Tanking along

Increasing fuel efficiency and cargo capacity of LNG carriers using electric propulsion

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As the world's demand for energy has increased, so too has the demand for large liquid natural gas (LNG) terminals and floating LNG production facilities. The transportation of LNG is, therefore, likely to increase rapidly in the coming years, requiring an increase in the number and size of LNG carriers.

Traditional LNG Carrier propulsion systems (steam turbines) deliver less than 30 percent fuel efficiency, however, today's electric propulsion systems can deliver more than 40 percent fuel efficiency. For LNG carriers, this translates to more than a 30 percent reduction in fuel consumption. In addition, because the electric propulsion system is more flexible, the cargo space can expand into the engine room, typically increasing capacity on a 145,000 m^3 vessel by a further 10,000 m^3.

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The steady growth in world energy demand continues to drive the search for new energy sources. Natural gas has satisfied some of this demand for more than 30 years. Most of the world's gas is transported by pipelines from the producing fields to the consumer (over land and, for shorter distances, across the sea bed, from the North Sea to Europe, for example). From the late 1960s through the 1970s, the development of gas fields further offshore, in deeper water, and at more remote locations from consumers, has led to a growth in the production of liquefied natural gas (LNG) and its transportation by ship. The ships used were constructed with special insulated cargo tanks so that the LNG could be carried at a temperature of –162°C.

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With increasing energy demand in Asia, and particularly Japan, imports of LNG increased steadily, requiring more ships with greater capacities. In the 1970s and 1980s the ships were built mainly in Japan, but in the 1990s, South Korea emerged as a leading ship building nation and, by the end of the 1990s and early 2000s, the majority of LNG carriers were built in South Korea. The size of vessels had also increased to a standardized cargo capacity of 138,000 to 145,000 m^3 LNG. All of these LNG carriers were built for long-term lease, up to 30 years. They were chartered for LNG transport from gas fields to consumers, where pipeline use was not economically or technically feasible. The LNG producing and receiving terminals, including the surrounding infrastructure, were built for continuous gas supplies. This means that if one LNG carrier misses its loading slot at the terminal, a severe disruption in energy supply would result.

With this pressure to provide extremely reliable ships, with robust machinery and propulsion systems, less importance was placed on efficiency and fuel consumption. Steam-turbine propulsion systems were most commonly used because they offered excellent reliability and could use the gas onboard as a fuel. LNG is transported at –162°C, however, depending on the efficiency of the insulation and the roughness of the voyage, a small amount of gas is lost in transit. This "boil-off" gas, supplemented with heavy fuel oil, was used to heat the boilers, producing steam to drive the ship's turbine.

From steam turbines to gas electric

Although the steam turbine is highly reliable and requires almost no maintenance, the boilers upon which they rely, require regular maintenance. Twin boilers are generally installed to ensure reliability; however, the thermal efficiency of this type of system is lower than 30 percent. Alternatives, such as combustion engines are known to be 45 to 50 percent efficient; therefore, the potential for fuel saving by changing the propulsion system is huge. Despite this difference, the steam-turbine propulsion system, due to its reliability, remained the preferred solution, and LNG carriers are among the last major shipping types still using this form of propulsion.

As the vessels increased in size, so too did their need for installed electric power, the main purpose of which is to operate the larger cargo pumps. These are electric-driven pumps, submerged in the LNG tanks, and used to pump the gas out of the vessel at terminals. The installed electric power was increased to more than 10 MW for 140,000 m^3 capacity carriers, requiring high-voltage (HV) onboard power equipment. The first LNG carriers equipped with HV power plants of 3.3 kV and 6.6 kV were ordered in 2000. As a major supplier of electric power systems in the marine market, ABB took part in the design and supply of HV air-insulated switchgear for use in 40 LNG carriers between 2000 and 2006.

LNG carriers, however, were still built with steam-turbine propulsion, but there was growing interest in alternatives. In 2000, the engine maker Wartsila introduced dual-fuel combustion engines to the market, which could operate using either gas or diesel. These 4-stroke engines were basically designed to generate electric power, operating at constant speed, and requiring an electric distribution and propulsion system to drive the propeller. Even accounting for electrical transmission losses, the total propulsion efficiency for the dual-fuel system, known as DFEP (dual-fuel electric propulsion) was about 42 percent, much better than the 30 percent delivered by steam turbines 1. Today there are two suppliers of dual-fuel engines on the market, Wartsila and MAN.

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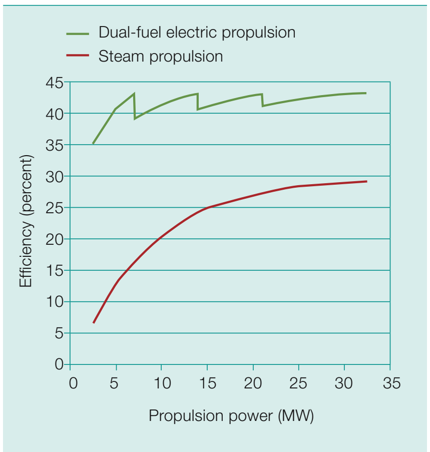
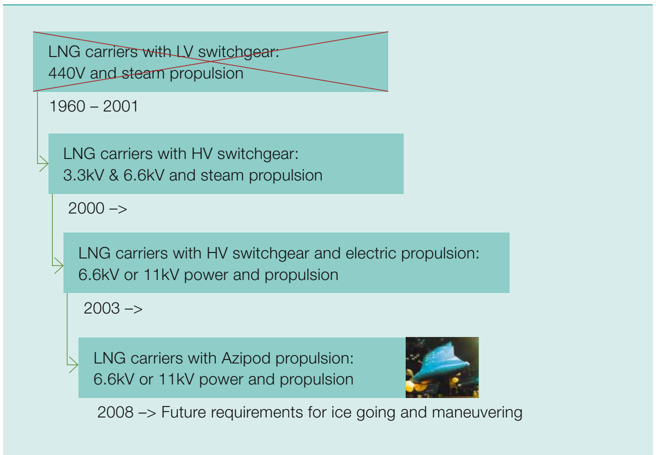
In 2003, Gaz de France (now GDF Suez) ordered the first three LNG carriers from Chantiers de l'Atlantique (now STX Europe) to be equipped with the new DFEP system. As soon as this first step was taken, other ship yards and owners followed, and by the end of 2005, almost all new orders for LNG carriers with capacities between 145,000 and 170,000 m^3, were

1 Fuel efficiency curves as a function of propeller loading of dual-fuel electric propulsion and steam turbine propulsion

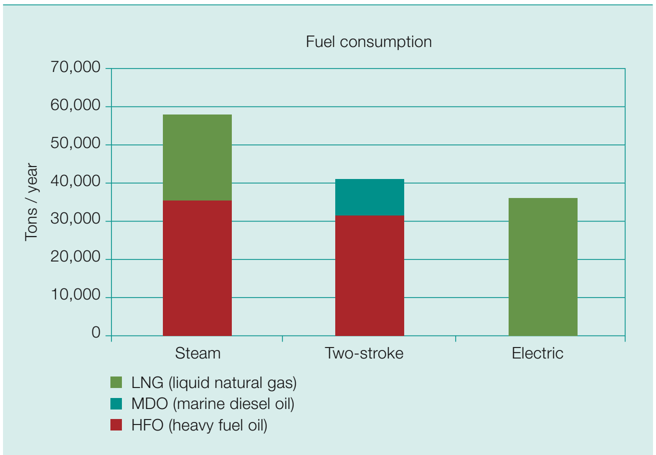


Productivity solutions

2 The basic steps in the development of new generation LNG carriers



3 The yearly calculated fuel consumption for the various alternatives based on efficiency considerations and an operation profile of 7,500 h per year



ordered with DFEP **2**. The main message from Gaz de France was that they could deliver more gas, more efficiently using clean gas as fuel.

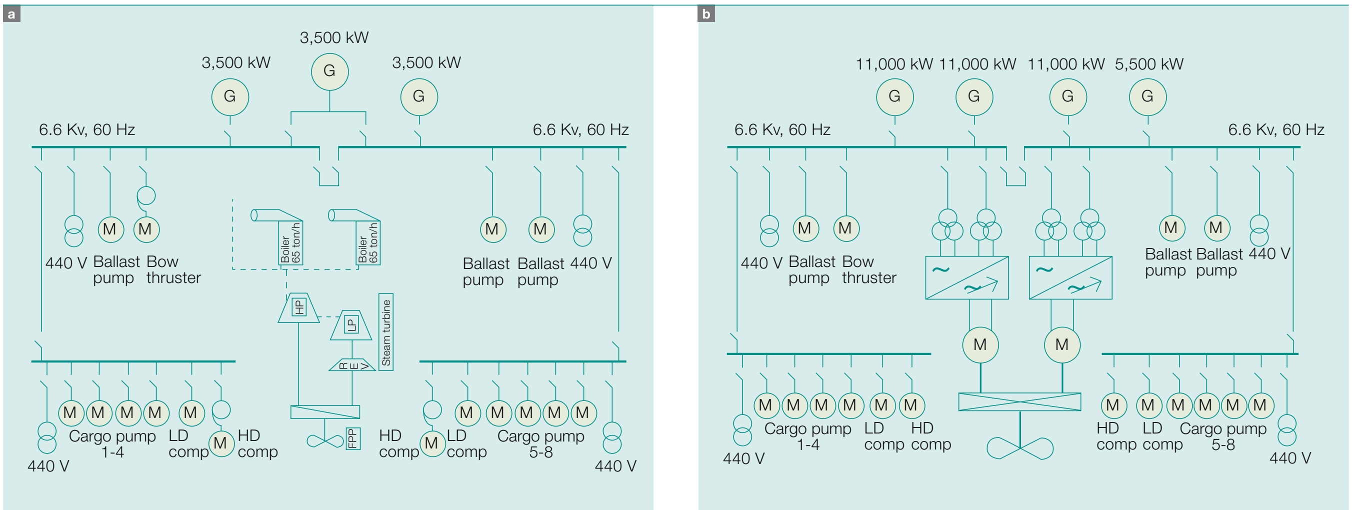
Not all LNG carriers have opted for the electric propulsion solution. The Qatar Gas Project has opted for LNG carriers with capacities up to 260,000 m³ and use a traditional two-stroke engine propulsion system alongside an onboard auxiliary plant to reliquefy the boil-off gas and return it to the tanks. This system, however, still requires quite a large HV electric power plant to feed the cargo pumps and the reliquefaction plant, which can consume up to 6 MW of electric power. This additional electric power consumption is much higher than the electrical losses experienced with an electric propulsion plant. With a propulsion power of 30 MW, for example, the electric propulsion plant's electrical losses would be at a maximum of 2.5 MW **3**.

The DFEP system not only provides energy efficiency, it also permits increased cargo capacity. The arrangement of the electric power and propulsion plant equipment is more flexible than that of mechanical propulsion systems. Even if additional electric components are installed, the flexibility of the DFEP system means it can still accommodate more cargo. The engines can be mounted on a higher deck level, reducing the volume of exhaust-gas piping that is usually required when engines are arranged on lower decks. There is no mechanical connection between equipment (ie, generators, converters, transformers and propulsion motors) only cabling, so the equipment can be arranged to optimize space savings. This has meant the capacity of standard LNG carriers of around 150,000 m³ capacity can be expanded by more than 6 percent, without altering the ships' external dimensions.

Configurations and ABB scope

DFEP has two main core technologies: dual-fuel, four-stroke engines, which are quite new to the general market especially to shipping, and electric propulsion, which is new to the LNG shipping market, but has been used,

4 The electrical power plant configuration for **a** an LNG carrier with conventional steam turbine propulsion, compared with **b** the configuration with electric propulsion.



especially in cruise ships, since the mid-1980s. However, the general shipping and LNG markets are quite conservative. Changing from a well-established and reliable propulsion system to a novel system has taken time. Before the first ship owners took the initiative, a period of product maturity and proven capability was required. Once the benefits of space and fuel savings were shown to be quite significant, other ship owners and yards could follow with more confidence. The potential operational cost savings were simply too large to ignore. However, such technology could be adopted only if its reliability was equal to that of conventional steam-turbine propulsion systems.

In the early stages of development, a great many different configurations were discussed, with respect to the number of engines, number of propellers, redundancy, etc. Of these alternative scenarios two or three alternatives were particularly favored, one configuration has become more popular and has been widely adopted 4.

In the most common arrangement, the power plant consists of four medium-speed, dual-fuel engines, each with a generator. The ratings of the generators vary slightly from project to project, but are usually optimized for the most commonly used operations, such as LNG loading and unloading, and transit sailing, each of which has a different power requirement. The HV power plant is split into four different sections, two main switchgears and two cargo switchgears. The reason for separating the two types of switchgear is purely to optimize the spatial arrangement of the installation. The propulsion system is also split into two separate drive systems, each with a corresponding drive transformer, frequency converter and propulsion motor. Finally, the two motors are mechanically connected via a common gearbox, with one shaft outlet to the propeller. This system combines simplicity with reliability. There is sufficient redundancy to keep the propeller operating even when maintenance or repair work force one of the engines or one of the electrical networks to be shut down. Mechanically, the propeller system is almost identical to that of the traditional steam-turbine system, with a gearbox and single shaft outlet to the propeller. Some schemes have twin propellers, which provide 50 percent redundancy all the way to the propeller shaft. Electrically, the twin system is identical to the single-propeller system, with the exception that the control system (located on the ship's bridge) allows the speed of each propeller to be controlled independently.

ABB has a long and proven track record in electric propulsion, especially in cruise vessels and has delivered or has on order, electric power and propulsion systems for 33 LNG carriers.

The propulsion power requirements for LNG carriers are in the range of 25 to 30 MW, which means each propulsion motor is usually rated somewhere between 12.5 and 15 MW. The power ratings vary depending on the ship's power to speed requirement and the design of the hull.

ABB typically supplies all HV electrical equipment for a ship, from the generators to the propulsion motors, and all the related propulsion control systems. ABB has a long and proven track record in electric propulsion, especially in cruise vessels with similar sized propulsion requirements and power plants to LNG carriers. In fact, as indicated in November 2008, ABB has delivered or has on order electric power and propulsion systems for 33 LNG carriers.

ABB's electrical propulsion products are manufactured in ABB factories dedicated to marine applications. To meet the high reliability demands of LNG carriers, ABB is able to draw on its long experience earned in the cruise-ship business and upon well-established ABB products. ABB's synchronous AMG generators and AMZ motors 5 have efficiency levels among the highest on the market. For some projects, these motors and generators have achieved efficiencies of 97.9 percent and 98.4 percent, respectively, in factory test facilities[1)].

ABB's robust medium-voltage switchgear (UniGear) and air-insulated motor control switchgear (UniMotor), including the HD4 (SF_6-type) and VD4 (vacuum-type) circuit breakers, are used for HV distribution networks. The metal-clad, arc-proof switchgear housing provides high-level protection for personnel, even working in the same room. The cabinets also have a door interlocking system and compartment segregation to prevent access to live parts when the equipment is operational.

The propulsion system's drives use ABB's unique resin-encapsulated transformer, the RESIBLOC® 6, and the ACS6000 medium-voltage frequency converter. The RESIBLOC trans-

5 AMZ propulsion motor

6 ABB RESIBLOC Transformer

Footnotes

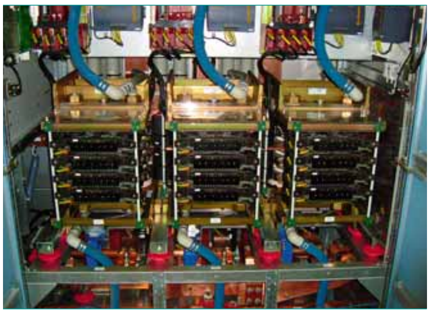
1) Efficiency is measured at the Factory Acceptance Test [FAT] with sinusoidal supply, and with the addition of harmonic and auxiliary losses.

formers have a high mechanical strength, well suited to marine environments, where they experience strong vibrations and rough sea movements. Another feature of the RESIBLOC design is the linear impulse voltage distribution between the windings. This feature is especially important for marine applications where the switching voltage transients are much steeper than the normalized impulse voltage used standardly in transformer design.

ABB's RESIBLOC transformers have a high mechanical strength, well suited to marine environments, where they experience strong vibrations and rough sea movements.

The ACS6000 is a voltage source inverter (VSI)-type frequency converter, introduced to the market by ABB in 2000 7. It is controlled by an ABB-patented algorithm known as Direct Torque Control (DTC®) and can be combined with the well-established, synchronous AMZ motors, which suit the power requirements of LNG carriers.

7 Inverter unit of ACS6000 frequency converter



Experience from sea trials

Since 2003, when the first electrical propulsion LNG carriers were ordered, more than six carriers have been delivered with ABB propulsion systems. The performance of these carriers, all of which are still in operation, has met or exceeded design expectation in terms of control and energy efficiency. When selecting the DFEP system, one of the key concerns is that, when operating in gas-mode, the engines are more sensitive to load variations than when operating in standard diesel-mode. It is, therefore, essential that the propulsion drive system (the largest onboard consumer of electric power) keeps the load on the switchgear as constant as possible, even in rough seas. For this reason the control system is equipped to perform in two operation modes:

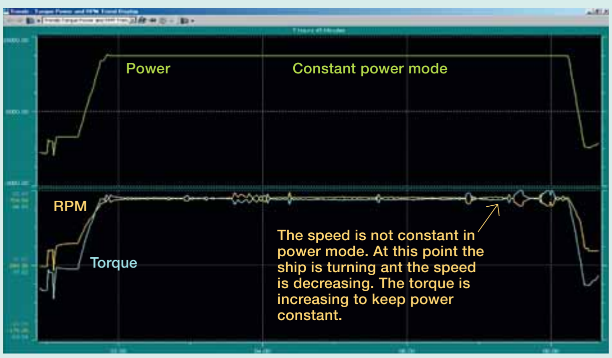
- RPM mode, in which the controller maintains a near-constant RPM.
- Power mode, in which the controller maintains a near -constant level of power.

When the ship is maneuvering, RPM mode is selected automatically in order to gain a rapid response to the captain's actions on the bridge. In open water, above a certain power level (>50 percent), power mode is selected, so that the RPM and torque on the propeller can fluctuate with sea conditions, while the electric power consumption remains near constant 8. During a six-hour endurance test, when the ship was sailing continuously at full propulsion power (ie, in power mode), data collected showed that the power consumed by the propulsion system indeed remained constant. One of the reasons for this unique performance profile was that the DTC algorithm, used in the ACS6000 frequency converter, was able to adjust the motor torque within milliseconds and compensate immediately for the varying wave-induced torque on the propeller.

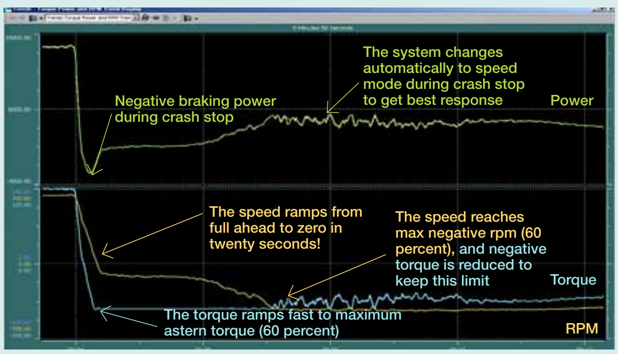
When a maximum (100 percent) load was applied to ABB's electric propulsion drives they showed a system efficiency of 94.3 percent, including the gearbox.

Crash-stop tests have also been performed and demonstrate that the machinery is capable of reversing the propeller thrust to rapidly bring the ship to a halt 9. In such situations the electric motor is superior to mechanical propulsion, since it can provide a stable reverse torque on the shaft whatever the RPM. Under such conditions, the motor actually operates as a generator, feeding energy from the propeller back to the drive system as the propeller speed is reduced to zero. This reverse energy is dissipated using separate brake resistors in order to avoid any reverse power disturbance

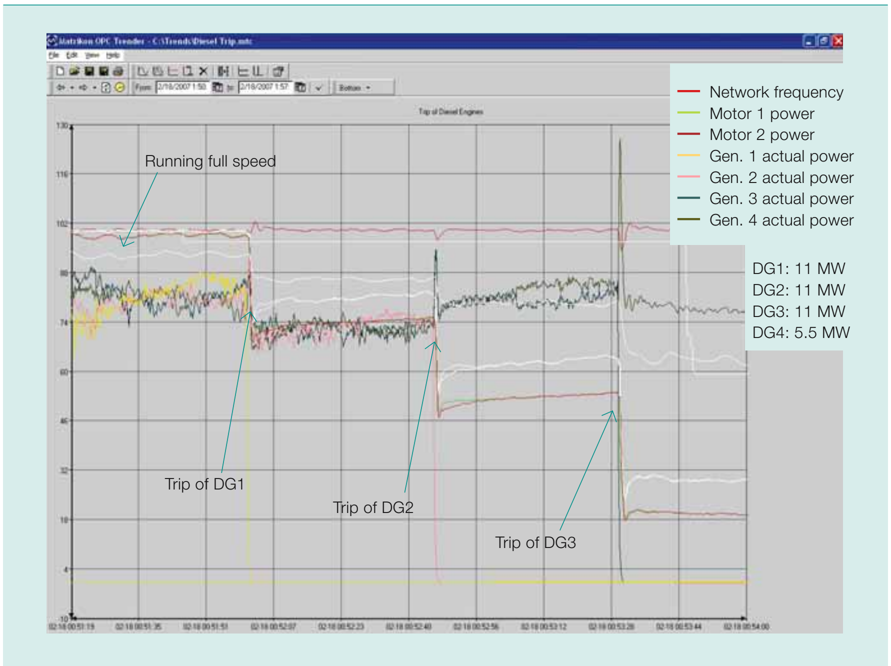
8 Power, torque and RPM recordings from sea trials; endurance test – constant power mode



9 Crash stop test recordings of propulsion motor power, torque and RPM



10 Blackout prevention test by intentionally tripping generators under conditions of 100 percent load



of the main engines. The test showed that the ship could be stopped within about 7 minutes, which is much faster than can be achieved using traditional steam-turbines. Here, reported stopping times are in the range of 20 to 30 minutes.

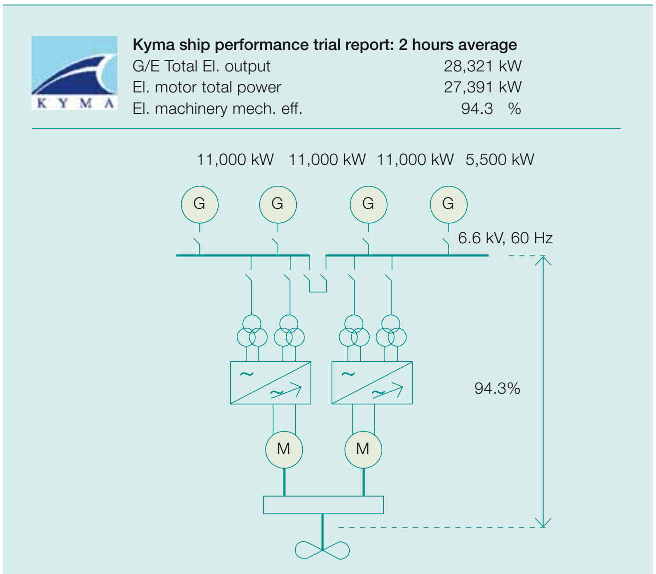
Another important feature of electric propulsion is the blackout prevention capability, which allows continued operation even during failure modes. The worst-case scenario is that one generator-engine trips and the disturbance from this leads to additional generator-engine trips, leading to a total blackout. The rapid load reduction in propulsion power protects the remaining generators. As soon as a generator trip is detected, the propulsion control system instantly reduces the propulsion power to avoid overloading the remaining generators. This feature was tested at sea with a generator configuration of 3 × 11 MW and 1 × 5.5 MW. During the test, the three 11-MW generators were intentionally tripped, one by one, until only the small, 5.5-MW generator remained. During this test, the generators were protected and the equipment passed the test without a blackout 10.

To measure efficiency, the ship's owner installed a system from KYMA[2] that was able to measure, using strain-gauges, the mechanical power driving the propeller shaft. By comparing the value obtained on the propeller shaft with the electrical load supplied to the propulsion drives from the switchgear, the efficiency of the propulsion drive system, including the gearbox, was obtained.

When a maximum (100 percent) load was applied to the propulsion drives, the reading showed an efficiency of 94.3 percent 11. The calculated expected efficiency of related equipment was approximately 93.6 percent (including 1.5 percent estimated losses in the gearbox). These measurements proved that the system efficiency was better than predicted by theoretical calculations.

The LNG market is still changing, and is expected to increase in volume more rapidly in the coming years than ever before. For LNG carriers, alternative propulsion methods are under consideration, such as steam-turbines with higher efficiencies, two-stroke motors with gas injection, etc. Today, with leasing contracts no longer tied to 30-year periods, LNG carriers must be more flexible. Carriers built for spot-markets need flexibility in operation speed, sailing distance, fuel type, etc. All these requirements make the electric propulsion system even more attractive. Future requirements for LNG carriers in the arctic will further strengthen demands for electric propulsion with ice breaker design, where ABB Azipod® propulsion has already proven its functionality and performance. The Azipod unit has previously been successful for ice-breakers and cruise ships, and also, more recently, for other vessels, such as oil tankers and container ships.

11 Efficiency measurement from propeller shaft to switchgear



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Footnote

[2] A company who supply various performance monitoring devices, in this case shaft power measurements. This was not ordered by ABB or the shipyard, but directly by the ship owner to verify the performance. See: http://www.kyma.no/