

# Hybrid propulsion concepts on ships

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## Keywords

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## Abstract

The hybrid technology is not only a current issue in the field of electric vehicles. Also in the area of ships there are some projects to replace the proven diesel mechanical drives by innovative drive concepts.

In this paper the feasibility of hybrid propulsion concepts is examined for different types of vessels. The paper shows that there are definitely opportunities to save energy by using hybrid drive systems on ships. In some cases this can even return the much higher investment by savings in fuel.

## Introduction

The hybrid drive technology is not only interesting for drive systems for electric vehicles. In the area of ships there are several activities to replace the proven diesel mechanical drives by new drive concepts. The triggers are firstly the ever increasing price of fossil fuels and the other a more stringent emission standard in so-called Sulphur Emission Control Areas (SECA) from 1 January 2015. After that, only fuels may be used with a sulfur content of 0.1% in many coastal regions, which means additional costs for the purchase of fuel.

The biggest difference in the use of electric propulsion on ships compared to electric drive systems in cars is the recovery of braking energy. The lack of direct adhesion between the propeller and the water makes it difficult to recover energy during braking for ships. This results in smaller

savings through the use of hybrid drive concepts compared to road vehicles.

In this paper the feasibility of hybrid drive concepts will be reviewed on different types of ships.

For ships that travel most of the time at constant speed, such as container ships, it make no sense to replace a diesel-mechanical drive by hybrid concepts, because the diesel-mechanical drives are optimized for this operation and then getting a lower consumption than a diesel-electric or hybrid system. Therefore, in this paper possible future hybrid drive concepts are investigating for a harbor tug and a motor ferry. The studied concepts consist of a diesel generator, electric drives and electric batteries as energy storage.

It is the first evaluation of the actual conditions of the study ships and the creation of an exemplary load profile based on local measurements.

Focus on the further investigation of the fuel consumption of different drive concepts and the resulting cost was calculated based on a cycle. Different hybrid drive concepts are investigated and compared with the classical diesel mechanical drive and a diesel-electric drive.

The potential savings are based in the optimization of the operating point of the diesel engine concerning speed and power. The operation at lower specific fuel consumption offers the possibility of saving energy.

This also requires a rethinking of the manufacturers of diesel engines because the engines are not operated at a constant speed. For every required drive power the diesel engine can be operated at the optimum speed now. This, however, requires a two-dimensional characteristic for the specific fuel consumption as a function of speed and power.

The paper shows that there are savings in special conditions by the use of hybrid drive systems on ships. In some cases, even the much higher investment can be

compensated by savings in fuel. Probably in the future due to the rising fuel price and the lower price of batteries such hybrid drive concepts will be even more attractive.

## Harbor Tug

First, a hybrid propulsion concept for a harbor tug is investigated. [2]

### Description of harbor tug

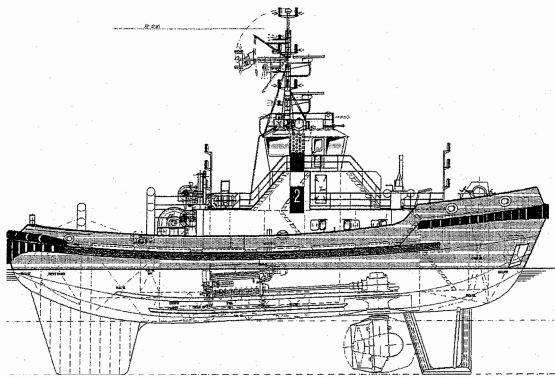


figure 1: Bugsier 2, harbor tug with thrusters

The investigated harbor tug is a tractor tug. That means it has two thrusters in the forward part of the vessel (see figure 1). The main task of a harbor tug is towing of large ships such as container ships in the harbor area. An exemplary load profile of a typical harbor tug use is shown in the following chapter.

### Load profiles for harbor Tug

An exemplary load profile is shown in figure 2. This load profile corresponds to a real operation.

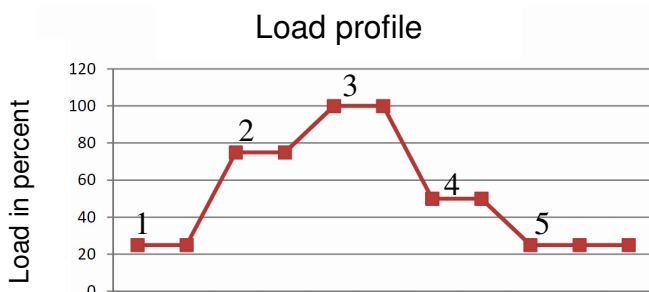


figure 2: load profile using a tug boat towing

1: Driving to ship 25% load

2: Turn the ship 75% load

3: Increasing load at maneuvers against wind flow or 85% -100% load.

4: Assistance in reduced load 50%

5: Return to Location 25% load

The percentage load times are shown in the diagram in figure 3. As the load profile in figure 3 shows, harbor tug operates mainly in part-load. This high proportion of part-load allows savings of fuel by the use of a hybrid drive system. The following chapter will present hybrid drive concepts. When using more than one combustion engine, one drive can optionally turned off or the combustion engines can run in the improved efficiency in the partial load operation.

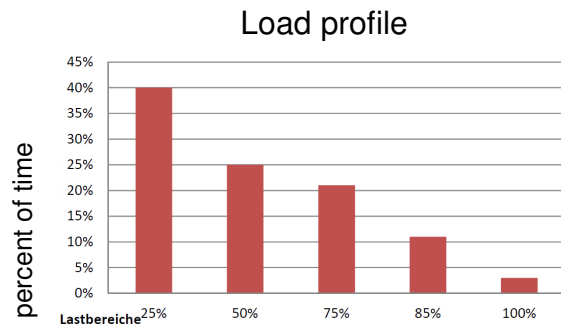


figure 3: load profile of harbor tug

### Propulsion concepts

In the following chapter a possible concept for a hybrid operation of diesel electric propulsion with battery is presented.

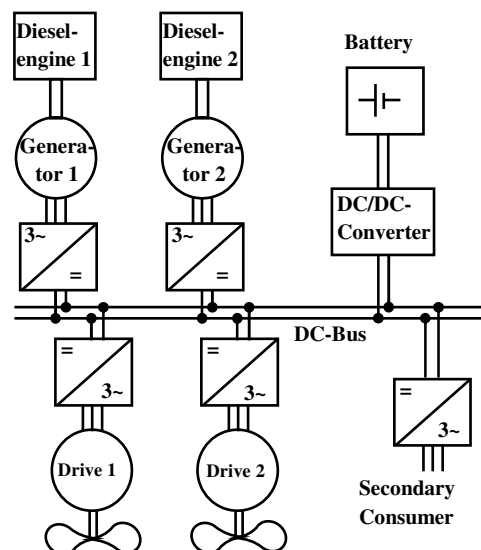


figure 4: Hybrid propulsion concept

Figure 4 shows the examined hybrid drive concept for the harbor tug. Here, the electric power is generated by two synchronous generators, which are driven by diesel engines, and fed into a DC bus by a rectifier. On this DC bus, the drive machines are now connected by an inverter. Moreover, battery modules are connected to the DC bus. Via a DC/DC-converter the power can be stored in the batteries, or be powered from the battery to the DC bus.

The savings potential of a hybrid drive system on ships is in the fact that this engine is used in operating areas, in which the specific fuel consumption is lower.

Figure 5 shows the specific fuel consumption of the diesel engine Wärtsilä 6 L 26 (2040kW). It can be seen that the specific fuel consumption under partial load increases in comparison to full load by approximately 25%. The graph in figure 5 is at a constant speed. With variable speed, which is possible with the concept described in figure 4, the differences in the specific fuel consumption can be even greater.

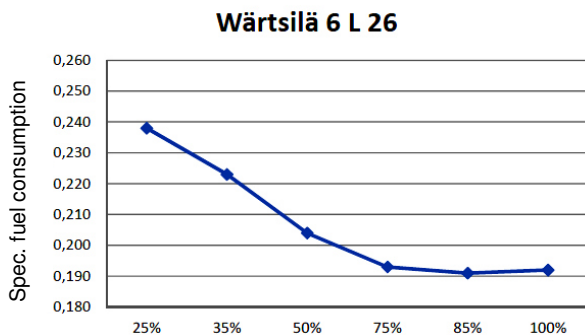


figure 5 specific fuel consumption

## Components of hybrid propulsion system

For a realistic concept the individual components are designed using the example of a real harbor tug.

## Propulsion drives and other consumer

For the required pulling force of the tug with two drives, the power must be 2400kW for each drive. The consumption of the secondary consumer is approximately 200 kW. This makes a maximum power of 5000 kW.

## Diesel motors and batteries

Since the load range of 25% is operating in 40% of the time, the battery performance is made on this value. This power should be provided by the battery for a period of one hour to support the operation for a hole cycle. Therefore, the batteries must have the energy of 1250 kW and the capacity of 1250 kWh.

These diesel engines must be able to supply at least 75% of maximum power, so that in the full traction is available. For the two diesel engines the Wärtsilä 6 L 26 were selected with an output power of 2040 kW each.

For each component of the electric part of the hybrid system the following efficiencies were assumed (table 1).

table 1: efficiencies of electric components

	efficiency
Synchronous generator	96,5%
Loading batteries	96%
Unloading batteries	96%
Inverter	98,5%
Rectifier	99,5%

## Investment costs

The following table 2 shows the investment costs for the different propulsion concepts compared to the diesel-mechanical system.

For these comparisons an annually operation of 2500 hours (bh) is expected. The fuel costs are assumed to be 0.78 €/kg. For the cost of a kWh of electricity the price of 9.11 cents is adopted.

The costs of different drive concepts compared to the diesel-mechanical concept and the diesel-electric concept is done now.

By reducing the specific fuel consumption of the diesel-engines at 2500 hours annual saving of € 29,250 in diesel-electric concept and € 46,800 and € 115,250 for the hybrid concepts is possible compared to the diesel-mechanical concept. The saving in the second hybrid concept is twice as high due to the use of electric power of the public grid to charge the batteries. The payback period compared to diesel-mechanical concept is far beyond the expected life of the systems.

(68 years for diesel-electric, 60 years for hybrid and 24,5 years for hybrid with charging by public grid)

In contrast, the comparison to the diesel-electric concept looks better. Here is the payback period of the hybrid concept at 47 years and the hybrid concept with public grid power at 12 years. It can be summarized that the use of a hybrid propulsion systems in a harbor tug only makes sense if already a diesel-electric system is planned or is already installed. A realistic payback time is here only possible with the use of public grid electricity to charge the batteries.

### Motor ferry

The motor ferry is another type of ship to investigate a hybrid drive system for in this paper. [3]

### Description of motor ferry

The motor ferry NORDENHAM (short: MF NORDENHAM) is a double-ended ferry owned by the Weserfähre GmbH, Bremerhaven and operates on the river Weser (figure 6).



figure 6: Motor Ferry Nordenham

The motor ferry is currently driven by two Voith-Schneider propellers, which are driven directly by a two gas engines.

The MF NORDENHAM drives on the Weser between the city of Bremerhaven and the district of the city Blexen Nordenham (figure 7). The trip included time spent lasts about 20 minutes. The distance is about 3 km.

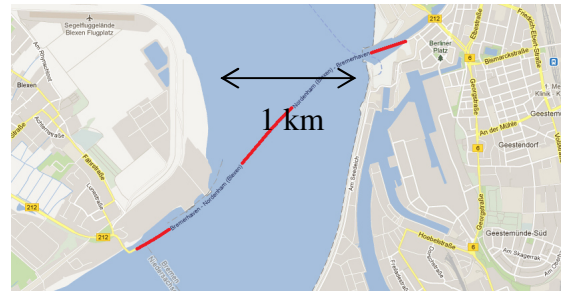


figure 7: ferry connection of the motor ferry Nordenham

In Table 2, the power requirement for the motor ferry is listed. The two Voith-Schneider propellers each require a drive power of 470 kW and for consumers in the electrical system are approximately 50 kW required.

table 2: Power Consumption

Consumer	Power Consumption
Propulsion drives	2 x 470 kW
Secondary consumers	50 kW
total	990 kW

The following figures 8 and 9 show the different drive concepts that are investigated for the motor ferry.

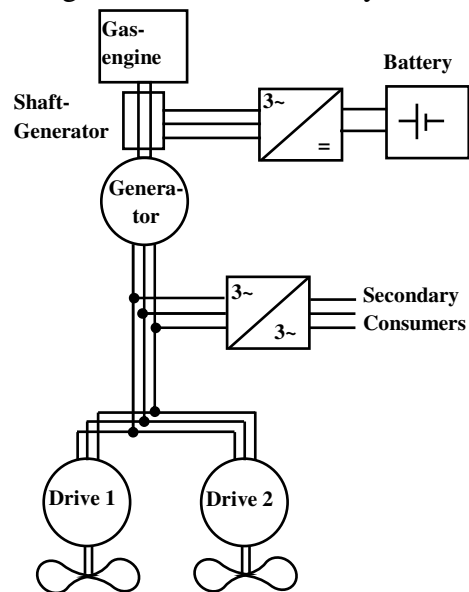


figure 8: Concept 1 and 2

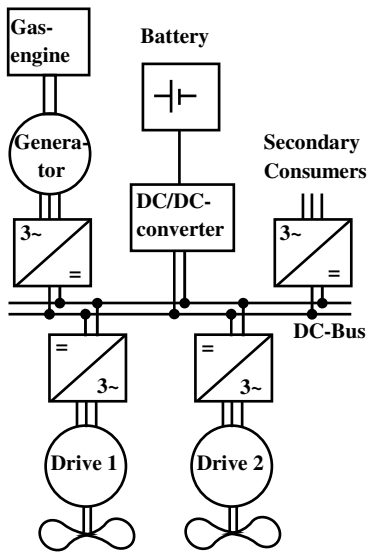


figure 9: Concept 3 and 4

All concepts include a gas engine with a synchronous generator and extra batteries as energy storage. The concepts differ in that the Concept 1 and 2 present a three-phase system as a distribution network on board and in type 3 and 4 there is a DC power supply. Moreover, the different coupling of the battery. The concepts 1 and 2, the coupling takes place with an additional drive, which is coupled to the mechanical shaft between the gas engine and the synchronous generator. In the concepts 3 and 4, the coupling of the battery is via a DC/DC-converter directly to the DC bus.

The following Table 3 shows the performance of gas engine and battery system and the capacity of batteries for the different concepts.

table 3: Drive Concepts

	Concept1	Concept2	Concept3	Concept4
$P_{Gaseng}$	850 kW	1200 kW	850 kW	1200 kW
$P_{Battery}$	83 kW	1040 kW	97 kW	981 kW
$E_{Battery}$	35 kWh	420 kWh	40 kWh	400 kWh

### Load profile of motor ferry

To design a drive system according to the power requirements of the MF NORDENHAM it is necessary to evaluate the actual driving behavior.

First, a typical load profile for a crossing of the river is created, which takes about 20 minutes.

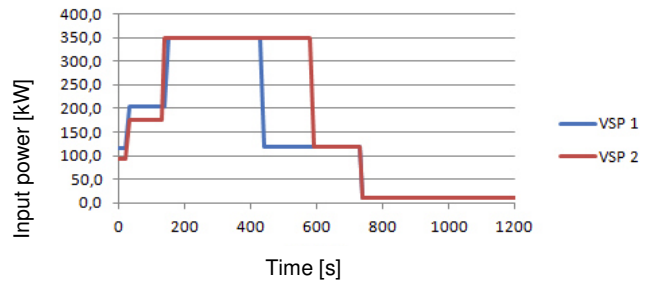


figure 10: Input power [kW] of the Voith-Schneider propeller crossing Bremerhaven Blexen

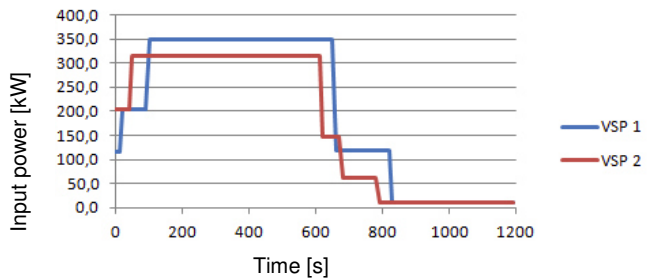


figure 11 Input power [kW] of the Voith-Schneider propeller crossing Blexen Bremerhaven

Figures 10 and 11 show typical load profiles for cruises from Bremerhaven to Blexen and back.

First, each maneuvered with partial load in the vicinity of the harbor. After 2-3 min the power is increased to nearly full power for the crossing.

After about 10 minutes, the power is reduced when approaching harbor. While the ferry is at the feeder, the power is reduced to about 10%.

The percentages of load conditions can be seen in the figure 12.

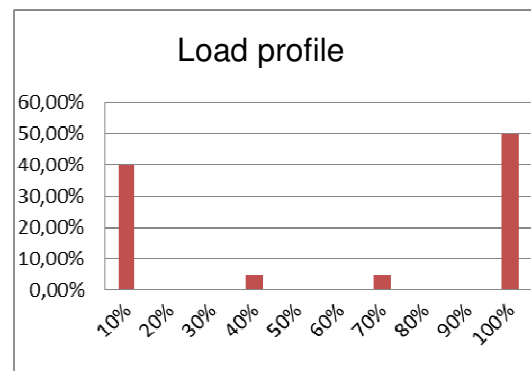
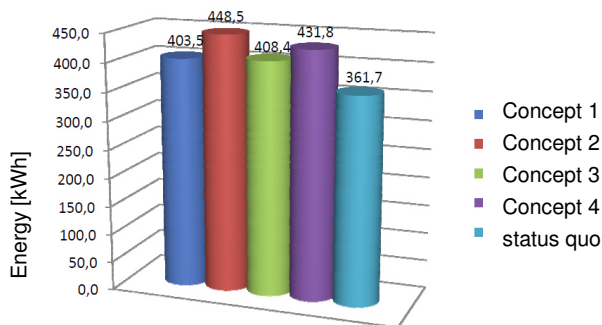


figure 12: Load profile of one of the engines of MF NORDENHAM

The following figure 13 shows the results of the comparison of the four different hybrid drive concepts in comparison to gas-mechanical system, which is described as a status quo.



**figure 13:** Comparison of drive concepts for motor ferry

Without consideration of the higher investment costs none of the considered concepts brings an energy saving in this load profile.

It is even so that all variants have an increased consumption compared to the gas-mechanical system, which is just in the variants with a large battery capacity at about 20%.

## Conclusion

In summary it can be said that the use of hybrid drive systems on ships, in certain circumstances make sense.

A hybrid drive concept offers the possibility by adjusting power and speed to achieve lower specific fuel consumption. This can have a big impact, especially in the partial load range.

In this paper different hybrid drive concepts for a harbor tug and for a motor ferry are investigated.

For the harbor tug the investment costs for the hybrid propulsion system are about 820.000 € higher compared to the diesel-electric system. These costs can only be saved during the lifetime of the system if the batteries are charged by the electricity of the public grid after each operation. But there must be enough time to charge the batteries during the break between two operations.

The second type of ship that is investigated is a motor ferry. The motor ferry operates every 20 min between Bremerhaven and Blexen/Nordenham. Compared to the harbor tug the time of full load operation is

much higher. This is the main reason, that the hybrid propulsion system does not save energy compared to the gas-mechanical system.

Finally, I would like to thank Mr. Götttsche and Mr. Nikolai for their preparation work for this paper as part of their Bachelor thesis.

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