Dual Fuel Electric Propulsion Systems in LNG Shipping

Alexander Harsema-Mensonides
Managing Director
MPT Consultancy

Introduction

Since the beginning of the 21st century, LNG has been very much in the picture. Oil majors are expecting that LNG will be taking a much larger share in the energy mix in the next 25 years. The LNG value chain necessarily involves LNG shipping. It's in this part of the value chain that we've seen some major technology changes recently. The introduction of the dual fuel diesel electric (DFDE) LNG carrier (LNGC) and the slow speed diesel driven LNGC with onboard reliquefaction (DRL) are radical departures from the currently dominant steam turbine drive technology. The introduction of the dual fuel diesel electric drive systems could also open the door for dual fuel gas turbine electric (DFGTE) propulsion systems, as they are based on the same electric drive concept.

Figure 1: LNG carrier "Provalys". Image courtesy of ABB Marine

In November 2006, the LNG carrier "Provalys" was delivered to her owner Gaz de France by French shipyard Chantiers de l'Atlantique (now part of Aker Yards). "Provalys" is the world's first operational dual fuel electric driven LNGC. Her sister ship "Gaselys" followed in early 2007. Firm orders for more than thirty DFDE LNGC's have been placed, mainly with Korean shipyards Samsung HI, Hyundai HI and DSME. Japanese shipyard Mitsubishi HI in Nagasaki is also building a pair of DFDE LNGC's. Korean shipyard Hanjin recently returned to the LNGC shipbuilding arena with orders for two LNGCs. STX Shipbuilding, also in Korea, scored an order for one LNGC. Since the first order for DFDE LNGC's at Chantiers de l'Atlantique in France was placed in 2003, alternative propulsion systems have steadily been gaining ground on the traditional steam turbine propulsion system. The erosion of the market share of steam turbines in LNGC propulsion accelerated further with the introduction of the DRL vessels by the Qatari LNG export ventures. With a planned acquisition of 55 DRL vessels, non-steam LNGC's have been dominated the global LNGC order book since late 2004.

Dual Fuel Diesel Electric Propulsion Systems

Electric propulsion systems for LNGC's include the following components:

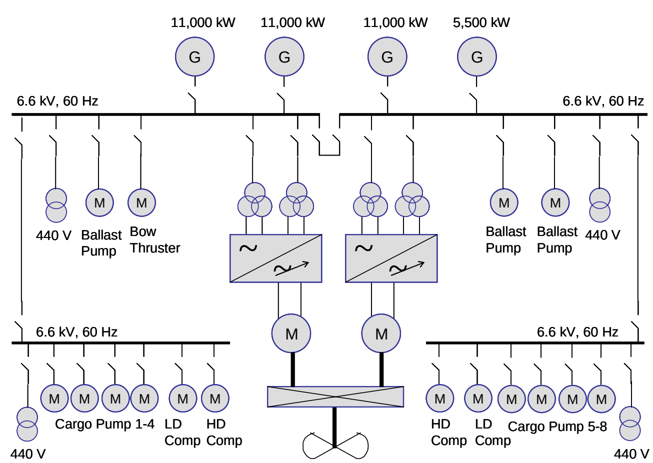


Figure 2: Electric propulsion system diagram. Image courtesy of ABB Marine

- Prime movers, i.e. dual fuel diesel engines;
- Prime mover driven generators;
- Main switchboard to distribute the generated power to the various consumers;
- Propulsion transformers;
- Frequency converters;
- Electric propulsion motors;
- Propeller(s);

The introduction of electric drive in LNGC propulsion might seem like a radical step, but in fact the move toward electric propulsion was an evolutionary process. With the LNGC growing in size, the onboard power requirements increased so much that 440 V installations couldn't handle the load safely. This led to the introduction of medium voltage switchboards and pumps motors. This familiarization with medium voltage systems was the first step towards electric propulsion. In cruise vessels, medium voltage propulsion systems were introduced more than a decade earlier and have since gained an excellent track record.

The advantages of the dual fuel electric propulsion system over the conventional steam turbine drive system are:

- Improved thermal efficiency of the propulsion plant, both at sea and in port;
- Lower installed power, as the power plant serves both the propulsion load as well as the harbor load;
- Increased redundancy with 4 prime movers and two (almost) independent drive lines;
- Increased cargo capacity within the same overall dimensions of the vessel;
- Crews with diesel electric experience are more readily available the crews with steam certification;
- Electric propulsion system is easier to operate and faster to start up and to shut down;

However, there are also a few disadvantages:

- Steam turbines have proven to be very reliable over time, more reliable than diesel engines;
- Steam turbine plants need less maintenance than diesels;
- Diesel engines have higher lube oil consumption than steam turbines;
- Electric driven vessels need additional equipment to handle excess boil-off gas;
- Steam turbines are very flexible in terms of fuel types and fuel mixing ratios, whereas dual fuel diesel engines operate either in gas mode or in diesel mode;

Fuel Cost

One of the strongest arguments against electric drive has always the losses in the electric transmission between the prime mover and the propeller, as illustrated in the diagram below.

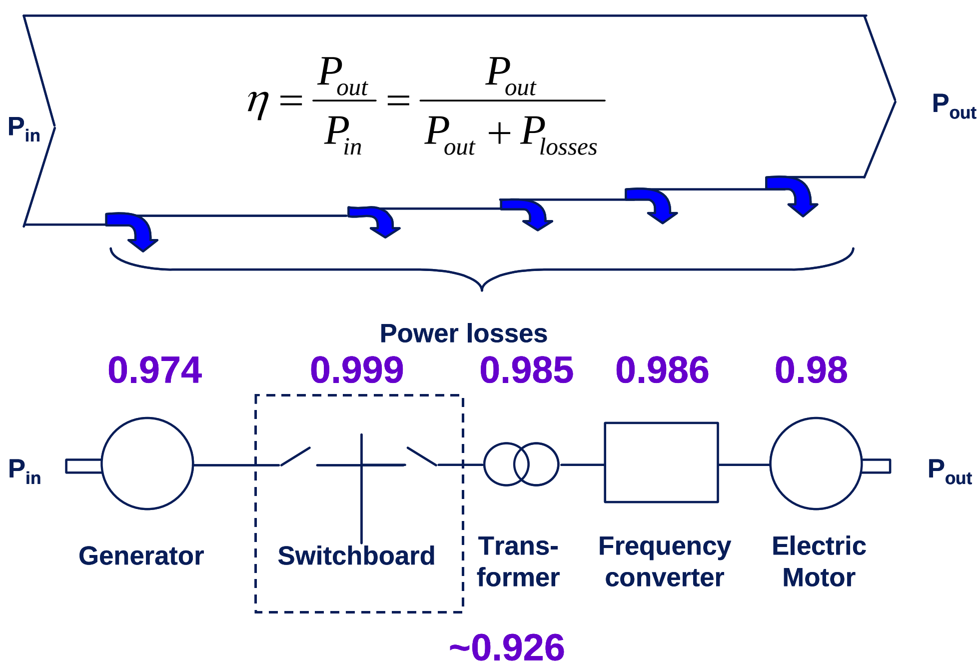


Figure 3: Electric transmission losses. Image courtesy of ABB Marine

Indeed there are electric transmission losses of less than 8%, but even with these losses a dual fuel electric propulsion system is far more efficient than a steam turbine drive system. The thermal efficiency of the dual fuel diesel engine in gas mode is approximately 47%. Then the thermal efficiency at the electric motor flange to the gearbox would be over 43.5%. Currently, all electric propulsion (EP) systems for LNGC's have medium speed electric motors driving the propeller via a reduction gearbox, because medium speed electric motors are cheaper and smaller than low speed electric motors. Factoring in the losses in the gearbox (1.5%) and the shafting losses (1%), the total thermal efficiency of the DFDE propulsion system is about 42.5%. This compares very favorably with the steam turbine drive system's thermal efficiency of less than 30%. Reducing fuel consumption by 30 – 40% has a significant impact on the total cost price of the LNG that is being transported to the consumer market.

Power Plant Configuration

During the loaded and the ballast voyage, the power plant onboard the EP LNGC services the propulsion load, the service load and the hotel load of the vessel. In the harbor, the power plant services the load required for the cargo operations, as well as the hotel load and other consumers. The multiple engine arrangement allows the power management system (PMS) to start up or shut down engines to match power generation and power consumption. Typically, the current DFDE LNGCs have three Wärtsilä 12V50DF and one 6L50DF dual fuel diesel engine driving generators to provide about 38.5 MW of electric power. This configuration allows the small generator to be off-line when sailing fully loaded. Depending on the vessel's schedule and the vessel's speed-power curve it might be possible to temporarily take one large engine off-line for maintenance during the ballast voyage. When loading the small generator should be able to generate sufficient power to service all consumers, when off-loading one large generator would be required. This configuration is suitable for both single screw and twin screw LNGCs with electric propulsion.

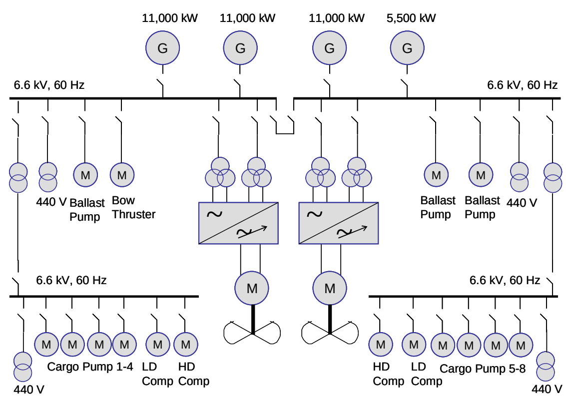
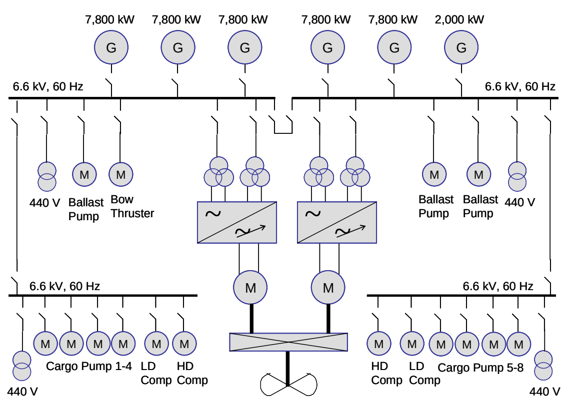


Figure 3: Twin screw electric propulsion system diagram. Image courtesy of ABB Marine



An interesting alternative is the arrangement that STX shipyard in Korea designed for their first electric propulsion LNGC. It features five MAN 8L51/60 dual fuel diesel engines fitted with waste heat recovery systems in the exhaust of each engine. These waste heat boilers raise steam for a steam turbine generator with an output of approximately 2 MWe. The heat recovery system increases the thermal efficiency of the whole power plant. The power plant layout allows for one engine to be off-line at any given time, which facilitates onboard maintenance.

Figure 4: STX Shipbuilding electric propulsion system diagram

Redundancy

The multiple engine arrangement makes the vessels less sensitive to a single failure in one of the engines. In the worst case, a failure in one of the engines might have some impact on the speed of the vessel, but it will not endanger safe operation of the vessel. A system availability study by ABB Marine concluded the following with regard to the amount of propulsion power available for a DFDE LNGC in the event of a failure:

Failure leading to	Availability	Downtime per year
Less than 100% propulsion power available	99.941%	5.2 hours
Less than 75% propulsion power available	99.989%	1.0 hour
Less than 50% propulsion power available	99.999%	~0 hour

Using the speed power curve below, the loss in ship speed in any of the above events is rather limited. It might well be possible that the temporary loss of speed is compensated further along the itinerary.

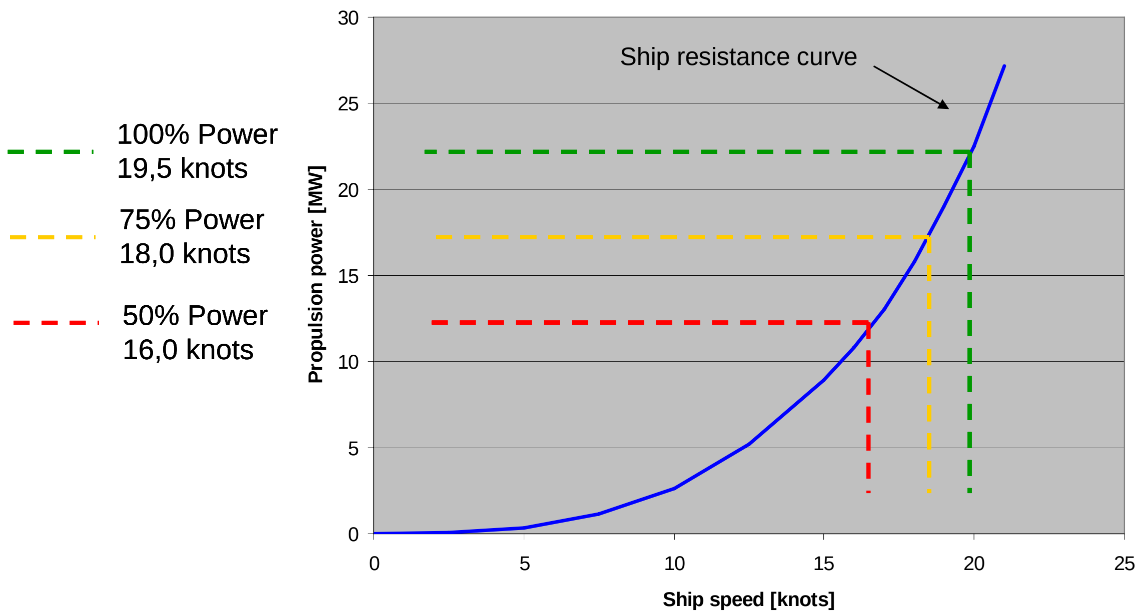


Figure 5: Power - speed curve for an LNGC.

Increased Cargo Capacity

A number of studies have focused on the increase in cargo capacity that could be obtained from changing to DFDE propulsion. When comparing the engine room size of the conventional steam LNGC with the DFDE LNGC, it would be possible to move the engine room bulkhead further aft when using DFDE propulsion. Electric propulsion systems allow the prime movers to be located away from the propeller shaft into areas where there is more space. By having only the propulsion motors and the reduction gearbox on the tank top, the engine room can be shortened substantially. While additional cargo capacity estimates fluctuate, the consensus is that it should be possible to gain some extra cargo space. The space saving argument is reinforced by the lower fuel consumption of the DFDE LNGC. Because the fuel consumption is lower, less bunkers need to be carried, which saves additional space and weight.

However, this additional cargo space is mostly located in way of cargo tank number 4 just in front of the engine room bulkhead, where the hull starts to taper in towards the propeller. Lengthening tank 4 too much would result in sloshing issues. Additional cargo capacity also results in higher cost for building the containment system and tanks with complicated geometry are more expensive to build than parallel mid ship tanks. Without having access to shipyard engineering data it is very difficult to exactly predict the cost of the additional cargo capacity. Consequently, it becomes difficult to precisely predict the economic benefits of the additional cargo space.

Crewing

Much has been written about the shortage of steam qualified crew for LNG carriers. By moving away from steam to DFDE propulsion this issue is not entirely solved, as there are still many steam driven LNGC on order and the current fleet of more than 200 steam driven LNGCs will need steam qualified crews for decades to come. However, it might be a bit easier for DFDE LNGS operators to find crews. The dual fuel diesel engines basically work on the same principles as regular medium speed engines. The dual fuel system is not very complicated to understand and has been in marine operations for a few years now. With a bit of equipment specific training most engineers should be able to operate and maintain the engines properly.

The electric drive system is mostly made up of components with which most engineers onboard are very familiar; switchboards, generators, electric motors and transformers. Everything is just a bit bigger and the voltage is higher. High voltage safety training should be a prerequisite for operation and maintenance of these systems. The only "new" technology for the crews to be introduced onboard the DFDE LNGCs is the frequency converters that control the speed of the electric motors. These frequency converters are actually not new technology as they have been used in many demanding on-shore applications for many years. There are equipment specific training courses available from the OEM to train the crews in proper operation and maintenance of these frequency converters.

Actually, the main question might not be whether the crews can handle the propulsion plant, but can they perform all cargo operations adequately and do these engineers have sufficient experience onboard gas vessels?

Operations

The EP LNGC concept has shown itself to be very easy to operate. The PMS matches power supply and demand, which results in smooth operation and low fuel consumption. Sea trials with the first DFDE LNGCs built in France by Chantiers de l'Atlantique (now Aker Yards) confirmed that the electric propulsion system works very well and performs excellently in extreme situations like crash stops. Recently, there have been some articles in the marine trade press regarding configuration problems with an electric drive system on the lead EP LNGC out of a shipyard in Korea. Due to intense price competition among shipyards, some yards prefer to buy the electric drive system in piece parts from a number of vendors and perform the integration themselves or assign this to one of the vendors. Even though the electric drive system is not rocket science, a fair degree of knowledge is required to make sure that all individual components are matched and will work together properly. The overall system integration, which includes power management, system controls, alarms and safeguards, is a very complex project, which requires detailed knowledge about the electric propulsion system, its components, its behavior at sea and the effects of a component failure. Piece part procured propulsion systems are more likely to suffer from equipment mismatches and consequent breakdowns than completely integrated systems delivered by the OEM.

The DFDE LNGCs currently being built are designed for a 30 – 40 year operational lifespan. With vessels costing anything upwards of USD. 200M, CAPEX is indeed a major part of the daily cost of owning and operating such a vessel. CAPEX of a DFDE LNGC was about 2 – 4% higher than for a comparable steam driven LNGC a few years ago. The recent entry of MAN in the market for dual fuel diesel engines might push the price level for the prime movers down. In the electric propulsion systems market competition between OEM system integrators also put the margins under pressure. A further reduction in CAPEX due to the use of cheaper piece parts might seem an attractive way of reducing the cost of ownership. However, there are a few reasons not to go this way:

- Late delivery of the vessel due to equipment mismatches and integration problems will result in claims from charterers;
- Multiple equipment vendors will make warranty claims difficult, as they will all point to other vendors, the system integrator or the shipyard as the cause of the equipment failure;
- Cost of lengthy off-hire due to equipment failure compared the initial savings, as many of the equipment vendors will not have a global service network capable of providing around the clock service.

Reliability

On paper it is hard to beat the steam turbine system in terms of reliability. Medium speed diesel engines are indeed a bit less reliable than steam turbines, but the main electric components of the electric drive system have proven their reliability in a large number of cruise vessels and passenger ferries. For the electric motors driving the propeller shaft, ABB quotes a mean time between failures of over 100 years. Due to their multiple engine configuration DFDE LNGCs have a certain amount of redundancy in their propulsion system, which will prevent catastrophic loss of power situations. With two almost or completely independent drive lines, the chances of a total loss of power are very slim.

The weakest link in the chain could very well be the dual fuel diesel engines. In its 2005 report on engine damage, leading marine mutual insurer Swedish Club found an overrepresentation of medium speed engines in its claims. The technology dual fuel diesel technology is relatively new; in 1996 Wärtsilä introduced the low pressure dual fuel diesel engine that is now being used for the DFDE LNGC. Since then, they have logged more than half a million operational hours in land applications. Eight marine engines in the two OSV built by Kleven shipyard in Norway have logged up more than 100,000 hours as of September 2006. From late 2006, three DFDE LNGCs have been delivered by Chantiers de l'Atlantique in France to French owner Gaz de France and their venture partners. The first few months of operations in LNG shipping have gone very well.

Maintenance

Medium speed diesel engines, which include the dual fuel diesel engines used in the DFDE LNGCs, need more maintenance and more manpower to carry out the maintenance than steam turbine propulsion systems. Wärtsilä currently quotes the maintenance cost for the DF50 dual fuel diesel engines at about USD. 3.60 / MWh. Steam turbine propulsion systems are much lower in maintenance requirements, at approximately USD. 0.50 / MWh. Apart from the maintenance on the dual fuel diesel engines, there is also maintenance required on the electric drive system. Initially, there was a great deal of uncertainty about these costs, but careful examination of the major cost drivers has shown that these cost are a mere fraction of the maintenance cost of the dual fuel diesel engines.

Lube Oil

Medium speed diesel engines have higher lube oil consumption than steam turbines. The main reason is that the lube oil in the diesel engine is exposed to the combustion process in the cylinders. The specific lube oil consumption for the dual fuel diesel engines is quoted at 0.5 g/kWh when running in gas mode. On an annual basis this means up to 100 tons of lube oil. When running in HFO mode the lube oil consumption might be higher as it has to protect the engine against the corrosive attack of the sulfur contained in the residual fuel. The difference in properties between gas fuel and HFO might make it necessary to change between lube oils with higher and lower TBN number to adequately protect the engines. Most recently a preliminary advice came to use a TBN 30 lube oil when alternating between HFO and gas fuels. At this stage experience with HFO on dual fuel engines is too limited to draw any firm conclusions.

CGU

Electric driven vessels need additional equipment in the form of a gas combustion unit (GCU) to handle excess boil-off gas (BOG), while steam turbine vessels burn the excess BOG in the boilers and dump the steam in the condenser. The additional CAPEX for procurement and installation of the GCU are included in the 2 – 4% higher initial price for a DFDE LNGC.

Fuel Flexibility

In steam driven LNGCs, all BOG from the cargo tanks is burned in the boilers to raise steam for the steam turbine. The power requirements for the LNGC at cruise speed are higher than the power that can be raised with only natural BOG. To raise additional steam either forced BOG or HFO could be used. In a steam boiler there is no problem using different fuels simultaneously in any mixing ratio, which makes the steam turbine system very flexible in the choice of fuels. Basically the cheapest fuel available can be used at any point in time. The down side is that a lot of this cheap fuel is needed, as the thermal efficiency of the main propulsion steam turbine is low. Recently, both Mitsubishi and

Kawasaki have introduced more efficient steam turbine designs, promising a 12 – 15% increase in thermal efficiency, which would put the total thermal efficiency of the steam system at about 32%.

Things are a bit different with a dual fuel (DF) diesel engine, as it is a derivative of a pure diesel engine. The DF engine operates either in gas mode or in liquid fuel mode; it is not capable of operating on a mixture of both gas and liquid fuel simultaneously. In gas mode, for which the DF engine is optimized, it uses gas fuel and combustion is initiated by a small amount of MDO pilot fuel being injected in the cylinder. In gas mode the thermal efficiency of the engine is about 47% as mentioned above. As the DF engine is optimized for gas operation, the compression ratio has been lowered a bit to avoid irregular combustion. The lower compression ratio has a negative effect on the thermal efficiency in liquid fuel mode. In liquid fuel mode, the DF engine operates on MDO or on HFO, but the thermal efficiency is reduced to about 43%. This in turn leads to a 39% thermal efficiency for the entire electric propulsion system from prime mover to propeller, which is still much better than the performance of the steam turbine drive system.

The fuel flexibility of the dual fuel diesel, combined with its high thermal efficiency, seems to offer the best possibility for reducing the transportation cost of LNG. The fuel flexibility allows the operator to select the cheapest fuel available, within the constraints of the charter agreement and proper BOG management. Fuel flexibility is definitely an advantage, as fuel cost have been fluctuating wildly in the last few years, much more so then in the previous decade, as shown in the graph below. Through the 1990's the Henry Hub price and the Houston HFO price were relatively close and if one went out of substitution effects brought the two together again. From the turn of the century, the Henry Hub gas prices are occasionally peaking very highly, often coinciding with a winter period. From early 2002 HFO-380 started rising, most probably because of the higher domestic demand in China and India.

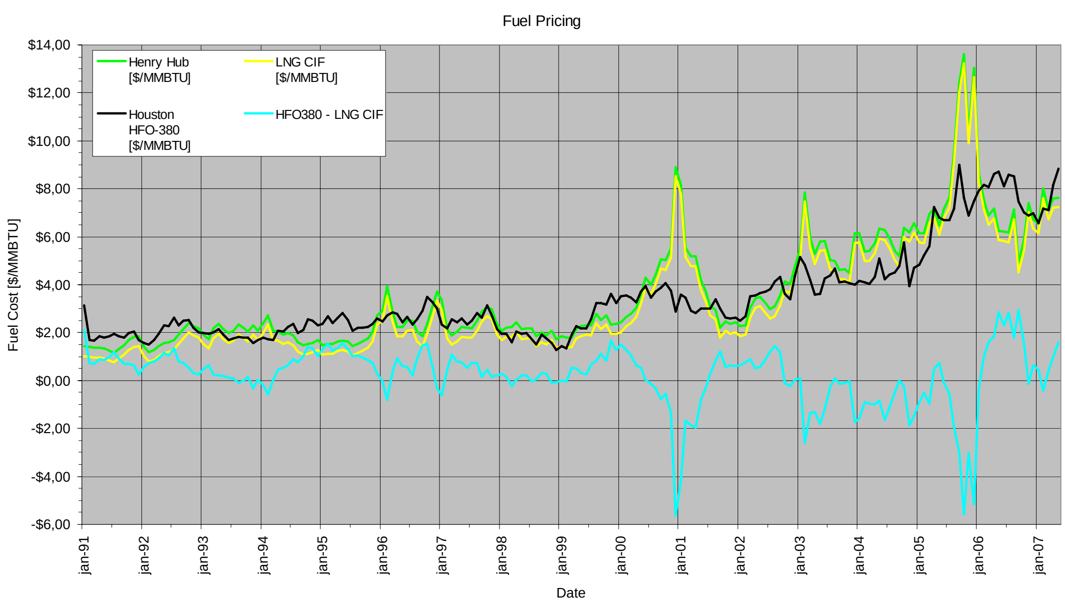


Figure 6: Henry Hub and HFO prices. HFO prices courtesy of Glander International Inc.

In a very interesting booklet called "Marine engines, catalytic fines and a new standard to ensure safe operation", major slow speed diesel engine manufacturer MAN B&W Diesel, together with fuel separator specialist Alfa Laval and BP Marine, concludes that anywhere within the next 30 years HFO will loose its status as the cheapest marine fuel. This is due to the improvements in the cracking processes in the refineries, which convert more and more crude oil into distillates. These improvements leave less refinery residue available for blending into residual fuels, such as IFO-380. There seems to be a rather remarkably linear trend that the amount of residual fuel oil produced from a barrel of crude decrease by about 4.6% per decade. In 1990, approximately 20% of a barrel of crude was processes into residual fuel oil against 14% in 2004. This process might continue as the demand for distillates around the world is increasing, especially so in emerging giants like China and India.

There will be an increasing number of competitors for the decreasing amount of residual fuel, most notably container vessels and bulk carriers that have no alternative fuel available, apart from even more expensive distillate fuels.

LNGCs have the option to use BOG from the cargo and even vaporize some additional LNG to cover the entire power requirement. With more and more countries discovering that they can generate income from their gas fields by exporting the gas as LNG, it seems that the LNG market will not be short of supply in the mid term future. Countries like Russia and Iran have vast gas fields, but the process to bring it to the market is going slowly. Other producers like Qatar and Nigeria fast track their LNG projects to take advantage of this situation. Using gas fuel on LNGCs also has the added advantage that it is more environmentally friendly in terms of emissions than HFO or even MDO. As it is difficult to predict exactly where the markets are going, multi-fuel capability is definitely an advantage for any LNGC.

Conclusion

The dual fuel diesel electric propulsion system has gained a strong position in the LNG shipping market in the last 4 years at the expense of the steam turbine propulsion system. Both DFDE and steam propulsion have their specific advantages and disadvantages. Currently, in terms of CAPEX both solutions are pretty much level now that increased competition is putting the OEM margins under pressure. In terms of fuel consumption it is a clear victory for the DFDE LNGC, with fuel savings of up to 35%. As fuel cost is the second biggest cost driver behind CAPEX, this has a big impact in the cost of ownership and operation of an LNGC. It's not so clear whether DFDE propulsion systems will also solve the crewing issue that is currently facing the LNG shipping business. In terms of maintenance cost and lube oil consumption, the steam turbine system has the advantage, but the total savings cannot compensate for the fuel cost disadvantage of the steam turbine. The superior reliability of the steam turbine system is compensated for by the redundancy in the DFDE propulsion system.

All in all, steam is certainly not dead, but the DFDE propulsion system has some very strong points. It will be interesting to see if in 35 years time we'll still see a number of the DFDE LNGCs currently under construction still engaged in active trade. Only time will tell.

About the Author

Alexander Harsema-Mensonides was initially trained as an economist, but graduated in 1995 with a B.Sc. in mechanical engineering. Since 1993 he has been active in the marine industry in various technical and commercial positions. In 1999 he founded MPT Consultancy to provided marketing services for technically advanced propulsion solutions for commercial marine applications. Major accounts include GE Energy in Houston and ABB Marine in Oslo. Alex can be contacted by e-mail at alex@mptconsult.com

Literature

J. F. Hansen, R. Lysebo, Electric propulsion for LNG carriers. LNG Journal, September/October 2004

J. F. Hansen, R. Lysebo, HV Electric Power and Propulsion Solutions for New Generation of LNG Carriers with Various Propulsion Systems. Proc. of the 28th Annual Event "The MotorShip Propulsion Conference", Copenhagen, April 2006

B. Thijssen, Dual-Fuel-Electric LNG carriers. Proc. of the 28th Annual Event "The MotorShip Propulsion Conference", Copenhagen, April 2006

MAN Diesel, L+V51/60DF Four-stroke Dual-fuel Engine. Product Introduction Brochure. MAN Diesel SE, Augsburg 2006

A. Harsema-Mensonides, Dual-Fuel Gas Turbine Propulsion Systems for LNG Carriers. Proc. of the 28th Annual Event "The MotorShip Propulsion Conference", Copenhagen, April 2006

A. Harsema-Mensonides, Gas Turbine Electric Propulsion for LNG Carriers; Myth or Money Spinner? Proc. of Gastech 2006 Conference, Abu Dhabi, December 2006

HFO prices from Glander International Inc, www.glander.net

MAN B&W Diesel, Alfa Laval, BP Marine, Marine diesel engines, catalytic fines and a new standard to ensure safe operation, Alfa Laval 2005, http://www.alfalaval.com/digitalassets/2/file41167_0_SPS_Booklet_050912_final.pdf