Danube Transnational Programme

GRENDEL

The concept of electrical propulsion systems is not new. The first ships with diesel-electric propulsion were in operation as early as 1904 and the concept has obviously made a lot of progress since then. The future belongs to green propulsion technologies. Diesel-electric propulsion combines the high efficiency in matching use-cases, low noise levels and environmental sustainability due to potentially lower emissions. This fact sheet offers insight into diesel-electric propulsion, ranging from relevant regulations, technical concepts, information on economics and environmental sustainability as well as references to deployed examples.

FACT SHEET N° 2

DIESEL-ELECTRIC PROPULSION

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In cooperation with INDanube

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REGULATIONS

Regulations for diesel-electric installations are set in the **European Standard laying down Technical Requirements for Inland Navigation vessels (ES-TRIN 2019)** which is updated regularly. If a classification of the vessel is necessary, there are also additional **rules from the classification societies available.** Due to the regulations a diesel-electric propulsion system must consist of at least two generator sets, one main switch board, one frequency converter and one electric motor on the propeller shaft. One of the generator sets must be able to ensure a safe ship operation for at least 30 minutes in case of a failure of the second generator set.

The emission limits of the diesel engines, which are used to drive the electric generators, are put into force in 2019, and 2020 for larger engines respectively, according to **Regulation (EU) 2016/1628 (NRMM).** To comply with the emission limits it is possible to add an exhaust gas after treatment to the diesel engine (see fact sheet exhaust gas after treatment systems).

Looking towards future technologies, it is possible to **combine diesel generators with batteries or fuel cells.** In case of using an alternative energy source, the energy source must comply with the same regulations on safety and redundancy as a diesel generator: at least two independent energy sources must be installed on board, each of them providing enough energy to achieve the vessel's minimum required manoeuvrability for at least 30 minutes.

TECHNICAL CONCEPT

The applied technical concept for the propulsion of inland vessels depends on the vessel type, targeted speed and sailing profile. To benefit from a conversion to diesel-electric propulsion, a vessel should meet one or more of following criteria:

- High electrical power demand with high degree of varying loads
- High degree of partial load for propulsion
- High comfort demands
- High demands towards redundancy
- High demands towards manoeuvrability

A diesel-electric drive train consist of energy sources, switch boards, electrical control units and electric main propulsion motor(s). A common setup of a diesel-electric drive train is shown in the figure below.

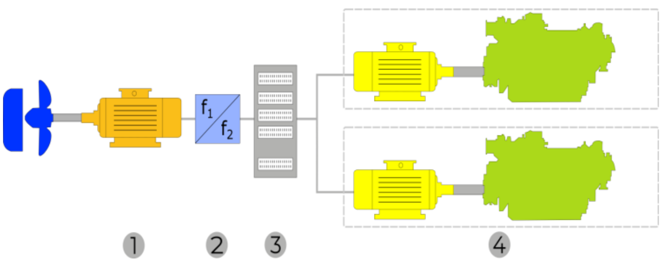


Figure 1: Setup of a diesel-electric drive train

1. *Electric Motor:* The electric motor drives the propeller at any load case. Its advantage is a nearly constant efficiency at all load cases. Depending on the selected electric motor a gear box can be omitted.
2. *Frequency Converter:* The frequency converter supplies the electric motor with a frequency and voltage amplitude variable AC voltage. The converter can be supplied by any AC or DC on-board energy grid. The rotational speed of the electric motor is controlled by varying the output frequency.
3. *Main Switch Board:* The main switch board distributes the energy from all sources to all loads. The loads are frequency converters at the propulsion systems, hotel load, pump systems and so on. It could be designed as a single AC or DC rail, which can be split into a starboard and portside system.
4. *Generator Sets:* Each generator set can consist of any combustion engine (e. g. diesel or gas) and an electric generator. The combustion engine drives the generator to convert the chemical energy from fuels to electric energy. The generator can provide AC or DC power, depending on the selected main switch board and frequency converters.

ENGINES FOR DIESEL-ELECTRIC PROPULSION

Any type-approved diesel engine for inland ships (NRMM Stage V category IWP/IWA or NRE and Euro VI truck engines after appropriate marinization) can be used. In combination with an electric generator, the system is known as genset (generator set). The diesel engine must comply with relevant regulations and provide enough power to drive the generator. For the electric propulsion motors different types are applicable.

ASYNCHRONOUS MOTOR

The asynchronous motor is the most widely used industrial motor. It can be connected directly to the three-phase mains and is very robust and easy to build. The asynchronous motor takes its name from the fact that it does not rotate exactly with the mains frequency. It only has a torque if its speed deviates from the synchronous speed. In the operating range, the torque is proportional to this deviation. This type of electric motor is characterized by low investment costs and small dimensions. Its nominal rate of revolutions is usually too high to be used as a direct drive. A gearbox between electric motor and propeller shaft is necessary. The gearbox increases the investment costs, lowers the efficiency of the drive train and could be a point of failure. If the advantages of asynchronous motors and the disadvantages of the gearbox are balanced correctly, a cost and energy efficient drive train can be designed.

SYNCHRONOUS MOTOR

For synchronous motors, the speed of the motor is equal to the mains frequency divided by the number of pole pairs. The rotor of a synchronous motor is permanently magnetized and follows the rotating field of the stator. Usually, the speed is given in revolutions per minute (rpm). This type of electric motor is characterized by high energy efficiency, low nominal rate of revolutions and a good torque/speed characteristic. This motor can be used as a direct drive, without a gearbox between motor and propeller shaft. Its large outer dimensions are disadvantageous like the high investment costs. Using a synchronous electric motor for the propulsion system leads to an efficient drive train with a sensitive control.

ECONOMICS AND ENVIRONMENTAL SUSTAINABILITY

In contrast to direct drives, the propeller of the diesel-electric propulsion is operated by an electric motor, which draws power from a diesel generator. Since the genset can be replaced by other energy sources like a gas genset, a battery or a fuel cell system, this concept can be regarded as a bridge technology. Another advantage of the diesel-electric concept is that the gensets are produced in larger quantities than engines for inland waterway vessels, which can result in a financial advantage.

INVESTMENT COSTS

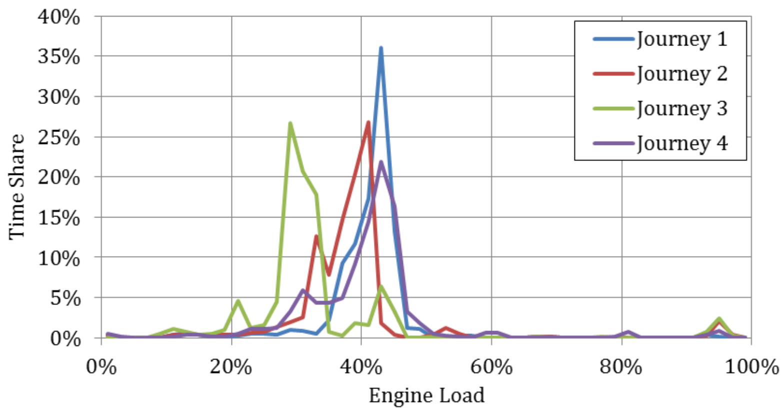
With a diesel-electric drive, additional costs incur for the electric motor, frequency converter and extended main switchboard. In the layout of the drive train it is aimed for matching the distribution of power with the operational profile so that diesel generators are either used in their sweet spot or not running.

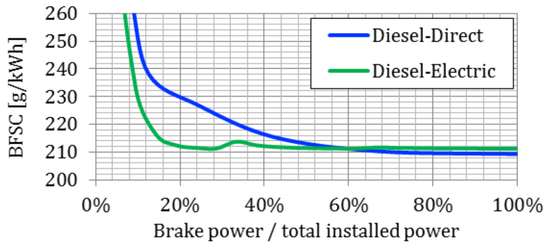
Cost category	Exemplary costs
Gensets	350 EUR/kW
Electric motor	120 EUR/kW
Installation costs	30,000 EUR for conversion, wiring and power management

ECONOMIC OPERATIONS

Depending on the operational profile, diesel-electric propulsion can significantly **reduce energy consumption and emissions** since it makes it possible to adjust propulsion needs to actual operational conditions. While direct drives have to cover the whole power range, diesel-electric drive trains consist of at least two gensets with suitable distribution of power. This allows using diesel engines more efficiently by switching off a genset when it is not needed. This leads to optimised loads of the engines. Due to the better fuel efficiency of the diesel engines at the optimum load, the operational costs and emissions are decreased with the reduced fuel consumption.

A common example for partial loads is the difference between upstream and downstream sailing. Most downstream sailing vessels only need less than half of the power needed upstream. When the vessel is sailing downstream at least one genset can be switched off. Other ships have an operational profile similar to the left plot below. Here engine loads were measured over several journeys including upstream, downstream and canalized sections without currents. Most of the time the vessel is operating at engine loads of less than half of the installed power. Only on small sections of the waterways and for emergency stops the full power is required.





Power [%]	Weighting E2/E3
100	0.20
75	0.50
50	0.15
25	0.15

In these cases the additional losses of energy conversions are overcompensated by the reduced fuel consumption of gensets either running in their sweet spot or stopped. The small plot on the right hand side above shows the specific fuel consumption over the whole load range of a single diesel engine (blue) and a setup of three smaller gensets (green) including all losses. The overall efficiency of the diesel-electric setup is higher up to 55 % load.

The table on the right hand side contains the test cycles E2 (constant engine rates) and E3 (variable rates) according to ISO 8278 used for the type approval of engines. For each of the four power levels a weighting factor is given. These weighting factors represent the relevance of the engine's working point for certification. Use-cases with an operational profile similar to this distribution are usually more energy efficient with a conventional direct drive and do not benefit from a diesel-electric setup.

BENEFITS

- Engines running in their sweet spot
- Low noise and reduced vibrations
- Increased efficiency for suited operational profiles
- Lower emissions of air pollutants
- More flexibility to generate auxiliary energy
- Easier implementation of batteries and fuel cells
- Additional freedom for engine positioning
- Trend to better manoeuvrability
- Highly redundant designs possible

DOWNSIDES

- Additional losses
- Higher weights
- Increased space requirements
- Higher investment costs

CONSIDERATIONS FOR DEPLOYMENT

Conventional direct propulsion layout is limited to the selection of a proper main engine matching the power demand and the propeller characteristics. Electric propulsion systems need to be designed specifically for the individual use-case. A detailed knowledge of the operational profile helps to distribute the total power over the gensets. The power management links the complete system taking into account the dependencies between the various components. To obtain a functional propulsion system, it is recommended to acquire the complete electrical system from the same provider.

The electrical system increases the weight of the machinery. This can be offset by less fuel being transported and / or the arrangement of components in different places. If a ship is suitable to retrofit a diesel-electric system also depends on the available space and the mechanical integration of the electric engine with the existing engine base.

In the case where batteries are included in the system, the design also involves providing space for the battery (20 % of the installation as a first estimate) and the safety elements (ventilation, battery temperature control, etc.). The battery packs can also be used to optimize the weight distribution and reduce ballast requirements without affecting operability at very low water levels too much.

DEPLOYMENT EXAMPLES

TMS Bilgenentöler 10

Operator: Bilgenentölungsgesellschaft (BEG)
Location: Regensburg (DE)
Organisers: Rensen-Driessen, Dolderman, Baumueller
ⓘ www.bilgenentoelung.de

Vessel type: bilge oil boat
ENI: 04812720
Vessel size: 40 m × 7.30 m (L × W)
Propulsion: Two 178 kW electric motors on one shaft and two gensets with 340 kVA from Caterpillar C 9.3.
Benefits: Low noise and combined supply of electric energy for propulsion, bow-thruster, pumps and separator.

MS NADORIAS RETROFIT

Operator: Sendo Shipping
Location: Netherlands
Organisers: MCS, Sendo Shipping, Koedood, Hybrid Ship Propulsion
In operation: 2009 (2014)
ⓘ www.sendo-shipping.nl

Vessel type: inland container vessel
ENI: 02331393
Vessel size: 110 m × 11.45 m (L × W)
Propulsion: Conventional diesel setup changed to hybrid: electric engine (385 kW) powered by two gensets (205 kW each, in the bow) was added to the 1250 kW main engine. About 85 % of the time the ship sails with the electric motor driven by one of the gensets. When more power is required, the second generator is started. The direct drive engine is only used when a lot of power is required (1-2 hours per week).
Benefits: Reductions in fuel consumption by 15 %, maintenance costs by 60 %.

Contact

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