

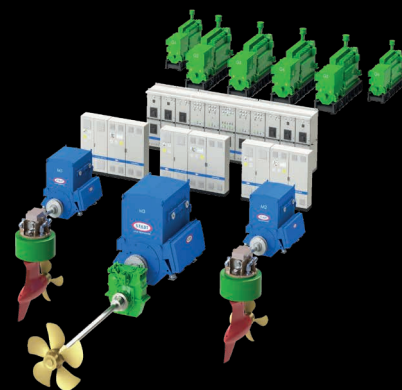


LEAN PROPULSION



THE GUIDELINE TO ELECTRIC PROPULSION

STADT LEAN DRIVE is specially developed for marine propulsion systems, where it is used together with controllable pitch propellers.



WINNER OF THE OSJ ENVIRONMENTAL AWARD 2014

WWW.STADT.NO

Electric propulsion is a natural choice for a lot of different ship types, and there are many reasons why this solution is so popular. Fuel savings, emission reductions, ECA regulations, redundancy, reduced noise & vibration, low maintenance, space utilization, battery storage, and the use of LNG –electric propulsion are just some of the reasons to choose electric propulsion.

These systems can be designed in many ways, with the following main elements:

Different prime movers: Typically 3 to 6 in parallel

- LNG
- Bio Fuel
- HVO
- MDO
- HFO
- Dual Fuel
- What RPM to run?
- Trifuel
- Fixed or variable?
- Rechargeable batteries and Fuel cells
- A combination of any of these

Switchboard MSB:

- Low voltage AC: 220 V to 690 V
- 50 - 60 Hz
- Medium Voltage AC: 1000 V to 15 kV
- Bus-Tie arrangement

AC Drives on the market today:

- PWM 6 pulse (very high THD – not applicable for EP solutions)
- LCI, Cyclo etc.
- PWM 12 pulse, or LLC
- AFE PWM– Active Front End
- **SINE WAVE technology like STADT LEAN DRIVES**

AC Motors and Generators:

We use well proven asynchronous AC motors while generators are synchronous. DC and PM motors are not recommendable.

Gearbox:

We always use a gearbox between the AC motor and propeller. This saves weight and space.

Propellers:

- Electrically driven shaft lines, CPP, plus tunnel thrusters.
- Azimuth thrusters with CPP, electric motor inside the hull.

To get a well-functioning ship; all elements must be suitable for the purpose. In an electric powered ship propulsion system, the most critical elements will be the electric AC drive technology, not so much the prime movers (nor the gear and propellers). Prime movers are typically arranged with 4 to 6 in parallel, enabling the ship to sail even with one out of 6 in operation. The electric system on the other hand could become a critical element if the technology is vulnerable.

Choosing the right propeller type is also very important when it comes to overall propulsion reliability etc. We do not recommend pod solutions, and prefer shaftline rather than azimuths. A fixed pitch (FP) propeller are not to be used together with the STADT Lean Drive. It has to be CPP.



Ship Type: Seismic Research Vessel, DNV Class, AUTR DP-2
Owner: Sanco Shipping AS – Chartered by PGS since 2011
Delivered: October 2009 (Sister vessel MS Sanco Star delivered in 2008)



Sanco Spirit has been a very successful ship for its owners and charters since it went in to operation in 2009. The ship's captain, Mr Ronny Muren, and the technical manager at Sanco Shipping, Mr Jon Aklestad both reports that the STADT LEAN electric propulsion technology has proven itself to be extremely reliable over the years. The ship has not gone off-hire at any time, and the crew has maintained the system easily with a very limited need for support from STADT. Also PGS is appreciating the use of this ship.

The robust and highly efficient drive technology has given the ship a minimal fuel consumption at all relevant operation point, including DP, and transit.

The system is remarkable in its compact design, and the No-Loss drive technology enables the designers of the ship to avoid any liquid pipes for cooling or ventilation to be used in switchboard rooms where also the STADT drives are located. Big power transformers used by most other drive manufacturers are completely eliminated, as well as the EMC noise and harmonic distortion from the drives.

The patented drive system from STADT is unique in the way it optimizes the use of 3 different power technologies, in segregated redundant modules (PCC1, 2 & 3). The PCC 1 is the traditional frequency converter, while PCC2 and 3 are independent power boosters for the inverter based on thyristors and bypass switching. DC capacitors are avoided since they may easily explode and lead to major injuries and fatale failures (ref DNV and MAIB reports). In the new STADT drives the energy goes AC-AC most of the time. One of the most important improvements found in this solution is that one possible failure in the drive will NOT stop the propellers operation. In this way the STADT technology solves many problems that is seen by other electric propulsion technologies on the market today.

The electric propulsion plant onboard is designed and delivered by STADT, similar to what was earlier delivered to the sister vessel Sanco Star one year earlier, operated by Georadar in Brazil.

Propulsion Drive: STADT LEAN FCT HY 2.2 G1 V0
2 x 2500 kW, 690 V
Full Diesel-Electric Propulsion

Evaluation of Different Drive Solutions and their Key Performance Indicators			
Lean Issues To Consider	STADT LEAN DRIVE	12/24 Pulse - PWM	AFE - PWM
Technology in AC drive	Sine Wave	PWM	PWM
No. of electric energy transformations	0	4	4 or 5
Power Train Losses	No,(negligible)	6 %	6 %
Cooling Type	Air is sufficient	Water	Water
Power Transformers Needed	No	Yes	Sometimes●
Redundant Power Units	Standard	Special	Special
Harmonic Distortion (THD)	No	High	High
Electromagnetic Interference	No	High	High
Acoustic Switching Noise	No	Yes	Yes
Screened Power Cables	No	Yes	Yes
Depending on Harmonic Filters	No	Yes	Yes
Designed Economic Lifetime	30 Years	6 Years	6 Years
Maintenance Requirement	Very Low	Frequent	Frequent
Onboard Crew Skills	Ordinary	Special	Special
MTBF (Mean Time Between Failure)	7 Years	1 Year	1 Year
MTTR (Mean Time to Repair)	1 Hour	1 Week	1 Week
Spares Globally Available	Yes	No	No
Weight of Drive System	100 %	1100 % - 1400 %	600 % - 1600 %
Size of Drive System	100 %	500 % - 600 %	450 % - 700 %
All Voltage Class (220V-15kV)	Yes	No	No
Power Scalable	Yes	No	No
Regenerates Power to Grid	Yes	No	Yes
No. of Power Components in Line	1	80 000	150 000
Capacitors In Main Power Circuit	No	Yes	Yes
Explosion Risk in Drive	No	Yes	Yes
Propeller Pitch Configuration	CP	CP or FP	CP or FP
Financial Risk (Service cost, Off-hire)	Very Low	High	High

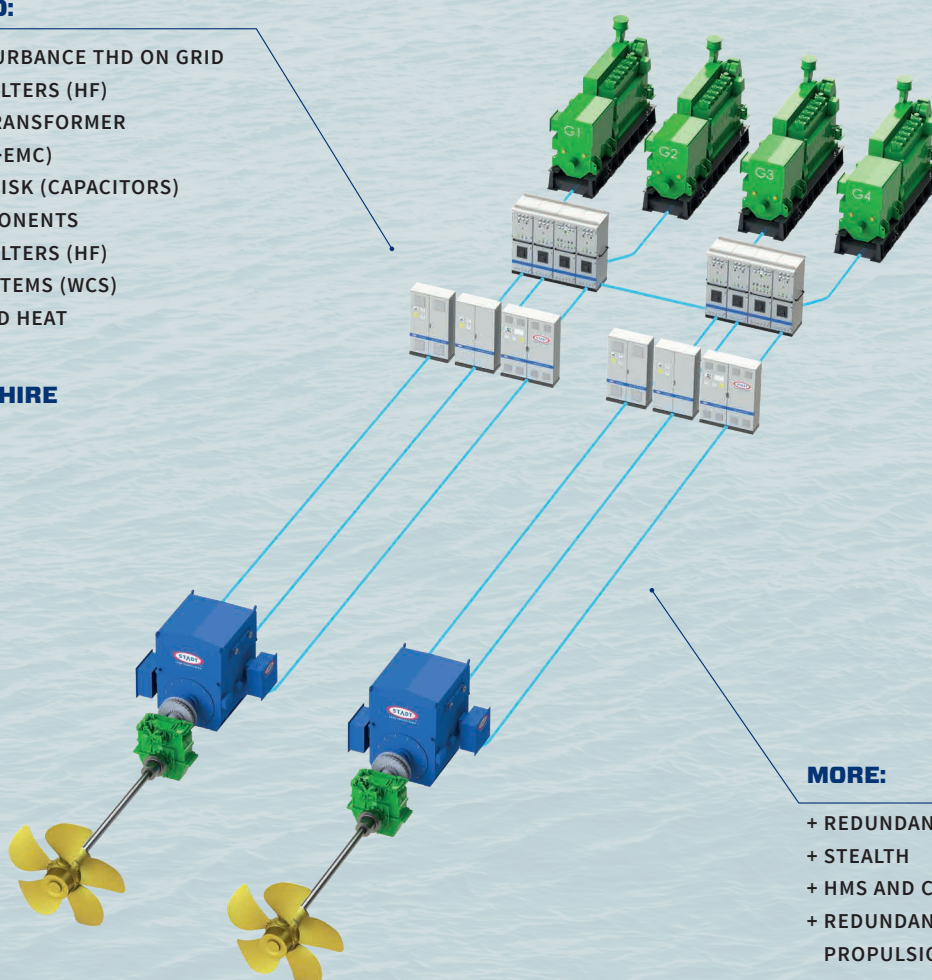
- Discover the Power of Simplicity -

DISCOVER THE POWER OF SIMPLICITY

ELIMINATED:

- POWER DISTURBANCE THD ON GRID
- HARMONIC FILTERS (HF)
- 12 P - 24 P TRANSFORMER
- NOISE (PWM>EMC)
- EXPLOSION RISK (CAPACITORS)
- 80.000 COMPONENTS
- HARMONIC FILTERS (HF)
- COOLING SYSTEMS (WCS)
- 5-6 % WASTED HEAT
- COMPLEXITY

= LESS OFF-HIRE



MORE:

- + REDUNDANCY IN DRIVE (FULL R.)
- + STEALTH
- + HMS AND COMFORT (SILENCE)
- + REDUNDANCY, ALSO IN AC PROPULSION MOTORS

= BETTER PERFORMANCE

Technology in The AC Motor Drive:

Sine Wave



or PWM



The use of Sinus vs PWM (Pulse Width Modulation) control technology will lead to many consequences. The sine wave technology is free from electromagnetic noise, while PWM is a powerful noise transmitter that can disturb all kinds of electric equipment on a ship. PWM can also force current to flow through roller bearings in AC motors or gearboxes, with mechanical breakdown as a result. PWM drives need special screened power cables, while Sine Wave drives can work with unscreened power cables.

Number of Electric Energy Transformations in Power Train:

Every transformation of energy creates power losses. Transformations based on rectifiers or PWM also create noise, both acoustic and electromagnetic.

Power Train Losses:

The losses are calculated from switchboard to the electric propulsion motor, through out the drive system. Losses in alternators and electric motors come in addition to these, and typically add 6 % extra, giving total electric losses of 12 – 14 % in a typical PWM based system. The STADT system has a total of 6 % electric losses, giving an improvement of the ship's efficiency by more than 6 % compared to other EP systems based on PWM.

Air Cooling or Water Cooling?

High losses and the use of power electronics in the inverters, normally force the designer of the drive to use water cooling in their electronics. Such cooling system consists of pumps, filters, pipes, sensors, fittings, sealings, heat exchangers, special water (de-ionised in high power drives) etc. If the cooling system is interrupted, the propeller stops, or the drive unit explodes in the worst case.

Air cooled drive solution is a very good and uncomplicated solution that easily can be used if the losses are low, as in the STADT LEAN DRIVES.

Are Transformers Needed?

Most of the drives used in electric propulsion systems on ships require big transformers in their systems. There are two reasons why they are introduced.

- 1: To filter harmonic disturbances from the electric grid.
- 2: To adapt the voltage level to be suitable for the drive unit, the reason why also AFE may use transformers.

Such transformers are very big in size, they are very heavy, and need cooling. They are of special design, so in case of damage or failure - it will be a big challenge to replace them.

STADT LEAN DRIVE is a unique patented solution that do not need the transformer for any of the 2 mentioned reasons.

Switching Noise from PWM Drives:

All drives using PWM type transistor switching will create annoying acoustic noise from the AC motor. Such noise does not exist when Sine waves are applied to the motor.

Are Redundant Power Units in AC Drive Needed?

Most AC drives on the market are made as one compact integrated unit consisting of rectifiers, DC capacitor banks, IGBT inverters, control boards & systems, water cooling items etc. In total, up to 80.000 small and big components plays together in a complex way. If one of these components fails, the drive (and the propeller) will stop working.

The STADT LEAN DRIVE on the other hand, is one of very few solutions on the market that offers redundant power units, in segregated cabinets that can be located in different physical locations. A single failure will not stop the propeller.

Do the System Depend on Harmonic Filters?

Most of the electric propulsion technologies generates harmonic distortion that needs filtering in special units consisting of inductors, capacitors etc.

It might look like just another trivial unit that is supposed to work without any problems. But this unit failed catastrophically at the cruise ship RMS Queen Mary II in September 2010 using GE Converteam PWM drives, resulting in total blackout, which is a very dangerous situation for the ship.

Read the MAIB report about this accident on page 13. It illustrates the problem with Harmonic distortion very well.

The STADT LEAN DRIVE is one of very few, if any drive solution - that does not need this type of filter devices.

Are there any Explosion Risk in Drive, Transformers or Filters?

Most of the PWM based drives on the market are working with high frequency IGBT transistor switching, with a DC capacitor bank as the power source.

The switching requires low inductive power foils to be used, with a minimum of clearance over the busbars, approximately 1 mm at full voltage, and far less in the capacitor bank. High energy is stored in these circuitries – with a potential to generate an explosive type of failure if something is not working as it should.

After such explosion, the complete drive normally has to be changed.

In the STADT LEAN DRIVES – the use of DC capacitors is avoided, and isolation between power live parts increased from 1 mm to more than 20 mm as a minimum in LV. This makes explosions in the drive not likely to happen.

Other Issues:

Please feel free to contact us if more information is needed.

STADT LEAN AC Drive

Datasheet FC SIN 3.1 G1 V3

For ship propulsion and compressor control



A Drive technology that combines RPM control with pitch control.

PATENTED BY STADT

SINUSOIDAL waveforms, not PWM

Combines 5 control elements

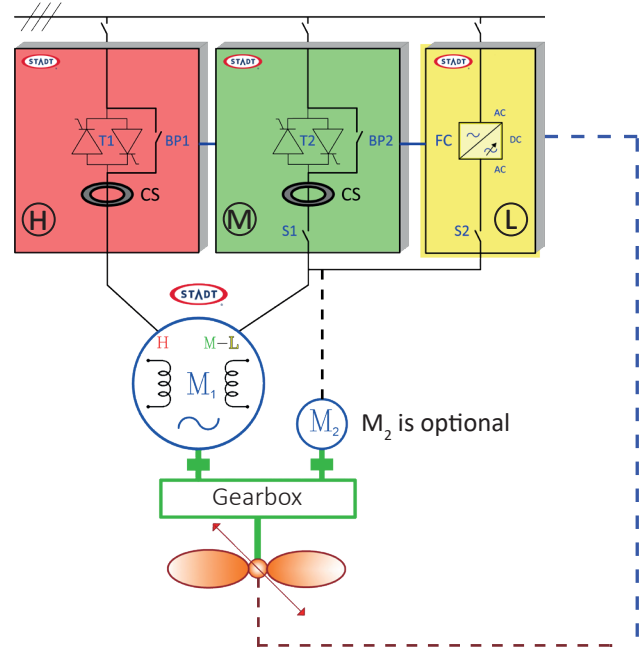
- IGBT control (FC)
- thyristor control (T1)
- bypass switch (BP)
- multi speed motor
- pitch propeller control



- NO LOSS due to bypass switching, BP
- no need for transformers
- no EMC problems
- very low THD in main switchboard
- redundancy, T1 - T2, BP1-BP2, FC, H - M - L
- handles regenerative power
- compact design
- air cooled
- no acoustic switching noise
- no bearing currents
- easy cabling, unscreened
- reduced number of active components
- can operate on very low generator capacity
- low voltage and medium voltage models
- 3 RPM modes gives very high propeller efficiency

REDUNDANT DRIVE MODEL

AC SUPPLY STADT LEAN FC SIN 3.1 G1 V3



Reliability

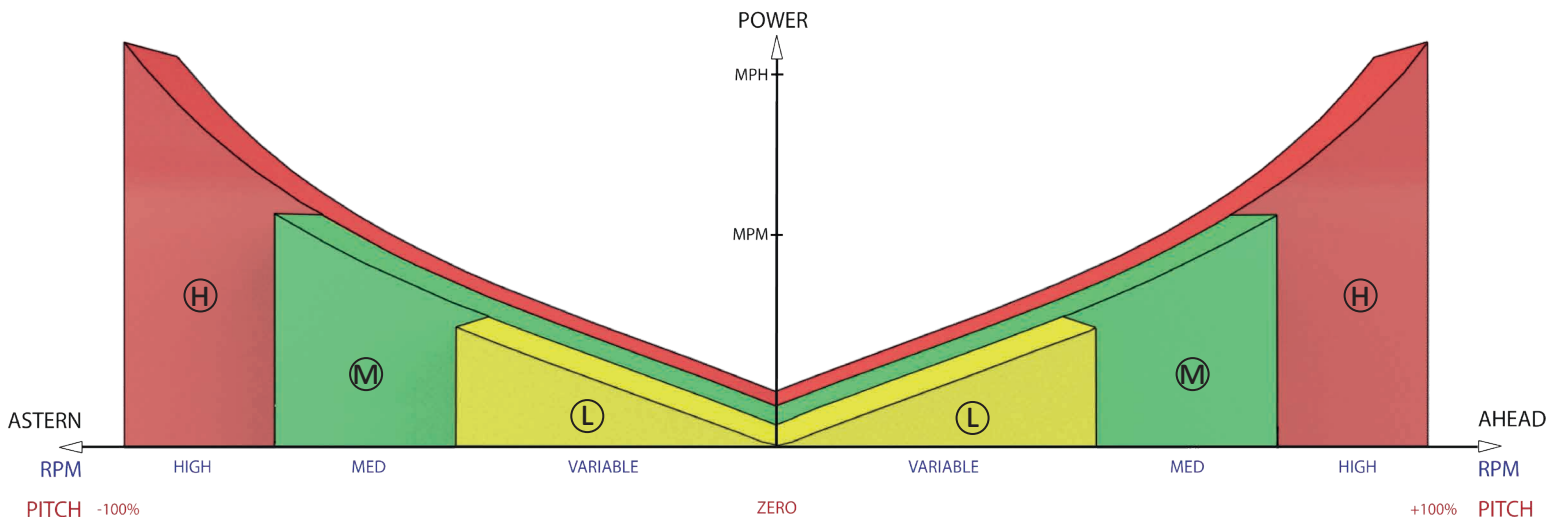
Less components and bypass leads to a very rugged system, with very limited maintenance and long lifetime, 25 years +. Limited risk for undesirable stops and off-hire. The bypass switch (BP) is the most important power element in the LEAN DRIVE. The FC, T1 and T2 are used only for short periods of time, and will have an easy life and long lifetime. The redundant, segregated H, M, L cabinets increases reliability to a even higher level.

Models available:

This model- FC SIN 3.1 G1 V3

is available from 100 kW to 20 MW

in voltages from 220 V up to 15 kV



What it typically looks like:

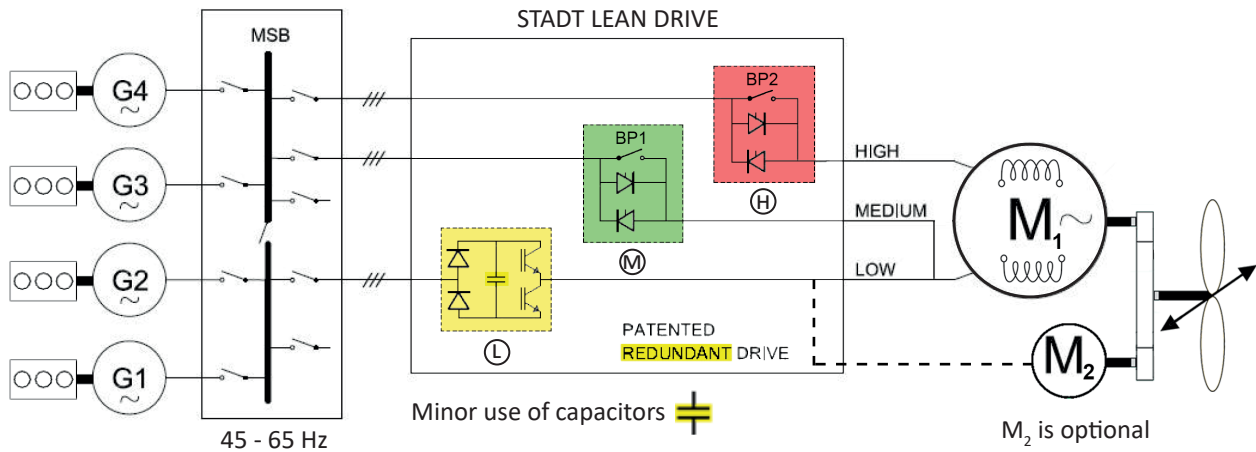


No-Loss makes air cooling possible

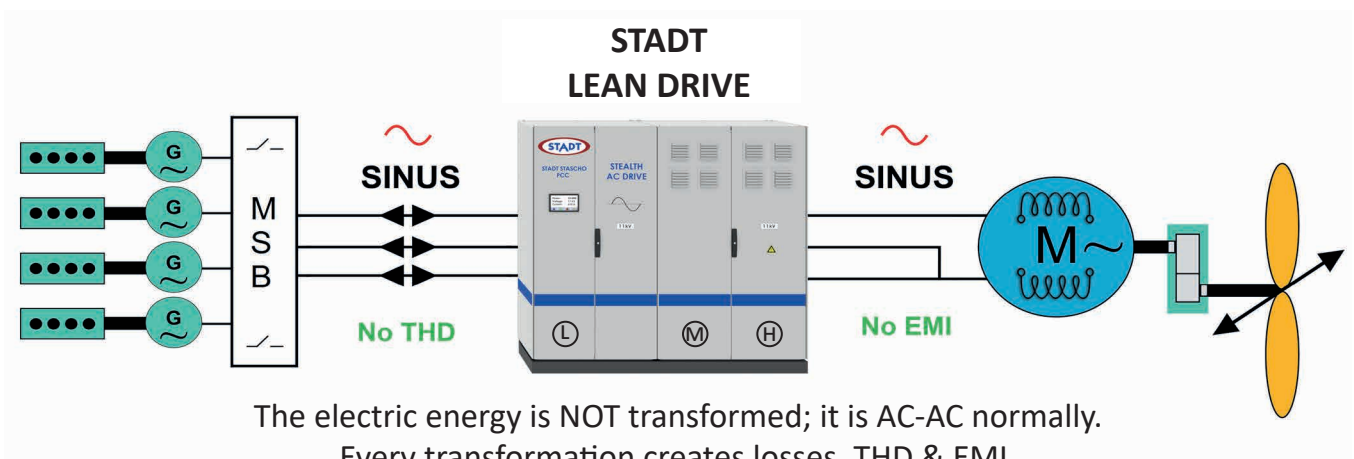


Compact

How it is arranged electrically in one of the STADT LEAN DRIVE models:



How it is working in a propulsion system:



The electric energy is NOT transformed; it is AC-AC normally.
Every transformation creates losses, THD & EMI.

STADT LEAN DRIVES creates no losses, no THD & no EMI.

12 Pulse AC Drive - PWM Frequency Converter

with Transformer

Competitors Technology

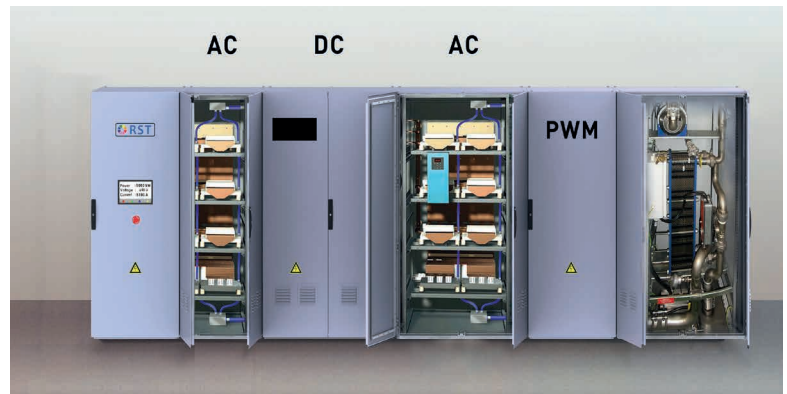
What it typically looks like:



HF Filter

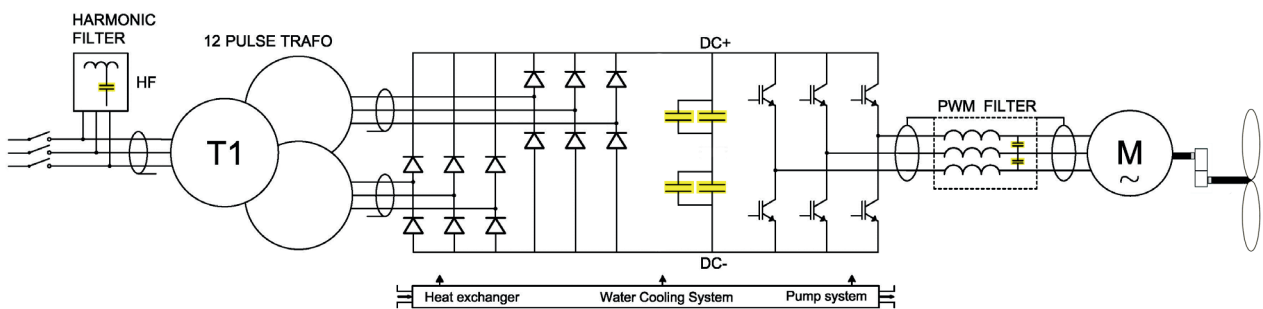


Big 12-pulse transformer

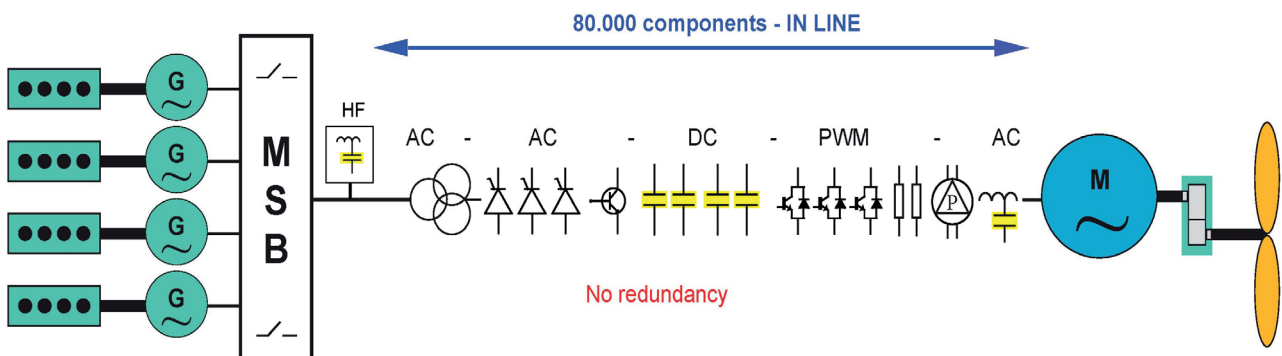


High losses - Needs complex water cooling

How it is arranged electrically:



How it is arranged in a propulsion system:



If 1 out of 80 000 components fails, the propeller will stop working.

Explosion may easily be the result as well.

Extensive use of capacitors.

All electricity is transformed **4 times**: AC - AC - DC - PWM - AC

Every transformation creates losses, THD & EMI

AFE - Active Front End Drive PWM

Competitors Technology

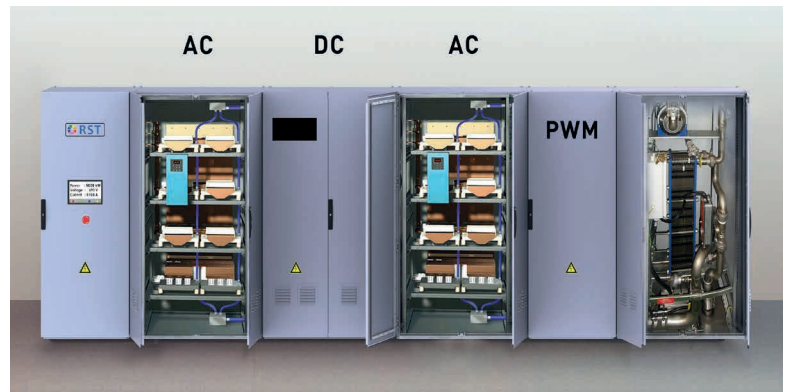
What it typically looks like:



Optional transformer

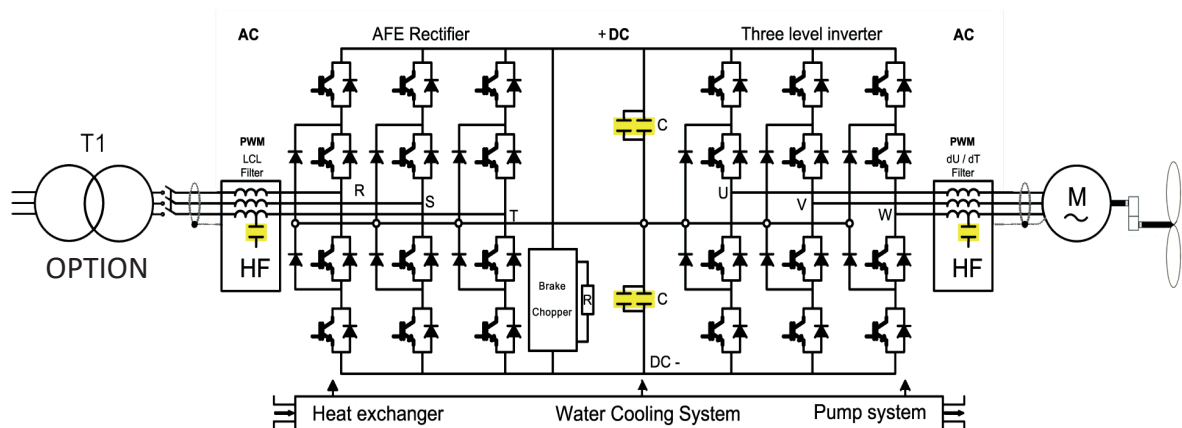


HF Filter

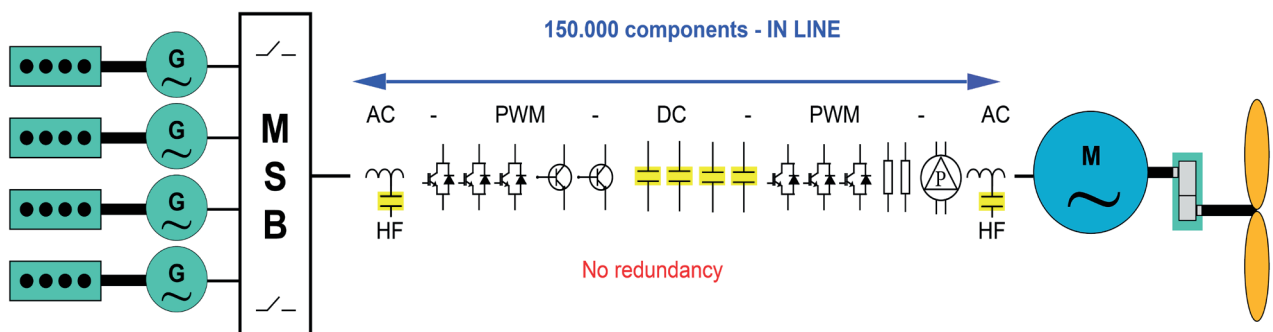


High losses - Needs complex water cooling

How it is arranged electrically:

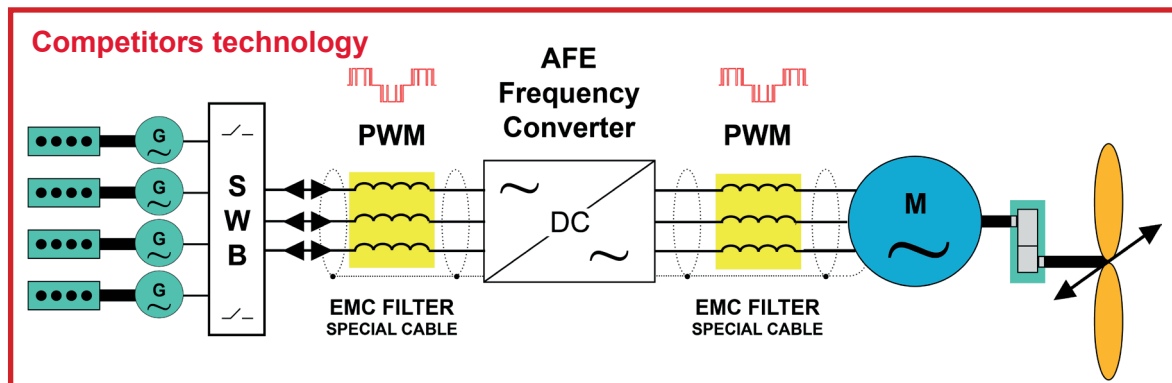
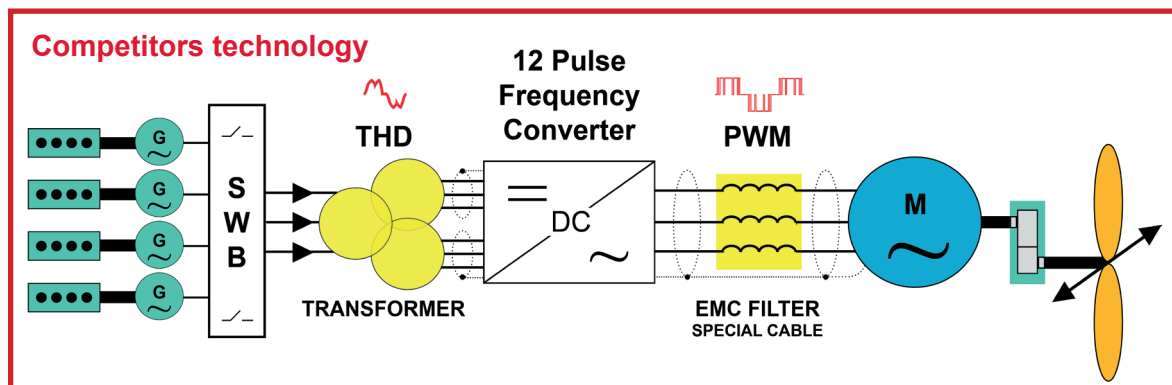
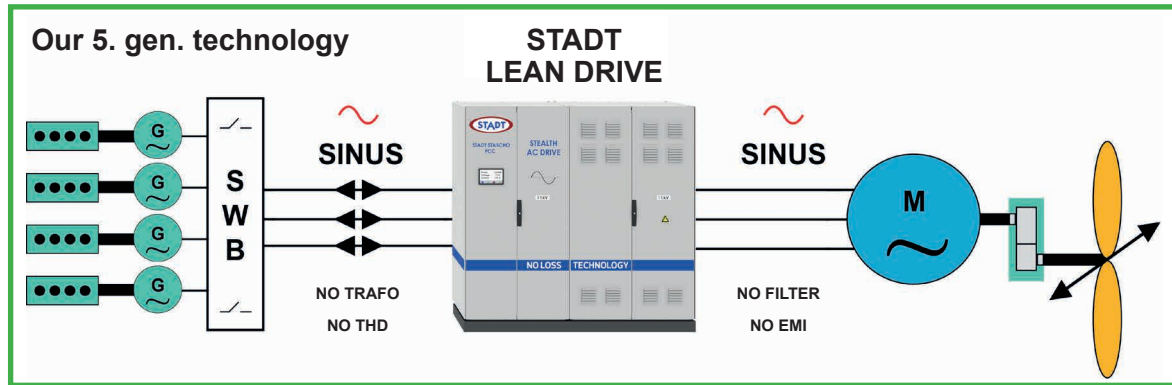


How it is arranged in a propulsion system:



If 1 out of 150 000 components fails, the propeller will stop working.
Explosion may easily be the result as well.
Extensive use of capacitors.

All electricity is transformed **4 or 5 times**: (AC) - AC - PWM - DC - PWM - AC
Every transformation creates losses, THD & EMI



Huge differences:

- TRANSMISSION LOSSES
- ECONOMICAL LIFETIME
- MTBF, MTTR
- REDUNDANCY
- EMI, THD
- VOLUME, WEIGHT
- COMPLEXITY
- **PWM RELATED ISSUES:**
 - Electric and acoustic noise
 - Bearing currents
 - Voltage stress in motors, Cabeling type
 - AC versus DC systems - Capacitors
 - PRICE, SERVICE COST




FLYER TO THE SHIPPING INDUSTRY

RMS Queen Mary 2: The catastrophic failure of a capacitor and explosion in the aft harmonic filter room

At 0425 on 23 September 2010, as the passenger liner *RMS Queen Mary 2* (QM2) was approaching Barcelona, a loud explosion was heard from the direction of the aft main switchboard (MSB) room. Within a few seconds, all four of the podded propulsion motors shut down. A few seconds later, the vessel suffered an electrical blackout. Thick black smoke was seen to be coming from the aft MSB room. Fortunately, the vessel was clear of navigational hazards and no one was injured.

By 0439, the crew had confirmed that the explosion had taken place in the aft harmonic filter¹ (HF) which was situated in a compartment next to the aft MSB room. After establishing with thermal imaging cameras that there were no hot spots, they ventilated the area and isolated the aft HF and MSB from the rest of the 11000 volt electrical network. The crew were able to restore some electrical power supplies and, by 0523, QM2 was underway using two propulsion motors powered from the forward MSB. Subsequent inspection of the aft HF revealed that one of its capacitors (**Figure 1**) had failed catastrophically due to internal over-pressure and another had developed a severe bulge.



Harmonic filter capacitors 

The vessel had a history of HF capacitor failures, at an average rate of one per year. Although the exact cause of the capacitor failures could not be determined, it was concluded that capacitor degradation was probably caused by a combination of transient high voltage spikes due to frequent switching operations and occasional network overvoltage fluctuations. The capacitor deterioration had not been detected, and because there were no internal fuses or pressure relief devices, it had continued until the capacitor casing failed catastrophically.

Although the aft HF circuit breaker disconnected the HF from the rest of the electrical network to isolate the electrical fault, the disruption was likely to have caused electrical instability in the electrical network which led to the loss of propulsion and blackout. The vessel's alarm logs were found to contain early warnings about the impending failure approximately 36 minutes before the accident. However, as the vessel's alarm systems regularly logged more than one alarm every minute, this information was not seen and could not be acted upon.

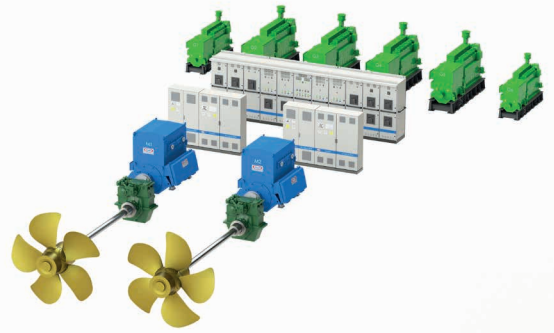
Current imbalance detection system

The only protection against catastrophic failure of the capacitors was a current imbalance detection system. It consisted of a current transformer (**Figure 2a**) which was connected to the capacitor circuit. Under normal conditions, little or no current should have flowed through the transformer. When a capacitor degraded, the current flow across the circuit became unbalanced and induced a current in the transformer's secondary winding. The system was set to give an alarm when the imbalance reached 400mA and to trip at 800mA. After the accident, the transformer's windings were found to have failed (**Figure 2b**). There had not been any alarms on this part of the system for several years and it was likely that the imbalance detection system had not worked for some time.

¹ Harmonic filter: Alternating current (AC) motors for electric propulsion operate on variable frequency and voltage. Thyristors used in the power converters result in voltage distortion. Passive harmonic filters mitigate the effects of excessive voltage distortion.

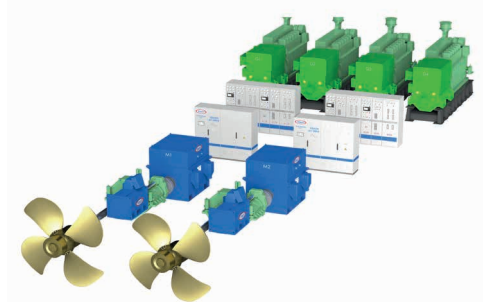
Twin screw, CP

- 6 generators
- 2 electric motors
- 1 main switchboard with Bus-Tie



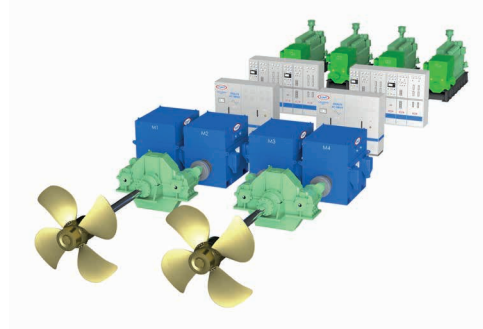
Twin screw PTI, CP

- 4 generators
- 2 electric motors + 2 small as option
- 2 main switchboards



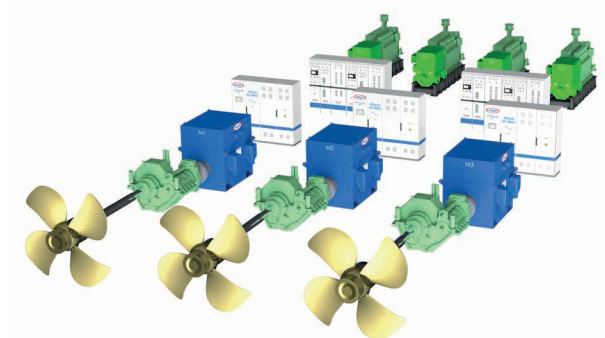
Twin screw Twin, CP

- 4 generators
- 4 electric motors + 2 small as option
- 2 twin input gearbox
- 2 main switchboards



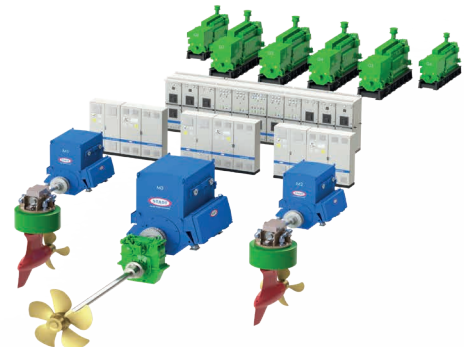
Triple screw, CP

- 4 generators
- 3 electric motors + small as option
- 2 main switchboards



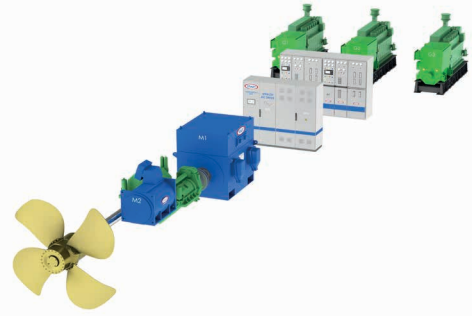
Triple screw (2 Azipulls), CP

- 6 generators
- 3 electric motors
- 1 main switchboard with Bus-Tie



Single screw, CP

- 3 generators
- 1 electric motors + small as option
- 1 main switchboard with Bus-Tie



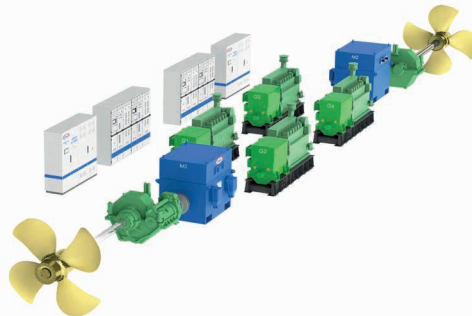
Single screw Twin, CP

- 4 generators
- 2 electric motors
- 1 twin input gearbox
- 2 main switchboards



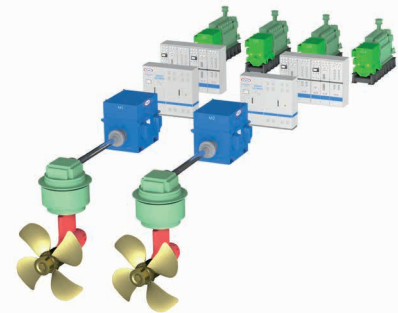
Double ended, CP

- 4 generators
- 2 electric motors
- 2 main switchboards



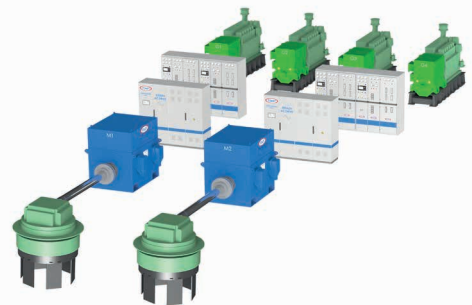
Twin screw (Azimuth), CP

- 4 generators
- 2 electric motors
- 2 main switchboards



Twin screw (Voith), CP

- 4 generators
- 2 electric motors
- 2 main switchboards



THE CASE FOR GEARED ELECTRIC PROPULSION

Power transmissions and propulsion systems are ubiquitous throughout the world. A sustainable approach to these technologies will therefore have a major impact on their environmental footprint.

Many developments and improvements have been seen in this field over the years, and new ideas show up regularly. Some of them are more reliable and efficient than others.

Stadt has been a part of these developments over many years, and the 5 generation of drive technology – the No-Loss drive – stands out as an obvious solution when it comes to sustainability. The technology also offers high efficiency, reliability and safety as well as stealth features that ensure that there is no interference with sensitive electronic equipment, and an absolute minimum of acoustic noise from electric motors and drives. It is a patented technology, and has received a number of awards.

These days, many claim that the use of gearboxes is obsolete, but this is far from correct. For example, popular electric cars like the Nissan Leaf and Tesla's models take advantage of a gearbox. This is a single shift gearbox, which is not obvious to the driver as there is no gear shift. But the gearbox is there, between the electric motor and the wheels. Typically these gearboxes have a gear ratio of 10:1, enabling the electric motor to run at 18,000 rpm or thereabouts at full speed.

People may be misled, even by engineers in the industry, saying that there is no gearbox. It may not be a standard gearbox, but there is still a gearbox involved. Even the world's fastest supercars – electric EV and others – use a gearbox in their transmission.

The electric motor, the gearbox and the AC drive must be evaluated as one unit together when it comes to questions such

Reports that the gearbox is obsolete are overstated says Hallvard Lidset Slettevoll, founder and chief executive of electric propulsion systems specialist STADT

as power, torque, weight, volume, efficiency, reliability and lifetime.

The use of permanent magnet motors does not make any difference here, as many tend to believe. The Tesla car, for instance, successfully uses a robust induction AC motor with gearbox. Since it can operate over a wide speed range from zero to 18,000 rpm, the motor and gear arrangement becomes very compact and has a low weight.

In ship applications the electric motor will have a maximum rpm of 1,800 or less, and a gear ratio of 6:1. This provides a set-up that is much more compact and far less heavy than if it was run at 300 rpm.

AC induction motors are easy to manufacture and maintain, and do not require rare and expensive magnetic materials. They have an efficiency of about 97.5 per cent at full load.

The nature of rotating machines and the laws of physics tell us that a gearless solution that uses an electric motor alone will not be able to deliver the required power and torque as efficiently as a geared solution.

There are many manufacturers of gearboxes in the world, and there are

many different designs. In general, a simple gearbox is a reliable and very efficient device. The power losses amount to somewhere between 1 and 2 per cent, depending on the gear ratio, teeth arrangement, bearings and lubricant.

A gearbox can also give operational advantages such as increased redundancy by using several electric motors with one gearbox. Separate clutches can engage the individual motors. Ships with turbine driven propulsion have always used gearboxes on the propulsion, because of the high turbine speed.

In the Stadt No-Loss electric propulsion drive system, the gearbox is also combined with the use of controllable pitch propellers. Very often the pitch controller is located in the gearbox as well.

So there are a number of reasons why all these applications are using the gearbox, but the most important is increased torque and power, space savings and weight savings.

How much is gained by using the gearbox varies from case to case.

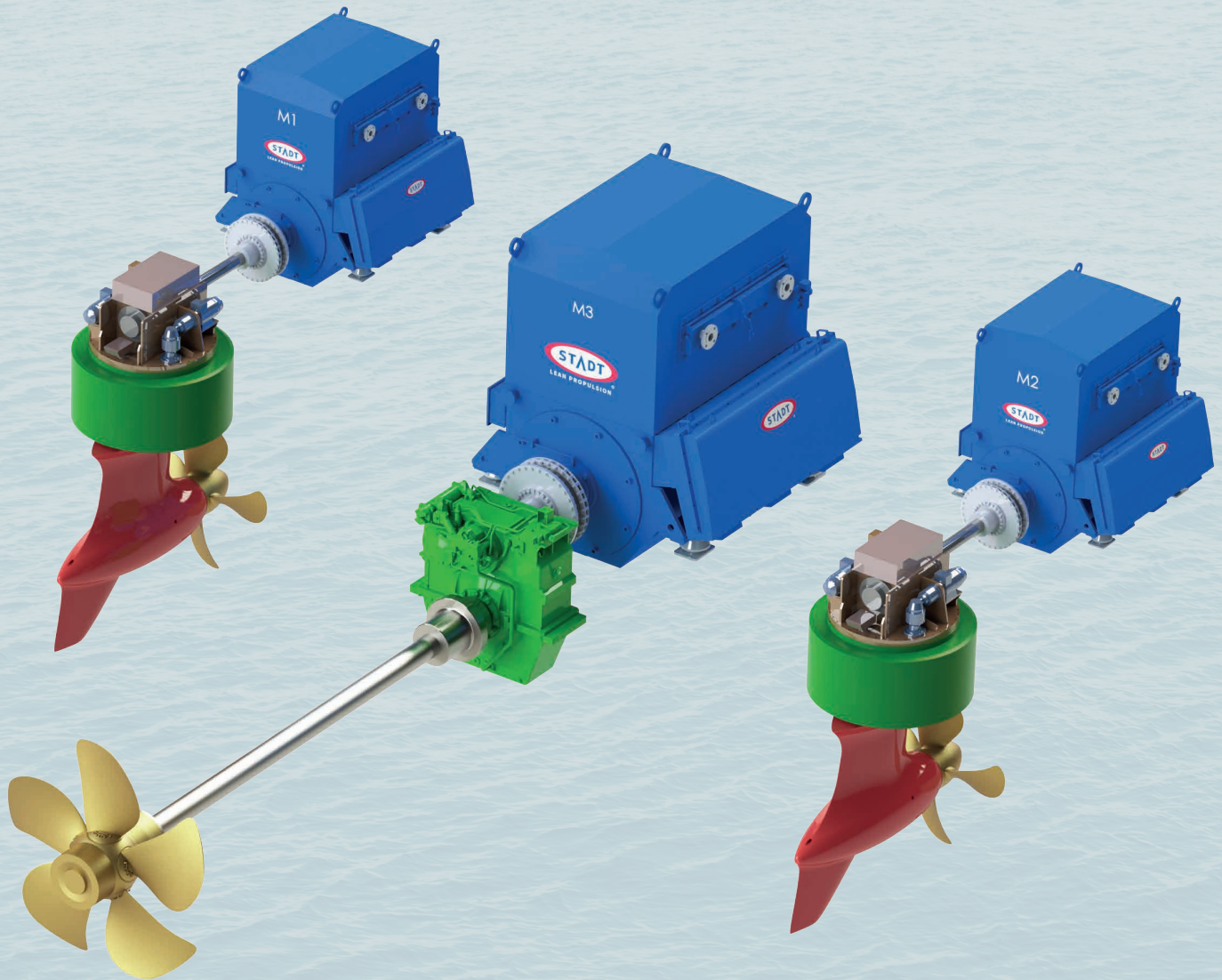
Stadt feeds its AC propulsion motors with sinusoidal voltage and power, eliminating the torque pulsation that is found in pulse width modulation type motor drives. Because of this Stadt can provide a stealth solution that has minimal vibrations and acoustic motor noise, and is free from electromagnetic interference.

When properly designed, the gearbox, too, can be operated at a very low noise level, as it is on a submarine.

Field experiments over several years combined with simulations have shown that the Stadt No-Loss drive will gain 5 to 6 per cent in fuel savings per year compared with traditional AC drive solutions based on non-sinusoidal drives, such as pulse width modulation, direct torque control, 6, 12, or 24 pulse, active front end or DC grid based. [MP](http://www.mpropulsion.com)

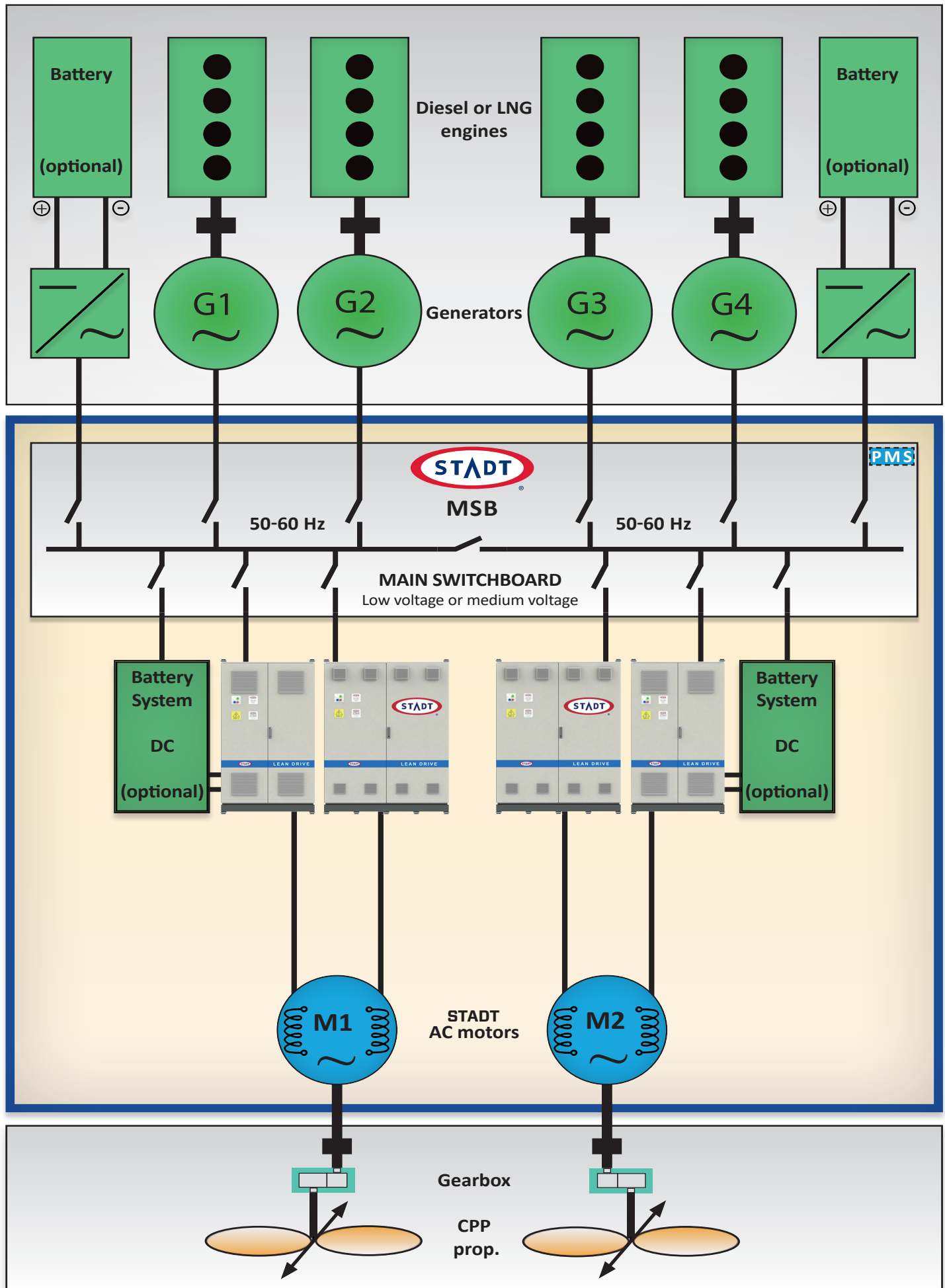
Geared Electric Propulsion

With our 5th generation LEAN DRIVE technology



- **Electric losses reduced by up to 55 %**
- **Weight reduction of 80 % vs AFE**
- **Volume reduction of 85 % vs AFE**
- **THD and EMI eliminated 100 %**
- **Redundancy built in to all items**
- **Lifetime improved from 10 to > 30 years**
- **MTBF and MTTR improved several folds**
- **FUEL SAVINGS – the best in class**

Example of System Overview





LEAN PROPULSION

LEAN BRINGS YOU

- + SAFETY & RELIABILITY
- + VERY LONG LIFETIME
- + COST EFFICIENCY

- + STEALTH & HSE
- + MORE CARGO CAPACITY
- + LESS EMISSION AND FUEL



SIMPLICITY IS THE ULTIMATE SOPHISTICATION

- LEONARDO DA VINCI



GET IN TOUCH!

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