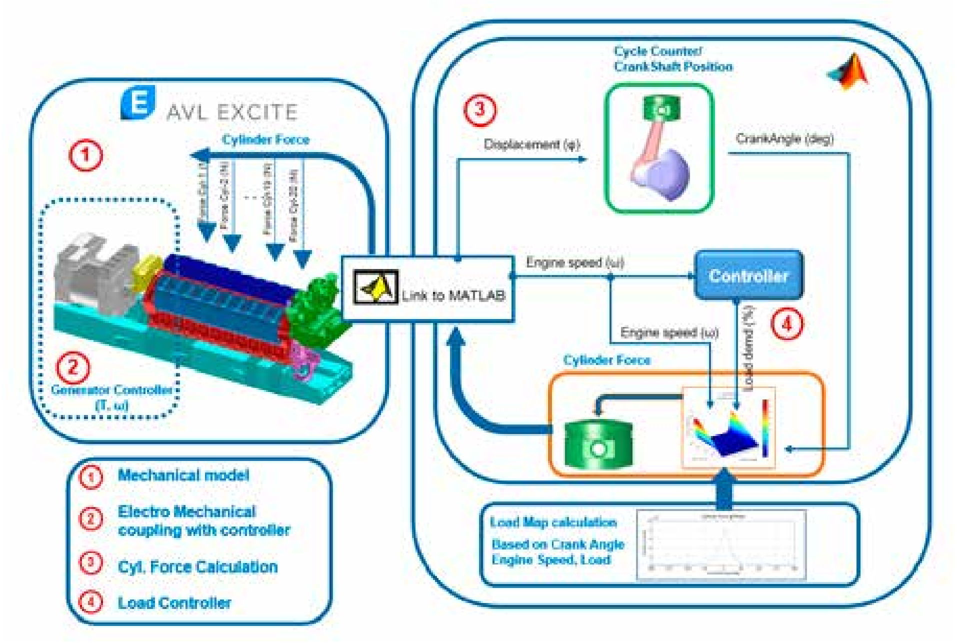
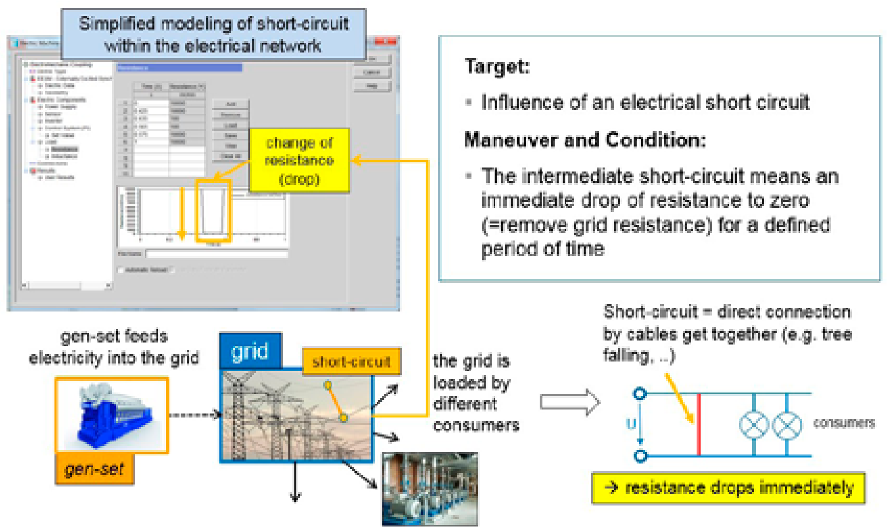


Fig. 1 - Overview of subsystems and signal flow.



Target:

- Influence of an electrical short circuit

Maneuver and Condition:

- The intermediate short-circuit means an immediate drop of resistance to zero (=remove grid resistance) for a defined period of time

Fig. 2 - Basic configuration of the short circuit case.

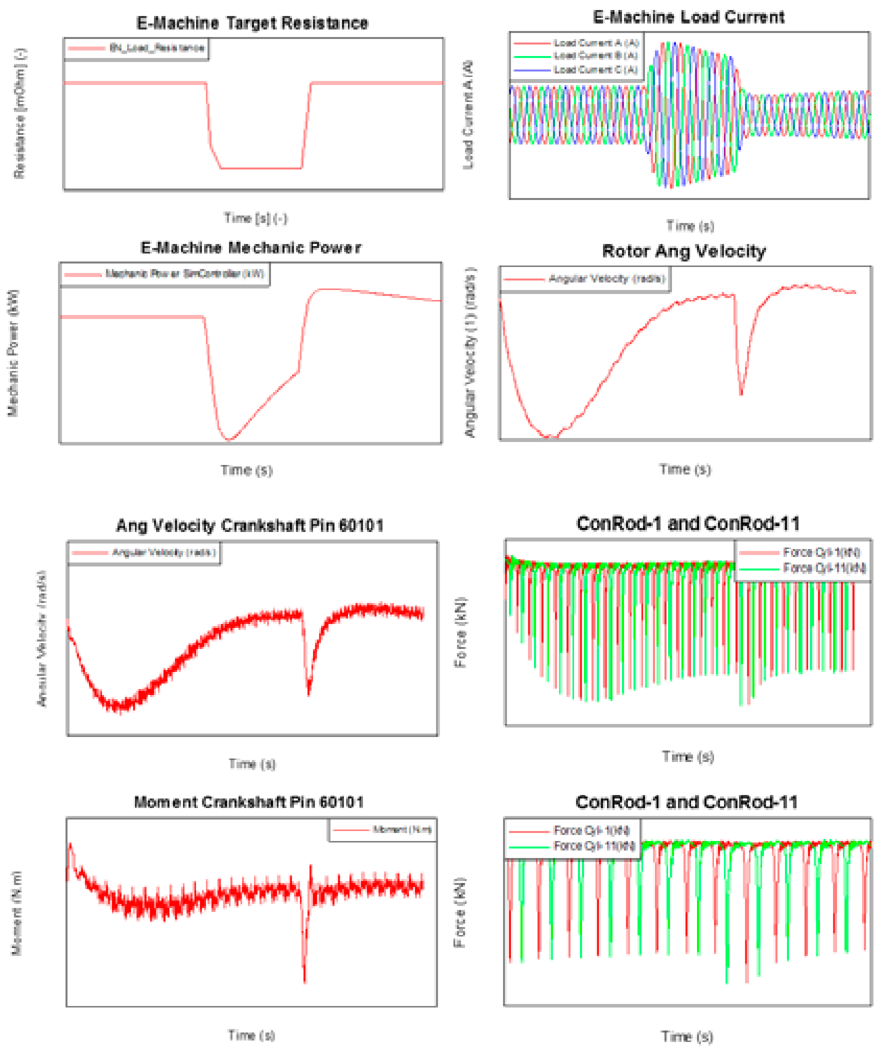


Fig. 3 - Effect of the short circuit on the electric machine and the engine.

Furthermore, there are limitations on the possible scenarios to be tested, due to, for example, the massive equipment needed to replicate a network transient on a 10 MW genset. Further considering some typical problems in testing, such as the large variety of installations with a different controller calibration, the virtual approach further shows its great potential and value. However, it must be noted that testing is always needed in calibrating the models, but the main advantage is the ability of the model-based approach to reach even those hard-to-test conditions which one often encounters in practice in field applications.

From the simulation point of view, the virtual model consists of a complex mechatronic system with four distinct subsystems:

1. Mechanical
2. Electrical with controlling
3. Pressure supply
4. Engine control

Figure 1 provides an overview of these subsystems and the signal flow with the required control loops, considering the load demand as input signal, the required cylinder pressure for each cylinder, the resultant crankshaft speed, and transition to the rotor speed which is the control target, induced electromagnetic forces and output torque, and the electric current, voltage and frequency. The mechanical and electrical subsystems (1 and 2) are computed in the multibody dynamics software EXCITE Power Unit. The pressure and load map calculation and load control (3 and 4) are computed in Matlab/Simulink. Both simulation platforms are coupled via co-simulation by means of an S-function in Matlab/Simulink.

For a proper dynamic response of the genset drivetrain, we consider on the mechanical side both the linear flexibilities of the mechanical components and the nonlinear behaviour of drivetrain components, such as bearings, mounts and coupling. In addition, for the generator we consider the electro-mechanical behaviour of the generator including electrical control and the behaviour of the high voltage grid. To complement the methodology, online load generation of the engine including engine control is included.

Test case: short circuit

The test consists of a steady state condition with an intermediate short-circuit for 100 ms, which is modelled as a sudden decrease of the load resistance, as demonstrated in Figure 2, which outlines this simple test case. Figure 3 shows the change of the angular velocity of the rotor during a short circuit after an initialisation period of three seconds for stabilisation of the entire system. Within the short circuit event, the speed first decreases, then increases and finally starts to stabilise again. Mechanical power enters a strong transient and then stabilises. Results for voltages A/B/C of the three phases are visible. The voltages are again very sensitive to the applied short-circuit resistance.

Also, one can see the change of angular velocity at the end of the crankshaft during the short circuit. Like the rotor shaft, after a period of initial stabilisation, the speed first decreases, then increases and finally starts to stabilise. The transient reaction at the cylinder loads are clearly visible. First, the engine tries to reach the target speed by applying full load. This is the initial start-up and stabilisation phase. During the short circuit the engine applies full load again due to the torque peak during the short circuit, trying to reach the maximum torque. All the results agree qualitatively very well with the phenomena witnessed in measurements.

This novel approach for investigating generating set grid compliance clearly agrees well with reality, given that the model parameters are correctly calibrated. One of the greatest benefits of such a model is the ability to simultaneously analyse the mechanical structure, including the stresses imposed on the components, directly together with the control system, and how they perform under different loading conditions.

Next generation UNIC automation system enables Wärtsilä 31 performance

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With its long history of technology leadership in advanced controls for medium- and low-speed combustion engines, Wärtsilä pushes boundaries with its second generation UNIC system and enables new performance leaps for the Wärtsilä 31 engine.

This article is based on the award-winning paper “Next generation UNIC automation system to enable Wärtsilä 31 performance” presented at the CIMAC Congress 2016.

Foundation of UNIC

Monitoring and controls for Wärtsilä engines have evolved since the 1970s from off-engine monitoring and alarm systems to an embedded engine control system. Control functions, such as electronic fuel injection, were introduced along with the common-rail and gas engine introductions. Around 2002, past automation system products had become increasingly demanding both to maintain and to use as basis for new product development. [1] Hence, the strategic decision was taken to develop a generic platform, UNIC, to be used on all Wärtsilä 4-stroke portfolio engines. However, older systems, such as the WECS 2000, 3000 and 8000, are still in active use on field engines.

With the introduction of UNIC, several high-quality, strategic design concepts were developed. These main concepts also use the second generation UNIC as a foundation.

On the hardware side, the main characteristic is the on-engine modular and distributed design. For wiring, connector-less, point-to-point cable connections and the so called “flying lead” concept are retained since they have proven their superior reliability compared to wiring-harness based solutions.

The modular system architecture, Wärtsilä Modular Application Platform (WMAP) design, continues as the software platform basis. Furthermore, model-based design principles, as well as a large part of application functionality, have proven their robustness and continue as part of the foundation. This proven and robust infrastructure functions as the stepping stone for new functionalities introduced.

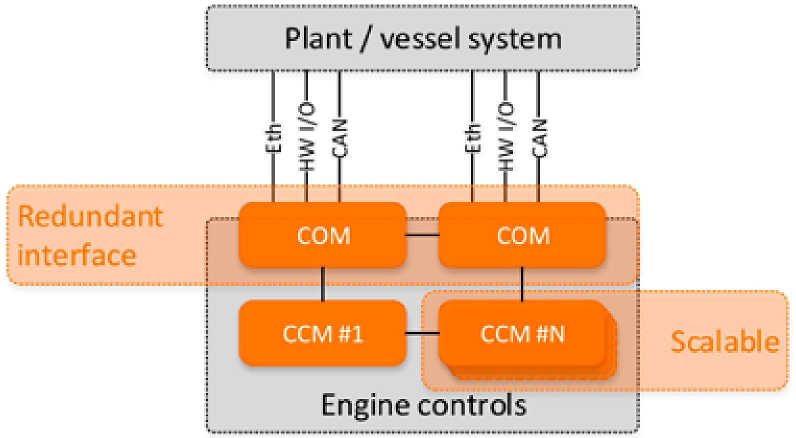

Fig. 1 - System overview.

Fig. 2 - Wärtsilä 31 with second generation UNIC system.

Flexibility

The need for flexibility grows along with increased variation in customer needs and the ever-changing market environment of today. Flexibility on the control system side comes in the form of the modularisation of hardware and software. Of equal importance is the flexibility with respect to changing operational profiles, both long- and short-term.

Modularity

Hardware-wise, the second generation UNIC is comprised of various modules with specific features – a Cylinder Control Module (CCM), Input/Output modules (IOM), and a safety module (ESM) – as well as a system interface consisting of Communication modules (COM) and local display units (LDU). (Figure 1)

With these building blocks, the system can range from simple, single-module speed/load controller applications up to any number of cylinder configurations, e.g. a 20V SG gas configuration with a total number of 12-14 modules. (Figure 2)

With multi-purpose input/output channels, an optimal number of modules builds up the system configuration to provide a cost-efficient solution. With the modularisation on the engine side, automation modules for each engine module can be mounted and pre-tested step-by-step, ensuring a solid validation chain.

With a platform software as its basis, the architecture is a modular hierarchy. The platform, together with application modules and configuration, forms the product-specific package. Maximum reusability is achieved when the platform is common for all, and application modules and configuration are selected depending on the product-specific needs. [1]

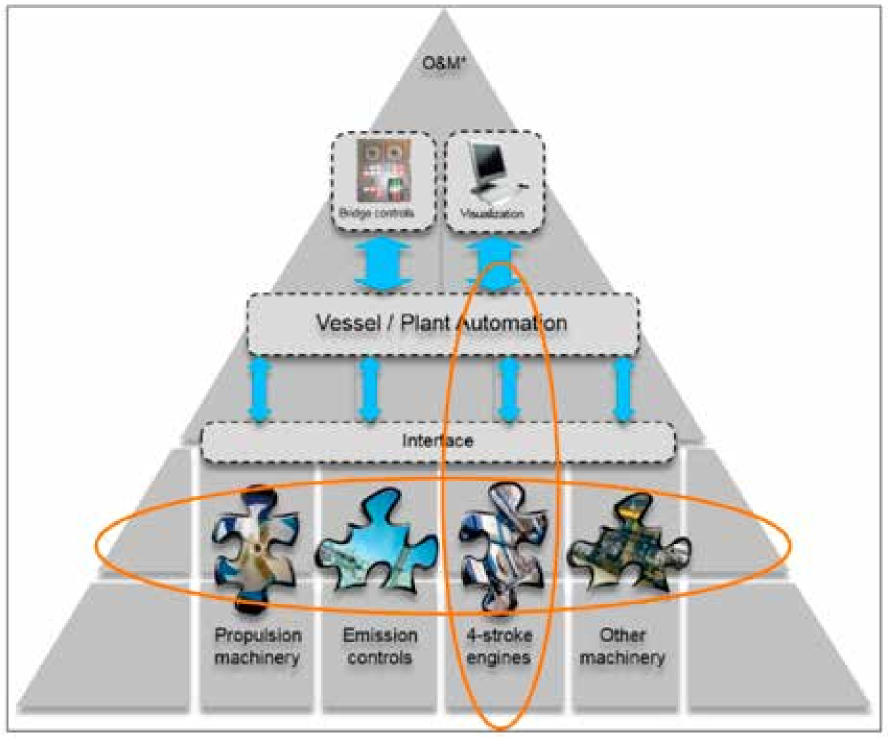

Fig. 3 - Systems integration.

Fig. 4 - Accelerated ageing test - HALT.

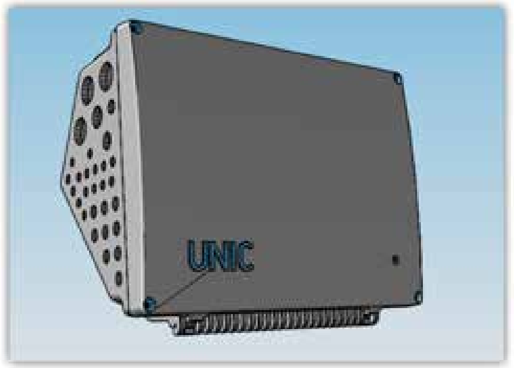

Fig. 5 - WTB-20.

Fig. 6 - Local Display Unit (LDU-30).

Fuel- and operational flexibility

Operational flexibility and capability to account for changing conditions, e.g. changing fuel type, provide a smooth transfer to new conditions, immediate real-time operational changes, as well as upgrades of system capabilities, e.g. retrofit value packages. With the modular architecture, for upgrades, such as fuel type changes, the automation system is easily rebuilt with additional control modules and functionalities. Furthermore, the extensive capacity of the second generation UNIC enables introduction of new functionalities for full flexibility in real-time operation, such as enabling smooth changes between fuel types.

Availability

Engine availability plays an increasingly important role in many engine applications. The second generation UNIC system considers availability through its architecture, design and diagnostics.

A typical engine control setup includes at minimum two COM modules to provide redundant connection interface for vertical and horizontal integration (Figure 3). Due to a dual-connection interface, connectivity to engine control always can be secured in case of a single failure. Two LDU displays can be mounted to ensure redundant local control.

Increased communication bandwidth enables easy data and control distribution within the distributed engine control system. Control execution can be synchronised to enable true redundant controls in case of a single point of failure.

In addition, improved availability is secured through improved diagnostics and prognostics. For example, the electrical actuators used in the Wärtsilä 31 installation can provide prognostics data to detect possible service needs before actual failure. This enables planned condition-based service when it is most convenient for a customer's operation schedule.

The UNIC system introduces a new level of reliability, which, along with high quality, is of utmost importance for the introduction of additional control demands in its second generation. Based on the experience from past system generations and new design quality assurance methods introduced in electronic design, a robust design of a second generation UNIC was created.

Wärtsilä continues to ensure automation component availability throughout the life cycle of Wärtsilä engine products. The electronics life cycle is getting shorter, due to the overall trend set by a high-volume consumer electronics business. The automation component availability challenge is addressed by careful electronic component selections, long-term obsolescence forecasting and obsolescence strategy implementation to secure engine control spare part availability. [2]

Temperature and failure rate simulation

Traditionally, electronic design selections have been based on component ratings and good design principles. During the prototyping phase, the design has been validated and the outcome taken to the next design iteration.

With today's simulation methods [3], it is possible to ensure design even before the actual prototype. Design failure rates can be simulated and forecast several years in advance. Most critical improvements can be done even before the first prototype.

By setting the product design reliability at an acceptable level, an improved validation chain has been used to ensure the design quality of the second generation UNIC automation components.

Automation component validation

With the previous UNIC generation validation experience as a basis, the automation component validation methods have been further developed and are today fully integrated into internal component release processes. In addition to on-engine operational testing, the validation process includes functional-, endurance- and accelerated ageing-testing. [4] For example, Highly Accelerated Life Test (HALT) [5] has been actively used, throughout the design cycle of the components, and proven to be a good validation method to detect and improve possible weak points in the automation design. (Figure 4)

Automated functional validation of the engine control system has supported efficient design cycles and good validation coverage. Overall results show a significant increase in the quality and maturity level of components. [4]

Automation electromechanical design

Wärtsilä's long experience in automation electromechanical design provided a solid base for the electromechanical design for the Wärtsilä 31 engine. Feedback from field experience has been consolidated into updated design guides and applied to the Wärtsilä 31 automation design to ensure high reliability as well as easy serviceability of the engine controls. The cable layout and routing of the engine automation components were considered in the engine mechanical design. Special attention was also paid to temperatures, vibrations, oil and avoiding sharp edges. Potential vibration issues of the engine control and automation modules were tackled by using proven wire rope dampers.

Electronic module enclosure

A new electronic module enclosure, WTB-20, was developed for the Wärtsilä 31 engine. In addition to providing proper IP protection for the electronic modules, one of the cornerstones for WTB-20 design is the lean mechanical fit to Wärtsilä 31 as well as easy accessibility for service and maintenance purposes. The enclosure provides easy access to all measurement and control signals, and enables easy spare part replacement. Heat dissipation simulation was also closely considered in the WTB-20 enclosure design. (Figure 5)

System usability

It is important to lower the complexity of the system to improve its usability for operators. In the second generation UNIC system, a new Local Display Unit (LDU) is introduced, along with improved diagnostics.

Local display unit (LDU-30)

LDU-30 was developed with a strong user focus, interviewing Wärtsilä service and customer representatives. Input from these interviews was consolidated to develop the LDU-30 usability and industrial design. (Figure 6)

LDU-30 provides an intuitive user

Fig. 7 - Double local displays.

interface with touch controls to easily browse through basic engine and measurement statuses. The LDU-30 light guide enables easy engine status indication through intuitive status colouring and blinking schemes, which guide operators through the desired controls and maintenance checks for Wärtsilä engines. Further, it enables a deep dive into engine measurement details and visualised engine diagnostics information when needed.

From the maintainability and service perspective, LDU-30 provides easy access to the engine process data and alarm log. Convenient data export and software update functionalities are provided through an integrated USB port.

From a usability point of view, it is important to have a similar look and feel, from a vessel-bridge or a plant-control level all the way to the machinery. It is important that the control functionality and information presentation are provided in a similar fashion, independent of which Wärtsilä equipment the operator is using. Therefore, the Wärtsilä look and feel are aligned in the design of all machinery interfaces. This also has been one of the key elements in the LDU-30 design, mirroring the Red Dot Award-winning [6] Wärtsilä propulsion control panel design in various ways. (Figure 7)

Diagnostics

While engine control functions are getting more advanced with more measurements and actuators added to the system, the increased complexity makes troubleshooting of engine functionality and controls more challenging. Traditionally, several individual alarms may be triggered due to a single failure in the control system. The improved capacity of the second generation UNIC system can now combine different alarms so that operators or service personnel are able to pinpoint the actual root cause for the failure. It also extends overall diagnostic functionalities, including stiction detection and cooling diagnostics. [7]

Electronic module spare part exchange

In addition to easy spare part replacement enabled by WTB-20, the second generation UNIC-controlled boot-up enables automatic software download and data synchronisation. When a spare part module is installed on the engine, UNIC automatically detects this and downloads the correct software for the module when it is safe to do so. When the module boots up with the new software, the system takes care of synchronising the system status and process data on the control module before it enters the operational mode and starts to control the engine. This enables safe and easy module replacement without powering off the entire engine control system.

Enabler of engine performance

Due to several drivers, such as tightening emission legislation, fuel consumption, variations in fuel quality and overall performance, great effort has been put into the second generation UNIC to optimise the closed-loop controls to achieve fast-acting and robust control dynamics. From a design point of view, it is very important that all aspects of the closed-loop control chain work together in an efficient way. Things that at first may seem unimportant or trivial can have a huge impact on the end result. It is not enough to base the system on solid control algorithms if other parts of the measurement or control chain fail. To optimise controls, it is important to identify the key aspects of the system that influence the control dynamics [8] and those for which design can make a difference. In this case, the main aspects are the following:

- Real-time control modules
- Sensors
- Measurement signal sampling
- Communication network
- Control algorithms
- Actuator control

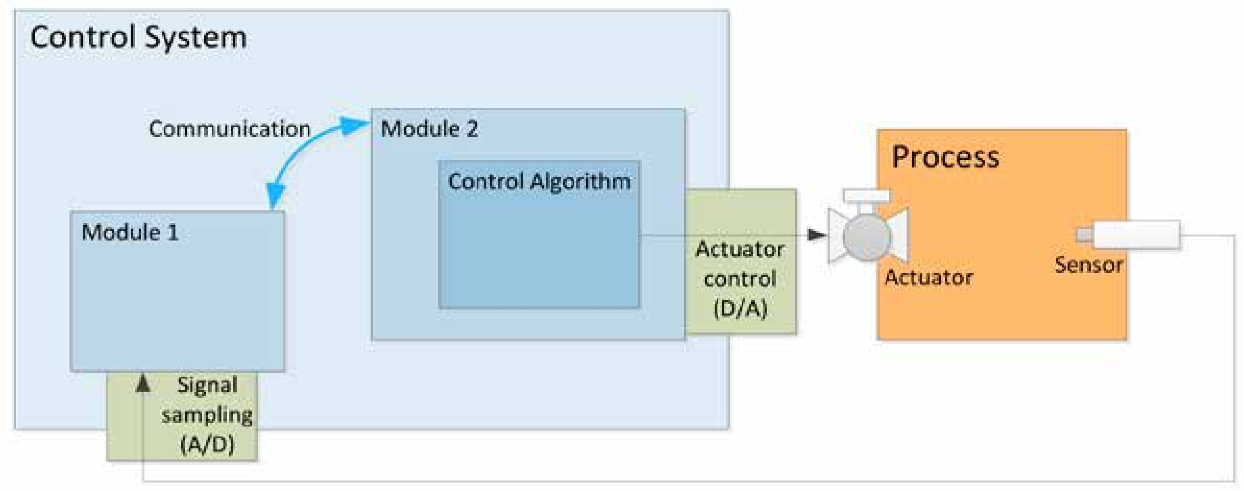

Fig. 8 - Closed-loop controller.

Each of these needs to be designed with precision to ensure high control quality. The second generation UNIC hardware enables improved timing restraints for measurement sampling, updating the control algorithm, driving the actuator control and increasing the speed and determinism of the communication network. This enables the system to move big amounts of data back and forth, which is partly a prerequisite for building solid control applications.

There has been significant effort in control development to improve the measurement quality. For example, the FPGA (field-programmable gate array) hardware provides an excellent platform for different types of signal processing, such as the anti-alias handling of measurement data. These improvements have shown a clear increase in the overall measurement quality, which also has a direct influence on the robustness of the different control loops.

With the well-proven foundation of the UNIC system, it is important to ensure that the different control modules of the system are synchronised to maximise their functionality. With efficient communication between control modules, it is possible to fulfil strict timing requirements and to ensure that control algorithms are provided with valid measurement data. The result is that the output of the controllers also reaches the actuators of the system without significant delays.

Transient controls

Trends in engine control show a clear shift in focus – from steady-state control towards transient control. [9] The engine's ability to move fast between different working points is something that is carefully monitored nowadays. Even though robust steady-state control is still very important, the ability to react rapidly to changing conditions also must be a part of the normal control routines, making transient control algorithms necessary.

To get a fast transient response from more traditional steady state controllers, different types of feedforward controllers have been introduced. A feedforward controller is normally implemented in parallel with a closed-loop controller to react on process disturbances [10] (Figure 8). For this, a fast measurement of a process disturbance is needed for the feedforward part of the controller to react to the disturbance before it is seen in the controller feedback. Though the process disturbance is not always measurable, it might still be possible to use feedforward control to achieve a good transient control response.

For example, pressure controls have significant potential for transient improvement. Typically, for a closed pressure control loop, the pressure in an enclosed volume is controlled. The pressure within the closed volume is measured and used as feedback for the closed control loop. Then the controller sets the position of the flow control valve to change the mass flow into the volume. In this case, the mass flow out of the enclosed volume can be seen as a process disturbance. Even if not measurable, it is important that the system also controls the mass flow out of the enclosed volume. This information can be used directly by the feedforward controller to improve the transient behaviour without additional measurements. With this type of feedforward control, the mass flow into the enclosed volume is compensated by the outgoing mass flow, even before the measured pressure changes. (Figure 9)

Different types of feedforward components can be used, depending on the circumstances. For example, the static relation between the flow control valve position and the mass flow out of the volume can be used. Other possibilities can be used to avoid the additional calibration of the feedforward element, e.g. self-tuning maps for keeping track of the relationship

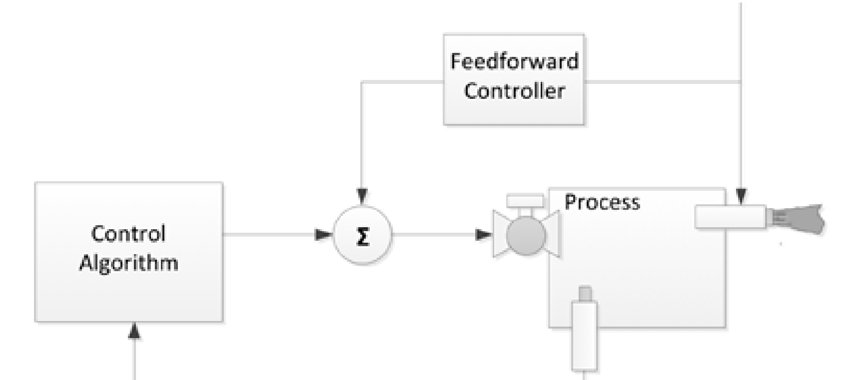

Fig. 9 - Feedforward add-on for closed-loop pressure control.

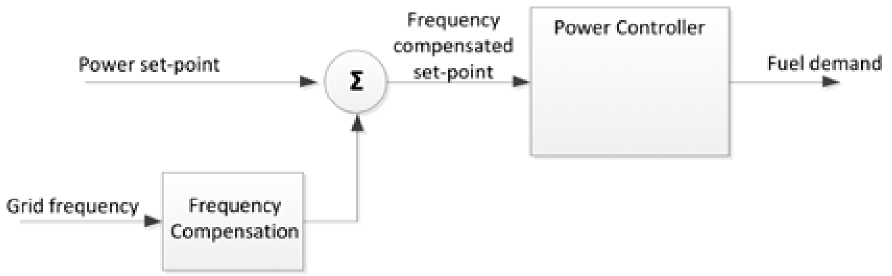

Fig. 10 - Frequency compensated power control.

between the valve position and mass flow.

In other cases, the feedforward controller does not necessarily depend only on a single signal. In such cases, an elegant solution is to use dynamic process models to further improve transient behaviour of the controller, such as to create virtual disturbance measurements that can be valuable for the transient controllers. A typical example could be the air-to-fuel ratio, which can provide vital information to several controllers in the system, e.g. an adaptive air-to-fuel limiter to optimise the gas admission to the cylinders during transients to accommodate for turbo-lag.

Combustion controls

In-cylinder pressure measurement is widely used nowadays for research and development of internal combustion engines. It is said that the cylinder pressure characterises the heartbeat of the engine and that it is an enabler for meeting future demands of internal combustion engine performance.

With the recent development of cylinder pressure sensors, the in-cylinder pressure measurement is finding its way onto production engines, where new, innovative ways to control the engine can be applied[9]. The in-cylinder pressure contains information that characterises the combustion behaviour, which then indicates that the many different feedback signals, together with the correct extraction algorithms, can be used for controlling the combustion in different ways. Generally, the most used combustion parameters extracted from cylinder pressure measurements are the indicated mean effective pressure (IMEP) and heat release (HR). From the cumulative heat release, it is possible to gain valuable information about the ignition delay, combustion duration and, perhaps most importantly, when combustion takes place in the cylinder.

The second generation UNIC control system supports the calculation of all the above-mentioned combustion parameters that will be essential for future combustion control concepts. The combustion parameters provide new means for further exploration of cylinder balancing, for example. Cylinder-wise combustion control can even be used to balance mechanical differences between the engine cylinders. This means that closed-loop combustion control also has great potential for reducing, e.g., the calibration work associated with engine development. In the long run, this decreases the number of tuneable parameters normally associated with the engine calibration. With the seemingly limitless possibility to create new feedback signals, the cylinder pressure will be one of the most important measurements to use for control going forward.

Grid code

Another important area where state-of-the-art control methods are needed is power-plant installations, where so-called grid codes[11] have recently started coming into effect. Basically, grid codes are a collection of firm requirements put on the primary power producers to ensure safe operation and, where applicable, safe integration of renewable energy sources into the power system. To be accepted as a primary power producer for the electrical grid, a high reliability and quality of produced power must be maintained even during transient conditions. The grid code requirements also limit the time to synchronisation, time to full load, etc.

Because of this market demand, several new control features were introduced to meet these requirements. For example, a new fast-start functionality was introduced to start injection already at a lower engine speed to save starting time. Fast starting also sets new demands, e.g., on speed sensors, as reliable speed sensing and position measurement is required almost immediately from the touch of the start button.

Another functionality to highlight is the frequency compensation control that has been added to the standard power controller (Figure 10), where all the primary power controllers actively connected to the grid try to assist and eliminate changes in the grid frequency. This frequency support functionality requires very accurate speed calculation algorithms to minimise the effect of calculation round-off.

Digitalisation

In addition to engine control and monitoring, an important task of the control system is the interaction with other machinery, functioning as the interface with a vessel or plant automation system. Digital services[12] are taking a leap forward with new offerings that enhance the performance of customers' assets and business. Several design aspects have been considered in the second generation UNIC to prepare for the Wärtsilä 31 integration with other machinery, as well as to provide for optimal integration of the digital service offerings with the engine.

Integration

The increasing complexity of vessel automation systems – often provided by several different suppliers – creates new needs for system integration fluency as well as vessel control, both in control rooms and on the bridge.

Interface standardisation and the proper definition of the automation system interface and functionality are increasingly important for avoiding integration challenges in commissioning. Therefore, close collaboration between Wärtsilä engine control, machinery control and vessel control interface development is required to ensure smooth integration of all Wärtsilä systems. Further, follow-up and active participation in the development of interface standardisation is needed to secure seamless integration with other suppliers' control systems.

The usability perspective, together with the increasing complexity of vessel automation systems, is challenging for the whole marine industry. Today, a single failure in one of the vessel automation systems, such as a communication line break, can lead to several different alarms from various automation systems, resulting in lot of failure indications in the vessel control room. The operator needs to interpret the alarm information to define potential root causes for the issues before starting to troubleshoot the actual problem. This requires a lot of technical know-how from the operator, especially due to the increasing complexity of the automation systems. Better integration with and added intelligence of Wärtsilä engine control, machinery control and vessel bridge control solutions will provide more accurate information for detecting the most likely causes of an issue.

Horizontal integration

Horizontal integration (Figure 3), or integration with other machinery, aims to enable solution level control with other machinery or systems, such as catalyst systems. The second generation UNIC supports a wide range of interfaces, Modbus/TCP, CANOpen, OPC, etc.

This support and carefully crafted functionalities enable machinery solutions to work together as one unit. For example, with an engine and SCR, the SCR urea dosing operation is optimised with critical engine combustion parameters as input.

Vertical integration

Whereas the horizontal integration is about connecting different machinery, the vertical integration connects the control system to the higher-level vessel or plant systems. With respect to new service offerings, this is the main link to engine optimisation. The second generation UNIC enables good connectivity to the vessel or plant automation systems through COM/IOM modules (see horizontal integration).

Conclusions

UNIC is the forerunner for high-performing engine automation – a necessity for high-performing engines. Wärtsilä has developed the second generation UNIC to enable the performance of Wärtsilä 31, the most efficient engine in the world.

At Wärtsilä, the cornerstones of engine automation development have been flexibility, modular architecture and more advanced controls for Wärtsilä engines. To meet both customers' demands and regulatory requirements, the role of engine automation in engine development, and UNIC itself, will have an increasingly important role in the future.

Definitions, acronyms, abbreviations

CCM: Cylinder Control Module
COM: COmmunication Module
CR: Common Rail
DF: Dual Fuel
ESM: Engine Safety Module
IOM: Input/Output Module
LDU: Local Display Unit
SCR: Selective Catalytic Reduction
SG: Spark Ignited Gas
UNIC: UNIfied Controls
WMAP: Wärtsilä Modular Application Platform

References and bibliography

1 ÅKERMAN J., HULTQVIST A. "Large engine automation, today and tomorrow" MTZ Conference 2012
2 BARTELS B., ERMEL U., SANDBORN P. "Mitigation and Management of Product Obsolescence", ISBN: 978-1-118-14064-2, 2012
3 GU J., PECHT M., "Predicting the Reliability of Electronic Products" 8th International Conference on Electronic Packaging Technology, ICEPT 2007 Obsolescence", ISBN: 978-1-118-14064-2, 2012
4 TAMMINEN J. "Front-loaded R&D process for high quality – development case Wärtsilä 31" CIMAC congress 2016, paper no 100
5 HOBBS G. K., "Accelerated Reliability Engineering: HALT and HASS", ISBN-13: 978-0471979661 Wiley 2000
6 Red Dot Awards http://en.red-dot.org/
7 ÖSTMAN F., RÖSGREN J., KAAS T. "Securing engine performance and safety through fault diagnostics" CIMAC Congress 2016, paper no 118
8 ÅSTRÖM K.J., WITTENMARK, B. "Computer-controlled systems: Theory and design" Prentice Hall. Inc 1997
9 PORTIN K. "Wärtsilä DF Engines for Offshore Applications and Mechanical Drive". CIMAC Congress 2010, paper no. 112
10 ÅSTRÖM K., HÄGGLUND T. "PID Controllers: Theory, Design and Tuning", ISA 1995
11 ENTSO-E Network Codes for Electricity, http://networkcodes.entsoe.eu
12 Wärtsilä Genius Services http://www.wartsila.com/services/lifecycle-solutions/wartsila-genius-services

The 1MW Pilot GasReformer in Bermeo, Spain.

The Wärtsilä GasReformer leaves Finland en route to Bermeo, Spain.

Turning waste gases into power: saving money and the environment.

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Oil produced from offshore fields contains associated gases from oil drilling and boil-off gases from tankers and carriers, but these side streams with fluctuating compositions are usually treated as waste. However, Wärtsilä, with the help of a marine customer, decided to find a way to utilise these side/wasted streams as fuel gas in DF engine gas mode operation. The 1MW Pilot Wärtsilä GasReformer in Bermeo, Spain, was the result.

Gas reforming has long been a holy grail for the offshore sector. Oil produced from offshore fields contains associated gases, mainly consisting of natural gas (methane) and heavier gaseous hydrocarbons, such as ethane, propane or butane, with traces of even heavier hydrocarbons.

Heavier hydrocarbons have low fuel quality, indicated by a low methane number – the measure of ability to withstand compression in the engine before ignition. If a gas's methane number is too low, it will self-ignite. The engine knocks and needs to be derated to function properly. Derating implies reduced power output and decreased engine performance.

When gas varies in composition so that it cannot be utilised normally, such as in power generation, it usually is regarded as waste or cargo losses. So this gas is just flared, reliquefied or in the worst case, vented. Hydrocarbons are a far more harmful greenhouse gas than carbon dioxide due to their higher global warming potential. Not to mention it is also a waste of resources.

If there was a way of cleaning up this gas, it could be used. But although Wärtsilä knew that its offshore and marine clients would be very interested in a solution that meant they could use that waste gas, the company needed to prove it could be done.

The challenge – turning waste gas into fuel

The idea for the project first bubbled to the surface in the autumn of 2015.

A Wärtsilä customer, one of the world's largest marine energy transportation, storage and production companies, was very keen to look at gas reforming technology at work in the marine industry. It is a technology used mostly in the refinery and petrochemical industries, and Wärtsilä was determined to convince the customer that the technology could be transferred to a different environment.

The customer operates an offshore-to-shore shuttle service in the North Sea, which is an Emission Control Area (ECA), and there are limitations on the types of gas that can be vented – hydrocarbons and CO$_2$ cannot be discharged, for example. On a five-day round trip of the shuttle service, the customer collected around 500 cubic metres of liquefied fuel (120,000 Nm^3 VOC). The customer wanted to use it as fuel, instead of venting the gas into the atmosphere from the tank or just trying to push it back into the cargo.

The customer gave Wärtsilä the liquefied volatile organic compounds (LVOC), which is a very heavy hydrocarbon feed, to work with in the test unit with the Wärtsilä engine. That was the background for this test unit. (Figure 1)

The process – making heavy gases burn

The design engineering for the unit was completed in November 2015. From December 2015 to February 2016, the unit was built in Finland. It was then transported to Spain where Wärtsilä has engine test facilities. The unit completed the commissioning phase in the spring of 2016, and then there were some internal Wärtsilä tests in June.

The GasReformer's technology is based on steam reforming (SR), a catalytic process familiar from the petrochemical industry and refineries, where traditionally hydrogen is produced from various hydrocarbon feeds. The Wärtsilä GasReformer exploits the same catalytic process but operates under different conditions. In the reformer, the methane number (MN) of any fuel gas is improved to 100 ± 5, by converting the heavier hydrocarbons to synthesis gas (H$_2$ + CO) and finally to methane (CH$_4$).

How does it work?

The Wärtsilä GasReformer takes the gas feed and 'polishes' it. It ensures that there is no sulphur left and then injects steam into the stream before feeding it into a catalytic

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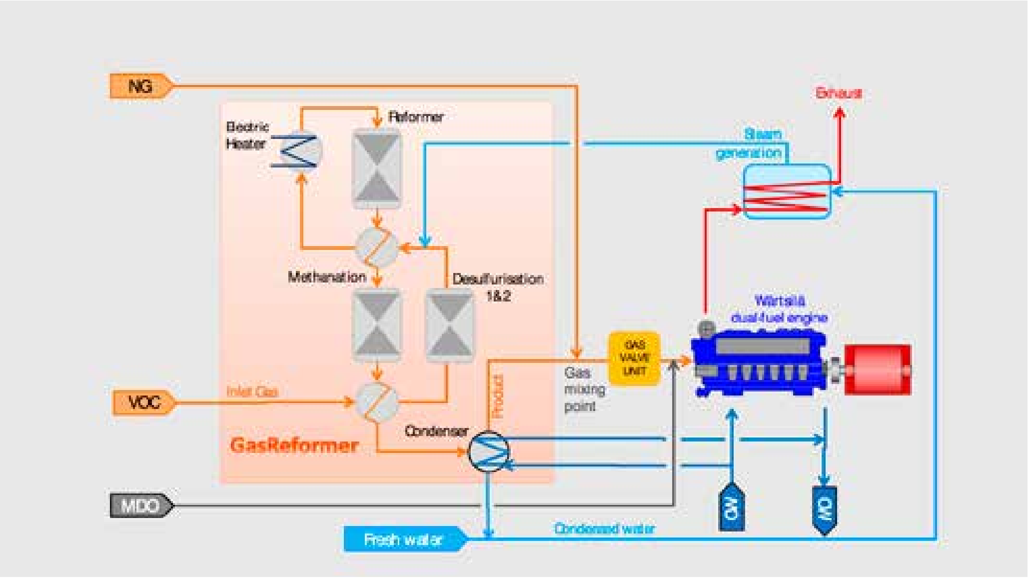

Fig. 1 - GasReformer and its interface to DF.

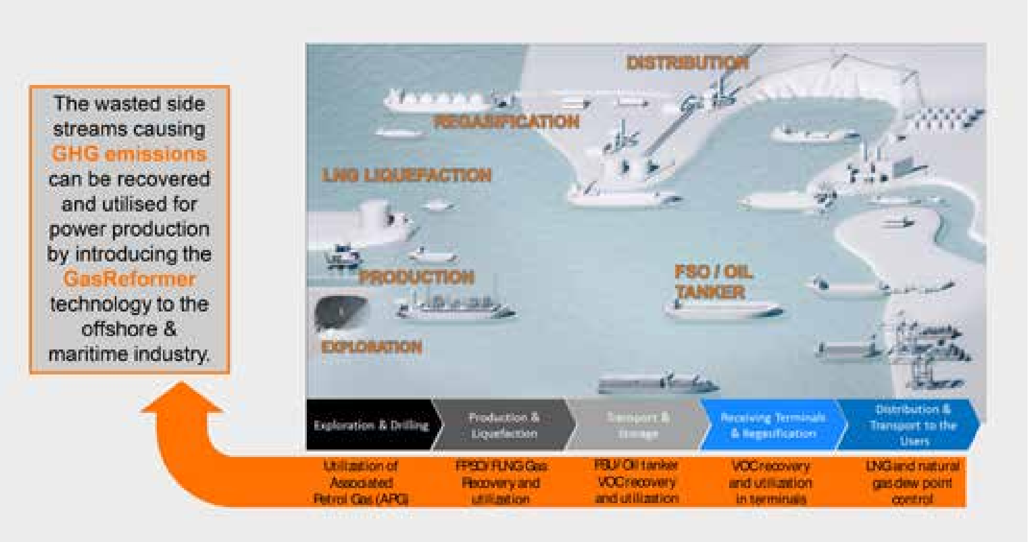

Fig. 2 - GHG emissions in the oil and gas value chain (production).

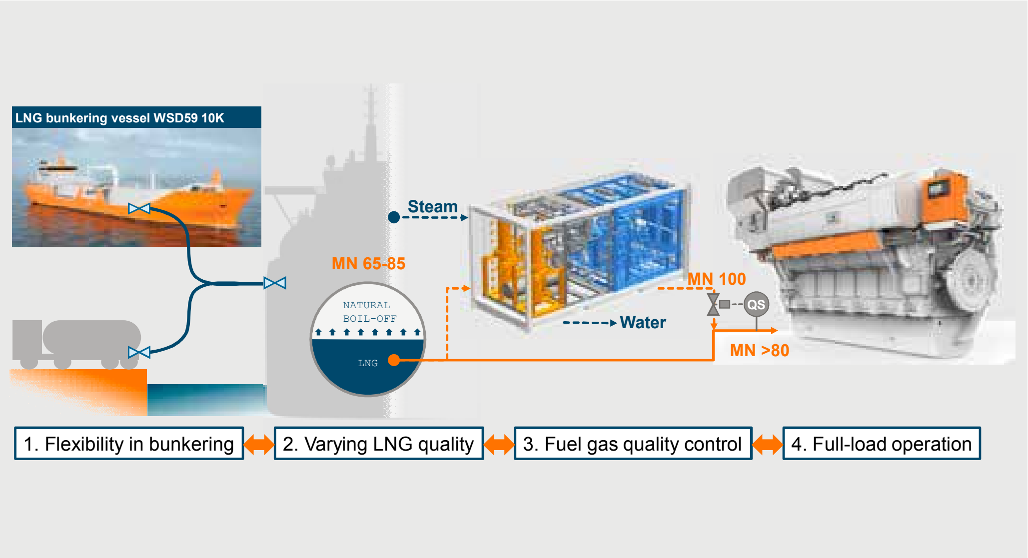

Fig. 3 - Fuel gas quality control with a GasReformer allows flexibility in LNG quality and bunkering on LNG-powered vessels.

reactor. On the catalyst surface, all the heavier hydrocarbons are split into smaller components, mainly methane and other constituents with only one carbon atom. The carbon chain is cut into small pieces and then built up again to finally form methane, with a little hydrogen and carbon dioxide produced, too. Then the Wärtsilä GasReformer cools it down, separates all excess steam in the system, and feeds it straight into the Wärtsilä 6L20DF engine. (Figure 2)

How did the Wärtsilä GasReformer perform?

In July 2016, a customer demonstration was carried out using the Pilot GasReformer in combination with a Wärtsilä 6L20DF engine. The GasReformer successfully demonstrated its capability to reform the LVOC into a high-quality gas that was successfully used in the Wärtsilä 20DF engine. Nitrogen oxide (NO_x) emissions were also confirmed to follow International Maritime Organization (IMO) Tier III limits when operating the engine on reformed LVOC. Furthermore, successful mixing tests were completed on the engine using ratios of non-reformed LVOC mixed directly into LNG.

LVOC is a heavy-fuel gas, consisting mainly of C3-C5 components, which the engine could not take, even if derated. Therefore, if there is any interest in utilising VOCs or boil-off gases (BOG), e.g. from very large gas carriers (VLGC) or LPG carriers, as fuel for DF engines, there is no other feasible way than improving the MN (either by GR or mixing with LNG).

Despite working with extremely heavy fuel gas, the Wärtsilä GasReformer produced a final fuel gas that was running with lower NO_x emissions than even natural gas.

By all measures, the demonstration for the customer was a success.

What are the reformer's proven benefits to customers?

The Wärtsilä GasReformer in Bermeo, Spain, demonstrated its ability to reform LVOC into methane. It also makes it possible for the Wärtsilä GasReformer to utilise gaseous fuels that either contain large amounts of heavier hydrocarbons (C_4+) or vary in their composition. Gases that were previously considered to be waste can now be converted into a valuable resource of energy.

Capital expenditure/operating expenditure (CAPEX/OPEX) concerns obviously still drive many customers, and this is where the Wärtsilä GasReformer excels.

By reducing greenhouse gases (GHG) emissions from the oil and gases value chain, through recovering vented and wasted hydrocarbons and utilising them for power generation, the operator or owner will get remarkable savings. For example, in fuelling costs, bunkering and transportation, saving could be around 50%.

When it comes to LNG-powered vessels, the GasReformer technology can be utilized for fuel gas quality control taking care that the methane number of the fuel gas to the DF engine is always above 80. This methane number control onboard will allow flexibility in LNG quality and bunkering. (Fig 3).

The environment also benefits

This new process boasts the environmental benefits derived from converting waste gas into usable fuel. Offshore gas flaring is increasingly recognised as a major environmental problem, causing 400 million tonnes of CO_2 in annual emissions, not to mention the valuable resources that go to waste. When considering the vented BOGs, i.e. the VOCs from the marine industry, the overall GHG effect becomes even more pronounced.

With the Wärtsilä GasReformer, this waste gas can be reliably and efficiently used by Wärtsilä dual-fuel (DF) engines. When utilising associated gas or recovered BOGs from tankers or gas carriers as a reliable source of energy, the operator can achieve self-sufficiency in terms of energy supply. Thus, the need for fuel bunkering or BOG reliquefaction, both costly operations, decreases. With a Wärtsilä 10 MW GasReformer combined with a DF engine, the operator can reduce the need for bunkered fuel oil by 39 tonnes per day (TPD) and reduce flaring by more than 1.1 million standard cubic feet of gas per day (MMSCFD), which equals >100 TPD equivalent carbon dioxide (CO_2eq). Where VOCs are usually vented, GHG emissions are reduced by 10.6 TPD CO_2eq per ton of recovered VOC.

Which industry will benefit most from the Wärtsilä GasReformer?

The offshore industry stands to gain the most because the biggest benefit to the offshore industry is the immediate reduction in the costs for primary fuel, transportation and bunkering. The offshore industry with all oil and gas production units does also have best knowledge and understanding on gas treatment processes.

If a customer is producing, for instance, LNG offshore, there are side streams such as natural gas liquids from LNG production or boil-off gases. These and other side streams can be utilised for power generation, so there will be no need for handling equipment of side streams such as reliquefaction, storage or shipping.

Also LNG-powered vessels in the marine industry can benefit from this technology, if it can guarantee full-load operation of the engine without limitations in LNG quality or bunkering. This fuel gas quality control will ease the operation and improve flexibility.

The investment into new, green technology, will usually have a payback time of one to three years.

Summary

Wärtsilä proved that the GasReformer can make use of gaseous fuels that either vary in their composition or contain large amounts of heavier hydrocarbons. Gases that were previously considered as waste can now be converted into a valuable energy resource. Especially in the offshore and marine industries, where cost savings and compliance with environmental regulations are critical, this development is significant. ●

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New Nacos Platinum navigation system complies with the toughest industry standards

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The latest version in Wärtsilä's series of navigation, automation and control systems – Wärtsilä Nacos Platinum 2.1 – brings new functionalities and a simplified user interface.

In response to increasing market and regulatory demands for maritime navigation system performance and safety, Wärtsilä has developed a new version of its cutting-edge system for commercial vessels, Wärtsilä Nacos Platinum 2.1.

Commercial vessels nowadays are equipped with electronic navigation systems to maximise navigational reliability and safety. In addition to essential navigation tools, such as radars and electronic sea charts, the newest systems also facilitate manoeuvring and dynamic positioning, power and propulsion and include tools for automation and monitoring on-board systems.

Wärtsilä Nacos Platinum is the most cutting–edge navigation system on the market for commercial vessels. It offers complete scalability and flexibility, from a stand-alone solution to a fully integrated system. Developed and marketed exclusively by Wärtsilä, Nacos Platinum was introduced in 2011 and achieved its next milestone in 2015 with the launch of Nacos Platinum 2.0. In late 2016, its features and functionality were further enhanced and are now available in the recent, most advanced version, Wärtsilä Nacos Platinum 2.1.

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New interface

Wärtsilä Nacos Platinum 2.1 comes with a simplified user-interface (HMI), which has been specifically designed for increased ease of use. Its user-centric design ensures easy, intuitive and safe operation across all systems and applications. Meanwhile, crew training and maintenance is facilitated, and it also allows for quick and simple introduction of future products and features.

The new HMI was based on feedback from a large number of Wärtsilä customers, after which it was aligned to create a series of new features. Wärtsilä Nacos Platinum is relevant to a wide variety of uses so a multitude of different functionalities were incorporated into the product to ensure that it fulfils a broad range of customer demands.

The more recent versions of Wärtsilä Nacos Platinum have been designed to cater to multiple market segments. In addition to the offshore segment, current versions are suited for a range of commercial cargo vessels, such as container vessels, as well as tankers, bulkers, cruise ships and yachts.

Multiple segments, discrete challenges

Every segment has its own unique navigational challenges. For example, cruise vessels and yachts typically have stricter demands regarding performance, functionality and redundancy, whereas cargo vessels may require primarily mandatory equipment. For example, specific functionality such as Speedpilot or Anchor Control are requested especially in the cruise and yacht market but not usually in the commercial cargo segment.

For Wärtsilä, the key to fulfilling these diverse needs is a scalable hardware platform with configurable functionality, which can be activated or deactivated depending on the specific requests made by a project, customer or market segment.

Another example of functionality that may be crucial to one segment but not to another is the Tender Tracking functionality, which is used to monitor online small watercraft around a main vessel (e.g., a yacht) and, therefore, is applicable primarily to the yacht segment. On the other hand, docking support systems, such as Fugro, are increasingly required by larger-size vessels – from cruise vessels to container ships to tankers.

New regulatory demands

Wärtsilä Nacos Platinum 2.0 was designed to fulfil the requirements of the international standards for Integrated Navigation Systems (INS) and Bridge Alert Management (BAM). With Wärtsilä Nacos Platinum 2.1, this development has progressed even further, incorporating additional functionality related to the new Electronic Chart Display & Information System (ECDIS) performance standard. Parts of the radar, as well as the ECDIS application and Conning application have also been redesigned.

The ECDIS standard increased the demands on alert management and the visualisation of objects in the electronic sea chart. New tools that have been introduced in Wärtsilä Nacos Platinum 2.1, as part of this new performance standard, include Detection and Notification of Navigational Hazards and Detection of Areas with Special Conditions. These new tools lead to increased safety and reduce the number of alerts due to the enhanced graphic visualisation of navigation hazards and special areas, thereby further enhancing the ways in which ECDIS outperforms a paper chart.

Wärtsilä Nacos Platinum 2.1 comes with a wide range of new visual formats, such as overlays, split screen views and merged radar images, all of which contribute to a vastly improved visual capability. For example, it is now possible to overlay environmental data, resulting in improved route planning. In turn, better routing enhances safety, increases efficiency and cuts fuel consumption. Meanwhile, radar merging creates a complete radar picture and eliminates the blind sectors that might typically be produced by the presence of a complex superstructure, such as a cruise ship or offshore jack-up vessel.

Integrated functionality

Farsounder Sonar is a forward-looking sonar function on Wärtsilä Nacos Platinum 2.1 that can detect obstacles in front of the vessel. This type of obstacle may range from foul ground to lost containers. The sensor enhances navigational safety by supporting "anti-grounding," which, besides the main radar task of "anti-collision," is the most crucial navigational task.

Another function that has been integrated into the navigation system with the release of Wärtsilä Nacos Platinum 2.1 is the Closed-Circuit Television (CCTV) video surveillance system. For safety reasons, systems of this kind are mandatory on a majority of vessel types. By integrating the CCTV into Nacos Platinum, Wärtsilä has taken another step towards unifying the hardware on the bridge into one master system.

Protection from cyber threats

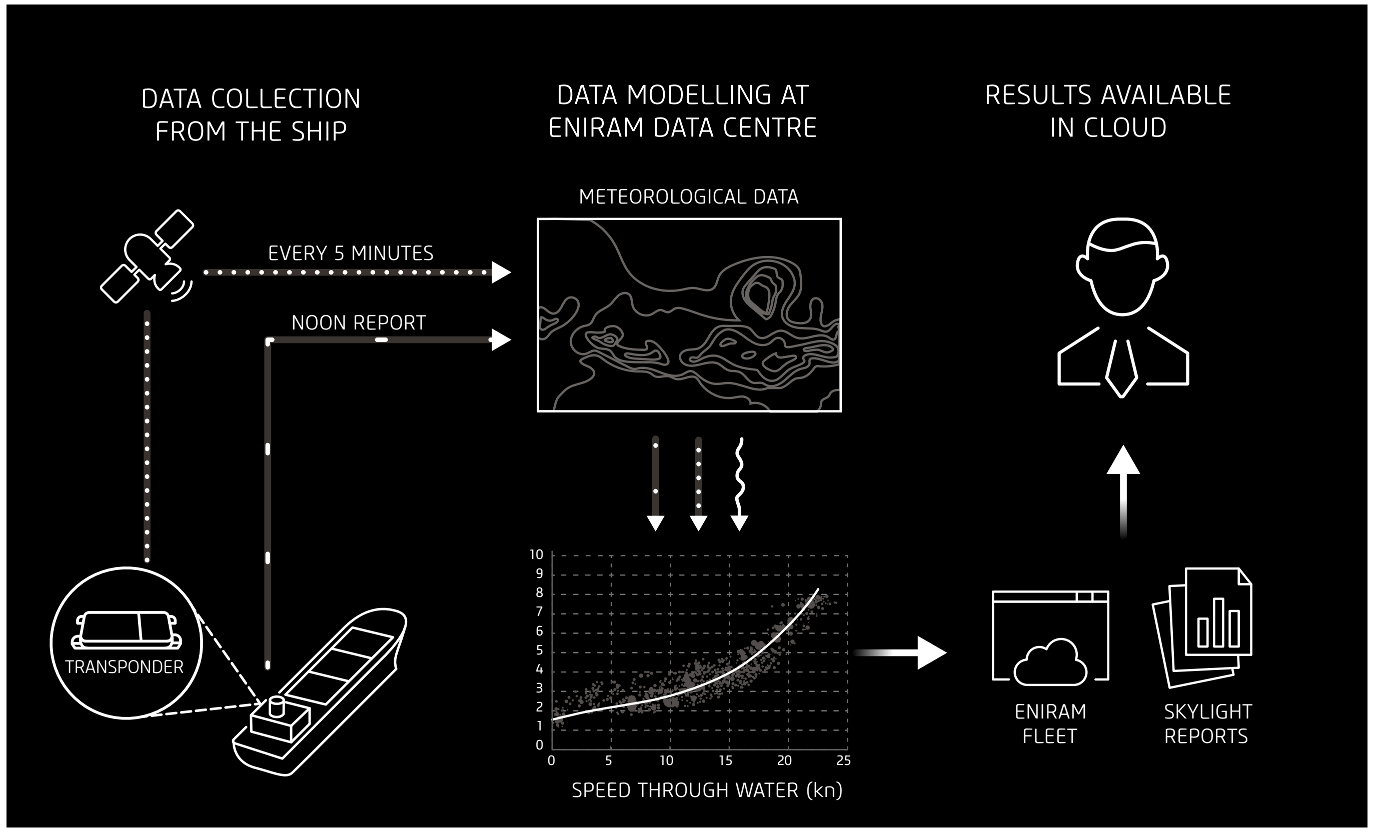
Another groundbreaking new feature on Wärtsilä Nacos Platinum 2.0 and 2.1 is the advanced cyber security protection.

In a world defined by ever-increasing connectivity and systems complexity, there is a growing need for vessel operators to exchange data with subsystems. For example, they may wish to integrate with third-party systems, to carry out energy efficiency evaluations, or they may need to set up ship-to-shore connections to exchange real-time data with land-based fleet operation centres. As connectivity increases, so do the number of cyber-security risks to which an advanced software and hardware solution, such as a navigation system, may become vulnerable. It may also run the risk of possible infection with a virus or malware via illegally connected storage media such as USB drives or service equipment.

Therefore, the Wärtsilä Nacos Platinum system has been hardened: no intruder can endanger the operation of the vessel, and only explicitly permitted processes can be started, thereby preventing malware from challenging the integrity of the system.

Market leadership

With its unrivalled features and user-friendly interface, Wärtsilä Nacos Platinum has been the navigation system of choice in the demanding cruise liner segment. With the new functionality and advanced safety features added as part of Wärtsilä Nacos Platinum 2.0 and 2.1, the current trend points to its adoption by a growing number of commercial cargo vessel and offshore operators going forward. ●



The SkyLight transponder starts the flow of performance-monitoring information from the ship to the cloud.

Joining forces with Eniram

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With the launch of SkyLight, a cost-effective, next generation fleet performance monitoring service, Eniram and Wärtsilä harness connectivity and the Internet of Things to support commercial ship operators' decision-making with the most current and accurate vessel data.

Years ago, Wärtsilä made the strategic decision to serve its customers, not only by providing the best possible engines, but by providing the best possible services as well. The traditional Services offering, based on statistical data about what is needed and when, will not change much. However, ongoing change is taking place, as the accuracy of the data that forms the basis of those decisions is continuously improving and adding new aspects of predictability.

Services, such as Condition Based Maintenance, are just small examples of what is and will be possible. For example, Wärtsilä's acquisition of Eniram, a world leader in vessel energy efficiency solutions, already broadens the offering to look at the overall picture of operating vessels.

Eniram has been in the maritime 'big data' business before that term was commonplace. Starting with collecting data to optimise the vessel trim, Eniram then moved into modelling the propulsion energy consumption to be able to prove savings achieved. This led to collecting more and more variables and modelling their effect on any given topic being studied. What resulted were more comprehensive energy management solutions and services that penetrated areas outside normal ship operations.

Now Eniram has supplied shipping companies with intelligent decision support tools for over 10 years. In collaboration with Wärtsilä, Eniram will use its existing ideology and technology to further extend Wärtsilä's capability to offer the best possible tools to manage everything for shipping companies and even beyond the maritime industry.

SkyLight enters the picture

In September, Eniram and Wärtsilä released SkyLight, a fleet monitoring service that facilitates the optimisation of a vessel's performance. This next-generation solution offers vastly improved and more accurate information compared to manual performance reporting with Automatic Identification System (AIS), which is common amongst providers offering similar services.

With SkyLight, commercial operators can cost-effectively monitor their fleet and compare in detail the fuel usage, speed and nautical performance between their vessels. The software keeps records of the ships' performance, enabling more prompt reporting, planning and cost optimisation. Not only does SkyLight allow for faster and more effective planning, but it also creates transparency for possible money-saving cuts in the Charter Party margins.

SkyLight is a subscription-based service delivered via a portable two-way transponder. As the transponder (with batteries) is the only hardware required, the small package of only a few kilos can be delivered to the customer via standard courier company.

A vessel's crew can easily install the transponder without requiring the help of specialists or engineers. In less than 15 minutes, it can be mounted to an outside deck railing, by using the mounting hardware provided and inserting batteries.

SkyLight has an independent satellite link that works around the globe. With its own built-in connection, SkyLight does not need to use the vessel's own satellite connection.

SkyLight's subscription fee is all-inclusive and incorporates the cost of the hardware, satellite link and satellite transmission, web application access, weekly reports and even shipping. If there should be a need to cancel the subscription for a particular vessel, the customer merely returns the transponder.

Real-time data fuels advanced analytics services

GPS data is sent from the transponder through its built-in satellite connection and compiled with other forms of data, such as weather data, on winds, ocean currents, etc., provided by an external company. The remainder of the data collected currently comes from the customer via the noon report. While there is an option to complete many additional fields, only a minimal set is necessary. Just a few numbers, such as the remaining fuel on board (ROB), is enough to get started.

Using the various inputs, Eniram then uses mathematical models to do 'data enrichment'. The models calculate and predict fuel consumption, especially the speed-fuel curve, which is key in shipping. Pulling out the weather effects of the speed-fuel curve creates a 'normalised' curve, which can be compared across vessels or routes.

The customer has instant access to the collected and analysed performance data via Fleet, Eniram's cloud-based software interface. Customers can track vessel positions on a map, see weather data and

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Customers have instant access to performance data via Fleet, Eniram's cloud-based software interface.

compare fuel data and fuel consumption next to the map. The collected vessel data is visible online, but customers can also extract it to Excel to do their own analytics.

In addition to the web-based data, three reports are sent to the customer in PDF format on a weekly basis:

1. The Charter Party Monitoring Report shows how well the vessel meets the agreement parameters. (Figure 1)
2. The Normalised Fuel Consumption Report shows a vessel's normalised speed-fuel curve and displays it in different contexts, such as laden vs. ballast. (Figure 2)
3. In figure 3, the Speed Profile Report shows what the speeds have been, i.e. sailing from point A to point B. It also compares the actual profile to the even speed profile and gives the difference in fuel consumption between the two models, which illustrates the percentage of fuel lost using a non-optimal speed profile.

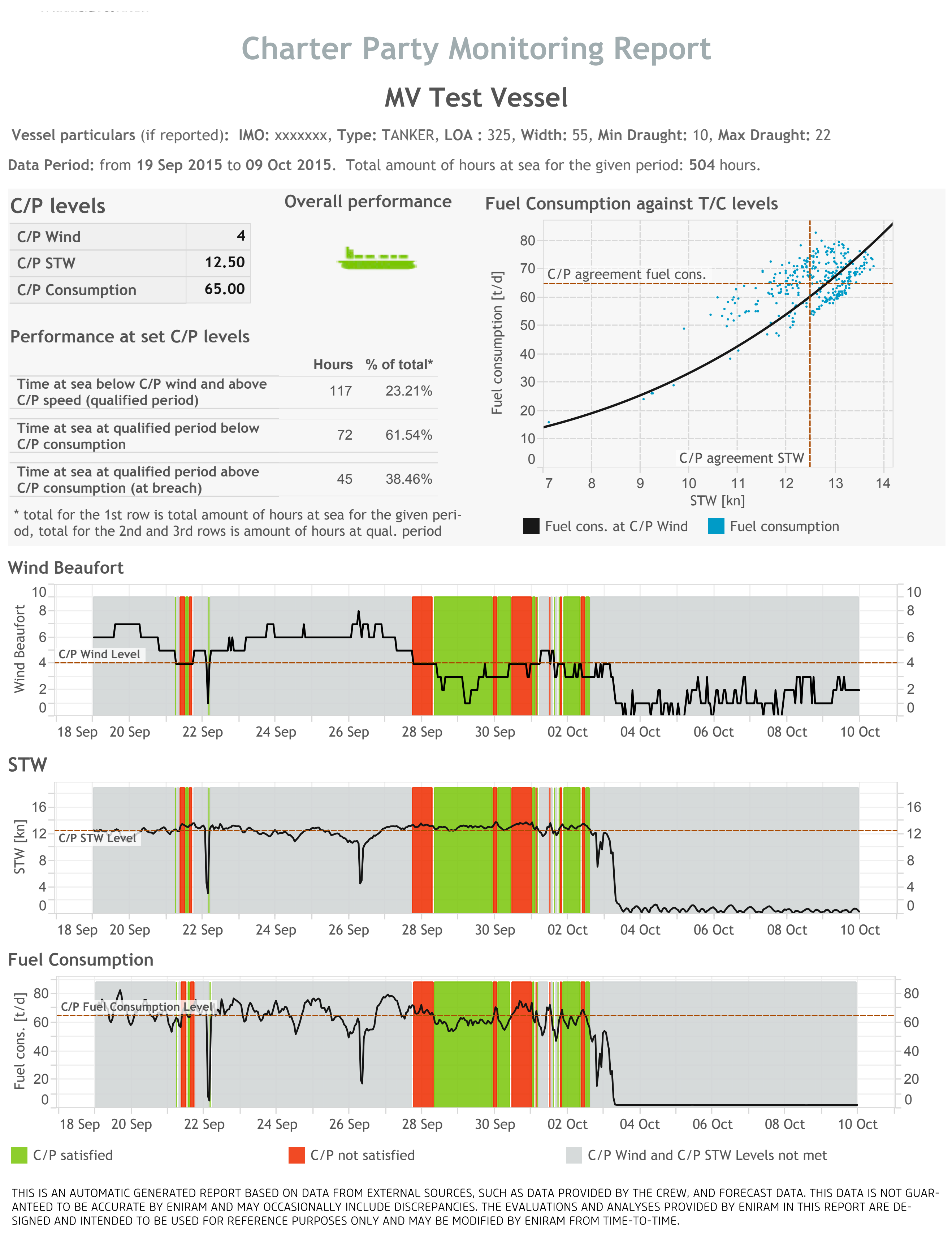
Looking ahead

Delivering performance monitoring through portable equipment as a service enables even operators with shorter business cycles to get the benefits of advanced data analytics. This type of service is a natural first step in the use of real-time data for fuel performance optimisation.

The cost-effective approach of SkyLight makes energy and performance management accessible for all operators, owners and charterers, regardless of the size of their fleet. Given that the service does not require any big investments or alterations to the ship, customers can minimise their investment by starting with a few vessels and expanding fleet-wide as their pace allows.

There are several elements in the development pipeline, with new features being added all the time. For example, in the future, customers will be able to do fouling analysis based on the data from the existing platform and will be able to add nautical charts in the web application as well as layer more data, such as weather data, on top of the map.

SkyLight's combination of intelligent built-in sensors, integrated satellite communication and tools for web-based analytics allows for optimisation of ship performance at cost levels never seen before. With opportunities created by connectivity and the Internet of Things, the potential for even richer data going forward is almost limitless. ●



Charter Party Monitoring Report

MV Test Vessel

Vessel particulars (if reported): **IMO:** xxxxxxx, **Type:** TANKER, **LOA :** 325, **Width:** 55, **Min Draught:** 10, **Max Draught:** 22

Data Period: from **19 Sep 2015** to **09 Oct 2015**. Total amount of hours at sea for the given period: **504** hours.

C/P levels

C/P Wind	4
C/P STW	12.50
C/P Consumption	65.00

Overall performance

Performance at set C/P levels

	Hours	% of total*
Time at sea below C/P wind and above C/P speed (qualified period)	117	23.21%
Time at sea at qualified period below C/P consumption	72	61.54%
Time at sea at qualified period above C/P consumption (at breach)	45	38.46%

* total for the 1st row is total amount of hours at sea for the given period, total for the 2nd and 3rd rows is amount of hours at qual. period

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Fig. 1 - The Charter Party Monitoring Report shows how well the vessel meets the agreement parameters.

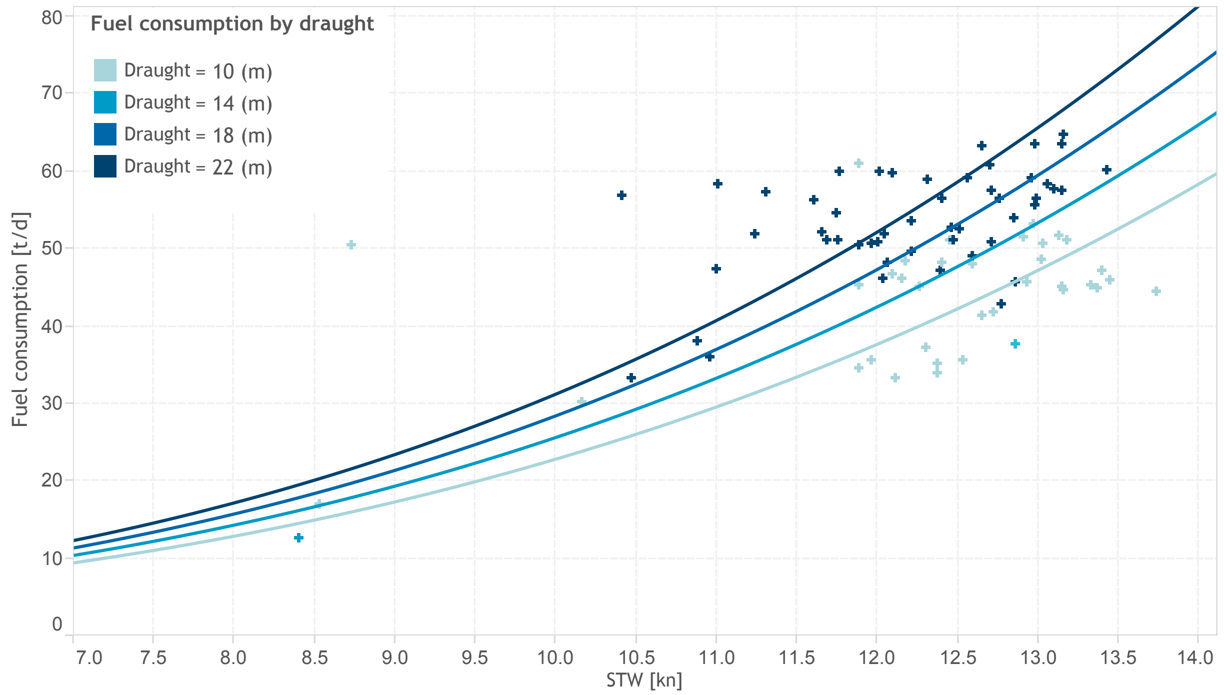
Normalized Fuel Consumption Report

MV Test Vessel

Vessel particulars (if reported): **IMO:** xxxxxxx, **Type:** TANKER, **LOA :** 325, **Width:** 55, **Min Draught:** 10, **Max Draught:** 22

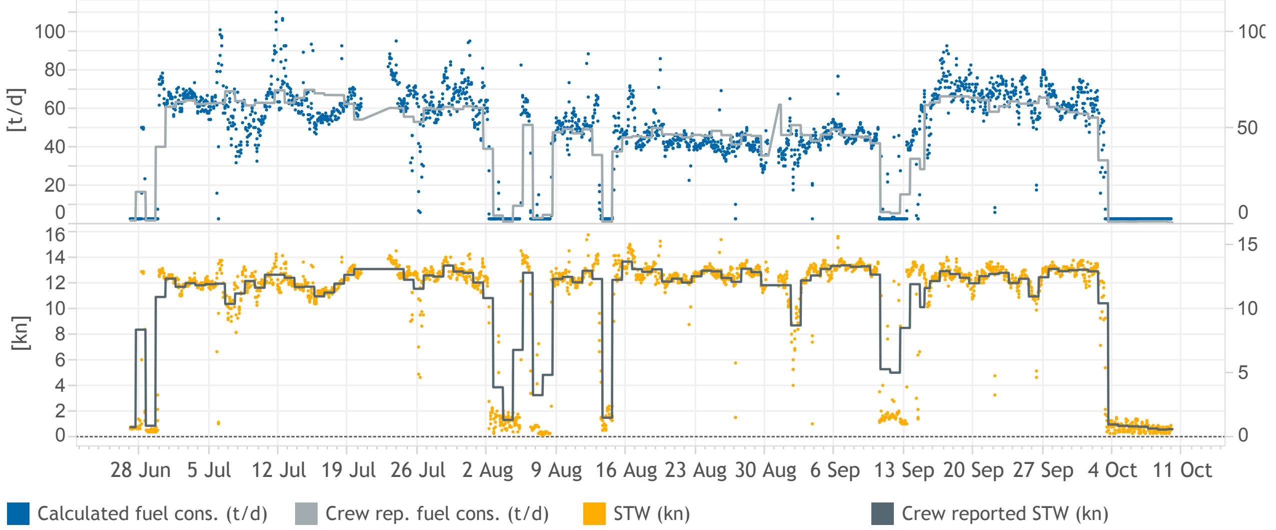
Data Period: from **27 Jun 2015** to **09 Oct 2015**.

Normalized Speed Fuel Curve*



* Normalized Speed Fuel Curve removes any weather effect from measured d

Speed and Fuel Consumption Profile



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■ **Fig. 2 - The Normalised Fuel Consumption Report shows a vessel's normalised speed-fuel curve and displays it with different parameters, such as laden vs. ballast.**

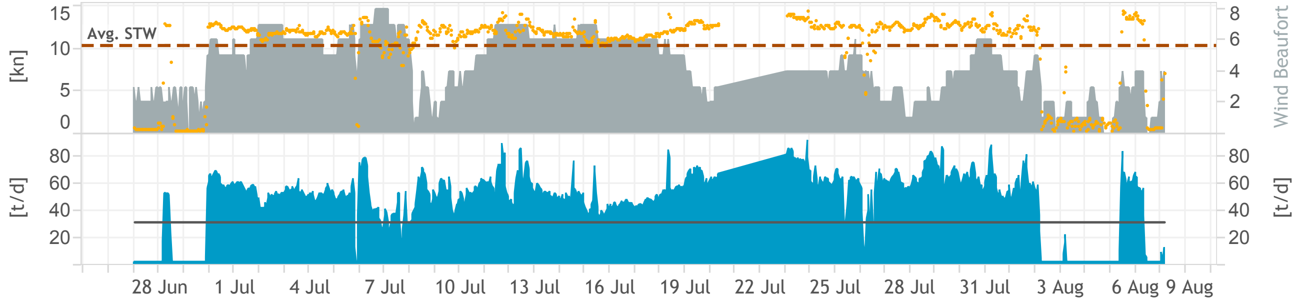
Speed Profile Report

MV Test Vessel

Vessel particulars (if reported): **IMO:** xxxxxxx, **Type:** TANKER, **LOA :** 325, **Width:** 55, **Min Draught:** 10, **Max Draught:** 22

Data Period: from **27 Jun 2015** to **09 Oct 2015**.

Voyage ID: 17



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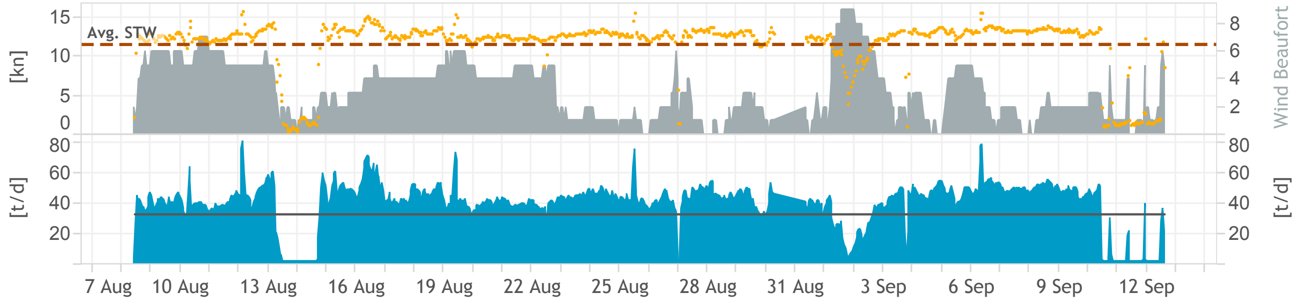

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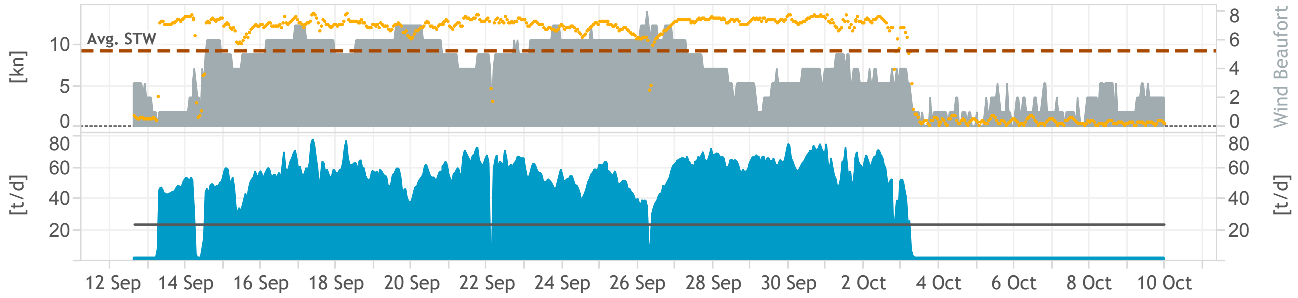

STW (kn) Wind Beaufort Normalized fuel cons. (t/d) Even speed fuel cons. (t/d)

Voyage ID	Leg start	Leg end	Normalized fuel consumption per leg (t)	Even speed fuel cons. per leg (t)	STW (kn)	Steaming days	Additional consumption caused by uneven speed profile (t)	Additional consumption caused by uneven speed profile (%)
17	27 Jun 2015 00:00	07 Aug 2015 03:00	1,938	1,308	10.27	32	629.9	48%
18	08 Aug 2015 10:00	12 Sep 2015 14:00	1,396	1,165	11.51	31	230.9	20%
27	12 Sep 2015 15:00	09 Oct 2015 23:00	1,112	637	9.23	20	475.1	75%

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■ **Fig. 3 - The Speed Profile Report shows what the speeds have been, i.e. sailing from point A to point B, and compares the actual profile to the even speed profile and gives the difference in fuel consumption between the models.**

Reinventing Wärtsilä

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As the second industrial revolution gives way to the third, the lines between manufacturing and services are blurring and leading to the integration of new digital tools and web-based services. Marco Ryan explains Wärtsilä's strategy for keeping pace.

"I invite you, our customers and stakeholders, to share in helping make it easier to do business with Wärtsilä," says Marco Ryan, Wärtsilä's Chief Digital Officer, who believes that the way forward is to enable the "reinvention of the company into 'Wärtsilä-as-a-Service' – a smart-technology company that takes a leadership role in the 'smart marine' and 'smart energy' ecosystems, aiming at increasing efficiency while enabling a zero-emission society."

Ryan is looking at every aspect of the business to find ways to ensure that 'digital' becomes infused throughout the company's DNA. "Rather than creating a separate digital silo, the future of Wärtsilä will require an integration of processes, solutions and business lines," he says.

Wärtsilä's Board of Management has launched a bold strategy – designed to drive digital competence pervasively across the business in support of this shift – based on five 'digital promises':

1. **Easy to Do Business with** – Wärtsilä will be agile, open and responsive and will maximise customer value by developing seamless integrations, a variety of partnerships, and more data transparency across the ecosystems it focuses on.
2. **One Wärtsilä** – Wärtsilä will be unified by a more digital culture, with new ways of working, state-of-the-art tools, and different organisational models.
3. **Digitised core** – Wärtsilä will increase efficiency and productivity across the supply chain, in manufacturing, R&D, in Sales & Marketing, in the development of new and more open platforms, in the integration of products and their user interfaces – everywhere!
4. **"Digital first" mind-set** – Wärtsilä will focus on new business models, new digital offerings that rely on data and analytics, as well as design thinking, to drive more robust product development, new approaches to innovation and investment in start-ups and "corporate venturing."
5. **Quality and security** – Wärtsilä will take a new, more standardised approach to all software development, product design, security and solutions. Cyber security as a new competence will be embedded into all products and solutions.

Ryan points out that the company's success depends on the partnership and collaboration of its customers and suppliers, as well as its employees. "We welcome any ideas or thoughts about how to make Wärtsilä's digital offering more relevant, more accurate and proactive in meeting your needs," he says.