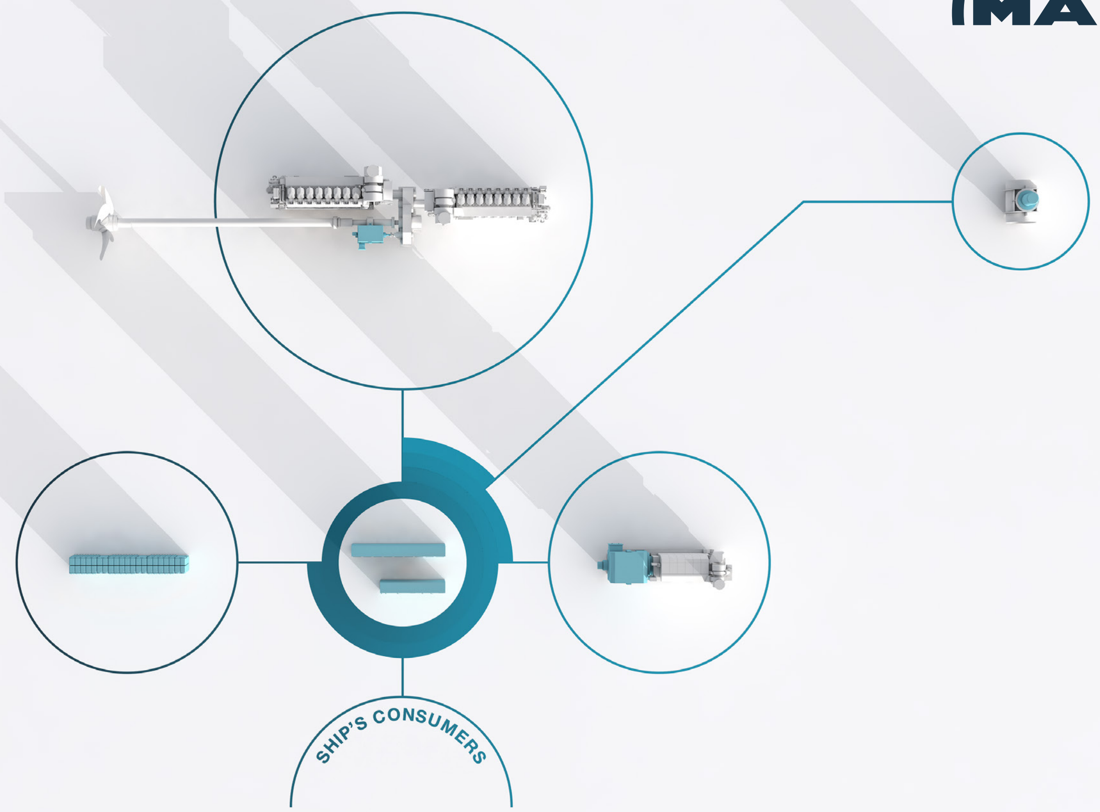

Hybrid power workboats

MAN Energy Solutions
Future in the making

A holistic approach for better CAPEX

Synopsis

Marine hybrid propulsion plants were seen as pure technology demonstrators a decade ago[1]. Today, as in the automotive industry, hybrid systems are proving theoretically superior to traditional propulsion trains in terms of operational expenditure (OPEX). However, hybrid systems are not as successful at sea as they are on the road. The main reasons are the higher capital expenditure (CAPEX) and a perceived high risk in certification, installation and operation.

Taking a holistic approach to these challenges, this paper presents the inherent flexibility and the innovative payload hybrid systems can bring to workboat applications. We show that hybrid systems not only make current operations more effective and efficient, but give access to more sophisticated capabilities, paving the way for new modes of operation with a similar CAPEX to traditional arrangements. Such a holistic view requires a wide-ranging approach to system design, based on a synergy of highly specialised products and competences. By merging the engineering expertise of three industry-leading system providers, a practical example of such a holistic hybrid design is given, highlighting how it can be used to:

- **Assess different vessel capabilities in regard to both CAPEX and OPEX**
- **Improve load response capabilities and extend the reliability of a vessel, while guaranteeing operational safety**
- **Tailor the design to specific operational requirements, paving the way for new modes of operation**

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Introduction

Over the last 10 years, the development of hybrid power trains in different forms of transport has continued to accelerate. It is obvious that progression has been faster in some applications than others (e.g. the consumer automotive industry vs the commercial marine sector). Why is there such a difference between one industry and another?

Of course, there may be a multitude of reasons why this should be the case. Some could be considered general issues – particular technological or safety restrictions and other factors can be related to a specific industry, perhaps because of differing government environmental incentives available in certain sectors.

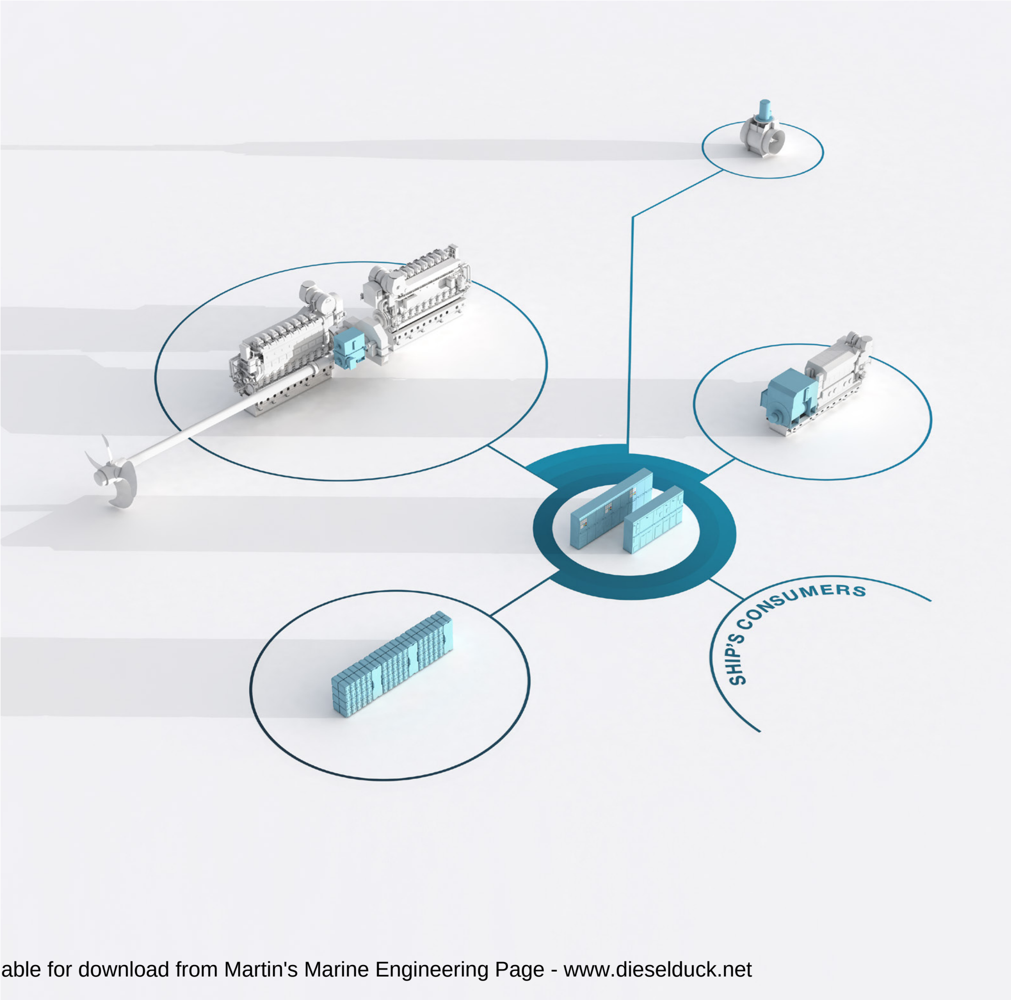
To show how this can be achieved, we shall consider five areas in this paper:

1. Experiences in hybrid power from other applications
2. Historical review of hybrid propulsion in the marine sector
3. Overview of the hybrid concept in the workboat environment
4. Benchmarking a conventional propulsion system against two different hybrid solutions (MAN HyProp ECO and MAN HyProp Battery), from technical and economic perspectives
5. Current evolution of hybrid technology and its future in marine industries

The CAPEX challenge

However, the biggest issue facing most industry sectors with regard to advancing hybrid propulsion, including the marine shipping industry and the workboat sub-sector, is this: how to achieve completely successful implementation of a cost-effective hybrid propulsion plant.

The operational benefits of these systems, such as running costs and emission reductions, are already well known and documented[2, 3, 4, 5, 6, 7]. The key challenge is CAPEX: keeping the capital expenditure of hybrid equipment aligned with that of conventional propulsion plants. Only by overcoming this CAPEX challenge can implementation be deemed to be completely successful.



1. Hybrid applications in other fields

As a first step in the search for an alignment of hybrid and conventional CAPEX, we must consider other fields where hybrid power systems have been applied and are accepted as a 'completely successful' solution.

Hybrid power in the automotive industry

The leading user of hybrid power train technology is the automotive industry. Car manufacturers have been developing and producing hybrid vehicles for considerably longer than the ten years associated with hybrid marine propulsion and, as a result, the technological developments (and consequently the benefits) are considerably more mature.

Taking the Volkswagen Passat as an example, Figure 1 compares a typical diesel engine variant (VW Passat Comfortline) and a hybrid variant with similar specifications (VW Passat GTE)[8]. From an economic point of view, the key fact is that here a relatively small price differential is involved in a switch from a conventional diesel to a hybrid drivetrain. However, another factor to consider is the significantly improved performance of the hybrid variant. An increase in power for the car offers further benefits, some of which also apply in a marine workboat environment, such as improved acceleration. In workboat terms, this can be translated into greater responsiveness of the propulsion equipment to load demand changes. Reduced fuel consumption and emissions are also shown, but these are already clearly established benefits.

2. History of hybrid marine propulsion: the last 10 years

Hybrid marine propulsion systems have slowly but surely made their way into the workboat market since the world's first hybrid tugboat was delivered in 2008. Early hybrid propulsion systems were limited, predominantly by the available energy storage systems (ESSs) and unproven hybrid systems. Early ESS models offered low energy densities, required significant installation space and provided minimal monitoring and safety functions.

Advances in energy storage systems

During recent years, ESS costs have decreased significantly[9, 10]. System sizes have also been reduced, and safety has advanced considerably through the development of mature battery management systems (BMS)[11]. Combining a modern ESS with parallel advances in power conversion technology, hybrid-ready drivetrains and more mature power management systems has proven to operators that these configurations can be more efficient, economical and reliable than a conventional vessel[12].

This has all been backed by a better understanding of various load conditions and profiles through the implementation of such technology on a variety of vessel types[13]. This has led to more efficient communications and control infrastructures for hybrid systems. The ultimate result is a safer and more efficient system that requires a smaller envelope on the vessel. As hybrid systems continue to develop and prove their benefits to operators and vessel owners, they will become more widely accepted and continue to push to become the industry's norm.

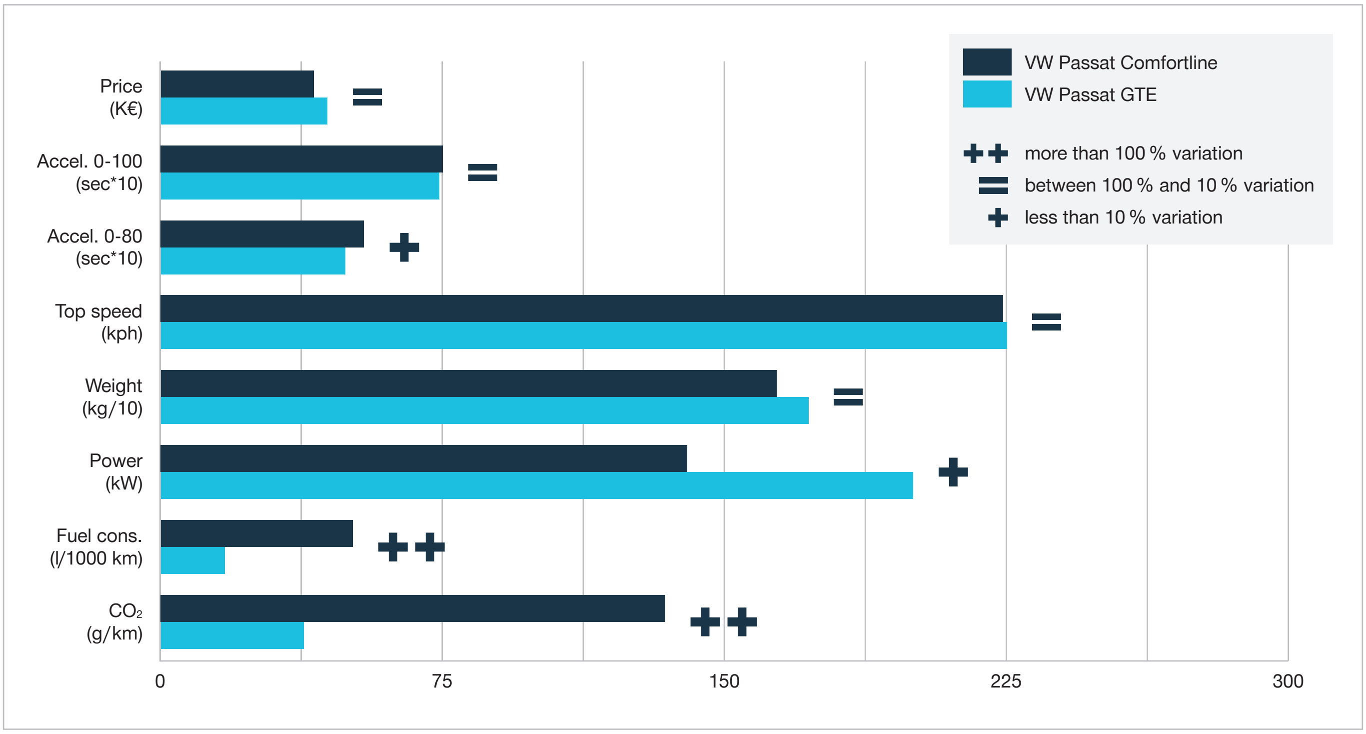


Figure 1: Comparison overview of a typical automotive conventional diesel vs hybrid drive

3. Hybrid concepts for workboats

Advantages for the workboat industry

A hybrid design offers additional advantages over the traditional workboat approach. By capitalising on motor/generator and auxiliary generator equipment, a power plant topology can be created that allows for maximum efficiency of some of a vessel's major consumers as well as the onboard diesel engines. This is accomplished by providing a variety of operational modes that configure the plant in ways that allow for a reduction in reliance on prime movers (main propulsion) as the sole source of propulsion. This puts smaller power supply systems in a direct path to more proportional operations in the vessel.

In a typical 80-tonne BP harbour tug, the main diesel engines support many operations that are not directly related to the vessel's principal task. This results in large and powerful propulsion systems that are very often lightly loaded. In this scenario, plant efficiency plummets. A hybrid solution would see these propulsion engines remain idle while other plant options are used for harbour transit, low power ship-assist operations and operational pauses, either at shore or in between jobs. Delegating the full power demand to electric motors has significant downsides in terms of weight and cost increases, space requirements and electrical losses at full load, but a modern hybrid solution, such as the MAN HyProp ECO or the MAN HyProp Battery, allows for efficient operation in a wide spectrum, combining the advantages of both a mechanical system and a diesel-electric one.

The primary advantages of adopting this kind of smart plant flexibility are directly visible in the fuel savings, reduced emissions and higher grade of reliability that this approach offers[2, 4, 5, 14, 15]. Vessels are now able to work in a wider variety of environments for lower operating costs, while also providing a more consistent means of support to vessels operating in critical areas, enabled by the faster response and higher capability of the complete power train.

The new harbour tug dilemma

Hybrid solutions for harbour tugs and the workboat industry generally provide a significant advantage over conventional configurations, but they have been predominantly geared towards improving OPEX. The approach has not been as advantageous from a CAPEX standpoint. Traditionally, the cost of the new diesel-electric or hybrid technology has only been mitigated by OPEX benefits over time. The solution is to find a balance of OPEX and CAPEX benefits.

State-of-the-art hybrid and diesel-electric solutions in the workboat industry today

The key to developing a workboat design that is accessible from a CAPEX standpoint, while also harnessing OPEX advantages, lies in taking full advantage of the technological and economic advances that have occurred during the last ten years. Since 2008, many features included in the traditional hybrid approach have become more readily available. In addition, the following key elements have been significantly improved upon:

- Power conversion equipment (AFE, VFD and DC-DC conversion)
- Thruster drives with multiple PTI/PTO inputs
- Power management systems (PMS) specific to hybrid propulsion
- Electric motor developments such as permanent magnet (PM) solutions
- Energy storage systems (ESS) such as lithium-ion battery arrays

Hybrid diesel-electric propulsion system – design approach and analysis

The two key elements involved in sustaining a higher tier approach to operational effectiveness with a hybrid diesel-electric power plant are:

- Configurability for a wide variety of operational modes
- High reliability based on autonomous functionality

Autonomous functionality

A flexible power plant consisting of multiple propulsion support mechanisms offers the most efficient approach. It allows a variety of plant configurations for the vessel's operational profile. The result is lower fuel costs, reduced maintenance on main engines and lower emissions. Modern systems employ an autonomous design philosophy. This removes the complexity of the upper-level PMS responsibility for plant stability and system control. Autonomous functions do not depend upon each other, resulting in a system that reduces cascade failure events and enhances the varied operating mode scheme.

Operational modes

A vessel of this sort can be operated in several modes. These determine which resources the hybrid diesel-electric system uses to support vessel services and provide power for propulsion.
The modes are selectable using multi-position switches on the control panel:

- **Stop.** Shore power or ESS supply hotel loads. No propulsion is enabled
- **Idle.** ESS supplies hotel loads and limited propulsion is enabled
- **Transit 1.** Aux Gen 1 supplies hotel loads and propulsion
- **Transit 2.** Aux Gen 1 and 2 supply hotel loads and increased propulsion
- **Power Assist.** Full power operation. Main engines 1 and 2 running. Aux Gens 1 and 2 supply additional propulsion power

Stop and Idle modes

Stop mode is used when the vessel is secured at dock. In this mode, the hybrid diesel-electric system uses both ESSs (if applicable) to support the DC bus via the DC/DC converters, therefore avoiding reliance on a shore connection. Idle mode is similar to Stop mode, and is specific to vessels with ESSs. It should be considered as a limited propulsion mode. The wheelhouse throttle controls are enabled, and limited propulsion and steering is available (see Figure 2).

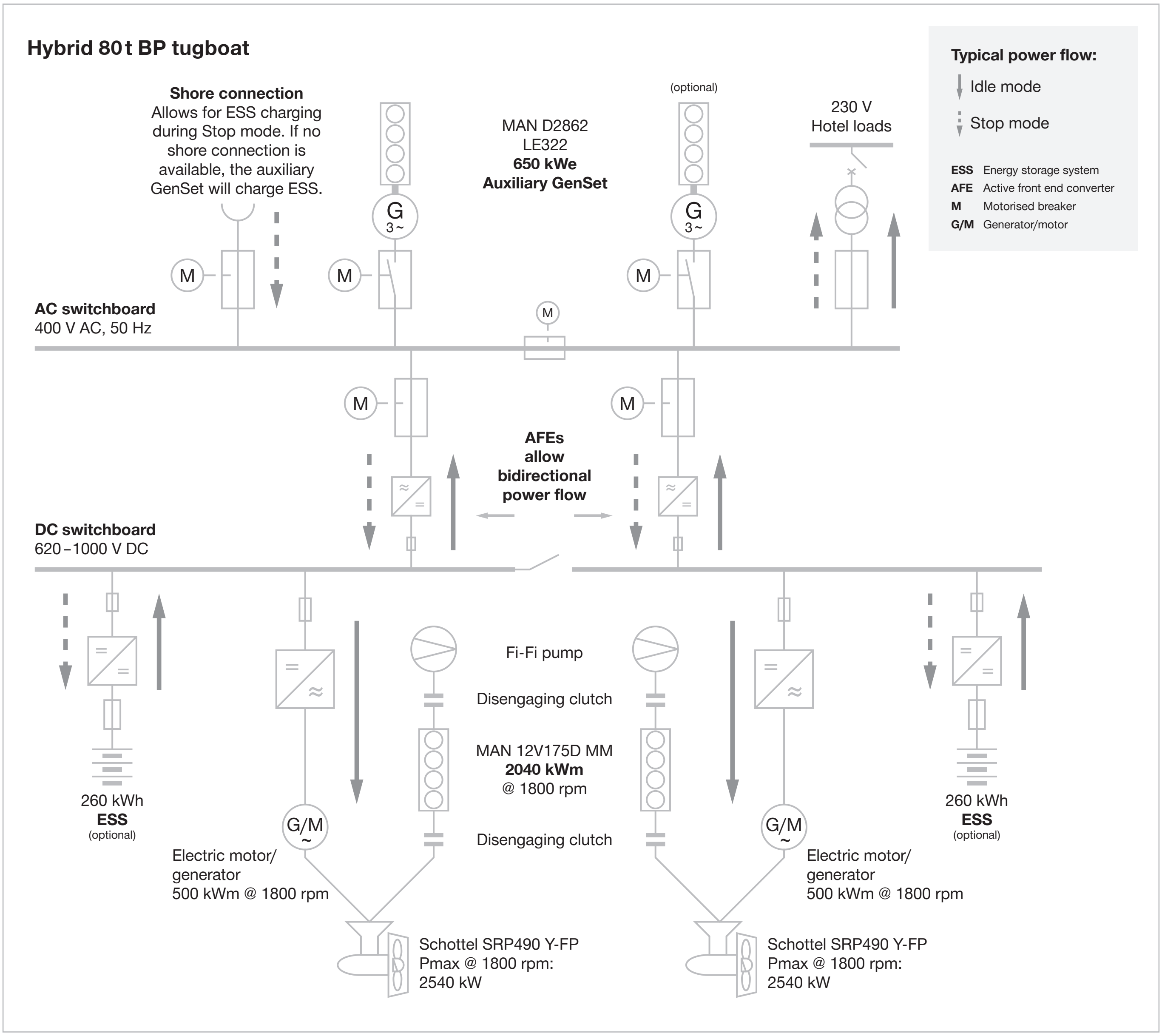


Figure 2: Stop and Idle modes power flow diagram

Transit modes

Two transit modes are highlighted here: Transit 1 and Transit 2. In Transit mode 1, propulsion and vessel services are supported by a single generator via the AFE converter and DC bus. The thrusters are driven by their respective propulsion motor/generators. Transit 2 provides the vessel with faster levels of transit speed by connecting the second auxiliary generator. The main engines are still kept offline in this mode of operation.

Assist mode

In Assist mode, the system operates the plant in almost the same configuration as a conventional tug. All main engines are started and drive their respective thrusters. The motor/generators in this configuration contribute power to, and allow for, an increase of power and bollard pull. In addition, the electric motors replace the HD slipping clutches to enable propeller speeds below engine idle speed (see Figure 3).

Additionally, during fire-fighting operation, the vessel is propelled by the electric motors only while water pumps are driven by the main engine(s).

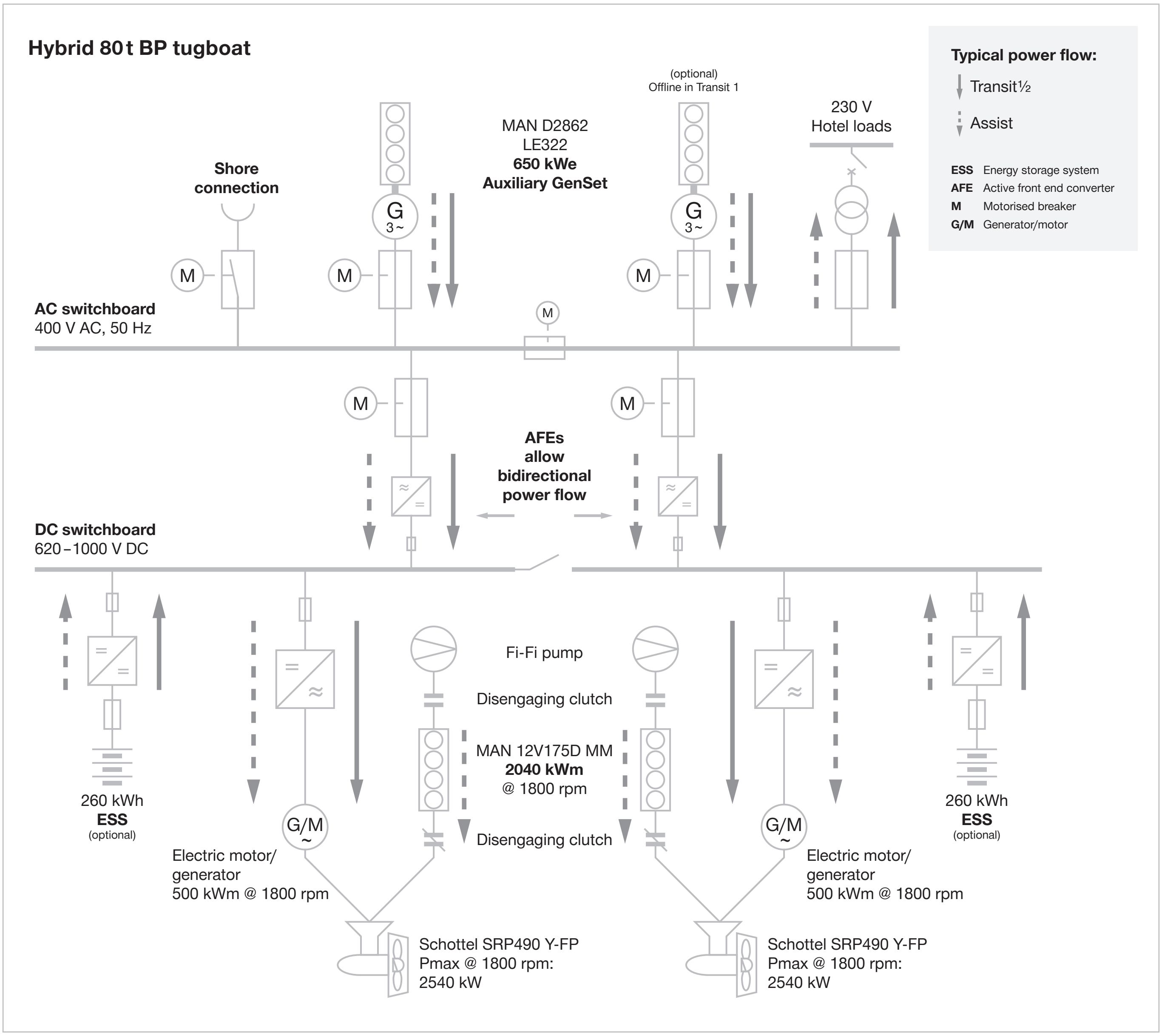


Figure 3: Transit and Assist modes power flow diagram

4. Benchmarking of conventional vs hybrid tugs

Benchmark specification

For this case study, a typical 32 m modern harbour tug design has been selected. Bollard pull is the most important characteristic, and the charter rates are always based on this figure. The achievable static bollard pull is therefore defined as being equal in all cases here, for both hybrid and conventional drive concepts. This benchmark value is defined as a common level of 80 tonnes. Figure 4 provides a comparative view of the different equipment items being considered.

Component	Conventional Fi-Fi tug, including FPP and HD slipping clutch	Hybrid tug (without ESS)	Hybrid tug (with ESS)
Thruster	•	•	•
Electric motor		•	•
VFD AC/DC link switchgear		•	•
Automation	•	•	•
PMS		•	•
Engine	•	•	•
SCR	•	•	•
GenSet	•	•	•
Battery pack			•
Battery infrastructure			•
Shore connection	•	•	•

Figure 4: Comparison of considered equipment: conventional vs hybrid (with/without ESS)

For a fair CAPEX comparison of the conventional and the hybrid tug, the operational behaviour and capabilities of both concepts need to be as similar as possible. In order to satisfy this requirement, a conventional power plant configuration for a multipurpose fire-fighting harbour tug has been defined as a benchmark, as follows (see Figure 5).

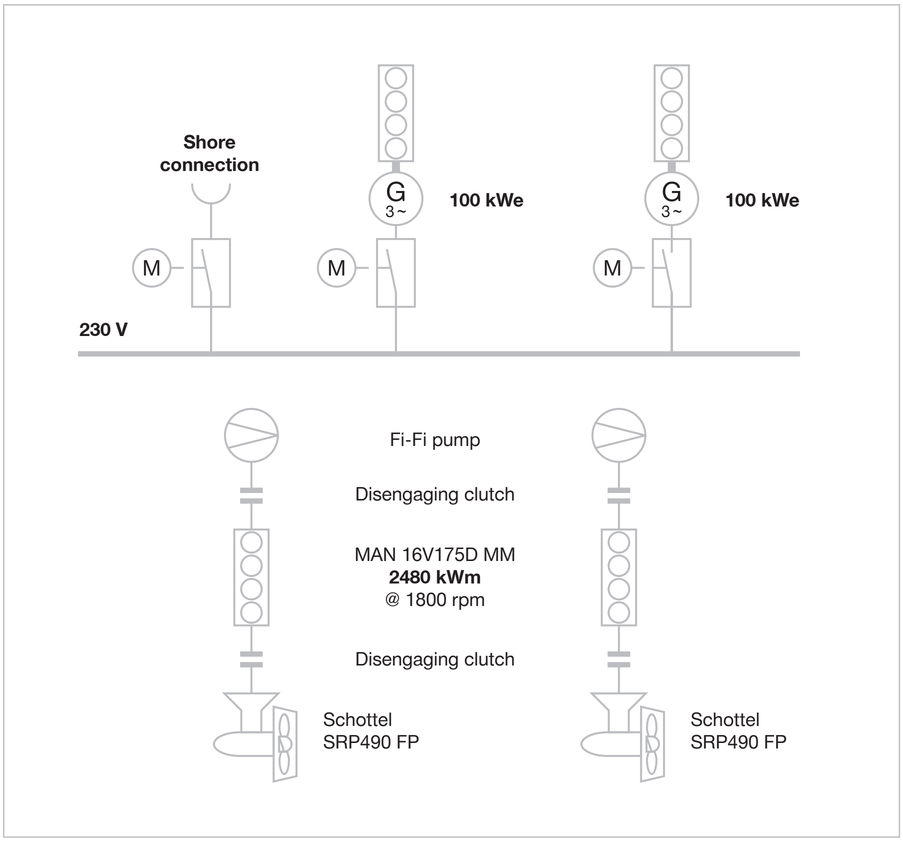


Figure 5: Conventional tug power plant single line diagram

Main engine

A single prime mover is installed per shaft line, such as a MAN 16V175D, with a rating of 2,480 kW at 1,800 rev/min. This supplies the power to the propeller, as well as to one fire-fighting pump driven directly from the front end of the crankshaft.

The speed ratio between the power input shaft of the thruster and the shaft line is controlled by a standalone HD slipping clutch. This clutch is able to modulate the speed of the output end from zero to the rated maximum speed of 1,800 rev/min on the drive end. Such a configuration enables the system to make use of full engine power during fire-fighting operations. While the pumps are running at maximum capacity, there is still sufficient power available for limited propulsion. The speed on both propellers is continuously variable for smooth manoeuvring via a slipping clutch.

In normal operation, the clutch controls the propeller speed from zero to engine idle speed and, consequently, the thrust. This is important if the tug is operating in sensitive areas such as locks and narrow waterways, where propeller wash has to be reduced to a minimum.

Azimuth thruster

Our selected azimuth thruster is a Schottel SRP 490 FP, a rudder propeller with a single power input pinion shaft. This is equipped with a hydraulic steering system for controlling the azimuth angle, and a 2.8 m fixed pitch propeller (FPP) running in an SDV45 XPA nozzle. Each unit produces more than 40 tonnes BP at 2,450 kW, taking account of an average thrust deduction on harbour tug hulls. As an alternative configuration, the slipping clutch could be substituted by a combination of a disengaging clutch and controllable pitch propeller. However, discussion of this configuration's advantages and disadvantages, as well as the impact on costs with regard to investment and operation, go beyond the scope of this study.

Boundary conditions for the alternative hybrid concept

While setting up a hybrid system concept as an alternative to the configuration shown in the diagram opposite, the focus is still set on the operational performance, in terms of costs and functionality, rather than fully on optimising the initial costs.

For the best operational performance, the system should cover as many daily operation tasks as possible while running the drivetrain in an electric-only mode and minimising the number of engine start-ups. While this is dependent on a safe and user-friendly layout, with a simple and flexible configuration, a problematic issue is the power distribution between the combustion engine and the electric motor/generator. The share allocated to the latter should be as large as possible in order to ensure maximum possible sailing speed and bollard pull without using the main engines. In addition, the electric power needs to be sufficient to enable smaller sized main engines to be selected. With regard to operational safety, a common requirement is the ability to run the tug without the use of the electric motor. Due to the ratio of the power demand from the propeller and the available torque of the engine, this defines the upper limit of the electric power share.

Pitch setting

To gain the maximum possible thrust, the pitch setting of the propeller blades is designed to absorb the total available power of the engine, plus the electric motor/generator, at rated speed. As a consequence, the propeller torque at all speeds in relation to the available engine torque is relatively high. Due to the engine's performance curves, this could lead to a situation in which the propeller demand exceeds the available torque with low rev/min values, preventing the engine from accelerating. Accordingly, the electric power share needs to be limited. In addition, a certain safety margin has to be considered, due to increased propeller torque during manoeuvring, and in case of water inflow discontinuity.

Comparative hybrid specification

The hybrid concept to be compared with the above-described benchmark layout follows similar operational and geometrical boundary conditions. Considering the same 32 m harbour tug hull, the drivetrain is designed to fulfil the same tasks: fire-fighting with engine-driven pumps and independent thrust control, as well as 80-tonne bollard pull in electric boost mode. The arrangement is illustrated in the single line diagram shown in Figure 6.

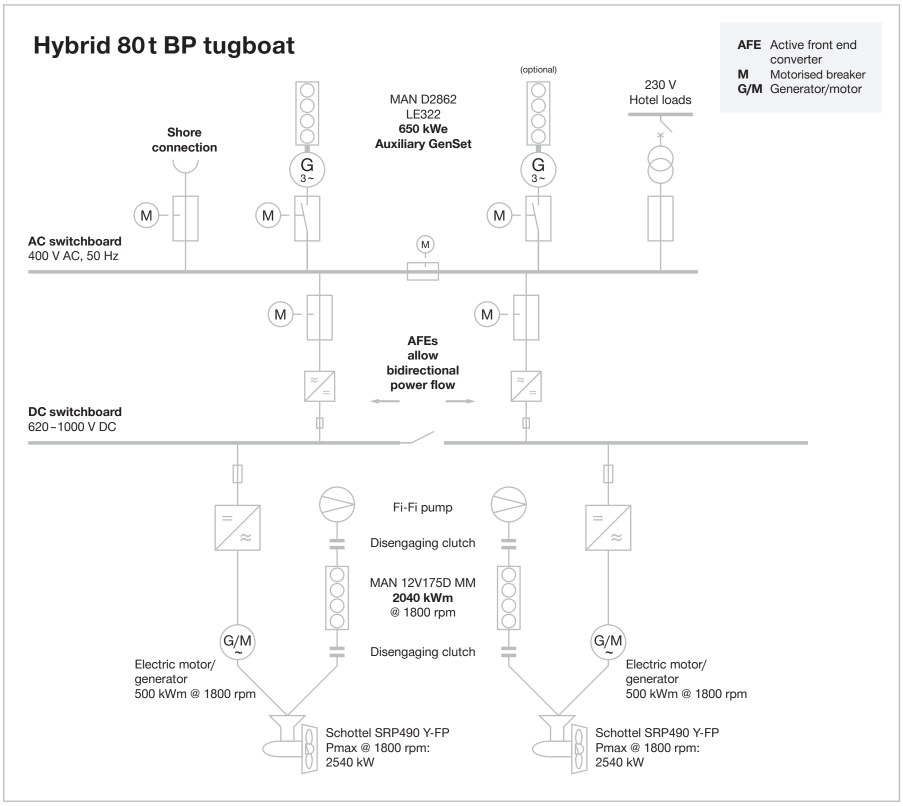


Figure 6: Hybrid tug power plant single line diagram (without ESS)

Smaller main engines

The primary power supply is still provided by the main engines. However, due to the electrical support, it is possible to select a smaller sized engine, such as a MAN 12V175D, with a power rating of approximately 2,000 kW at 1,800 rev/min. As stated above, the limiting factor in the selection is the available torque in partial load conditions. In Figure 7, the power curve shows the layout in such a way that the propeller absorbs the total combined power at rated speed in bollard pull (zero ship speed) condition.

In Figure 8, by contrast, the behaviour in diesel-only mode shows a break-even of propeller power demand and engine capability just below rated speed. Nevertheless, in a critical partial load condition – at about 1,000 rev/min – the torque of the relatively small engine is sufficient to accelerate the propeller to ensure safe and redundant operation.

A secondary PTI/PTO at the upper gearbox of the azimuth thruster is equipped with a 500 kW electric asynchronous motor, resulting in an equal total input power to the thruster, as in the benchmark case. Due to the main diesel engine's characteristics, the torque demand for the electric motor is important at lower speeds, whereas the available power is predominant at the rated nominal speed. This is demonstrated in Figure 9.

As a result, it is possible to operate the motor in field-weakening conditions, leading to reduced current and subsequently lower costs for motor and power electronics, as well as frequency converters. A further advantage is the compactness of such a motor design.

Figure 10, on the next page, shows the layout of the hybrid-capable azimuth thruster and power train. The thruster is a close relative of a conventional SRP 490 FP unit. The upper gear is extended with additional power intake positions (of a total of three). Each thruster can be equipped with a disengaging clutch, and is capable of transferring equal amounts of torque.

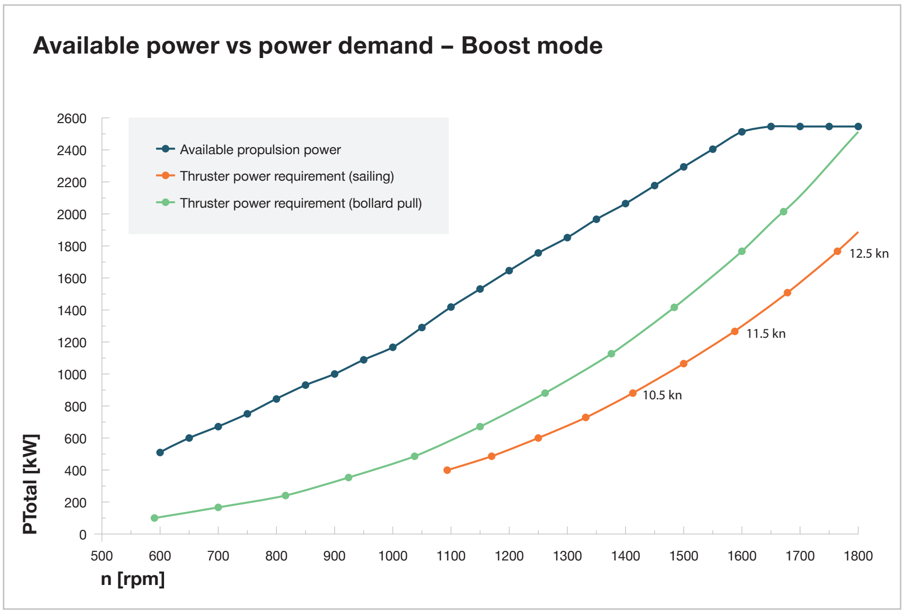


Figure 7: Power curves for hybrid diesel-electric operation

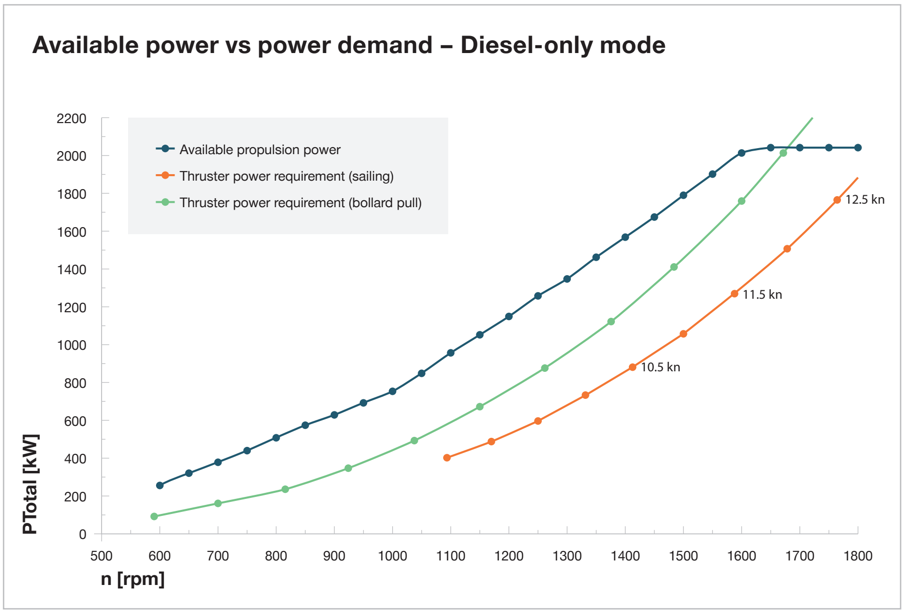


Figure 8: Power curves for diesel-only operation

To achieve maximum layout flexibility in terms of geometry, they are arranged with an offset angle of 90 degrees and 135 degrees to each other. Any two of these can be used as parallel power inputs. The third serves as an inspection opening. This arrangement provides for a highly flexible layout of the thruster room space. Mechanical diesel-driven firefighting pumps are connected directly to the engine front ends in both cases.

As was seen in Figure 6, in order to provide sufficient electric power, the increased consumption due to the electric drives is catered for by the selection of two 650 kW GenSets. These provide for the peak power requirements, consisting of the PTI motor demands, hotel load and power conversion losses.

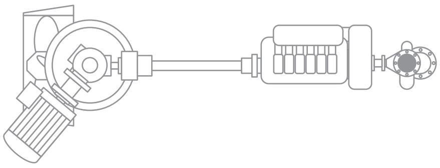


Figure 10: Hybrid power train with thruster-mounted electric drive

The selection of two equal sized generator sets and a symmetrical layout is based on redundancy requirements and the simplicity of the overall system. In the event of shore power not being available, an additional harbour GenSet, or alternative GenSet configuration, could be considered for supporting vessel hotel loads when berthed.

Even with just one generator running, the power is sufficient to sail at 7 knots in full electric mode. Other advantages, such as spare parts management, are also retained.

Optional variant with energy storage systems

In the case of an optional ESS, the number of GenSets can be reduced, as short-term demand is buffered or replaced. The ratio of generator power and ESS capacity depends mostly on

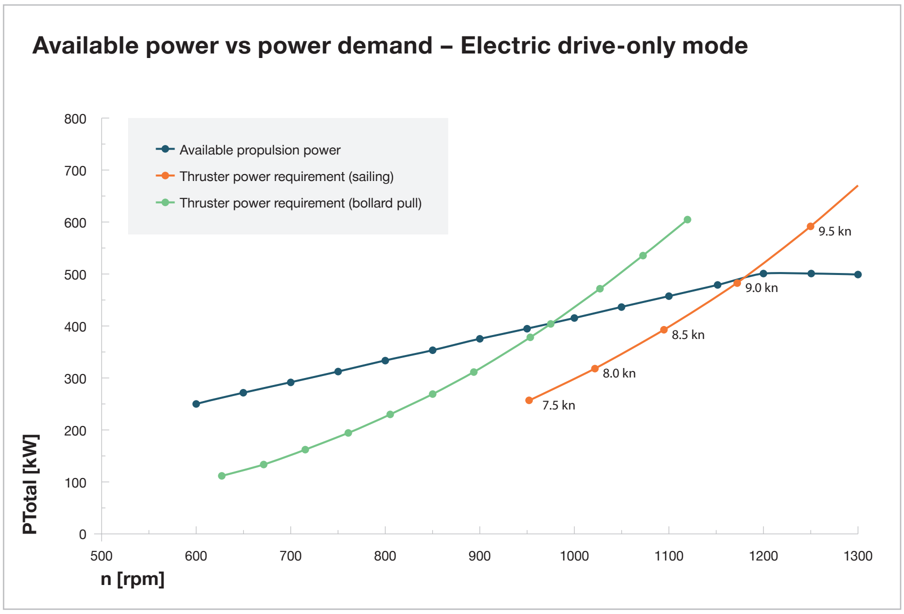


Figure 9: Power curves for electric-only operation

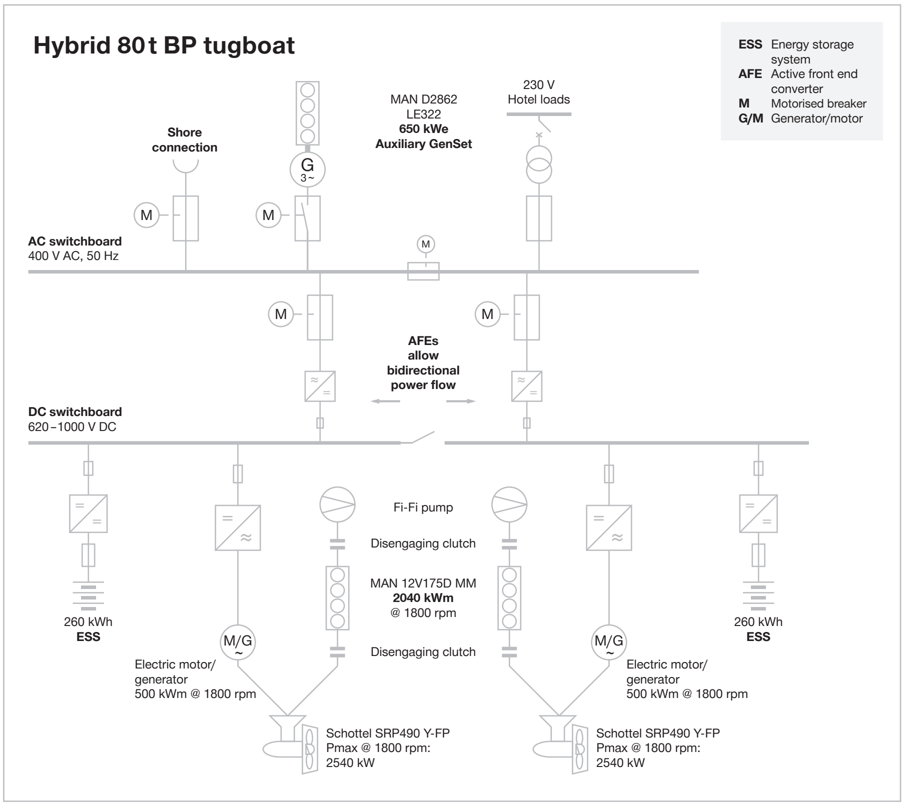


Figure 11: Hybrid tug power plant single line diagram (including ESS)

operational requirements specific to an individual location, such as the distances to be covered, loiter times for zero emissions Idle mode, and the time required to start back-up generation in the event of a generator failure. This especially applies if zero emission and/or low noise operation is necessary. Depending on the size of the protected area, the capacity could vary significantly. In the case shown in Figure 11 due to the experience gained from a number of operating vessels in the case under consideration, one of the GenSets has been substituted by a 520 kWh ESS arrangement. With this system, it is also possible to engage the motor/generators in a power generation mode, driven by the associated main engine, with virtually zero cost increase on the system. This has the additional benefit of potentially reducing operating hours on the remaining auxiliary GenSet.

Having set up the alternative drivetrain configuration, the individual components can be carefully selected and matched in order to enable a comparison of decision-relevant capital expenditure.

Integrated power management system

The hybrid system is also equipped with an integrated PMS, which provides high-level control of the power plant and its associated auxiliary systems. The PMS also allows for mode selection and operator interaction via a dedicated Human Machine Interface (HMI). Depending on the mode of operation selected, the PMS automatically configures the power plant as required. It is able to start and stop auxiliary GenSets, main engines, power converters and system auxiliaries, such as cooling and lubrication pumps. All monitored system values, detailed alarms and trending screens are also accessible via the HMI.

CAPEX comparisons

When considering total expenditure, the operational proportion of the ownership costs of hybrid vessels (OPEX), and especially tugs, has been widely discussed in the past. Without losing sight of these, we will focus here on CAPEX.

The latter consists, in the most common view, of three components: procurement costs, interest and resale value recovery, with the most important being the procurement costs. The aim of this study is to find a superior hybrid arrangement which, in terms of upfront equipment costs, is competitive when compared to a conventional multi-functional harbour tug. To achieve this, a careful combination of (preferably standard off-the-shelf) products was selected, as described above.

Overlooking the practical operational needs and optimising the equipment solely and exclusively on the basis of procurement costs (e.g., by selecting the smallest possible electric motors, frequency converters and GenSets) would be one way to address our goal of aligning CAPEX with conventional solutions. However, when it comes to taking a holistic approach, this would prove unsatisfying and impractical.

Conventional – Hybrid – Hybrid Battery

The cost structure for our study is illustrated in Figure 12. The left-hand column represents the benchmark case, the central column the comparative case and the right-hand one the optional version with battery support. All items of the propulsion drivetrain affected by the different concepts are represented and grouped into 10 major functional assemblies.

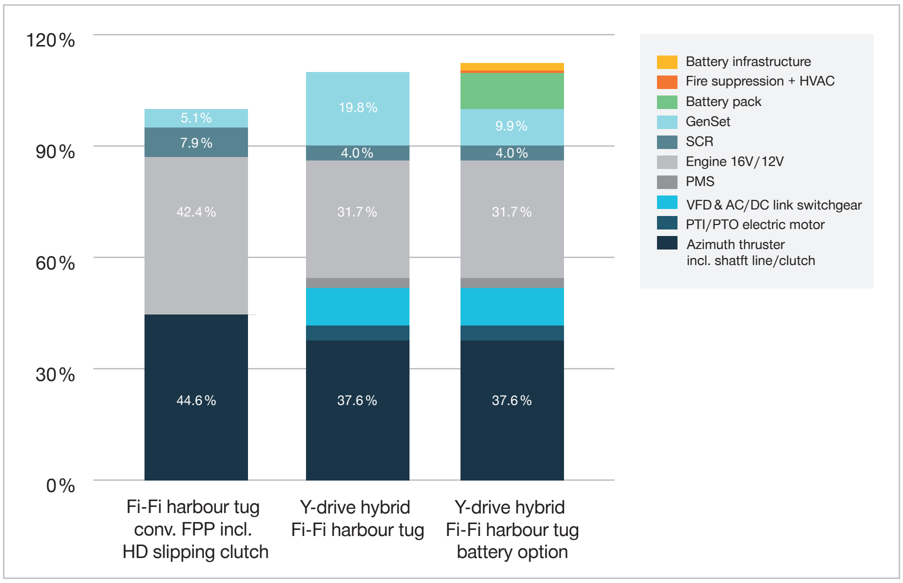


Figure 12: Cost structure comparison

Cost savings and increases

The percentage values are for the propulsion package cost only and are all relative to the benchmark case (defined as 100 per cent). Even though the overall percentage increase only varies by 10-12 per cent, the distribution and structure change considerably. Some significant benefits are apparent from this:

- The largest saving potential is in the main engine selection. The reduction from 16 to 12 cylinders decreases initial expenditure of the drivetrain by more than 10 per cent.
- In conjunction with this engine downsizing, further savings are possible due to cost reductions in the exhaust gas after-treatment selective catalytic reduction (SCR) system. In more detail, the application of a modular after-treatment system allows for a 12V engine, the usage of an optimised, scaled-down system, with an overall reduction of the number of components utilised.
- The other major cost reduction factor relates to the rudder propellers (including the associated auxiliary equipment) and the shaft line. Even though most components remain the same, as the total torque on the shaft does not change significantly, there are savings of about 7 per cent. This is predominantly due to the substitution of the slipping clutch by the secondary power input and a conventional disengaging clutch where additional costs are overcompensated.

On the other hand, there are, of course, additional equipment costs to be incurred:

- Increased costs for the larger GenSets (in the range of 10-20 per cent, depending on the use of an ESS). As power provision is shifted from the main engines to the electrical system, the size of the generators needs to be increased accordingly. Consideration of IMO Tier III compliance also has to be factored in here.
- This electric power needs to be controlled and converted into mechanical torque by the PTI/PTO electric motors, the associated VFDs, additional switchgear and a more complex PMS. Despite the fact that the procurement costs of these electrical components will tend to reduce in the future, they should not be underestimated. This additional cost group results in up to 17 per cent higher expenditure.

If we then go a step further by using an ESS, this also has an effect on CAPEX:

- Auxiliary equipment also needs be considered. In addition to the ESS installation itself, the BMS and other infrastructure is mandatory. Furthermore, fire suppression and HVAC for the ESS room plays a role. These cost groups add another 12.5 per cent in relation to the benchmark configuration. As with the other electrical components, this will be significantly impacted by future cost reduction trends. This expenditure is partially counteracted by a definite possibility of reducing onboard GenSet capacity.

Slightly higher investment

Overall, this represents a slightly increased cost framework for the propulsion plant of less than 10 per cent for the hybrid concept and 12.5 per cent if we also add an ESS option. Considering that the propulsion train typically contributes about 25-30 per cent to the overall tugboat procurement cost, an additional overall extra investment in the range of 2.5-3.8 per cent can be proposed. It must nevertheless be mentioned that extra costs on the shipyard side for foundations, wiring, installation and testing of the components have not been considered at this stage.

Due to its small impact and the very individual structure of this scheme, considerations of interest and other supplementary costs have been ignored. However, following this survey of pure investment costs, we should not overlook a sideways glance at some operational benefits for the main engines.

Reduced OPEX, better amortisation and value preservation

As previously mentioned, one important aspect of the hybrid concept is the maximisation of full electric operation. This is ensured by providing sufficient electric drive power. If we observe the typical operating profile of a harbour tug, where power consumption versus time share is plotted, it would be expected that performance in electric mode with regard to sailing speed and bollard pull is sufficient to cover approximately 70 per cent of all load profiles. However, this value needs to be considered as a maximum possible theoretical number. Due to dynamic load variations, and for safety reasons during operations with the target vessel, the engines will usually be running on standby even in times when the electric motors would be sufficient to satisfy power demand. With this in mind, and as experience shows, a realistic share of full electric operation can achieve 50 per cent, as long as loitering and transit can be covered in such a way that operational procedures are not affected.

Considering an average annual operation time of 3,000 hours for the propulsion plant, this leads to about 15,000 hours in ten years, which corresponds to the normal mean time between overhaul of the main engines. As a result, downtime and the number of overhauls are reduced accordingly. This, of course, is an important contribution towards decreasing repair and maintenance costs, and in this respect is an important factor in scaling down operational expenditure. In addition, the extended lifetime of the engines due to fewer operating hours and a less demanding load spectrum should not be underestimated. This positive impact on amortisation and value preservation, when interpreted holistically, further reduces the gap with regard to the capital expenditure for the different variants introduced.

5. Hybrid marine propulsion with ESS today and future development of markets and applications

Technological progress

Recent technological advances are making ever-leaner solutions possible for fully integrated hybrid propulsion systems. This includes better options for key components, such as power conversion equipment, thruster drives with secondary PTI/PTO options, and ESSs. It also covers better PMSs for more optimised plant topology configurations. Another highlight is the closer relationship between the ESSs and diesel power generation. This leads to a better understanding of load processes, allowing for reduced communications infrastructure between autonomous functions and supervisory systems. This in turn drives a more CAPEX-friendly approach towards newbuild development and retrofit projects that are more elegant and less complex.

Falling price of energy storage systems

ESSs can now be equipped with more versatile management systems. These allow smarter cell balancing and charging schemes that reduce battery replacement costs by extending life cycles. This is complemented by the plummeting prices of batteries per kWh. By combining longevity and ease of procurement with smart operational modes, specifically tuned for ESSs, a demonstrable bridge is established between CAPEX and OPEX for hybrid workboat propulsion systems.

More reliability, less downtime

Predictability and reliability lie at the core of these advancements. This equates to a better approach to addressing risks in the workboat industry. Data collection methods are continuously advancing, and have already resulted in improved analytics for vessel operation at key nodes [13]. This leads to a better understanding of what can cause reliability issues and allows for the prevention of vessel failure events. The consequence is a highly reliable plant for the vessel that is predictable and tuneable to minimise and address vessel risk. This, in turn, reduces downtime and equipment failure costs, and provides an environment that is focused on safety.

Better for vessels with more load variations

Looking at other workboat applications, any vessel with significant operational time, utilising a multitude of different load levels on the propulsion system, is potentially well suited to a hybrid drive concept.The operational advantages improve and the payback time reduces as the variations between partial and full load and operational time in partial load increase.

Lower emissions in restricted areas

In addition, the increased introduction of restricted sea areas with strict regulations in terms of exhaust gas and noise emissions leads to a high demand for ‘green’ operation which can more easily be implemented using dedicated hybrid or all-electric modes.

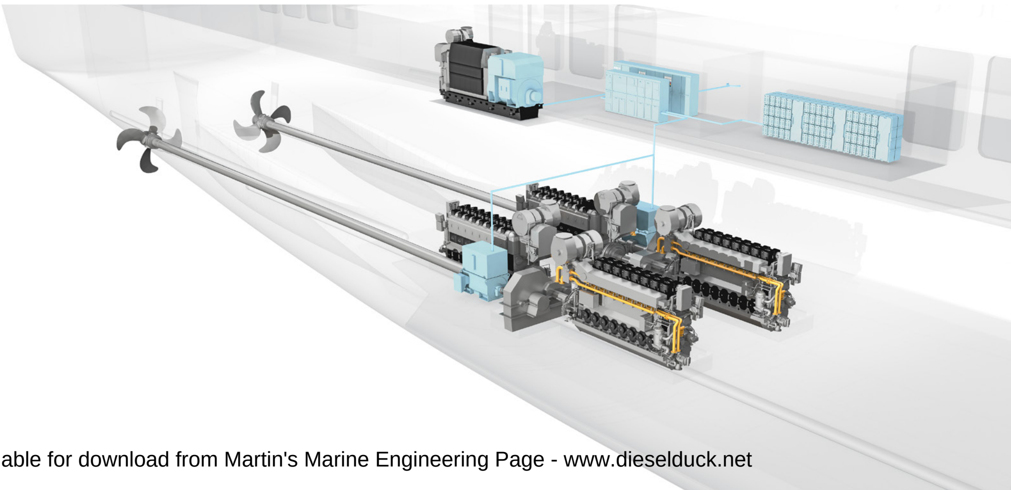
Faster load response

In this respect, hybrid concepts have already been successfully introduced into harbour and anchor handling tugs, OSVs, as well as into different types of ferries. Clearly, opportunities can be found in offshore windfarm support and maintenance vessels, where a high degree of dynamic positioning (DP) accuracy is always required for safe operation. This can be achieved as a result of hybrid propulsion systems offering significant improvements in terms of rapid load response compared with conventional diesel.

The same can be said for different types of emergency vessels, which use their relatively high propulsion power in (thankfully) rare cases of maritime incidents. In the case of emergency rescue response vessels (ERRVs), it is known that they spend most of their lifetime on standby, weathervaning at very low load conditions. Light DP operation in all-electric mode could be very favourable in these circumstances. Emergency towing vessels or search and rescue (SAR) applications, where again there is a requirement for rapid response to load change on the propulsion line and short-term propulsion power boosts, would also benefit from hybrid technologies, especially if the ESS were available for immediate power availability and peak shaving.

New applications

Looking further ahead, developments in the field of autonomous workboat operations will also be greatly progressed and better advanced by utilisation of a hybrid propulsion system e.g. the MAN HyProp ECO and MAN HyProp Battery, with all its benefits (as highlighted above) when compared to conventional diesel-mechanic or diesel-electric options.



Conclusion

In this paper it has been shown that the move towards much needed vessel optimisation and efficiency, through the inclusion of hybrid propulsion systems, can be achieved without being significantly hindered by major increases in capital expenditure. This has been proven by looking at another industry case study, considering important and modern technological developments, and by using a typical and realistic tugboat example. At the same time, existing operational benefits and safety considerations are not only uncompromised by this approach, but are in fact even enhanced in some aspects of power plant and vessel performance.

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